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Exposure Levels to Dust in Grain Storage and Milling among the Selected Mill Workers in Greater Gaborone District, Botswana

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Abstract

The different processes of grain milling generate dust, which can be inhaled as respirable or inhalable dust, may contain hazardous substances that can cause eye or skin irritation, acute and chronic health effects on the respiratory system, or impaired lung function leading to worker disability. There is currently limited literature on exposure levels to dust among mill workers in Botswana. The study's aim was to assess the exposure levels to dust in grain storage and milling among mill workers in the Greater Gaborone District. A cross-sectional analytical study was conducted among 176 mill workers in eight (8) grain mills. Data was collected through a modified standardized British Medical Research Council (BMRC)Structured questionnaire, Key Informant Interviews, and an observation checklist. A particulate matter counter, JD3003, was also used to collect dust samples from three fixed points, i.e., milling, packaging, and storage, to measure exposure levels for PM2.5 and PM10. SPSS v29 and Stata 14 were used for data analysis. This study recorded high arithmetic mean dust concentrations of 39.0µg/m^3 for PM2.5 and 127.7 µg/m^3 for PM10. These concentrations exceeded the World Health Organization Air Quality limits of PM2.5, 5µg/m^3, and PM10, 15µg/m^3. The highest dust concentrations were recorded in milling sections, followed by packaging areas in all the mills. Prolonged work shifts (> 8 hours) were linked to 18.4% higher PM2.5 and 44.2% higher PM_{10} dust exposure levels. A proportion of workers presented with chronic respiratory symptoms (39.2%), skin problems or irritation (4.6%), and itching or tearing eyes (8%), indicating health implications of exposure to high grain dust concentrations. Safety training and PPE use were associated with increased exposure to dust. These findings underscore the need to strengthen preventive safety measures and policy enforcement to address non-adherence to safety protocols.

Keywords: *Grains milled, Exposure levels, Factors associated, Safety measures*

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1. Introduction

The milling industry exposes workers to hazards, including physical, biological, chemical, ergonomic, and psycho-social despite the efforts through Occupational Safety and Health (OSH)for many years. These exposures go to the extent of workers losing their lives.

Occupational exposures to grain dust are still a global challenge and accounted for close to 12% of deaths associated with Chronic Obstructive Pulmonary Diseases in 2019 (International Labour Organisation [ILO], 2023).

Generally, grain dust consists of organic and inorganic particles that can easily become airborne and be inhaled by workers as respirable or inhalable dust, affecting their lung functions and further posing risks to their quality of life and productivity. The history of respiratory diseases associated with inhalation of grain dust dates as far back as 1555, when Olaus Magnus and 1713, Bernardino Ramazzini, found that grain workers in sifting and weighing sections experienced difficulty in breathing and on rare occasions reached older age (Martinelli et al., 2020).

The Global estimates by the ILO (2023) indicated that in 2019,2.93 million employees worldwide died due to workplace factors, and this was an increase of 12% more than in 2000. These deaths were mostly aggravated by factors such as socio-demographic and occupational exposure risks. Asia and the Pacific recorded the highest work-related deaths at 63%, while the highest attributable fraction of work-related deaths was estimated as follows: Africa 7.39 %, Asia and the Pacific 7.13 % and Oceania 6.52 %. Among these deaths, 2.6 million were associated with occupational diseases, and work-related respiratory diseases were among the three that contributed three-quarters of total work-related mortality. This concurs with Blanc et al. (2019) in their study, where they indicated that occupational exposures increase the burden of non-malignant lung conditions in adults, as indicated by the following Population Attributable Fractions (PAF): idiopathic pulmonary fibrosis 26%, chronic obstructive pulmonary disease 14%, Asthma 16% and chronic bronchitis 13%.

Generally, studies reveal that exposure to grain dust in different industrial settings is still a challenge; exposure to flour dust was noted to be the second cause of occupational Asthma at 38.8 cases per 100,000 population in the United Kingdom, Health and Safety Executive (2020). In Ethiopia, flour mill workers had a 58.3% prevalence of chronic respiratory health issues. Furthermore, factors such as age group, monthly salary, work and dust exposure experience, and use of respiratory protection equipment were linked to the health symptoms (Alemseged et al., 2020). Ensuring work safety is a critical aspect to be considered by organizations as it directly affects the well-being and productivity of employees.

The global status indicates that Botswana is also affected by the prevalence of diseases and injuries associated with work. It is important, therefore, to assess the health and safety of the mill workers in Botswana as the grain milling industry is Botswana's greatest source of food due to factors including the traditional consumer preference for sorghum meal and strong financial support to millers from the government (Ofentse, 2022). There is currently limited regional and local literature on mill workers' exposure levels to grain dust. Studies conducted globally mostly focused on exposure levels to flour dust in bakeries with control groups from different industries, and a few on the milling industry. The study aimed to assess the exposure levels to dust in grain storage and milling among the selected mill workers in the Greater Gaborone District, Botswana.

1.1 Problem Statement

This study was influenced by the growing global concern over the health implications of exposure to dust particles from grain and flour dust among workers in milling enterprises. Botswana is not excluded from the global concern for reasons that Agriculture is among Botswana's important economic sectors and covers around 2% of the Gross Domestic Product

(GDP). The agriculture sector also employed about 23% of Botswana's total workforce in 2018 (World Bank, 2019).

The health implications of exposure to dust have been noted in different studies, implying the need to intensify safety culture at workplaces. A study conducted in Nigeria highlighted that flour-millers had lower mean lung functions than the control group. The findings showed that, in comparison to 15% external and 10% of internal controls, 29% of flour millers had at least one abnormal ventilatory function test result, and airway obstruction was identified as the dominating pattern of respiratory disease (Iyogun et al., 2019). Abdulrahman et al. (2022) study showed that 31.7% workers had impaired lung function and presented with the following: sneezing 25 %, rhinorrhea in 20.6%, change of voice in 12.7%, chest wheeze in 20.6%, and 28.6% had dyspnea.

The mill workers in the area of study are likely to present with acute or chronic respiratory symptoms, irritation of the eyes, nose, throat, and skin associated with the grains milled. The Global estimates indicated that in 2019, Botswana had 72.65 deaths per 100,000 population due to lower respiratory tract infections, which were noted to be the second leading cause of deaths (WHO, 2020). The District Health Information System (DHIS2) extracts for 2019 and 2023, respectively, indicated that the Greater Gaborone District experienced higher cases of respiratory infections, 33265 and 113292 (Pneumonia, Asthma, and Influenza-like symptoms), than the second City, Greater Francistown, 22230 and 65154. The DHIS2 reports do not indicate cases associated with occupational exposure to dust to ensure evidence-based interventions. Based on the above background, the study was purposively conducted in the Greater Gaborone District.

1.2 Research Objectives

i. To establish the types of grains stored and milled among the selected mills in the Greater Gaborone District.
ii. To determine the exposure levels to dust in grain storage and milling among the selected mill workers in the Greater Gaborone District.
iii. To establish the factors associated with exposure levels to dust in grain storage and milling among the selected mill workers in the Greater Gaborone District.
iv. To identify the available grain dust safety measures in storage and milling among the selected mills in the Greater Gaborone District.

2. Literature Review

2.1 Types of grains stored and milled among the mills

The mills mostly process different grains like Maize, Sorghum, wheat, and rice, which can comprise mixtures of organic and inorganic materials, contaminants not limited to fungal, bacterial, and pesticides. Occupational exposure to grain and flour dust can have adverse effects on the respiratory system, eyes, and skin. These reactions to grain and mill dust can increase the prevalence and incidence of dust-related respiratory conditions, trigger allergic reactions or existing conditions, and increase work-related deaths (Enitan et al., 2023). The gaps in safety measures in the workplace have negative effects on the health and safety of workers.

Mohamad Asri et al. (2020) in their study in Malaysia respectively highlighted a 2.22 ng/m3 ± 0.07 and 0.25 ng/m3 ± 0.24 mean airborne Aflatoxin B1(AFB1) at the rice mill area and personal exposure. The AFB1 mean contamination level of 0.25 ng/ml was detected on the hands of two rice millers (2.3%) and not detected in non-exposed workers, while wheezing and breathlessness (n = 6, 9.2%) were noted among rice millers.

The association of flour and grain dust with respiratory and skin reactions is revealed in studies from different regions. In India, the findings indicated a high prevalence of allergic disorders. The respondents presented with nasal congestion, cough, eczema, wheezing, poor sense of smell, shortness of breath, itchy nose, headache, and sneezing due to flour dust. The workers also reported skin problems, including skin rash, itching, dry skin, swelling, and blistered rashes (Lohani et al., 2020).

Furthermore, Lagiso et al. (2020) reported a higher prevalence of chronic respiratory symptoms among flour mill workers than soft drink workers (56.6% vs.12.9). Elghazally et al. (2023) also revealed that 36.4% out of 94% male flour mill workers aged 19-60 had pulmonary function abnormalities, while 20.7% were diagnosed with Bronchial Asthma. Abnormal pulmonary function tests were noted in workers more than 40 years old, who had worked for over 10 years, and those with low educational levels. It is important then to conduct risk assessments and evaluate the work environment, assess production processes, equipment, and working practices. These will help to ensure that possible risks are addressed and that the required safety measures are taken.

2.2 Exposure levels to dust in grain storage and milling

Various factors can lead to exposure to dust above expected levels, for example, safety practices, workstations, duration of work, experience, and years of work. Studies conducted globally have noted exposures above the set standards, OEL (10mg/m3). This was noted among studies conducted in different regions for different cereals or grains. In Bangladesh, a higher frequency of respiratory symptoms (41.3% and 39.8%, respectively was recorded among rice mill workers who had worked more than 10 hours and over 15years. The milling section displayed higher than average dust concentration levels (PM 2.5 492.1 µg/m3) than other working areas (Choudhury et al., 2023). Furthermore, (Lamba et al.,2025) in Indonesia reported the highest dust concentrations in the milling (17.77 µg/m^3) and packaging (15.68 µg/m) sections than in other sections.

In a study done in Tanzania, the findings revealed that 26% and 21% of grain workers were exposed to higher dust levels of GM 12.15mg/m3 (GSD 1.53) than the control GM 0.17mg/m3(GSD 0.35). The majority of workers 66.7% were exposed to dust concentrations above the OEL (10mg/m3), leading to a higher prevalence of respiratory symptoms than the control group (Ulanga et al., 2021). (Daniel et al., 2022) also reported values of dust measured in the two rice mills, which were greater than 15 mg/m3 OEL, ranging from 18.22- 34.88 mg/m3 and 10.50-21.05 mg/m3.

The exposure level challenges highlight the need for improved safety control measures, such as dust collectors, filters, training, supervising workers on safety measures, medical examinations, hazard identification, and audits. These measures will help align services with the Occupational Safety and Health goal, hence prevent work-related injuries, illnesses, and mortality.

2.3 Factors associated with exposure levels to dust in grain storage and milling

According to the ILO (2020), Micro Small and Medium-Sized Enterprises (MSMEs) generally face poor occupational safety and health (OSH) conditions, a low level of awareness and compliance with OSH standards, which expose their workers to safety and health risks. The limited resources also hinder their efforts to improve working conditions. Mekonnen et al. (2021) in Ethiopia reported 63.9% and 20.7% higher prevalence of respiratory symptoms among flour mill workers than the control groups, respectively. Factors such as age over 35, lack of education, inadequate ventilation, work experience of more than 5 years, and lack of safety training were linked with respiratory symptoms among the flour mill workers. The study concluded that age, monthly salary, and exposure status significantly influenced respiratory symptoms in both exposed and unexposed models.

A study in Bangalore rural revealed that 82% of flour mill workers had below average knowledge, 10% average knowledge, and only8% had good knowledge regarding the negative effects of grain dust (Usha et al., 2023). (Siddique et al., 2024) found that 52.2%, of the workers used protective equipment 47.8% did not use any protective measures, while Seema et al. (2020) noted that usage of PPEs was only among 126 (64%) workers.

In view of the above results, employers should implement health and safety programs to reduce dust at the point of origin. This will help to protect workers from prolonged exposure to high levels of grain and flour dust, which causes respiratory diseases such as Chronic Obstructive Pulmonary Disease (COPD). The employers can ensure a healthy and safe environment through the provision of adequate ventilation systems, training programs, health assessments, and personal protective equipment (Asgedom, 2023).

2.4 Available safety measures in Grain Storage and Milling

According to the Control of Substances Hazardous to Health(COSHH), concentrations of dust that exceed 10.0 mg/m3 or 4.0 mg/m3 for inhalable and respirable dust, respectively, expose workers to respiratory problems. Different studies have revealed exposure levels above the Occupational Exposure limits according to different regional guidelines and further highlighted recommendations in line with gaps in safety measures.

Mishra et al. (2024) in their study recorded high dust levels of PM2.5 (330–385 µg m-3) and PM10 (420–470 µg m-3) and health issues, including respiratory problems (20%), shortness of breath (31.4%), eye irritation (8.6%), and headache (11.4%), among workers. The study then recommended improved ventilation, implementation of appropriate personal protective equipment, regular medical care, and installation of exhaust systems. Meanwhile, Matosa and Cardosob (2024) also found that all values obtained exceeded the Exposure Limit Value TWA 0.5 mg/m3 proposed by the Standard NP 1796:2014, indicating the need for mitigation with PPE like FFP3 masks to protect workers.

Rashmi et al. (2022) reported that the structured teaching programme on prevention of occupational health hazards among flour mill workers was logical and cost-effective. Flour mill workers also approved the teaching program to enhance the prevention of occupational health hazards.

3. Materials and Methods

3.1 Research Design

A cross-sectional analytical design was used to collect data from the mill workers at a single point in time and to investigate the association between a risk factor and a health outcome. The design also addressed how or why a certain outcome might occur in environments where workers are exposed to a hazard. The design helped to gather information on the study's aim, questions, and objectives. The design assisted in setting up future steps to be taken to ensure that the practices in the milling companies are aligned with the current emerging occupational health and safety needs, and also to address the outcomes related to exposures above the estimated limits.

3.2 Sampling Techniques and Sample Size Determination

The stratified sampling technique was utilized to select eight (8) milling companies across various areas of the Greater Gaborone District. Mill workers were selected through simple random sampling from areas directly involved in the milling processes, that is, milling, packaging, and storage. The sampling techniques helped to minimise bias and identify participants to provide appropriate and useful information. A sample size of 170 out of 303 was determined using the Krejcie & Morgan (1970) method.

3.3 Data Collection Techniques

A modified standardized British Medical Research Council (BMRC)structured open-ended questionnaire, and Key Informant interviews were used to interview workers and to obtain the company's profile. An observation checklist was used to conduct a walk-through survey to assess the working conditions. A dust particle counter, JD3003, was used to collect dust samples from each milling company. The dust samples were collected from 3 fixed points: milling, packaging, and storage on different days to estimate dust exposure limit levels for Long-term Time Weighted Average (TWA 8hrs) exposure to particulate matter PM2.5 and PM10.

3.4 Data Analysis

Data analysis was performed using Statistical Package for Social Sciences version 29 (SPSS V29.0), Stata 14, and Microsoft Excel. The results were presented as percentages and frequencies, and standard deviation as a measure of variability. Relationships and associations were tested at a 95% confidence interval ($p < 0.05$). The descriptive results of dust exposure levels were described by the arithmetic mean. A linear regression model was used to identify significant determinants for average dust exposure levels among mill workers. The dust exposure levels were concluded based on the analysed exposure data in line with the WHO, AQG 2021 for PM 2.5 and PM 10(5ug/m3, 15ug/m^3) respectively.

3.5 Conversion of Particle Counts to Mass

The JD3003 measures particles per unit volume in the air (N/L). As PM_{10} and $PM_{2.5}$ are mass-based, data from the JD-3003 device were transformed using below

Equation 1 (Hinds, 1999; Franken et al., 2019). Where C_m is mass concentration (µg/m^3), ρ_p Particle density (g/cm^3), C_{number} number concentration (particles/m^3), and d the particle size in the size bin (µm).

$$C_m = \frac{\pi}{6}.d^3.C_{number} \qquad 1$$

Equation 1: Particle number concentrations to mass concentrations equation

An average density of 1.65 g/cm^3 (equivalent to 1.65×10^{-6}µg/µm^3) was used for the mass conversion based on the average particle density for urban areas (Wu, T. and Boor, B. E., 2021). The results were expressed in micrograms per cubic meter of air (µg/m^3). Long-term (TWA 8hrs) exposure to particulate matter PM_{10} and $PM_{2.5}$ are represented mathematically by:

$$\frac{C_m \cdot T_n}{8} \qquad 2$$

(Where C_m is the occupational exposure, and T_n is the associated exposure time in hours.

3.6 Logistical and Ethical Considerations

The study was ethically approved, and permits were obtained. The consent was sought from the participating milling companies. Participation was voluntary, and participants were above 18 years old. Written informed consent was signed before participation. Interviews were held privately to ensure dignity and privacy. Study participants had the freedom to discontinue from the study anytime without consequences. Data was coded and protected with a password to ensure confidentiality and anonymity.

4. Results and Discussion

A total of 176 questionnaires were issued, all were filled out and returned for data analysis, indicating a 100% response rate.

4.1 Demographic characteristics of the respondents

Table 1 shows demographic characteristics of mill workers who participated in this study. Age ranged from 21 to 58 years with a mean of 29.32 ± 7.48. The analysis indicated that up to 129 (73.3%) respondents were between 21 and 30 years old. Nearly three-quarters (74.4%) of the studied workers were male. Regarding the highest education attained, the majority (93.8%) of the workers attained secondary education.

Table 1: Socio-demographic characteristics of respondents (n=176)

Characteristic	Frequency	Percent
Sex		
Male	131	74.43
Female	45	25.57
Age group (years)*		
20 to 30	129	73.30
30 to 40	30	17.05
40 to 50	12	6.82
50 to 60	5	2.84
Level of education		
Primary	9	5.11
Secondary	165	93.75
Technical	2	1.14
Marital status		
Married	13	7.39
Single	163	92.61

*Mean (±SD) of the participants is 29.32 (±7.48)

4.2 Types of grains stored and milled

Most mills in the survey handled more than one type of grain, including wheat, sorghum, maize, and millet, with wheat being universal across all mills. Two (2) medium-scale mills stored four types of grains, indicating the highest level of grain variety. The medium-scale workers worked in specific assigned areas, whereas the small-scale workers operated in all the working sections. The observation results revealed that all the mills stored grains differently, either in silos or 50kg bags in storerooms, where the cleaning process is also done to remove foreign particles or objects. The grain milling processes differed; that is, millet, sorghum, and maize are manually transported to the dehulling machines to remove bran, then milled through the hammer mill. Wheat grains are processed in the hammer mill without removing the bran. The milled grains/ flour are then manually weighed, packaged, and stored in sealed bags within the packaging area.

4.2.1 Medical information of the mill workers

Table 2 presents the medical history of the mill workers. A proportion of the mill workers (39.2%) reported having at least one chronic respiratory symptom, (4.6%) reported skin problems or irritation, and (8%) reported having itchiness or tearing of the eyes. There was no medical history of Asthma recorded among the respondents.

Table 2: Medical data of the respondents (n=176)

Characteristic	Frequency	Percent
At least one chronic respiratory symptom		
Yes	69	39.20
No	107	60.80
Have skin problems or irritation		
No	168	95.45
Yes	8	4.55
Have itchiness or tearing of the eyes.		
No	162	92.05
Yes	14	7.95

4.3 Exposure levels to dust in grain storage and milling among the selected mill workers

Three medium and five small-scale mills were assessed for exposure levels in three working sections (milling, storage, packaging). Generally, the daily activities for each section involved: off-loading grains and cleaning grains in the storage, milling grains at the milling section, manually weighing, packaging milled products and grains, and dispatching orders at the packaging section.

Table 3 presents the results of the levels of $PM_{2.5}$ and PM_{10} of various work sections in the (3 medium and 5 small-scale) target milling companies in Greater Gaborone, Botswana, respectively. The high concentration of $PM_{2.5}$ was found in the milling sections, followed by the packaging sections. This was consistent for all milling companies surveyed. The maximum $PM_{2.5}$ concentration was 108.8 $\mu g/m^3$ In the milling area. The high concentration of PM_{10} was also realized in the milling area, followed by the packaging area, with a PM_{10} maximum concentration of 591.3 $\mu g/m^3$.

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Table 3: Levels of PM2.5 and PM10 in various work sections in the target mill companies

Milling ID	Facility Scale	Milling		Storage		Packaging	
		PM2.5	PM10	PM2.5	PM10	PM2.5	PM10
A	Small	54	273.91	7.69	17.93	16.38	26.8
B	Medium	103.55	591.28	17.33	38.94	14.24	62.91
C	Small	33.45	54.02	8.46	21.12	23.15	39.39
D	Small	28.19	97.79	14.38	34.47	12.13	23.83
E	Medium	47.52	72.37	11.45	18.24	41.42	60.69
F	Medium	50.07	147.58	21.44	55.18	49.66	83.48
G	Small	59.56	296.08	28.96	88.65	56.38	276.28
H	Small	108.84	540.73	45.8	164.79	37.05	131.09

Note: unit = $\mu g/m^3$

Mean PM 2.5 and PM10 concentration at different working sections of the milling factories by scale

Table 4 shows that the milling section had the highest average concentrations of PM10 and PM2.5, at 259.2 µg/m³ and 60.7 µg/m³, respectively. The arithmetic total dust concentration of PM2.5 and PM10 were 39.0 µg/m³ and 127.7 µg/m³, respectively.

Table 4: Mean PM 2.5 and PM10 concentration at different working sections of the milling factories by scale

Section	$PM_{2.5}$ ($\mu g/m^3$)			PM_{10} ($\mu g/m^3$)		
	Small	Medium	**Total**	Small	Medium	**Total**
Milling	56.01	68.38	**60.65**	252.51	270.41	**259.22**
Storage	21.06	16.74	**19.44**	65.39	37.45	**54.92**
Packaging	29.02	35.11	**31.30**	99.48	69.03	**88.06**
Total dust concentration	**35.36**	**40.08**	**38.97**	**139.12**	**125.63**	**127.67**

4.4 Factors associated with exposure levels to dust in grain storage and milling

4.4.1Workplace and behavioral characteristics of the respondents

Table 5 shows the workplace and behavioral characteristics among mill workers surveyed. Majority of workers (81.8%) had between 1 and 5 years of employment at their current milling company. Nearly all workers (98.3%) were involved in cleaning the working areas, and more than three-quarters (76.7%) were working in the storage section. The majority, 167 (94.9%) of the study participants worked above eight hours per day. The majority (95.5%) worked for more than 5 days per week. Regarding personal protective equipment (PPE), the majority (94.3%) used PPE.

Table 5: Workplace and behavioral factors of the respondents (n=176)

Characteristics	Category	Frequency	Percent
Years of experience in milling (years)	0-5	144	81.82
	5- 10	26	14.77
	10-15	5	2.84
	15 and above	1	0.57
Job category*	Administration	13	7.39
	Grinding	75	42.61
	Packaging	112	63.64
	Storage	135	76.70
	Cleaning	173	98.30
Shift work	Day shift	52	29.55
	Sometimes day and night	168	70.45
Working hours per day	8 hours	9	5.11
	More than 8 hours	9	5.11
	Sometimes more than 8 hours	158	89.77
Working days per week	5	8	4.55
	>5	168	95.45
PPE use	Yes	166	94.32
	No	10	5.68
Smoking habits	Non-smoker	165	93.75
	Smoking	11	6.25

Note: *multiple responses. [a]Minimum years of experience is 2 years, and a maximum of 32 years.

4.4.2 Regression analysis

Linear model of log-transformed mean $PM_{2.5}$ and PM_{10} dust concentrations among workers in grain storage and milling in Greater Gaborone.

The distribution of the dust exposure measurements was positively skewed and was log-transformed before regression analysis. The model in Table 6 shows that types of grain stored (especially millet-containing mixes), prolonged working hours (> 8 hours), and provision of PPE and safety training significantly influenced PM2.5 dust exposure levels. The workplaces storing wheat, sorghum, and millet demonstrated 56.8% lower PM2.5 concentrations ($\beta = -0.84$, $p < 0.001$) compared to wheat-only facilities, while those storing all four grain types (wheat, sorghum, millet, and maize) showed 7.7% lower concentrations ($\beta = -0.08$, $p < 0.01$).

Working hours significantly affected exposure, with mill workers working more than 8 hours daily experiencing 18.4% higher PM2.5 dust concentration levels ($\beta = 0.17$, $p < 0.05$) compared to those working standard 8-hour shifts. Safety training correlated with 11.9% higher dust exposure ($\beta = 0.11$, $p < 0.001$), while PPE use correlated with 51.8% higher dust exposure ($\beta = 0.42$, $p < 0.001$). There were no statistically significant associations found between dust exposure levels and explanatory variables, including years of employment and specific job tasks involving grinding, cleaning, and storage.

Regarding log-transformed PM10 concentrations and dust exposure levels, mill facilities storing wheat and sorghum demonstrated 47.7% lower PM10 dust concentrations ($\beta = -0.65$, $p < 0.01$), while those storing wheat, sorghum, and millet showed 73.4% reduction ($\beta = -1.33$, $p < 0.001$) compared to facilities storing wheat only. In addition, the four-grain combination (wheat, sorghum, millet, and maize) was associated with 53.5% lower concentrations ($\beta = -0.77$, $p < 0.01$) compared to wheat-only facilities.

The mill workers consistently working more than 8 hours daily were experiencing 44.2% higher PM10 dust concentration levels ($\beta = 0.37$, $p < 0.05$) than those working standard 8 hours. PPE use was associated with 59.7% lower dust concentrations ($\beta = -0.91$, $p < 0.001$). Regarding safety training, the results are similar to what was observed in PM2.5 dust concentration: it was correlated with 125.8% higher exposure ($\beta = 0.81$, $p < 0.001$).

Table 6: Linear model of log-transformed mean $PM_{2.5}$ and PM_{10} dust concentrations among workers in grain storage and milling in Greater Gaborone

	PM2.5				PM10			
Determinants	**β(SE)**	**95%CI**	**Effect (e^{β})**	**p-value**	**β(SE)**	**95%CI**	**Effect (e^{β})**	**p-value**
Constant	3.88(0.042)	3.80 to 3.96		p≤0.001	5.50(0.093)	5.32 to 5.68		p≤0.001
Types of grain stored								
Wheat	Ref.				Ref.			
Wheat, sorghum	-0.15(0.113)	-0.37 to 0.07	0.861	0.188	-0.65(0.206)	-1.05 to -0.24	0.523	p≤0.01
Wheat, sorghum, millet	-0.84(0.054)	-0.95 to -0.73	0.432	p≤0.001	-1.33(0.129)	-1.58 to -1.07	0.266	p≤0.001
Wheat, sorghum, millet, maize	-0.08 (0.030)	-0.14 to -0.02	0.923	p≤0.01	-0.77 (0.052)	-0.87 to -0.66	0.465	p≤0.001
Years of employment in years								
1-5	Ref.				Ref.			
6-10	-0.04(0.064)	-0.17 to 0.08	0.957	0.498	-0.11(0.117)	-0.34 to 0.13	0.900	0.369
11+	0.02(0.015)	-0.01 to 0.05	1.021	0.163	0.02(0.041)	-0.06 to 0.10	1.020	0.626
Working hours								
8 hours	Ref.				Ref.			
More than 8 hours	0.17(0.065)	0.04 to 0.30	1.184	**0.010**	0.37(0.145)	0.08 to 0.65	1.442	**0.012**
Sometimes more than 8 hours	-0.08(0.049)	-0.18 to 0.02	0.924	0.107	-0.13(0.091)	-0.31 to 0.05	0.877	0.153
Provision of training on PPE use								
No	Ref.				Ref.			
Yes	0.11 (0.020)	0.07 to 0.15	1.119	**p≤0.001**	0.81 (0.052)	0.71 to 0.92	2.258	**p≤0.001**
Provision of Personal Protective Equipment (PPE)								
No	Ref.				Ref.			
Yes	0.42(0.053)	0.31 to 0.53	1.518	**p≤0.001**	-0.91(0.129)	-1.16 to -0.66	0.403	**p≤0.001**
Grinding, packaging, cleaning, and storage job tasks								
No	Ref				Ref			
Yes	-0.11(0.010)	-0.01 to 0.03	1.011	0.266	-0.11(0.010)	-0.03 to 0.04	1.006	0.740

Note: β=regression coefficients, SE= standard error of regression coefficient, Ref. = reference, effect e^{β}= exponentiated coefficient for each category of an explanatory variable that represents the ratio of the expected dust concentration for a category of an explanatory variable. Safety committee (audits), facility scale, and medical examination dropped due to collinearity.

4.5 Available grain dust safety measures

Figure 1 provides information on the reported dust management control measures by mill workers at milling companies in Greater Gaborone, Botswana. The majority of workers (94.9%) reported that their mill factories provide personal protective equipment. A quarter (25.00%) of mill workers in medium-scale reported that they received training on the usage of personal protective equipment.

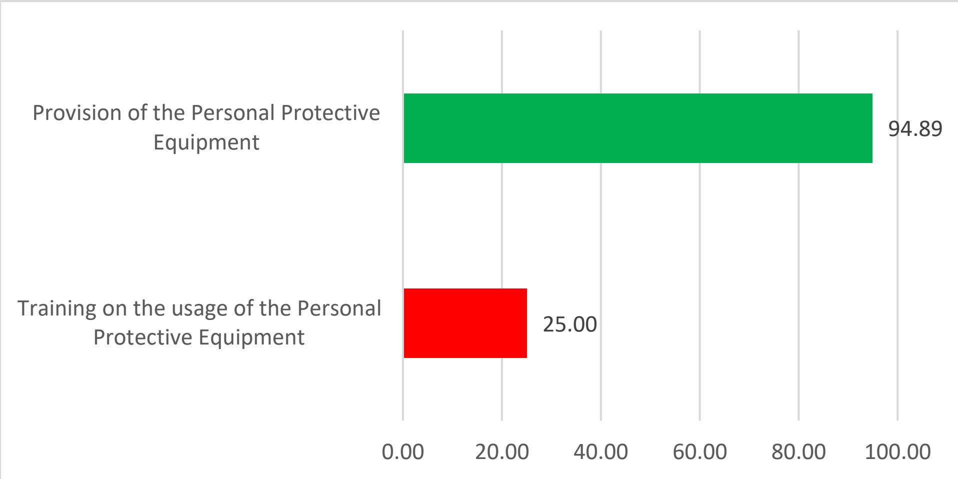

Figure 1: Reported dust control measures by mill workers in the 8 mill factories surveyed (n=176)

4.5.1 Key Informants Interviews (KII) on dust management control measures

Table 7 provides information on the reported dust management control measures by KIIs at milling companies in Greater Gaborone, Botswana. None of the 8 mill factories had conducted a formal risk assessment as required under the Factory Act Regulations. Regarding safety training, only 2 medium-scale mills provided safety training on PPE use.

Table 7: Key Informants' Interviews response to dust management control measures (n=8)

Dust management control measures	Number of mill factories (n=8)	
	Yes	No
Formal risk assessment under the Factory Act Regulations	0	8
Health and Safety training on PPE use	2	6
Medical examinations	1	7
Safety committee	1	7

4.5.2 Workplace Observation

A checklist was used to carry out on-site observation in the milling environment of the 8 surveyed mills. Based on walk-through observations, it was found that the majority (75%) of the grain mill factories were congested without workspace. Observational findings also revealed that grain dust had accumulated on the walls, floors, and machines of the different working sections, particularly high in the milling section due to the absence of a dust absorber, leaking grinding machines, and inadequate ventilation. None of the grain mills had Local Exhaust Ventilation systems (LEVs), air filters, and dust collectors; they had fans on the ceiling, wall-mounted, and standard fans in different working sections. Although windows and doors were present, airflow was obstructed due to poor facility layout and the positioning of working units. In terms of personal protective equipment (PPE), one milling company did not provide PPE to its workers. Additionally, in some of the grain mills, some workers were observed wearing dust masks incorrectly, and some were not putting on dust masks at all.

5. Discussion

This study assessed the dust exposure levels and their determinants among grain mill workers in the Greater Gaborone District, Botswana. The study found that particulate matter concentrations exceeded the WHO-recommended 8-hour exposure limits of 5 µg/m³ for $PM_{2.5}$ and 15 µg/m³ for PM_{10}, indicating the high-risk environment within grain milling operations.

5.1 Types of grains stored and milled

The mills stored and milled more than one type of grain. Generally, grain dust consists of organic and inorganic particles that can easily become airborne and be inhaled by workers, affecting their lung functions and further posing risks to their quality of life and productivity. This is supported by Elghazally et al. (2023) and Mohamad Asri et al. (2020) in studies conducted in Egypt and Malaysia, who respectively revealed that 36.4% out of 94% male flour mill workers had pulmonary function abnormalities, 20.7% diagnosed with Bronchial Asthma, while airborne Aflatoxin B1(AFB1) was detected in the rice mill. A study conducted by Lagiso et al. (2020) in Ethiopia reported 56% prevalence of chronic respiratory symptoms among flour mill workers, representing the health risks suggested by the elevated dust levels in the Greater Gaborone study. The presence of chronic respiratory symptoms among a proportion of mill workers (39.2%), skin problems or irritation (4.6%), and itching or tearing eyes (8%) found in this study further supports the health implications of prolonged exposure. In this current study, it was observed that facilities storing and milling a wider variety of grains, particularly millet and maize, tended to have lower dust concentrations for both $PM_{2.5}$ and PM_{10} compared to those milling wheat only. The lower dust levels could be attributed to differences in the physical characteristics of these grains, moisture content, milling processes, and availability of adequate space in the mills. These results indicate the importance of grain-specific risk assessments, as advocated by the ILO (2023), and highlight the need for tailored dust control strategies based on the types of grains processed to ensure workers' well-being and health safety.

5.2 Exposure levels to dust in grain storage and mills

This study recorded the elevated arithmetic mean of total PM2.5 and PM10 dust concentrations of 39.1 µg/m^3 and 127.7 µg/m^{3,} respectively. The high-level dust concentrations show compliance gaps with occupational health standards. Long-term exposures can lead to inhalation of respirable dust, resulting in increased risks for respiratory diseases like Chronic Obstructive Pulmonary Disease (COPD) and Occupational Asthma. This concurs with Enitan et al. (2023), who highlighted that the reactions to grain dust can trigger allergic reactions or existing conditions and increase work-related deaths. The concentration findings are consistent with previous studies conducted in Nigeria (Daniel et al., 2022), Tanzania (Ulanga et al., 2021), and Bangladesh (Choudhury et al., 2023), which documented elevated exposure levels. The observational findings of the study also support and strengthen this result. A study conducted by Lagiso et al. (2020) in Ethiopia reported a 56% prevalence of chronic respiratory symptoms among flour mill workers, representing the health risks suggested by the elevated dust levels in this study. The presence of chronic respiratory symptoms among a proportion of mill workers (39.2%), skin problems or irritation (4.6%), and itching or tearing eyes (8%) found in this study further supports the health implications of prolonged exposure.

5.3 Factors Associated with exposure levels to dust in grain storage and milling

The findings of the present study revealed that occupational safety training on PPE use was provided by only 2 medium-scale mill factories. The regression analysis indicated that safety and health training was associated with increased exposure to high dust levels in both $PM_{2.5}$ and PM_{10} models. This may reflect a reactive approach to training rather than a preventative one, whereby workers are only trained after high exposure is identified. The current findings are in line with previous research from Ethiopia (Mekonnen et al., 2021) and India (Lohani et al., 2020), which highlighted gaps between knowledge and practice in PPE use. The results are also contrary to Rashmi et al. (2022), who found that there was an effectiveness of a structured teaching programme on occupational health hazards and prevention among mill workers. Conversely, PPE use yielded differing effects: it correlated with 51.8% higher $PM_{2.5}$ exposure but 59.7% lower PM_{10} levels. This difference could indicate inconsistent or ineffective use of PPE across different exposure contexts, as supported by observational data where some workers wore masks incorrectly or not at all due to discomfort when putting on dust masks. The gaps in PPE use were also noted in the following studies: Siddique et al . (2024) found that 52.2% of the workers used protective equipment, 47.8% did not use any protective measures, while Seema et al. (2020**)** noted that usage of PPEs was only among 126 (64%) workers.

Prolonged work shifts (> 8 hours) were linked to 18.4% higher $PM_{2.5}$ and 44.2% higher PM_{10} dust exposure levels, consistent with Choudhury et al. (2023), who identified extended exposure durations as a key risk factor for respiratory symptoms. In this study, 39.2% of workers reported chronic respiratory symptoms. These results indicate the workers' increased vulnerability and the need to organise the work to minimise the number of workers exposed, duration, frequency, level of exposure, and mandatory health surveillance in high-exposure environments. The findings also revealed that there was no significant relationship found between dust exposure and workers' years of experience or specific job roles, such as grinding or cleaning. This could be due to dust being uniformly distributed throughout the mill environment, affecting workers regardless of their roles. These findings agree with a study done in Tanzania by Ulanga et al. (2021), which did not find strong associations between dust exposure levels and years of experience, possibly due to the uniform exposure environment in small-scale mills. Furthermore, Lagiso et al. (2020) in their study in Ethiopia highlighted that dust was pervasive across all work sections, and respiratory symptoms were common regardless of specific job tasks, and this is in agreement with the current findings. The findings also reinforce the need for comprehensive facility-wide interventions.

5.4 Available grain dust safety measures

There was a grain dust accumulation observed in the workplaces in high amounts on the walls, floor, machines, and the mills also lacked effective dust extraction or Local Exhaust Ventilation systems (LEVs). The findings are in line with ILO (2020), as they stated that Micro Small and Medium Sized Enterprises (MSMEs) generally face poor workplace safety and health (OSH) conditions, which expose their employees to safety and health risks. The highest concentrations were observed in milling and packaging sections, supporting findings by Mishra et al. (2024), who attributed this to mechanical grinding and poor ventilation systems. The gaps in the availability of safety measures highlight the need to invest in preventive interventions and agree with studies conducted by Asgedom (2023) and Matosa and Cardoso (2024), who recommended mitigation by improving ventilation systems and the use of PPE.

6. Conclusion

The mills stored more than one type of grain, with wheat cross-cutting. A proportion of workers presented with chronic respiratory symptoms (39.2%), skin problems or irritation (4.6%), and itching or tearing eyes (8%), indicating health implications of exposure to high grain dust concentrations. Mill workers were exposed to high dust levels, with particulate mean concentration of $PM_{2.5}$ (39.0 μg/m³) and PM_{10} (127.7 μg/m³) exceeding the WHO AQG (2021) occupational exposure limits. The milling section had the highest concentrations, followed by packaging, highlighting the need for targeted dust control measures in these high-risk areas. The analysis showed that longer working hours and a lack of dust control measures significantly contributed to higher dust concentrations. Safety training and PPE use correlated with exposure to higher dust levels. There is a need, therefore, to organise work to reduce the duration and frequency of exposure. The study also found gaps in safety measures. Only a quarter of workers had received PPE training, and most mills lacked basic dust management systems such as risk assessments, LEVs, and safety committees. These deficiencies expose workers to preventable harm and reveal compliance gaps with occupational health standards.

7. Recommendations

The following measures are recommended to improve the health and safety of grain mill workers in Greater Gaborone.

7.1 Recommendations from the Study

The milling facilities management should strengthen health promotion and preventive measures, including educating workers on possible effects of exposure to grain dust, provision of personal protective equipment, and ensuring annual health assessments. This will help to ensure the prevention, early diagnosis, and management of grain dust health issues.

The management should improve dust control measures by installing local exhaust ventilation (LEV) systems, air filters, and dust collectors. These systems are essential to reduce airborne particulate matter at the source, especially in milling and packaging sections, where high dust concentrations were recorded.

The study also recommends that the milling industry management should collaborate with the regulatory bodies in the Government sector to develop a standardized, regular training program focusing on the proper use of PPE, hazard awareness, respiratory protection program, and behavior change. The facility management also needs to organise work to reduce the duration and frequency of exposure.

The milling industry should ensure collaborative efforts with regulatory authorities so as to enforce and strengthen regulatory compliance. This is important to enforce mandatory risk assessments, safety audits, develop safety policies, and implement dust exposure limits in line with the Factory Act of Botswana and international standards.

7.2 Recommendations for Future Research

1. Assess the long-term health effects of exposure to grain dust among mill workers.
2. Conduct a study on personal dust exposure levels.

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