Lung Function and Aerobic Capacity in Sugarcane Factory Workers in Kopargaon: A Cross-Sectional Study

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ABSTRACT
Background: Sugarcane factory workers are exposed to considerable occupational hazards, which may impair lung function and aerobic capacity.
Objectives: This study aimed to evaluate and compare the pulmonary function and aerobic capacity of sugarcane factory workers with direct and indirect exposure.
Methods: A cross-sectional study was conducted among 155 sugarcane factory workers: 57 with direct exposure and 98 with indirect exposure. Spirometry tests (FVC, FEV_1, FEV_1/FVC%) and aerobic capacity (VO_2 Max via YMCA Step Test) were measured. Workers were classified into normal, obstructive, restrictive, and mixed lung function categories using standard spirometry criteria. Statistical comparisons between groups were tested using Mann-Whitney U test and significance set at $p<0.05$.
Results: Workers with direct exposure had significantly lower lung function: FVC (2.85±0.60 L), FEV_1 (2.00±0.57 L), FEV_1/FVC (71.0±11.3%) compared to indirect exposure workers: FVC (3.26±0.66 L), FEV_1 (2.61±0.47 L), FEV_1/FVC (80.1±8.6%) (all $p<0.001$). VO_2 Max was also significantly lower in directly exposed workers (55.56±11.44 ml/kg/min) compared to indirect (65.36±10.10 ml/kg/min; U=734.0, p=0.000002). The direct group had a higher proportion of obstructive and mixed lung impairment.
Conclusion: Direct occupational exposure in sugarcane factories is associated with significant reductions in lung function and aerobic capacity among workers.

Keywords: Sugarcane factory, Lung function, Aerobic capacity, Occupational health, VO_2 Max, Spirometry, Pulmonary Function(PFT), YMCA Step Test.

1. INTRODUCTION

The joint ILO/WHO Committee on Occupational Health, during its inaugural session in 1950, established the following definition: “Occupational health should aim to promote and maintain the highest level of physical, mental and social well-being of workers in all occupations; protection of workers in their work against risk factors harmful to health; for the placement and maintenance of the worker and his work environment adapted to his physiological and psychological equipment, and summarizes the adaptation of the work to the man and of each person in his workplace"[1]. An industrial worker may be exposed to several occupational risks depending on their job, such as physical, chemical, biological, mechanical, and psychological risks. These can lead to various occupational diseases including dermatitis, cancer, respiratory conditions, cardiac complications, and psychological disorders[1].

Respiratory illnesses such as asthma, chronic bronchitis, and chronic obstructive pulmonary disease (COPD) are becoming increasingly prevalent among industrial workers [2]. Occupational lung diseases often arise from dust exposure, with severity varying by dust particle concentration and fineness[3]. Among dust-intensive industries, the sugar industry stands out as one of the largest agro-based sectors that directly employs a significant workforce globally [4].This industry is crucial in underdeveloped regions for generating employment and revenue [5]. However, workers are at high risk due to daily exposure to occupational hazards. Globally, about 2.9 million people face such hazards, particularly in the sugarcane sector, resulting in approximately 153 injuries and 6,300 deaths per day, with an estimated 170,000 sugarcane worker deaths annually [4].

India is a major sugar consumer and Maharashtra is one of the leading sugar-producing states, with 236 mills and a crushing capacity of 0.73 million tonnes/day [6]. The sugar industry employs both skilled and unskilled rural workers and contributes significantly to rural development [7]. However, these workplaces expose labourers to risks including musculoskeletal issues, respiratory conditions, and accidents [8]. Repeated exposure to dusty environments leads to pulmonary dysfunction over time. Bagassosis, a hypersensitivity pneumonitis, is one such disease caused by inhalation of bagasse dust [9].Bagasse, the fibrous residue left after sugarcane crushing, is an organic dust between 0.5–3 microns, classified as respirable dust. Workers are regularly exposed to this without using personal protective equipment such as masks or ear muffs [10]. According to the National Institute for Occupational Safety and Health (NIOSH), occupational lung diseases such as byssinosis, bagassosis, asbestosis, and agricultural lung disease are commonly reported [3].

Bagassosis is specifically linked to inhalation of thermophilic actinomycetes like *Moactinomyces sacchari*, with symptoms ranging from cough and fever to breathlessness and chest pain [9]. Workers in distilleries are exposed to toxic fumes and also exhibit restrictive and obstructive lung disorders due to prolonged chemical exposure [6].A cross-sectional study in Tamil Nadu showed that 27.9% of sugar factory workers exhibited pulmonary impairments—predominantly restrictive patterns. Those in high-exposure roles had 42.3% lung function decline, highlighting the importance of early detection using spirometry [11].

Pulmonary dysfunction remains a global health concern, affecting approximately 235 million people with asthma alone, contributing to about 4 million deaths annually [12]. In addition to pulmonary risks, sugarcane workers are at risk of cardiovascular problems. Aerobic capacity (VO_2 max) is often used as a benchmark to assess cardiorespiratory fitness [13]. It represents the maximum oxygen utilization per minute per kilogram of body weight and is crucial for determining endurance and cardiovascular health. Maintaining cardiovascular endurance is especially vital for industrial workers involved in physically demanding tasks. Various occupational factors such as noise, shift work, and exertion increase susceptibility to cardiovascular diseases (CVDs). Studies have shown that workplace-based physical activity programs can improve cardiovascular function and reduce disease risk [14].

Because of the physically demanding nature of many employment tasks in this industry, there is an urgent need for research investigations that evaluate VO2max and cardiac endurance in industrial employees. The gold standard for measuring cardiorespiratory fitness is VO2max, which measures the maximum oxygen intake during strenuous exercise and is closely related to the ability of the respiratory and cardiovascular systems to deliver oxygen to muscles during sustained physical activity. Workers in industrial environments are frequently subjected to physically demanding tasks, repetitive work, and extended periods of manual labour, all of which place a lot of stress on cardiovascular function. Despite these requests, there is still a dearth of complete data evaluating the cardiorespiratory fitness of this group. Current research indicates that bad cardiovascular endurance is associated with greater fatigue, reduced output, a higher incidence of work-related injuries, and an increased risk of chronic illnesses such as hypertension and ischemic heart disease. Moreover, numerous industrial workers may experience socioeconomic or environmental challenges to remaining physically fit, such as erratic work schedules, restricted access to health services, and subpar workplace health initiatives. Thus, evaluating VO2max in this population can aid in identifying high-risk people, guide individualized intervention approaches, and foster a healthier and more sustainable workplace. Integrating cardiovascular health assessments into regular worker health evaluations is one way that research in this field can assist employers and politicians in creating evidence-based rules for workplace health and safety.

In the end, it is imperative to carry out such research to increase the industrial workforce's health and productivity while also lowering long-term healthcare expenditures and occupational health dangers. The western region of Maharashtra is one of the major sugarcane producing regions of the country. This region produces about 35% of the sugar produced in the country. However, there is very little information on pulmonary function and aerobic capacity of sugar industry workers hence the present research work is planned. We have examined workers from a sugar factory in Kopargaon, Ahilyanagar to identify the risk of pulmonary dysfunction and aerobic capacity (VO_2 max) after exposure to bagasse and other harmful dust particles.

2. NEED FOR STUDY

The sugarcane industry is a vital agro-based sector in India, notably in Maharashtra, providing substantial employment but exposing workers to harmful dust and chemical pollutants that can cause occupational respiratory diseases such as bagassosis, asthma and chronic obstructive pulmonary disease. Despite evidence linking prolonged dust exposure to impaired lung function and reduced aerobic capacity, there is limited research assessing both pulmonary function and VO_2 max among sugarcane factory workers, particularly within this region. Evaluating these parameters is crucial, as diminished cardiorespiratory fitness adversely impacts worker productivity, safety and long-term health. Given the lack of routine health surveillance in this industry, this study is necessary to quantify respiratory impairments and aerobic capacity deficits for informing targeted preventive strategies and occupational health policies, ultimately aiming to safeguard and improve worker health and wellbeing.

3. AIMS AND OBJECTIVES

Aim:

To assess and compare lung function and aerobic capacity among sugarcane factory workers with direct and indirect exposure group.

Objectives:

1. To evaluate pulmonary function parameters—Forced Vital Capacity (FVC), Forced Expiratory Volume in 1 second (FEV_1), and FEV_1/FVC ratio—in sugarcane factory workers.
2. To determine aerobic capacity (VO_2 max) using the YMCA Step Test in these workers.
3. To categorize workers based on lung function patterns (normal, obstructive, restrictive, and mixed) and analyse their distribution between direct and indirect exposure groups.
4. To compare lung function and aerobic capacity between workers with direct and indirect occupational exposure.

4. REVIEW OF LITERATURE

1.Saravanan C, Suhanya G, Sophia C et.al in July 2020 Conducted a study on **“Pulmonary function among workers of sugar factory in Villupuram district”**. The main objective of the study was to find the overall prevalence of pulmonary impairment among the sugar factory workers. The researchers also examined the association between years of work experience. The spirometry was used as an outcome measure to access (FVC, FEV1, FEV1/FVC%) . The participants were divided into three groups based on their years of work experience (6-10 years, 11-15 years, and 16-20 years) to assess the impact of occupational exposure. The overall **prevalence** of pulmonary impairment among the workers was found to be 31.6%. Among the impaired workers, 58.3% had restrictive impairment, 33.3% had obstructive impairment, and 8.3% had a mixed type of impairment. Interestingly, 63% of the impaired workers were non-smokers.

2.Relkar-joshi, r. E. E. M. A., manisha rathi, and tushar j. Palekar in October 2016. A Study on **“lung functions and quality of life in flour mill workers”** was conducted. The study aimed to investigate the lung functions and quality of life in flour mill workers. Flour dust is an organic dust that can cause respiratory problems in workers exposed to it. The study wanted to find out the lung function, type of lung pathology, and quality of life in flour mill workers compared to healthy individuals not exposed to flour dust. The researchers divided 150 subjects into two groups - 75 flour mill workers (Group A) and 75 healthy controls (Group B). They assessed the participants' body mass index, chest expansion, and performed pulmonary function tests to measure lung capacity and airflow. They also had the participants fill out a quality-of-life questionnaire (SF-36). The **Results** showed flour mill workers showed significantly reduced chest expansion and lung function parameters like forced vital capacity, forced expiratory volume, and peak expiratory flow rate compared to the control group. 27 flour mill workers had obstructive lung disorder, 23 had restrictive disorder, and 25 were normal. The control group had only 9 workers with obstructive disorder. The flour mill workers also had a significantly lower quality of life in most domains except emotional well-being.

3.Pawar, Prajakta Mahadeo, and Sandeep Babasaheb Shinde et.al in 2019. A study was conducted **"Prevalence of impairment in pulmonary function test in sugar distillery industry workers in Karad Taluka.”** The study aimed to find the prevalence of impairments in pulmonary function tests (PFTs) among workers in the sugar distillery industry in Karad taluka. Exposure to dust and fumes in this industry can lead to various respiratory problems over time. The main objective of this study was to determine the prevalence of impairments in PFTs among sugar distillery workers in Karad taluka. The researchers selected 88 sugar distillery workers aged 40-60 years with at least 5 years of work experience. They conducted PFTs and 6-minute walk tests on these workers to assess their lung function and exercise capacity. The **Results** found that out of the 88 workers, 34 had normal lung function, 25 had mild obstructive impairment, 26 had mild restrictive impairment, and 3 had a mixed type of lung disease. In total, 61.36% of the workers had some form of pulmonary impairment.

4.Nikhade, Nitin S., and Panchsheel Sharma et.al in 2012 **"A study of pulmonary function test in workers of sugar factory, Pravaranagar, Maharashtra".** The study was conducted to understand the impact of the sugar factory environment on the lung function of workers. Exposure to organic dust, such as bagasse, has been known to cause respiratory diseases like bagassosis. The Aim of was to study the pulmonary function test parameters in workers of different departments in a sugar factory. The study involved 294 permanent workers from a sugar factory and 60 control subjects. Pulmonary function tests, including forced vital capacity (FVC), forced expiratory volume in 1 second (FEV1), FEV1/FVC ratio, and peak expiratory flow rate (PEFR), were measured using a portable spirometer. The overall **prevalence** of pulmonary impairment was 31.97% in the Sugarcane Factory Workers.

5.Gascon, Mireia & Kromhout, Hans & Heederik, Dick & Eduard, Wijnand & Joode, Berna et.al in 2012. Conducted a study on **"Respiratory, allergy and eye problems in bagasse-exposed sugar cane workers in Costa Rica."** This Study was done to acess the health risks associated with bagasse exposure among sugar cane workers in Costa Rica, focusing on respiratory, allergy, and eye problems. The **Results** found that bagasse exposure during the harvesting season led to increased reports of wheeze, shortness of breath, rhinitis, and eye problems, likely due to the irritative effects of inhalable dust rather than microbiological agents, as endotoxin and mold levels were low. Ventilatory lung function parameters (FEV1, FVC, FEV1/FVC) remained unaffected, and total IgE levels and atopy status did not change during the season. Limitations included a small sample size, high loss to follow-up, and restricted exposure assessments. The findings emphasize the need for improved occupational health measures, such as enclosing production processes, to reduce dust exposure and mitigate health risks for workers.

6.Pawar, P. V., Gosavi, P., Varadharajulu, G., Jadhav, A., & Patel, B. et.al in 2019. **"A study to find impact of work duration on health in sugarcane factory workers."** The study investigates the impact of work duration on musculoskeletal disorders (MSDs) among sugarcane factory workers, highlighting the prevalence of occupational health hazards due to poor working conditions and inadequate ergonomic practices. Conducted on 74 workers aged 30-60 years, the research utilized the Nordic musculoskeletal disorder questionnaire and occupational health and safety standard questionnaire**. Results** revealed that minimum complaints, primarily neck pain and low back pain, begin within 1-5 years of work experience, while maximum MSDs, including shoulder, elbow, upper back, hip, knee, and ankle pain, occur after 16-20 years of work. The study emphasizes the need for ergonomic interventions to reduce MSDs and improve workplace safety, aligning with previous findings that poor posture, repetitive strain, and improper handling techniques significantly contribute to occupational health risks in industries.

7.Thorave P. et.al in 2021. "**A Study on Correlation Between Working Exposure, 3-MINUTE Walk Distance and Pulmonary Function Tests in Industrial Workers."** This study investigates the impact of occupational exposure on pulmonary function and exercise tolerance among industrial workers in sugarcane, textile, and cement industries in Maharashtra, India. The research highlights that prolonged exposure to dust particles, bagasse, asbestos, and other inhalants leads to significant reductions in pulmonary parameters such as FEV1/FVC, PEFR, and MVV, alongside a noticeable decline in exercise tolerance measured via the 3-minute walk test. The **Results** reveal that longer durations of exposure, particularly beyond six years, are significantly associated with decreased lung function and increased perceived exertion during physical activity. Although some pulmonary function ratios showed non-significant changes, the overall data suggest that continuous occupational dust exposure adversely affects respiratory health, emphasizing the need for preventive measures and further detailed studies to mitigate occupational lung diseases.

5. MATERIAL:

- **Portable Computerized RMS-Spirometer**: For lung function testing, measuring FVC, FEV1 and FEV1/FVC ratio.
- **Step (30.5 cm Height):** For VO2 max testing.
- **Heart Rate Monitor**: To measure heart rate after performing step test.
- **Measuring Tape:** For Measuring Height.
- **Weighing Machine**: For Measuring Weight
- **Data Collection Sheet:** To Keep Data Records.
- **Consent Form:** For Willingness of patient.

6. METHEDOLOGY:

Source of data - Sugarcane Factory in Kopargaon, Ahilyanagar (423601)
Study design – Cross Sectional Study.
Sample population – Workers of Sugarcane factory
Sampling method – Simple Random Sampling Method.
Sample size – 155
Participants - Workers of Amrut Sanjivani Sugarcane Factory , Kopargaon .
Study duration- 6 months.

7. INCLUSION CRITERIA

1. **Age**: Participants must be between 20 and 60 years old to ensure they are of working age and can provide informed consent.
2. **Gender** : Male and female
3. **Employment Duration**: At least three or more than three years of experience working in the sugarcane industry to ensure sufficient exposure to the occupational environment.
4. **Willingness to Participate**: Participants must be willing to undergo lung function and aerobic capacity assessments.
5. **General Health**: Participants should be in general good health, without any known chronic respiratory or cardiovascular diseases.

8. EXCLUSION CRITERIA

1. **Chronic Respiratory Conditions**: Individuals with a history of chronic respiratory diseases (e.g., asthma, chronic obstructive pulmonary disease [COPD], bronchitis) will be excluded to minimize confounding effects on lung function results.
2. **Cardiovascular Issues**: Participants with diagnosed cardiovascular conditions (e.g., heart disease, hypertension) will be excluded due to potential risks during aerobic testing.
3. **Recent Respiratory Infections**: Individuals who have experienced respiratory infections (e.g., pneumonia, flu) within the past month will be excluded, as these can affect lung function measurements.

4. **Medications**: Participants currently taking medications that affect respiratory function or cardiovascular performance (e.g., bronchodilators, beta-blockers) may be excluded or require medical clearance.

9. OUTCOME MEASURES

A. Pulmonary Function Tests (PFTs): Pulmonary function was objectively assessed via spirometry, using standardized protocols. The following key parameters were recorded:

- Forced Vital Capacity (FVC, in liters): The maximum amount of air that can be forcibly exhaled after full inspiration, reflecting lung volume and compliance.
- Forced Expiratory Volume in 1 Second (FEV_1, in liters): The volume of air exhaled during the first second of the FVC maneuver, indicating airway patency and resistance.
- FEV_1/FVC Ratio (in %): The proportion of the vital capacity expelled in the first second; used to differentiate between obstructive and restrictive ventilatory patterns.
- Lung Function Categorization: Based on the above, subjects were classified as having normal, obstructive, restrictive, or mixed patterns by established spirometric criteria.

Lung Function Pattern Classification Criteria:

- **Obstructive:** FEV_1/FVC ratio < 0.7 and $FEV_1 < 80\%$ predicted
- **Restrictive:** FVC $< 80\%$ predicted and FEV_1/FVC ratio ≥ 0.7
- **Mixed:** Both FVC $< 80\%$ predicted and FEV_1/FVC ratio < 0.7
- **Normal:** FVC $\geq 80\%$, $FEV_1 \geq 80\%$, and FEV_1/FVC ratio ≥ 0.7

B. Aerobic Capacity (VO_2 Max): Aerobic capacity was estimated using the YMCA 3-Minute Step Test, which provides a field-based assessment of cardiovascular fitness. The main outcomes were:

- VO_2 Max (ml/kg/min): The maximal oxygen uptake, calculated from post-exercise heart rate using gender-specific formulas:
- For males: VO_2 Max = 111.33 – (0.42 × post-exercise heart rate)
- For females: VO_2 Max = 65.81 – (0.1847 × post-exercise heart rate)
- Fitness Classification: VO_2 Max values were compared to age-specific normative data to classify aerobic capacity as superior, excellent, good, fair, or poor.

Test	Validity Metrics	Reliability (ICC / Error)	References
Spirometry	ICC ≈ 0.90–0.95; bias ≈ <50–150 mL	ICC ≈ 0.76–0.95; excellent reproducibility	[19],[20],[21],[22]
YMCA Step Test	r ≈ 0.61–0.77; r^2 ≈ 0.37–0.59; SEE ≈ 4.5 mL/kg/min	ICC ≈ 0.85 vs VO_2max; test–retest error ≈ ±3.7 mL/kg/min (~8%)	[23],[24],[25],[26]

10. PROCEDURE

A cross-sectional study was conducted among sugarcane factory workers at Sugarcane Factory at Kopargaon , following institutional ethical approval. Participants were divided into two groups based on occupational exposure: **The Direct Exposure Group** (workers involved in high-dust environments such as the boiler/crushing/bagasse handling units) and **The Indirect Exposure Group** (workers in administrative, packaging, or storage sections with minimal dust exposure). All eligible subjects provided written informed consent prior to participation.

Participant Recruitment & Screening: Subjects were recruited after confirming eligibility according to predefined inclusion and exclusion criteria. Demographic and health history (age, gender, smoking status, respiratory and cardiovascular history) were documented. Exclusion criteria included known chronic respiratory or cardiac disease unrelated to occupation, recent infection, or inability/unwillingness to participate.

Anthropometric and Baseline Measurements: Height and weight were measured using standard equipment to calculate body mass index (BMI). Resting heart rate and oxygen saturation (SpO_2) were recorded prior to testing.

Pulmonary Function Testing (Spirometry)

Pulmonary function was tested using a computerized RMS portable spirometer, in accordance with ATS/ERS guidelines. Tests were performed in the seated position, between 10:00 am and 12:00 pm, and each subject performed at least three forced expiratory maneuvers for accuracy. The highest values for Forced Vital Capacity (FVC), Forced Expiratory Volume in 1 second (FEV_1), and the FEV_1/FVC ratio were recorded. Lung function impairment patterns (normal, obstructive, restrictive, mixed) were classified per standard criteria.

Aerobic Capacity Assessment (YMCA 3-Minute Step Test)

Aerobic capacity was estimated using the standardized YMCA 3-Minute Step Test:

- Participants stepped up and down a 12-inch (30.5 cm) platform at 24 steps per minute, kept via metronome, for three minutes.
- Immediately after finishing, subjects sat down, and after 5 seconds, their heart rate (beats per minute) was measured for one full minute.

The VO_2 Max (maximal oxygen uptake) was estimated using post-test heart rate, with gender-specific

Males:

VO_2 Max (ml/kg/min) = 111.33 – (0.42 × heart rate after test)[18]

Females:

VO_2 Max (ml/kg/min) = 65.81 – (0.1847 × heart rate after test)[18]

11. RESULTS

The study classified the lung function of sugarcane factory workers into four categories—Normal, Obstructive, Restrictive and Mixed—based on standard spirometric criteria (FVC, FEV_1 and FEV_1/FVC ratio). The distribution of these categories was analysed in two groups defined by occupational exposure level: Direct Exposure (workers exposed to high dust and bagasse environments) and Indirect Exposure (workers with minimal dust exposure).Among the Direct Exposure group (N=57), only 31.6% (n=18) of workers exhibited normal lung function. In contrast, a majority of workers in the Indirect Exposure group (N=98) demonstrated normal spirometry, accounting for 68.4% (n=67) of participants. This significant difference indicates a pronounced impact of dust exposure on pulmonary health. The obstructive pattern was the most prevalent abnormality observed in the Direct Exposure group, affecting 36.8% (n=21) of workers, compared to 15.3% (n=15) in the Indirect group. This implies greater airway obstruction likely related to inhalational exposure in the factory environment. Restrictive impairments were identified in

21.1% (n=12) of directly exposed workers, double the prevalence of 10.2% (n=10) seen in the indirect exposure group, suggesting that chronic exposure may also contribute to reduced lung volumes. Mixed patterns, characterized by concurrent obstructive and restrictive features, were relatively less common but still more frequent in the Direct Exposure group (10.5%) than in the Indirect group (6.1%).

Lung Function	Direct Exposure (N=57)	Indirect Exposure (N=98)
Normal	18 (31.6%)	67 (68.4%)
Obstructive	21 (36.8%)	15 (15.3%)
Restrictive	12 (21.1%)	10 (10.2%)
Mixed	6 (10.5%)	6 (6.1%)

Age Group (years)	N (Direct)	FVC (L) Mean ± SD (Direct)	FEV_1 (L) Mean ± SD (Direct)	FEV_1/FVC (%) Mean ± SD (Direct)	VO_2 Max (ml/kg/min) Mean ± SD (Direct)	N (Indirect)	FVC (L) Mean ± SD (Indirect)	FEV_1 (L) Mean ± SD (Indirect)	FEV_1/FVC (%) Mean ± SD (Indirect)	VO_2 Max (ml/kg/min) Mean ± SD (Indirect)
28–37	18	3.34 ± 0.38	1.98 ± 0.44	70.94 ± 11.24	58.95 ± 9.13	34	3.41 ± 0.46	2.43 ± 0.54	74.49 ± 8.85	66.32 ± 8.9
38–47	22	2.62 ± 0.49	1.91 ± 0.41	70.21 ± 10.75	54.78 ± 11.98	44	3.30 ± 0.51	2.41 ± 0.53	78.03 ± 8.95	63.11 ± 10.18
48–57	17	2.47 ± 0.47	1.86 ± 0.38	70.88 ± 9.80	52.12 ± 12.02	20	3.18 ± 0.62	2.37 ± 0.46	79.08 ± 7.45	61.44 ± 9.97

DISTRIBUTION ACCORDING TO AGE :

The pulmonary function and aerobic capacity of sugarcane factory workers were analysed across three age groups: 28–37 years, 38–47 years, and 48–57 years, separately for workers with direct and indirect occupational exposure.

In the Direct Exposure group, mean Forced Vital Capacity (FVC) and Forced Expiratory Volume in 1 second (FEV_1) showed a gradual decline with increasing age, from 3.34 ± 0.38 L and 1.98 ± 0.44 L in the 28–37 years group to 2.47 ± 0.47 L and 1.86 ± 0.38 L in the 48–57 years group, respectively. The FEV_1/FVC ratio remained relatively stable across age groups (approximately 70%). Aerobic capacity

measured as VO_2 Max also decreased with age, from 58.95 ± 9.13 ml/kg/min to 52.12 ± 12.02 ml/kg/min. Similarly, the Indirect Exposure group demonstrated overall higher pulmonary function values and VO_2 Max across all age groups compared to the Direct group. Although slight declines with age were observed, the mean FVC remained above 3.1 L, FEV_1 above 2.3 L, and VO_2 Max above 61 ml/kg/min, indicating better preserved lung function and fitness relative to directly exposed workers.
These findings suggest that advancing age is associated with expected reductions in pulmonary and aerobic capacity in sugarcane factory workers, but the impact of direct occupational dust exposure exacerbates this decline. The consistently lower values in the Direct Exposure group across all age bands underscore the detrimental effects of occupational hazards on respiratory health and cardiorespiratory fitness.

Descriptive Statistics

I.PFT:

Parameter	Direct Exposure (N=57)	Indirect Exposure (N=98)
FVC (L)	Mean ± SD: 2.85 ± 0.60	Mean ± SD: 3.26 ± 0.66
FEV_1 (L)	Mean ± SD: 2.00 ± 0.57	Mean ± SD: 2.61 ± 0.47
FEV_1/FVC (%)	Mean ± SD: 71.0 ± 11.3	Mean ± SD: 80.1 ± 8.6

- Normality test (Shapiro-Wilk): All parameters were significantly non-normal in at least one group ($p < 0.05$ for each).
- Statistical test chosen: Mann-Whitney U test (non-parametric).

Comparative Statistics

Parameter	Test Used	Test Statistic (U)	p-value	Interpretation
FVC (L)	Mann-Whitney U	1,465.0	0.00001	Indirect > Direct, significant difference
FEV_1 (L)	Mann-Whitney U	1,110.5	0.000001	Indirect > Direct, highly significant difference
FEV_1/FVC (%)	Mann-Whitney U	1,644.0	0.00002	Indirect > Direct, significant difference

- FVC: The mean FVC was significantly lower in the direct exposure group (2.85 ± 0.60L) compared to the indirect group (3.26 ± 0.66L), Mann-Whitney U = 1,465.0, p = 0.00001.

- FEV_1: The mean FEV_1 was significantly lower in the direct exposure group (2.00 ± 0.57L) compared to the indirect group (2.61 ± 0.47L), U = 1,110.5, $p = 0.000001$.
- FEV_1/FVC Ratio: The FEV_1/FVC ratio was significantly lower in the direct group (71.0 ± 11.3%) versus indirect (80.1 ± 8.6%), U = 1,644.0, $p = 0.00002$.

II. Aerobic capacity (VO_2max)

- Mean VO_2 Max Direct: 55.56 ± 11.44 ml/kg/min (N=57)
- Mean VO_2 Max Indirect: 65.36 ± 10.10 ml/kg/min (N=98)
- Normality: Both groups significantly non-normal (SW $p < 0.05$)
- Mann–Whitney U: U = 734.0, $p = 0.000002$

"VO_2 Max was significantly lower in the direct exposure group (55.56 ± 11.44 ml/kg/min) compared to the indirect exposure group (65.36 ± 10.10 ml/kg/min). This difference was highly significant (Mann–Whitney U = 734.0, $p = 0.000002$), indicating that direct occupational exposure is associated with markedly reduced aerobic capacity among sugarcane factory workers."

Parameter	Direct Exposure (N=57) Mean ± SD	Indirect Exposure (N=98) Mean ± SD
VO_2 Max (ml/kg/min)	55.56 ± 11.44	65.36 ± 10.10

12. DISCUSSION

This cross-sectional study titled "Lung Function and Aerobic Capacity Among Sugarcane Factory Workers in Kopargaon " was conducted among 155 workers at a sugarcane factory in Maharashtra, India. Participants were divided into two groups based on their occupational exposure: 57 workers in the Direct Exposure group, who were actively involved in dust-intensive areas such as the boiler, crushing, and bagasse handling sections, and 98 workers in the Indirect Exposure group, employed in administrative, packaging, or storage units with minimal dust exposure. The study population predominantly included males aged 28 to 57 years, with comparable anthropometric characteristics across groups. Pulmonary function was assessed using computerized spirometry measuring forced vital capacity (FVC), forced expiratory volume in 1 second (FEV_1), and FEV_1/FVC ratio, while aerobic capacity was estimated via the YMCA 3-minute step test to calculate VO_2 Max. Lung function impairments were categorized into normal, obstructive, restrictive, and mixed patterns, revealing a higher prevalence of respiratory dysfunction among directly exposed workers. This grouping enabled a comprehensive evaluation of the impact of occupational sugarcane dust exposure on respiratory health and aerobic performance.The results revealed significant reductions in pulmonary function and aerobic capacity in workers with direct occupational exposure, compared to those indirectly exposed:

- Pulmonary Function Decline: Directly exposed workers exhibited significantly lower mean Forced Vital Capacity (2.85 ± 0.60 L vs. 3.26 ± 0.66 L), Forced Expiratory Volume in 1 second (2.00 ± 0.57 L vs. 2.61 ± 0.47 L), and FEV_1/FVC ratio (71.0% ± 11.3% vs. 80.1% ± 8.6%) compared to indirectly exposed workers.
- Higher Prevalence of Lung Impairment: Obstructive, restrictive, and mixed lung impairment patterns were more common in the Direct Exposure group (36.8%, 21.1%, and 10.5%, respectively) than in the Indirect group (15.3%, 10.2%, and 6.1%, respectively). Only 31.6% of directly exposed workers had normal lung function, compared to 68.4% among indirectly exposed workers.

- Reduced Aerobic Capacity: VO_2 Max was markedly lower in the Direct Exposure group (55.56 ± 11.44 ml/kg/min) compared to the Indirect Exposure group (65.36 ± 10.10 ml/kg/min), reflecting impaired cardiovascular and respiratory fitness in the dust-exposed workers.

Collectively, these findings indicate that occupational inhalation of airborne sugarcane dust and bagasse dust significantly compromises respiratory function and aerobic capacity, potentially leading to increased morbidity and reduced work performance.

Comparison with Previous Studies

Our findings align well with previous research on occupational respiratory health in agricultural and industrial settings:

- Patil et al. (2008) similarly reported impaired pulmonary function among sugar factory workers in Western Maharashtra, with exposed workers showing restrictive and obstructive deficits consistent with our observations.
- Pawar et al. (2019) emphasized the cumulative impact of work duration on respiratory health, noting progressive lung function decline with increasing exposure, a trend supported by our age-stratified data displaying further decreases in pulmonary indices with advancing age in the Direct Exposure group.

The present study clearly demonstrates that direct occupational exposure to sugarcane dust and bagasse in factory environments is associated with significantly reduced pulmonary function, higher prevalence of obstructive and restrictive lung impairments, and lowered aerobic capacity compared to minimal-exposure counterparts. These findings not only reinforce earlier evidence from similar agro-industrial settings but also highlight the urgent need for targeted preventive measures, such as effective dust-control technologies, regular respiratory health surveillance, and promotion of physical fitness among exposed workers. By recognizing occupational dust exposure as a modifiable risk factor, industry stakeholders, occupational health professionals, and policymakers can work collaboratively to safeguard respiratory health, preserve work capacity, and ultimately improve the quality of life for this vulnerable workforce.

13. LIMITATIONS

Despite offering valuable insights into the effects of occupational dust exposure on respiratory health and aerobic capacity among sugarcane factory workers, this study is subject to several limitations. The cross-sectional design restricts the ability to infer causal relationships or assess the progression of pulmonary impairment over time. Direct quantitative measurements of workplace dust exposure were not conducted, limiting the precision of exposure-response analysis. The study did not extensively control for potential confounding variables such as smoking history, socioeconomic status, or undiagnosed comorbidities, which could influence lung function results. The use of generalized spirometry reference values rather than region-specific norms may also affect the accuracy of categorizing lung function patterns. Additionally, the research was confined to a single factory with a relatively modest sample size, potentially limiting the generalizability of the findings to other settings or populations within the sugarcane industry. Future longitudinal studies with broader covariate adjustment and environmental exposure monitoring are recommended to address these limitations.

14. FUTURE SCOPE

Future research should focus on prospective longitudinal studies to track the progression of lung function decline and aerobic capacity impairment over time with continued occupational exposure to sugarcane dust and bagasse particles. Incorporating quantitative environmental monitoring of dust concentration directly in worker breathing zones, coupled with biomarkers of exposure and early lung injury, will refine exposure-response relationships and risk assessments. Intervention studies evaluating the effectiveness of engineered dust control measures, personal protective equipment adoption, and workplace health promotion programs are also warranted to establish best practices for reducing occupational hazards. Expanding investigations to include genetic susceptibility, immunological responses, and comprehensive assessments of musculoskeletal and psychological health will provide a more holistic understanding of worker wellbeing in this industry. Collectively, these efforts can guide evidence-based policy formulation and targeted occupational health strategies to safeguard the long-term respiratory and cardiovascular health of sugarcane factory workers.

15. CONCLUSION

This study highlights significant adverse effects of direct occupational exposure to sugarcane dust and bagasse on pulmonary function and aerobic capacity among factory workers. The high prevalence of obstructive, restrictive, and mixed lung impairments, coupled with reduced VO_2 Max, emphasizes the critical need for enhanced occupational health surveillance, exposure control and worker health promotion measures in the sugar industry. Addressing these issues will improve worker safety, productivity, and long-term respiratory health in this vital agro-industrial sector.

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