EFFECTS OF EXPOSURE TO GRAIN DUST ON PULMONARY FUNCTION OF SELECTED ANIMAL FEED MILL WORKERS IN KIAMBU COUNTY, KENYA

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Effects of exposure to grain dust on pulmonary function of selected animal feed mill workers in Kiambu County, Kenya

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other University

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DEDICATION

This work is dedicated to my family and friends for supporting me during my graduate studies.

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My appreciation goes to those who have been fundamental in the success of this study.

Firstly, I wish to thank God for giving me the knowledge and health to carry out this study.

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ABBREVIATION AND ACRONYMS

ACGIH	American Conference of Governmental Industrial Hygienists
AKEFEMA	Association of Kenya Feed Manufacturers
AQG	Air Quality Guideline
COPD	Chronic Obstructive Pulmonary Disease
DOSHS	Directorate Of Occupational Safety and Health Services
$FEF_{25-75\%}$	Forced Expiratory Flow at 25%-75% of lung volume
FEV_1	Forced Expiratory Volume in the first second
FEV_1/FVC	Forced Expiratory Ratio
FVC	Forced Vital Capacity
HSE	Health and Safety Executive
MVV	Maximum Voluntary Ventilation
NIOSH	National Institute for Occupational Safety and Health
OEL	Occupational Exposure Limit
OEL-CL	Occupational Exposure Limit - Control Limit
OEL-RL	Occupational Exposure Limit - Recommended Limit
PEF	Peak Expiratory Flow
PFT	Pulmonary Function Test
PM	Particulate Matter

PM_{10}	Particulate Matter with diameter less than 10 μm
$PM_{2.5}$	Particulate Matter with diameter less than 2.5μm
PPE	Personal Protective Equipment
TEOM	Tapered Element Oscillating Microbalance
TLV	Threshold Limit Value
TLV-C	Threshold Limit Value-Ceiling
TLV-STEL	Threshold Limit Value-Short-Term Exposure Limit
TLV-TWA	Threshold Limit Value -Time-Weighted Average
TSP	Total Suspended Particulate
WHO	World Health Organization

ABSTRACT

The animal feed industry in Kenya experienced rapid growth, attributed to increased demand for animal feed around major towns in Kenya. This proportionately increased the risk of exposure to grain dust among industrial workers. These risks and health-related impacts have not been adequately studied in Kenya. The goal of the study was to assess the effects of exposure to grain dust on the pulmonary function of selected animal feed mill workers in Kiambu County, Kenya. The study adopted both a cross-sectional and a case-control study design. A total of 355 animal feed mill workers from 35 animal feed firms were included in the study. Assessment of dust management systems was done through structured questionnaires, interviews, and walk-through surveys. The grain dust exposure levels (PM_{10} and $PM_{2.5}$) in the study sites were measured using a portable particulate matter sensor model (Temtop, US). A total of 81 animal feed mill workers participated in the assessment of their lung function and respiratory symptoms using the spirometry model. A total of 81 workers from the milk processing companies formed the matched control group. SPSS was used to process and analyse the collected data. The results showed that the majority of the workers had not been trained in grain dust management. The proportion of workers trained on various aspects was as follows: dust management procedures (16.44%), grain dust hazards (3.42%), and usage of PPE (13.70%). None of the workers was aware of the air sampling measurements or the exposure limits. Only 16.13% of the feed mills controlled the dust using engineering and administrative controls, apart from ventilation. The mean PM_{10} of 53.72±71.32 $\mu g/m^3$ and $PM_{2.5}$ of 36.54±41.56 $\mu g/m^3$ found in this study exceeded the WHO Air Quality Guideline level of a 24-hour exposure time of 45 $\mu g/m^3$ for PM_{10} and $PM_{2.5}$, 15 $\mu g/m^3$. The mean predicted lung function parameters were FEV_1(%)±SD (82.64±21.17), FVC(%) ± SD (88.44±21.76), FEV_1/FVC(%)±SD(95.42±20.76), and FEF_{25-75}(%)±SD(80.60±30.69). These were significantly lower for the animal feed mill workers than the control workers for all the parameters *($p<.05$)*. Obstructive lung abnormalities were reported among the target group and none in the control group. The most prevalent symptom among the respondents was a stuffy, itchy, and running nose (53.77%), followed by watery and itchy eyes (30.48%), phlegm first thing in the morning during cold periods (13.70%), and cough first thing in the morning during cold periods (12.33%). This study reveals that declining lung function among animal feed mill workers is associated with exposure to grain dust. The study recommends continued implementation of the dust control measures and the introduction of controls, hazard awareness, medical examinations for the workers, and adherence to the set safety and health guidelines by the workers and the firms.

CHAPTER ONE

INTRODUCTION

1.1 Background to the study

Globally, diseases linked to occupation-related factors account for approximately 4-10 million cases per year, whereas an estimated 3-9 million cases are reported in developing countries per year (Tulchinsky & Varavikova, 2014). Occupational exposures to grain dust account for approximately 12% of deaths linked to chronic obstructive airway diseases (Iyogun et al., 2019). This may be a result of the pathogenic response of victims to their occupational environments due to prolonged exposure to allergens that are present in grain dust resulting in acute or chronic respiratory ailments (Poole et al., 2021). These diseases induced by grain dust attack the respiratory system and are influenced by the type of dust, dose, duration of exposure, and genetic factors (Lagiso et al., 2020; Meo & Al-Drees, 2005; Subbarao et al., 2009). There exists sufficient well documentation of the respiratory health effects on workers exposed to various dust particles in their respective occupational environments during the production processes (Alemseged et al., 2020; Iyogun et al., 2019; Nordgren & Charavaryamath, 2018). It is acknowledged that limited research and documentation on the same exist in developing countries including Kenya which is attributed to poor record-keeping of occupational diseases and non-existent health surveillance systems in developing countries (Aiguomudu, 2018).

Grain dust might contain a large number of contaminants. The contaminants that might be contained are metabolites of fungi and silica, bacterial endotoxins, insects, mites, mammalian debris, pesticides, and herbicides (Mohammadien et al., 2013). Feed mill workers are potentially exposed to grain dust that may adversely affect their respiratory health (Liebers et al., 2020). Researchers have attributed the increase in the prevalence of respiratory symptoms and lung function impairment in various work environments due to exposure to grain dust (Lagiso et al., 2020; Mekonnen et al., 2021). These studies have highlighted the significance of grain dust exposure in the animal feed industries. Consequently, it should be noted that most occupational exposures can be reduced or eliminated through engineering controls and the use of personal protective equipment (PPE), which are absent in most animal feed mills in developing countries (Aiguomudu, 2018).

Several studies have reported mill workers exhibiting various clinical symptoms due to grain dust exposure (Lagiso et al., 2020; Meo & Al-Drees, 2005; Tosho et al., 2015). These studies have highlighted the significance of grain dust exposure in the milling industries. However, health challenges occurring because of exposure to grain dust have not been recognized because they show up less frequently compared to major disabling diseases or accidents. Respiratory diseases due to exposure to grain dust present a serious health challenge with significant potential for acute and chronic morbidity, long-term disability and adverse socio-economic impacts, especially in developing countries (Wisnivesky & De-Torres, 2019). These clinical symptoms are critical and may result in workplace absence, change of job, disability, and work cessation (Jeebhay, 2000). An improved exposure characterization is required to assess the prevalence and impacts of grain dust on animal feed workers' health, realizable through the assessment of pulmonary functions and level of exposure.

Feed mill workers in Kiambu County, Kenya, like mill workers everywhere, are at a high risk of developing both acute and chronic pulmonary symptoms linked to their occupation. The risk of exposure and later developing occupation-related illness is higher in small-scale mills in developing countries due to poor enforcement of occupational health and safety standards, use of older technology, poor working environment, lack of awareness of potential health hazards, and lack of use of personal protective equipment (Iyogun et al., 2019). Occupation-related illnesses have been documented in various regions where workers are exposed to grain dust in industries that generate dust during production (Aiguomudu, 2018; Alemseged et al., 2020; Mohammadien et al., 2013).

1.2 Statement of the problem

Kenya has experienced steady growth in the animal feed industry. In 2020, national production was projected to range between 0.76 to 1.02 million metric tonnes (Auma et al., 2018). This was linked to the increased demand for animal feed around major towns, leading to an increase in unregulated animal feed mills (Lukuyu et al., 2011; Omanga et al., 2014). Kiambu county borders major urban centres where demand for animal products, including milk, meat, and eggs, is very high. This implies that animal production is intensive, which has subsequently attracted many unregulated feed mills setting up production units in the county (Munguti et al., 2021). This has resulted in increased risks of occupational and health-related impacts arising from poor implementation of regulations such as The Occupational Safety and Health Act, 2007 and The Factories and Other Places of Work Act (Hazardous Substances) Rules, 2007, lack of awareness and low personal protective equipment usage among workers (Omanga et al., 2014). Private ownership of most animal feed mills, where a large proportion of them are small-scale, has resulted in the industry focusing more on business continuity and less on regulatory obligations such as health and safety standards in the workplace (Kenya Markets Trust, 2016). This exposes the workers to grain dust. Exposure to grain dust in various quantities has been reported to cause either acute or chronic respiratory ailments (Health and Safety Executive, 2013). In Kenya, no public data existed where actual grain dust concentrations had been investigated in relation to lung health among workers in the animal feed industry; as a result, little awareness and practice on safety and health standards had been made. The awareness of the standards positively impacts a safe work environment (Oluoch et al., 2017). Consequently, there was a need to assess exposure levels to grain dust, response, and awareness of health and safety in the workplace. Thus, the purpose of this study was to evaluate the levels of exposure to grain dust at the selected feed millers and their impact on the respiratory function of the selected feed milling workers in Kiambu County.

1.3 Justification of the study

A decreased pulmonary function was reported in Egypt as a significant health concern to feed milling workers due to the substantial bio-contamination in their work environment. This bio-contamination was due to the presence of bacteria, mold, and actinomycetes in the air, which can lead to respiratory health problems. (Hameed et al., 2003). In an animal food-processing factory in western Turkey, a pronounced higher prevalence of respiratory symptoms and a decline in lung function were observed in exposed workers compared to controls, attributed to the animal feed dust (Baser et al., 2003). The exposure and the subsequent health disorders have contributed to decreased productivity in feed mill workers. Some of the predisposed workers experience aggravating respiratory health disorders that burden the individual through medical expenses, and at large, the organizations through hospital bills, insurance, compensation claims and loss in work hours. The purpose of this study was to build on the existing knowledge to obtain the relationship between the lung function of the feed milling workers and exposure levels to grain dust as a stress factor. This study forms the basis for an analysis of preliminary health risks of workers in the feed mills and helps policymakers with improving health and safety strategies in the animal feed industry.

1.4 Hypothesis

H_0 = There is no significant association between exposure to grain dust and the pulmonary function among workers in selected animal feed mills in Kiambu County, Kenya

1.5 Objectives of the study

1.5.1 Main objective

The aim of the study was to assess the association between exposure to grain dust and pulmonary function of selected animal feed mills' workers in Kiambu County, Kenya.

1.5.2 Specific objectives

i. To assess the current dust management systems in the selected animal feed mills in Kiambu County, Kenya.
ii. To determine the exposure levels to the grain dust (PM_{10} and $PM_{2.5}$) among selected animal feed mills' workers in Kiambu County, Kenya.
iii. To determine the lung function of the selected animal feed mills' workers in Kiambu County, Kenya.

1.6 Research Questions

i. How have the current dust management systems impacted selected animal feed mills in Kiambu County, Kenya?
ii. How has the production of feeds influenced the exposure levels of grain dust in selected animal feed mills in Kiambu County, Kenya?
iii. How has exposure to grain dust impacted on lung functions of selected animal feed mill workers in Kiambu County, Kenya?

1.7 Scope of the study

In Kiambu County, feed milling operators are primarily concentrated in urban areas, such as where there is infrastructure. These feed milling industries operate in various capacities, with the majority being small-scale operators (Lukuyu et al., 2011). The study determined the exposure to grain dust among the workers and assessed the respiratory effects of the machine operators and the administrative staff in the selected feed milling enterprises in Kiambu County, Kenya. Other health effects related to grain dust exposure were not evaluated.

1.8 Limitation of the study

The healthy worker effect is a bias that could occur since the exposed workers who had developed respiratory symptoms might have left employment, leaving the healthier cohort who have low prevalence rates.

1.9 Conceptual framework

Figure 1.1 provides a visual representation of the conceptual framework of the study, which includes the key variables and their relationships.

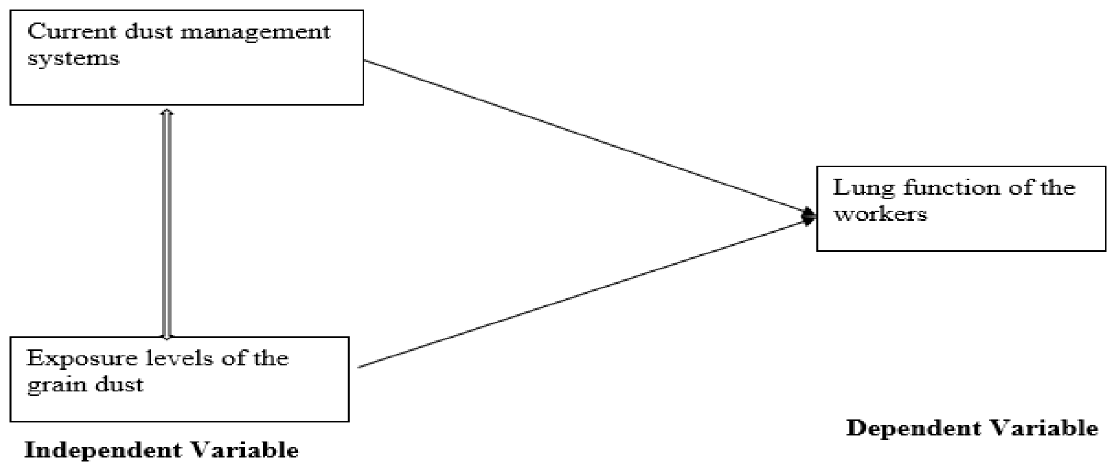


Figure 0.1: The study's conceptual framework

Grain dust is produced during various processes of animal feed production. As such, animal feed workers are exposed to varying concentrations during multiple processes of production through inhalation. Following exposure to animal feed workers, harmful incidents are likely to occur. To address this issue, the conceptual framework presented in Figure 1.1 proposes the implementation of improved dust management systems and maintaining exposure levels to recommended limits, which can reduce workers' levels of exposure and enhance their ability to recognise dust hazards, leading to improved respiratory health and a safer work environment.

This theory is supported by a study conducted in the western Australian Wheatbelt that found that increased knowledge and awareness through training can lead to improved safety and the adoption of dust mitigation controls such as safe work procedures and practices (Rumchev et al., 2019). In this framework, the levels of exposure and dust management systems are dependent variables that are likely to influence the lung function of workers, which is the dependent variable that determines overall health and safety outcomes.

This framework (Figure 1.1) covers the prevalence of respiratory diseases among workers due to exposure to grain dust, which has been shown to increase the likelihood of respiratory symptoms (Aiguomudu, 2018). By implementing effective dust management systems and maintaining exposure levels within acceptable limits, we can reduce the risk of respiratory illness among animal feed workers and promote a safer work environment. This is supported by a study conducted in Dutch flour processors that recommended the need for a more rigorous approach to substantially decrease grain dust exposure levels as there were no significant changes observed after safety training on the risks (Meijster et al., 2009). This suggests that a more comprehensive approach, such as adopting multiple control strategies, may be necessary to mitigate the risks associated with grain dust exposure effectively.

The conceptual framework presented offers valuable insights into the impact of improved dust management systems and adherence to recommended exposure limits on the respiratory health of animal feed workers. However, there are several limitations to the framework that must be acknowledged.

One key limitation is the lack of consideration for the cost associated with training workers to create awareness and knowledge about dust hazards, as well as the cost of implementing engineering controls and purchasing personal protective equipment. Cost is an extraneous variable that can significantly influence the administrative role in providing a safe and healthy work environment.

By acknowledging the limitations of the current framework and building upon the findings of previous studies, effective measures can be developed for promoting respiratory health among animal feed workers in Kiambu County, Kenya. This will ultimately lead to a safer and healthier work environment.

CHAPTER TWO

LITERATURE REVIEW

2.1 Theoretical principles

This study seeks to evaluate theoretical information about animal feed production, grain dust characteristics, dust management, health effects, and modes of occupational exposure.

2.1.1 Production of animal feed

The production of animal feed is an elementary manufacturing process whereby the raw materials are transformed into a suitable form. Then, they are mixed to make nutritionally balanced feed, packaged in sacks or bulk. The flow of materials follows a four-step production scheme: raw materials reception, processing, packaging, storage, and distribution (Hardy, 1980). The level of automation within the plant facilities varies from manual operation to a fully automated system.

At the reception of the raw materials, there are several categories of raw materials: animal-based, plant-based, or inorganic additives. The ingredients are received in sacks or in bulk and transported using pick-ups, trucks, and trailers. The personnel properly inspect its traceability and quality control checks to ascertain its physical and chemical properties before its usage. The sacked ingredients are stored in the form of stacks in a dry and cool location after weighing and pretreatment (Smid, Heederik, Mensink, et al., 1992). The liquid bulk ingredients such as molasses are stored in heavy-duty tanks, while the solid bulk such as cereals is stored in bins or silos. Temperature, oxygen concentration, and humidity monitoring are essential to avoid spoilage (Hardy, 1980).

During processing, the transport of the materials within the plant facility is done using forklifts, conveyor belt systems, and elevators. The main unit operations during the process include particle size reduction, premixing, mixing, pelleting, and sacking, whereby correct weight measurement is crucial in all the processes. In the first stage of particle size reduction, the first step is that the coarse materials undergo an inline magnetic filtration stage where ferromagnetic impurities such as iron are attracted to a magnet trap and subsequently removed. The second step is the reduction of the size of the material that occurs when they pass through the grinding process, enabling them to penetrate through the screen openings, giving the desired size. Various grinding techniques include the application of roller mills, hammer mills, multicrackers, and multi-stage grinding. The hammer mills are the most commonly used, which have a greater reduction ratio than the roller mills (Hardy, 1980; Lyu et al., 2020). The operating principle of the hammer mill is that it crushes the materials through the impact of the materials with the high-speed pivoting hammer, which is mounted on a rotor. The impact grinding results in dust generation. (Basu & Debnath, 2019; Hardy, 1980).

In the second stage of mixing, there is premixing of the inorganic feed additives such as vitamins with a filler material in a batch mixer and thereafter composite mixing of the macro and micro elements of the feed in a bulk mechanical mixer. The working principle of the mixer, whether vertical or horizontal, is to ensure product homogeneity within a set period whereby its rotary blades cause circulatory mixing of the materials around its axis. In the third stage of pelleting, the first step is conditioning, where the compound feed is agitated and exposed to highly pressurized steam in the conditioner section of the pelletizer to improve the sanitary conditions of the feed and particle compactness for easier material handling (der Poel et al., 2020). Depending on the feed composition, molasses is added at this point. In the second step, the feed passes through a rotating metal ring-type die inside the centrifugal press where it is compressed against its inner wall lining by a set of rollers; thereby, extrusion occurs, leading to raised feed temperatures (Gupta & Anjum, 2020).

The extruded pellets of suitable sizes are cut off by a set of knives assembled on the interior layer of the die casting. The freshly pressed pellets are air-cooled and dried in a vertical or horizontal cooler-dryer to eliminate excess heat and moisture, improving the pellet’s durability. The air current flows through the layers of pellets and is emitted into a dust collector chamber, whereby the fine material is sorted from the pellets. The sorting or grading step can be either manual or mechanized. In the mechanized one, the sifting equipment rotates the material and passes it over the standardized screen spacing where the desired pellets are segregated. The equipment is enclosed in a casing to trap dust escaping from the process. The fine material is then continuously returned for a repeat pelleting cycle (Hardy, 1980). The pellets or the mash are then stored in bins or silos.

During packaging, the feed pellets or the bulk feed mash are sacked. Alternatively, they are packaged in bins or silos. During sacking, proper product coding, bagging, and sewing are vital procedures to avoid business losses.

During storage and distribution, the feed is loaded into specialized bulk cargo trailers or lorries for deliveries.

Figure 2.1 shows a standard animal feed manufacturing process, whereby each stage is critical to the quality and nutritional value of the final product.

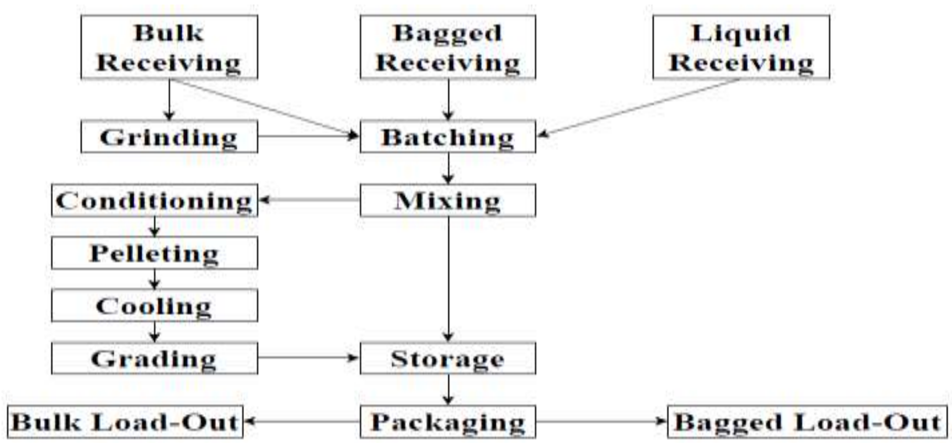


Figure 0.1: Animal feed milling process

(Modified from Huss et al., 2018).

2.1.2 Biological and physical characteristics of grain dust

Grain dust is the dust produced from the harvesting, drying, handling, storing, or processing of barley, wheat, oats, maize, or rye (Health and Safety Executive, 2013). This definition includes any contaminants or additives within the dust, including inorganic soil particles, plant fragments, insects and mites' body parts, fungicides, pesticides, fertilizer residue, fungi and bacteria, and microbial toxins (Halstensen et al., 2013). Consequently, during the feed milling and mixing process, additives consisting of milling plants (cereals and legumes), animal products (omena), and mixing of other additives (minerals, antitoxic materials) are added. This results in contaminated grain dust and may cause respiratory health effects and lung dysfunction. Endotoxin exposure due to their presence in grain dust has also been linked to chronic obstructive pulmonary disease among grain handlers (Poole et al., 2021). However, in the animal feed industry, workers are exposed to fungi spores and cultivable bacteria commonly found in stationary sampled air, particularly around grain elevators and grain terminals (Halstensen et al., 2013). Several studies have highlighted β-1→3-Glucans as a bioactive component possessing immune-modulating properties with their sources being fungi and grain fragments (Caseiro et al., 2022).

Grain dust consists of approximately 70% organic matter particles varying in size, density, and shape and can impact the health of grain handlers in various ways, su (Sobczak et al., 2019; U.S. Environmental Protection Agency, 2003).

Grain dust, just like any particulate matter, is characterised by its mass fractions. In 1997, the American Conference of Governmental Industrial Hygienists defined and characterised three particulate mass fractions and their potential health effects: These were the inhalable fraction (particulate matter (PM) with a median cut-point aerodynamic diameter of 100 μm that enters the airway region), the thoracic fraction (PM with a median cut-point aerodynamic diameter of 10 μm that deposits in the tracheobronchial regions), and the respirable fraction (PM with a median cut-point aerodynamic diameter of 4 μm that enters the gas exchange regions) (Nitter Moazami et al., 2022). During milling, the husk and germ separate from the endosperm and are reduced to small particles of ≤6 μm. Flour dust consists of a bimodal distribution reaching a peak of 5 μm for fine dust particles and 15–30 μm for coarse dust particles, which accounts for about 50% or more of the airborne flour dust particle mass with an aerodynamic diameter of over 15 μm (Rumchev et al., 2021). Most particles greater than 10 μm and an upward figure of 87% of particles above 5 μm are trapped in the nasopharyngeal region due to anatomic formation within these parts of the respiratory tract (Ou et al., 2020; Wang et al., 2021). Normally, these particles are situated in the upper parts of the respiratory tract, where they are trapped and deposited. However, they are removed within a few hours by the mucociliary system or due to expectoration. The huge volume of dust particles exposure may limit the ability of macrophages to eliminate them, leading to their penetration into the interstitium. Particles with 0.5 μm diameter and above are deposited because of sedimentation and impaction, which takes place in the bronchi, bronchioles, and alveoli (Thakur et al., 2020). This is attributed to air velocity, which is low, and their deposition probability, which is directly proportional to their residence time.

In the lower respiratory tract, deposits of dust particles are removed much slower due to the absence of cilia epithelium (Stobnicka & Górny, 2015). This is due to the retention time of the particles within the respiratory tract, which is critical in determining the interactions between the bioaerosol particles and human cells at their place of deposition. Inhaled particles with aerodynamic diameters equal to or above 10 μm cause eye or nose irritations. Particles with sizes between 5 and 10 μm may provoke asthmatic reactions. Particles smaller than 5 μm may evoke an allergic alveolitis type of reaction (Stobnicka & Górny, 2015).

Figure 2.2 shows a diagrammatic representation of how various PMs interact with different surfaces of the respiratory tract.

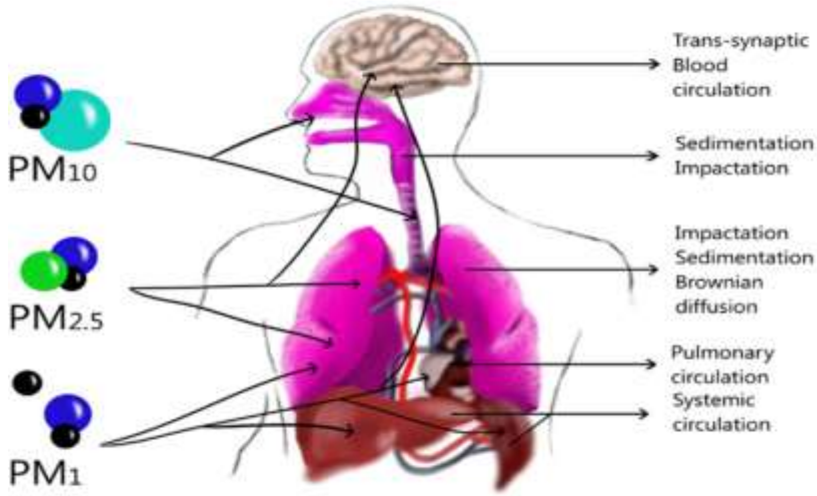


Figure 0.2: Various PMs of dust with different surfaces they use to enter the body

(Modified from (Falcon-Rodriguez et al., 2016)

2.1.3 Dust management controls against grain dust exposure

Since grain dust has been identified as a respiratory sensitizer, it is vital to reduce its exposure levels as far as is reasonably practicable. The existence of occupational exposure limits prevents excessive exposure by controlling it below the safe limits. This helps evaluate the adequacy of the dust management controls available. These controls are combined, depending on the process structure of the facility, to reduce grain dust exposure. The controls include eliminating or substituting processes or products; engineering controls (such as adequate general ventilation, local exhaust ventilation, process segregation, and equipment modification); administrative controls (such as material handling, housekeeping, improved task organisation, and staff training); and the use of personal protective equipment (Health and Safety Executive, 2013).

In a study done in the United Kingdom to assess the current control measures in bakeries, only 27% of the bakeries were aware of the maximum exposure limits and short-term exposure limits. The authors stated that to achieve compliance with the exposure limits, the bakeries and their workers should implement proper working practices and operate the local exhaust ventilation correctly (Elms et al., 2005).

A study was conducted in an animal feed handling facility in the Port of Inchon, Korea, to determine the effects of wind speed and particle size on dust control. The researchers found that the facility was not designed well to ensure reduced fugitive dust and suspended matter and recommended a proper ventilation system for dust control, which corroborates the findings of other researchers (Jeon et al., 2000).

In East Africa, a study in Ethiopia analysed the prevalence and risk factors for respiratory symptoms at work among Ethiopian flour mill workers in Bahir Dar City. The findings were that poor ventilation in the workplace and lack of safety and health training were significant contributors to respiratory deficiencies at work. It was recommended that they need to properly implement health and safety programmes that factor in the application of engineering controls (for instance, the installation of proper ventilation systems), the utilisation of administrative provisions (for example, training programmes and health surveillance), and provision of appropriate protective clothing (Mekonnen et al., 2021).

The implementation of proper dust management controls is crucial to reducing exposure levels and preventing health hazards such as impaired respiratory function. The utilisation of eliminating or substituting processes or products, engineering controls, administrative measures, and personal protective equipment should be combined to achieve compliance with exposure limits. The studies conducted in different regions show that there is a need for effective implementation of health and safety programmes that take into account the setting up of suitable ventilation systems, training programmes, and health monitoring to prevent respiratory deficiencies.

2.1.4 Occupational exposures to grain dust

The levels of exposure to grain dust are determined by the size of the industry and vary considerably between workstations, places, and seasons (Ruiter et al., 2023).

As such, different tasks may result in varying levels of exposure. Straumfors et al. (2016) characterized task-dependent exposure differences at Norwegian grain elevators and compound feed mills to create knowledge and awareness of the exposure risks and variations within the field, reporting that working in compound feed mills was associated with higher dust exposure than working in grain elevators. Similarly, Halstensen et al. (2013) found that despite similar dust levels, exposure to bacteria and fungi varied across different workplaces in Norway, thus emphasizing the need for a comprehensive task-based evaluation of exposure levels. A study carried out in Nigeria also showed that flour mill workers were at risk of high dust exposure, particularly in the mixing and packing areas, and reported that PM_{10} and TSP in the production section were higher than those for the maintenance unit. The TSP concentration at the production unit was statistically significantly higher compared with the maintenance unit ($P<0.05$), and exceeded the national standards of 0.25 mg/m^3 (Tosho et al., 2015). Additionally, a study in Ethiopia reported significant variations in flour dust exposure levels among the various departments of flour mill processing plants (Alemseged et al., 2020). These findings highlight the importance of task-specific evaluations of occupational exposure to grain dust.

Thus, it is important for the management of the millers to conduct regular monitoring of grain dust levels in the workplace and implement appropriate control measures based on the specific tasks and exposure levels to minimise exposure.

2.1.5 Health effects of grain dust

In the animal feed industry, exposure to grain dust may cause diverse respiratory symptoms with varying severity, ranging from irritation to allergies or respiratory-related illness (Nordgren & Charavaryamath, 2018). Chronic exposure to grain dust can result in lung dysfunction (Baser et al., 2003). Existing studies corroborate these assertions. A study on cross-shift respiratory responses of several bioaerosol components of the dust in the grain and feed industry in Norway found that exposure to grain dust exhibited a stronger relationship with respiratory symptoms compared to exposure to endotoxin. Cough with or without phlegm and wheeze/tight chest/dyspnea were the most common respiratory symptoms associated with grain dust, but the exposure did not lead to lung function deterioration (Straumfors et al., 2016).

In Denizli, Western Turkey, a study was carried out to assess the prevalence of chronic occupational respiratory symptoms and ascertain lung function performance in animal feed workers. The prevalence of respiratory symptoms such as cough (12%), dyspnea (5.6%), and sinusitis (8.3%) was significantly greater among the workers compared to the control group ($p<.05$). This was similar to irritation symptoms, which were significantly higher compared to the control group ($p<.05$). The prevalence of the irritation symptoms in the exposed group was pruritus of the eyes (11.1%), skin lesions (7.4%), and nose symptoms (8.3%). All pulmonary function parameters' mean percent predicted values (FVC, FEV_1, PEF, and FEF_{25-75}) were significantly lower for exposed subjects compared to control participants ($p < .0001$) (Baser et al., 2003).

Another case-control study was done among animal feed workers in the Netherlands to assess the lung function changes and occupation-related symptoms associated with grain dust and endotoxin. A self-administered questionnaire was used to assess the respiratory and other symptoms of the workers while at work and just after work. 119 production workers undertook the lung function tests, which were done before and after the shift on Mondays, Tuesdays, and Fridays. The most commonly recorded symptom among the animal feed workers was sneezing (21%), followed by nasal irritation (15%) and cough (9%). These symptoms were significantly higher compared to those of the control group ($p<.01$). A decrease in nearly all lung function parameters was observed during the work shift (Smid et al., 1994).

Iyogun et al. (2019) discovered a significant ($p < .05$) decrease in $F.E.V_1$ values among the grain millers (1.61 L) compared to the control group (2.10 L). Furthermore, Iyogun et al. (2019) and Abdulsalam et al. (2015) findings showed that the mean P.E.F.R. value was significantly ($p < .05$) reduced in grain mill workers compared with controls. Using P.E.F.R. provides for an objective assessment of functional changes associated with occupational exposures and it is used to indicate acute or chronic diseases.

The obstructive respiratory effects seem to have the strongest prevalence, and the symptoms related to chronic bronchitis are present as being the most typical (chronic phlegm and wheezing) (Smid, Heederik, Mensink, et al., 1992). These symptoms are self-reported using standard questionnaires, which are an effective in screening for respiratory impairment and can supplement spirometry tests (Huynh et al., 2022). However, spirometry is more reliable as a method, which allows for determination of obstructive or restrictive pulmonary function. A normal or decreased FVC, reduction in FEV_1, and absolute FEV_1/FVC ratio signal obstructive pulmonary function. Restrictive lung function may exist if FVC is decreased, FEV_1 is decreased or normal, and the absolute FEV_1/FVC ratio is normal or increased (Barreiro & Perillo, 2004). Obstructive lung disease occurs because of airway blockages or obstructions that narrow the airways, resulting in airflow limitation and difficulty in breathing. There are various types of obstructive lung disease, such as chronic obstructive pulmonary disease (COPD), bronchiectasis, emphysema, and asthma (Chaudhuri et al., 2018). The COPD is characterized by respiratory symptoms such as dyspnea, cough, and phlegm production, and its frequent clinical forms are chronic bronchitis and emphysema (Murgia et al., 2020). These symptoms are highly prevalent in studies highlighted in this section. On the other hand, restrictive lung diseases are distinguished by a decline in the normal elasticity of the lungs and the thoracic wall, culminating in the patient's incapacity to inhale the normal volume of air (Martinez-Pitre et al., 2022). They are predominantly asymptomatic but aggravate existing lung function abnormalities (Ward, 2019).

2.2 Previous work relevant to the study

Grain dust exposure is a serious occupational hazard that poses significant health risks to animal feed manufacturers. Despite the significant health risks, previous studies show grain handlers and manufacturers have not implemented effective dust management systems to reduce exposure levels. This is partly due to a lack of knowledge and awareness regarding the potential hazards of grain dust and the importance of dust management systems. A study in Midwestern states found that there are knowledge gaps among the farmers regarding hazardous exposures and long-term health consequences. (Cramer et al., 2017). These knowledge gaps can hinder the implementation of effective dust management systems and use of personal protective equipment.

In order to address the issues, a study in Dutch flour processing industry recommended the need to prioritize the implementation of rigorous dust management systems to reduce dust levels in the manufacturing facility and ensure proper use of personal protective equipment as awareness creation alone was not enough (Meijster et al., 2009). Effective dust management systems should include the installation of dust collection systems, ventilation systems, and regular cleaning and maintenance of equipment. Additionally, employers should provide regular training and education on the hazards of grain dust exposure, the importance of PPE, and proper use and maintenance of equipment.

The relevance of measuring the grain dust levels in the animal feed milling units is very crucial in understanding its impact on the health outcomes of the workers: Iyogun et al. (2019) noted that exposure to grain dust above WHO (World Health Organization) guidelines of 50 $\mu g/m^3$ increased diverse respiratory problems and abnormalities among grain millers. In the working environment of the milling units, the grain dust forms part of small-sized particulate matter that transmits different toxicants into the alveoli that trigger numerous physio-pathological processes that result in lung function abnormalities, which are experienced in either acute or chronic exposure (Singh *et al.,* 2017). In 2019, the World Health Organization (WHO) reported that particulate matter (PM), which includes grain dust, is accountable for nearly 7 million deaths globally, making air pollution the most prominent single environmental health risk (Seddon et al., 2019; World Health Organization, 2019).

Spirometry has been identified as one of the fundamental pulmonary function tests (PFTs) used to evaluate the breathing patterns that help diagnose occupational respiratory diseases and other lung function abnormalities. The method showed a significant decline in the pulmonary function of flour milling workers in Iran, which was higher compared to the controls (Zamani et al., 2019). Similarly, this has been identified in grain millers in Nigeria, where forced expiratory volume (FEV) was 23.8% lower for the exposed group compared to the control group (Iyogun et al., 2019). Spirometry is an effort-dependent test that displays normal, obstructive, and restrictive lung function even if the disease is not clinically apparent among the workers (Iyogun et al., 2019). In addition, it can be used in health surveillance over a defined period of time.

Respiratory effects from organic dust have been reported in several studies. The main exposure attracting scientific attention is from grain dust (Baser et al., 2003). The authors acknowledged that exposure to animal feed dust is an important factor in the occurrence of respiratory symptoms and a decline in lung function. This is because contaminants get attached to grain dust, including silica, bacterial endotoxins, pollen, insect fragments, mites, faeces, pesticides, and herbicides (Iyogun et al., 2019). Various studies have recorded significant increases in respiratory symptoms and decreased pulmonary function due to grain dust exposures (Demeke & Haile, 2018; Lagiso et al., 2020; Zamani et al., 2019). Grain dust has seriously affected the forced vital capacity and forced expiratory volume in one second (FEV_1) of exposed workers and influenced other clinical symptoms such as conjunctivitis, allergic asthma, wheezing, febrile reactions, grain fever, lung fibrosis, rhinitis, allergic alveolitis, lung dysfunction, and chronic obstructive pulmonary disease (Iyogun et al., 2019).

Straumfors et al. (2018) undertook a study to evaluate pneumoproteins and markers of inflammation and platelet activation in the blood. The researchers observed higher concentrations of CC-16 and IL-16 in exposed grain workers compared to controls ($p< 0.001$ in both) and lower fibrinogen (p=0.005) (Straumfors et al., 2018). This meant that exposure to grain dust induced inflammatory and anti-inflammatory reactions but not systemic inflammation. The researchers ascertained that grain dust and its components might induce inflammation, allergies, and impair the lung function of workers in grain elevators and compound feed mills (Straumfors et al., 2018).

A different study by Straumfors et al. (2016) evaluated the exposure-response relationship between bioaerosol exposure and respiratory effects in Norway. The researchers observed that workers were exposed to an average of 1.0 mg/m^3 of grain dust, 440 EU/m^3 of endotoxin, 6 $\mu g/m^3$ of β-1,3-glucans, $17\times10^4/m^3$ of bacteria, and $4\times10^4/m^3$ of fungal spores during work (Straumfors et al., 2016). This resulted in an increased prevalence of self-reported eye irritation, fatigue, respiratory-related symptoms, and nose irritation linked to fungal spores' exposure; cough with or without phlegm linked to grain dust and fungal spores; strong wheezing or tight chest or dyspnea resulting from grain dust exposure (Straumfors et al., 2016). They concluded that grain dust consists of other components that induce these effects.

On the other hand, a study by Tosho et al. (2015) evaluated the prevalence of respiratory symptoms and lung function of flour mill workers in Nigeria. The researchers found that respiratory-related symptoms were significantly higher in the flour mill workers (49.5%) than the controls (27.7%) (Tosho et al., 2015). Similarly, they recorded a significant reduction in the overall mean values of FVC, FEV1, PEFR, and MVV in the flour mill workers, with their mean concentrations of TSP being 6.20±0.07 mg/m3 and 4.25±0.03 mg/m^3 for the study and control groups, respectively (Tosho et al., 2015). The researchers concluded that due to grain dust exposure, there was an increased prevalence of occupation-related respiratory symptoms and a significant reduction in lung function among flour mill workers (Tosho et al., 2015).

2.3 Legal Framework

The legal framework consists of legislation that empowers the relevant institutions to carry out their mandate. Kenya, being a member state of the ILO (International Labour Organization) and WHO (World Health Organization), prescribes the Occupational Exposure Limits (OELs) of hazardous substances that are based on Threshold Limit Values (TLVs) issued and recommended by the American Conference of Government Industrial Hygienists (ACGIH) and the National Institute for Occupational Safety and Health (NIOSH).

The TLV is defined as the concentration of the substance in the air that can be repeatedly exposed to nearly all the workers daily for five consecutive eight-hour workdays (40-hour workweek) without adverse effect (American Conference of Governmental Industrial Hygienists, 1972). Its units are in milligrams per cubic metre (mg/m^3) for particulate matter. The three classes of TLVs are: threshold limit value-time-weighted average (TLV-TWA), threshold limit value-short-term exposure limit (TLV-STEL), and threshold limit value-ceiling limit (TLV-C). This study will focus on TLV-TWA, which is the average exposure of the substance in the air over an eight-hour workday and a 40-hour workweek. The ACGIH set these limits based on the available toxicological and epidemiological data on a guideline basis. This is different from the regulatory exposure limits enforceable by the legislation. A TLV of 4 mg/m^3 8-hour TWA of grain dust has been provided for by ACGIH as the threshold limits in breathing zones for workers in the feed industry(American Conference of Governmental Industrial Hygienists, 1997).

The WHO Air Quality guidelines provide stringent standards for indoor exposure to particulate matter, where grain dust falls into that category. During the global update in 2005, the annual mean concentration of PM_{10} was 20 $\mu g/m^3$ and for $PM_{2.5}$ was 10 $\mu g/m^3$ whereas for 24-hour mean concentration, PM_{10} was 50 $\mu g/m^3$ and for $PM_{2.5}$ was 25 $\mu g/m^3$. This is because numerous epidemiological studies have identified a strong exposure-effect relationship with little evidence to indicate a threshold limit below which no adverse health effects would be expected (World Health Organization, 2006). These standards are the same as those of the ambient (outdoor) air, despite indoor particulate matter pollutants normally being higher than those of the outdoor (World Health Organization, 2010).

During the global update in 2021, the recommended air quality guideline (AQG) levels were reduced since there has been a significant increase in evidence of the health impacts on exposure to even low concentrations of PM_{10} and $PM_{2.5}$. The guidelines now stated for the annual mean concentrations at, PM_{10} 15 $\mu g/m^3$ and for $PM_{2.5}$ 5 $\mu g/m^3$ whereas for 24-hour mean concentrations at, PM_{10} was 45 $\mu g/m^3$ and for $PM_{2.5}$ 15 $\mu g/m^3$ (World Health Organization, 2021).

The main Acts of Parliament in Kenya that shape occupational exposure levels are The Occupational Safety and Health Act, 2007, and The Factories and Other Places of Work Act (Hazardous Substances) Rules, 2007. Researchers have rightly pointed out that developing countries such as Kenya have limited systems used in managing air quality due to lack of enforcement capacity, high cost of equipment for monitoring, unfriendly government regulations, and corruption by government regulatory agencies (Omanga et al., 2014). Additionally, inadequate investment in pollution prevention technologies poses a challenge to maintaining a balance between economic development and a sustainable environment (Omanga et al., 2014). More attention usually goes to the short-term benefits from increased production and job creation because of a lack of air quality management capability, translating into a lack of air pollution data, hence the false belief that there is no problem (Omanga et al., 2014).

Kenya enacted the Occupational Exposure Limits in 2007 under The Factories and Other Places of Work Act (Hazardous Substances) Rules, 2007, which states the Time Weighted Average (TWA) OEL-RL for grain dust is 10 mg/m^3. This is the time-weighted average concentration for a normal 8-hour workday for a five-day workweek or 40-hour workweek without adverse effects. The chemicals are designated as either an Occupational Exposure Limit – control limit (OEL-CL) or an occupational exposure limit – recommended limit (OEL-RL). Similarly, it stipulates the conditions under which the employer can introduce measures to protect the employee by providing exhaust appliances to remove dust and fumes and protective clothing to prevent injuries and ill-health that may occur as a result. The Occupational Safety and Health Act, 2007 is a legal requirement that facilitates the provision for the health, safety, and welfare of people employed in factories and other places. Exposure by inhalation to a substance assigned an OEL-RL should be reduced to that standard. However, if exposure by inhalation exceeds the OEL-RL, then control will still be deemed adequately provided that the occupier has identified why the OEL-RL has been exceeded and is taking appropriate steps to comply with the OEL-RL as soon as is reasonably practical.

For dust sampling, there are existing standards for sampling and determination of dust concentrations. These standards are described in BS EN 12341:2014 for PM_{10} and $PM_{2.5}$ and Methods for the determination of hazardous substances (MDHS) 14-“General method for Gravimetric determination of Respirable and Total Dust” (Health and Safety Executive, 2000).

The Factories and Other Places of Work Act (Hazardous Substances) Rules, 2007, stipulate that the animal feed manufacturers conduct medical examinations for the exposed workers. The Factories and Other Places of Work (Medical Examination) Rules, 2005 state that lung function tests and clinical examinations are to be done on a pre-employment and annual basis, though this is not expressly provided for grain dust. The rule has been applied to the general class of substances that contain dust from plant matter where grain dust falls.

The accepted manoeuvres that should be accomplished during a spirometry test are provided in the American Thoracic Society (ATS)/European Respiratory Society (ERS) Task Force guidelines.

2.4 Grain dust measurements analytical techniques

The size, composition, and quantity of grain dust particles influence the technique to be applied. Due to the wide range of particulate matter sizes, PM_{10} is the coarse dust particles that settle in the upper airways, while $PM_{2.5}$ is the fine dust particles that gather within the lung parenchyma (Mack et al., 2019). Thus, occupational hygienists have classified the grain dust concentrations into two impact zones: the total inhalable dust/inhalable dust present in the respiratory tract and the respirable dust, which spreads between alveoli and the blood capillaries (Health and Safety Executive, 2000).

Grain dust measurement techniques can be either direct or indirect. Direct methods are either filter-based or use the principles of mechanics, such as gravimetric, inertial microbalance, and Quartz Crystal Microbalance. They are precise and are not affected by the particulate matter's size and distribution. Indirect methods are beta attenuation and optical methods such as light scattering (Amaral et al., 2015; Held & Mangold, 2021).

Gravimetric involves a steady supply of air siphoned through a collection medium such as a filter and a foam, fitted in a sampler, and a pre-and post-filter weighing method applied to establish the mass of the dust that calculates the dust concentration. The respirable fraction is separated from the other dust particles using a cyclone preselector. Inhalable dust is determined using fixed-point sampling, although this will fail to provide an accurate dust concentration due to an unbalanced air pattern. Personal sampling overcomes the aerodynamic challenges by affixing the sampler to either the worker's breathing zone or head height to measure the respirable and inhalable dust, respectively. Longer sampling periods reduce sample errors (Health and Safety Executive, 2000; Kheiralipour et al., 2018). This method is an elementary test that can only perform static monitoring (Zhang et al., 2018). Gravimetric methods are widely used in other similar case studies (Aiguomudu, 2018).

An inertial microbalance is a direct sample mass determination based on Hooke's law. At a constant flow rate, the ambient air sample gravitates through a tube to an exchangeable sample filter. The sample filter is connected to a hollow tapered tubular coil driver sustained in a fixed amplitude oscillation by opposing magnets. Particulates deposit on the filter while weighed, which steadily loads the tube, reducing its oscillation frequency. Through this, we derive the near real-time mass concentrations of particulate matter. Differential temperature and pressure conditions have an impact on mass measurement. The instrument using this method is the Tapered Element Oscillating Microbalance (TEOM) monitor (Patashnick & Rupprecht, 1991).

The Quartz Crystal Microbalances instruments measure the particulate matter directly using either inertial impact or external force impact collection of the ambient particles on an adhesive crystal electrode. Measurement errors may occur due to particle bouncing, uneven mass distribution, and saturated electrodes (Ngo et al., 2019; Ngo & Jang, 2021).

A beta attenuation monitor is a continuous monitor that measures the particulate matter by its accumulation on the filter tape using a detector. The detector detects the extent of beta particle reduction as a result of radioactive decay experienced when particulate matter passes between a radioactive source and the detector. The method is highly dependent on the instrument calibration and sample composition (Shukla & Aggarwal, 2022).

There are two types of light scattering instruments: optical particle counters and photometers or nephelometers. An optical particle counter measures the particulate concentration by measuring the flash intensity released by a particle sample when illuminated at a particular angle using a diode laser (Molaie & Lino, 2021). This study will use a laser air quality monitor (Temtop, US), which works using an optical sensor that converts the pulse signal to digital signals following light scattering through the particles (Nguyen et al., 2021). The device's microprocessor processes the digital signals to the measurable parameters. However, these types of sensors have one main disadvantage, which is the load size of the scattered light, which is a determinant of the particle parameters such as size dimensions, structure, density, and refractive index (Shao et al., 2017). Nephelometry is an indirect technique that measures the light scattered or reflected by the suspended particulate matter in the direction of the detector and not in the path of transmitted or incident light using a nephelometer in a rapid response (Hagan & Kroll, 2020). This method provides a real-time evaluation of the dust concentrations, although this is influenced by dust properties such as optical composition and moisture content that may result in inaccurate mass measurements. Thus, a gravimetric method is required to validate its readings (Kheiralipour et al., 2018).

An indoor comparison study between real-time monitoring and gravimetric monitoring in Serbia showed real-time monitoring undervalued PM_{10} and $PM_{2.5}$ concentrations by roughly 12% and 63%, respectively (Tasić et al., 2012).

The dust measurement methods can be either reference methods or equivalent methods. Reference methods gather an integrated air sample over 24 hours and analyze it using gravimetric methods. They are defined by a combination of design and performance-based criteria for the sampler and the sample filter operating procedures. The equivalency method compares to the reference method to varying degrees based on measurement technique (Noble et al., 2001).

2,5 Pulmonary function tests techniques

Pulmonary function testing is a comprehensive assessment of the respiratory tract through physical examinations, pulmonary function tests, and evaluation of the patient's history to diagnose the onset, progression, and treatment of respiratory diseases and disorders.

Pulmonary Function Tests (PFTs), also referred to as Lung Function Tests, are a group of non-interfering assessments that measure the vital capacity, reserve capacity, tidal volume, airway resistance, flow rate, maximum flow, forced expiratory volume, gaseous exchange, and signs of inflammation (Ponce et al., 2022). The test results help in epidemiological studies and exposure monitoring of workplaces (Haschek et al., 2013). The cluster of tests measures different parameters that give lung function indicators and not the causes of the disease. The spirometry and lung volume tests are the most common tests that evaluate lung muscular mechanics by measuring lung volume and airflow (Ponce et al., 2022).

The spirometer was used in the study because the portable and electronic spirometry tools can be used outside of hospital settings and are widely accessible (Mario Morais-Almeida et al., 2022).The operating principle for the electronic (digital) spirometer is that once the test participant forcefully exhales, the blown-out air rotates the blades of the turbine. The turbine is fitted with infrared pair diodes that perform dual functions during blade rotation: emitting infrared rays and receiving the infrared rays. The diodes transduce the received infrared rays into signals through subcarrier multiplexing. The microprocessor then receives the signals and generates the various test results on the display screen (Mhetre et al., 2018). Spirometry derives useful respiratory markers such as forced vital capacity (FVC), forced expiratory volume in 1 second (FEV_1), FEV_1/FVC ratio, and airflow between 25% and 75% of the FVC (mean maximal flow [MMF] $_{25\text{-}75}$) (Ponce et al., 2022). The accuracy of the tests is dependent on the patient's effort (Kellerer et al., 2019). However, it is limited in determining the Residual Volume (RV) and Total Lung Capacity (TLC), and these challenges are addressed by the use of lung volume tests, also known as body plethysmography and diffusing capacity for carbon monoxide (DL_{CO}) (JJ et al., 2018; Modi & Cascella, 2020).

The lung volume test is a reliable method for detecting restrictive lung disorders, airway resistance and intrathoracic gas volume (ITGV) while the patient is at rest position (Langton et al., 2020; Radovanovic et al., 2018). Diffusing capacity for carbon monoxide (DL_{CO}) measures the gas fl28mow resistance across the alveolar-capillary interface using a test gas such as carbon monoxide (CO) (Modi & Cascella, 2020). Spirometry, volume tests, and DL_{CO} are jointly used in determining the presence of lung diseases, distinguishing whether they are restrictive or obstructive, and their severity.

Pulse oximetry, alveolar-arterial gradient, and arterial blood gas analysis evaluate the performance of gaseous exchange within the pulmonary circulation (West et al., 2018). Pulse oximetry is useful in identifying low arterial blood oxygen levels (Hafen & Sharma, 2022). The alveolar-arterial gradient evaluates the different oxygen levels between the alveoli and the blood from the arteries to diagnose hypoxemia (Hantzidiamantis & Amaro, 2022). Arterial blood gas analysis quantifies the pH of the blood and the levels of oxygen and carbon dioxide in the arterial blood (Pompey & Abraham-Settles, 2019). The three analyses are usually carried out on patients with evident respiratory conditions to assess the required assisted ventilation (Bi et al., 2021; Van Woensel et al., 2021; Vonderbank et al., 2020). Fractional exhaled nitric oxide (FeNO) measures exhaled nitric oxide, a non-invasive biomarker for lung inflammation and hyper-responsiveness. It uses an online chemiluminescence detection monitor. It is more suitable for diagnosing asthma (Heffler et al., 2020). Flow Volume Loops is one of the most accurate methods to measure upper airway obstructions (Fiorelli et al., 2019).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study design

This study adopted a cross-sectional research design to determine the dust management strategies in place, the monitoring of dust levels (PM_{10} and $PM_{2.5}$), and the prevalence of respiratory symptoms among animal feed mill workers in Kiambu County, Kenya. A case-control study design was adopted to identify the status of lung function between the target group and the control group in connection with the causal factor variable (exposure to grain dust).

3.2 Study area and population

A target group and a control group were used in the study. The target group was the feed milling companies' workers in Kiambu County. Kiambu County covers an estimated area of 2,543.5 km^2 within the central Kenya region, with most millers located in Thika's industrial zone (Figure 3.1).

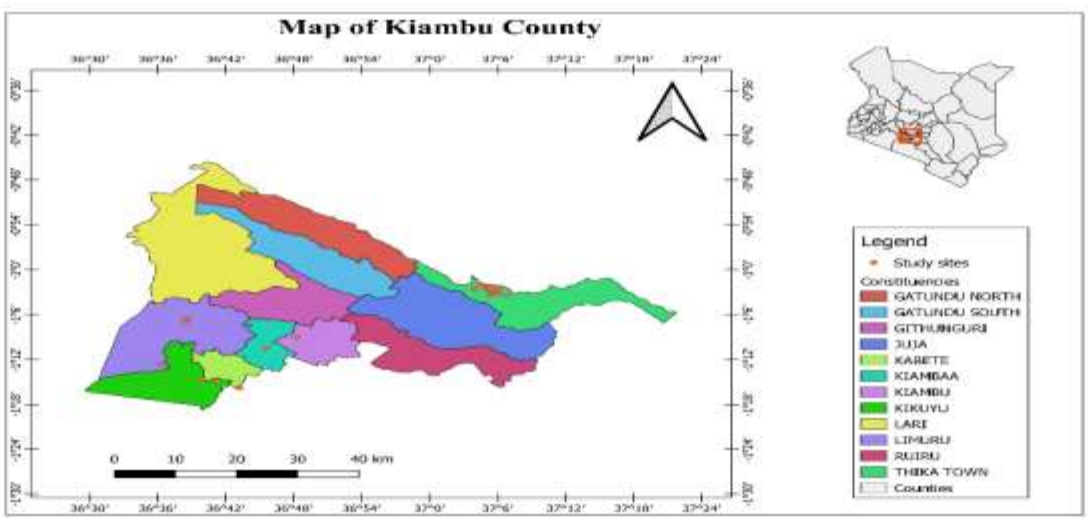


Figure 0.1: Map of the study area

Source: (QGIS Development Team, 2022)

It had 35 registered feed milling manufacturers duly recognised by the Association of Kenya Feed Manufacturers (AKEFEMA) (Appendix I). AKEFEMA was formally established in 2004 as an authorized representative of the Kenyan registered feed manufacturers and related businesses. A total of 31 millers consented to participate in the study. The control group included workers from three milk-processing companies within the county. They were perceived not to be exposed to grain dust at their workstations.

The target population was composed of the management, middle-level employees, and operational level employees in 35 feed mills in Kiambu County recognised by AKEFEMA, as shown in Table 3.1 below. They were involved in various job roles: administration, machine operator or attendant, manager or supervisor, and engineer.

Table 3.1 shows the distribution of the target population

Table 0.1: Target population

Category	Target Population	Percentage
Management	208	7
Middle-level employees	575	18
Operational level employees	2,353	75
Total	**3,136**	**100**

Source: Administrative Departments (2020)

The control group was constituted of workers in the milk processing companies in Kiambu County. The milk processing companies were selected because they are not exposed to grain dust during their commercial operations.

For the target group and control group participants to be eligible for the spirometry test, they had to fulfil the inclusion criteria: worked for more than 6 months and aged above 18 years. Participants with the following characteristics were excluded from the study: history of smoking, history of bronchial asthma before joining work; present or past history of severe respiratory infection (extensive pulmonary tuberculosis, bronchiectasis, and COVID-19); and clinical abnormalities of the vertebral column and thoracic cage.

Additionally, control group participants who had previously worked in dusty environments were excluded.

3.3 Sampling method

The study adopted a stratified, random sampling method to draw respondents from the target population in the two sampling strata, that are, middle-level employees and operational level employees. A representative sample was based on an equal chance of selection and free from classification error. However, purposive sampling was performed to select the management or owners and the animal feed mills.

The study adopted Halstensen's sampling technique to select eight different grain handling areas within the industries. These areas were within administration offices, finished goods loading, grain elevators or storage areas, grinding, mixing, raw materials reception, transport areas, and weighing (Halstensen et al., 2013).

3.4 Sample size determination

3.4.1 Dust management system sampling

The Yamane formula was used to select a representative sample size that was provided with the questionnaires. The sample was from the management, middle-level employees, and operational level employees in 35 feed mills in Kiambu County (Yamane, 1967).

Based on Yamane's formula, 355 respondents from a total of 35 feed mills in Kiambu County formed the sample size from a population of 3,136. Yamane's statistical formula was used to derive the sample size from the target population.

$$n = \frac{N}{1 + N(E)^2}$$

n –sample size,

N -Size of population,

E – 0.05, at 95% confidence level.

$$n = \frac{3{,}136}{1 + 3{,}136(0.05)^2} = 355$$

The sample size was therefore 355 distributed among the stratas as shown in table 3.2.

Table 3.2 shows the distribution of the sample Size

Table 0.2: Sample Size

Category	Target Population	Sample Size	Percentage
Management	208	25	7
Middle-level employees	575	64	18
Operational level employees	2,353	266	75
Total	3,136	**355**	**100**

3.4.2 Dust monitoring sampling (PM_{10} and $PM_{2.5}$)

Fisher's formula recommends a characteristic interest of 50% to determine the sample size where the target population is less than 10,000 and the proportion of the targeted population with the characteristic is not known (Fisher, 1998). Thus, seventeen (17) animal feed millers were sampled. Purposive sampling was used to select the animal feed millers whereby they have to be registered with the Directorate of Occupational Safety and Health Services (DOSHS) (Appendix I).

PM_{10} and $PM_{2.5}$ sampling was conducted during the active production process at eight stationary sampling points for each of the seventeen millers. These were the administration offices, finished goods loading, grain elevators or storage areas, grinding, mixing, raw materials reception, transport areas, and weighing sections. These points were selected because activities are highly concentrated in those work sections (Halstensen et al., 2013; Smid, Heederik, Houba, et al., 1992).

3.4.3 Pulmonary Function Test sampling

Kelsey's formula was used to calculate the minimum sample size for comparing the exposed groups and unexposed groups (Kelsey et al., 1996).

$$n = \frac{2(Z_\alpha + Z_\beta)^2\, ṕ(1 - ṕ\,)}{(p_1 - p_2)^2}$$

Where;

n = number per group

$p_1$prevalence in the first group

p_2 = prevalence in the second group

$$ṕ = \frac{(p_1 + p_2)}{2}$$

Z_α = standard normal deviate for two tail test based on α level (α = 0.05) then Z α = 1.96

Z_β = standard normal deviate for two tail test based on beta level (β = 0.10) Z β = 1.28

p_1 = prevalence of respiratory symptom in exposed group = 74.7% (Kuchuk et al., 2000)

p_2 = prevalence of respiratory symptom in unexposed group = 50% using Fisher's formula (1998)

$$ṕ = \frac{(0.747 + 0.5)}{2} = 0.6235$$

Hence,

$$n = \frac{2(1.96 + 1.28)^2\ 0.6235(1 - 0.6235\ )}{(0.747 - 0.5)^2} = 81$$

Eighty-one (81) respondents were selected from the seventeen animal feed millers with more than 20 employees and duly registered by DOSHS and AKEFEMA. A total of 81 workers selected from the three milk processing companies formed the control group.

The respondents who met the inclusion criteria for the spirometry test were grouped into stratas using their age, gender, and height. These were matched with the control group at a 1:1 ratio until the sample size was attained.

3.5 Research instruments

3.5.1 Dust management systems

Dust management systems data was collected using structured questionnaires and a walk-through survey.

The researcher trained the interviewers on how to carry out the surveys. A modified form of the British Medical Research Council questionnaire (Appendix II) was administered to the respondents by the researcher and the trained interviewers (Medical Research Council Committee on the Aetiology of Chronic Bronchitis, 1960; Yawn et al., 2021). An approval from the university was obtained to conduct this study. The questionnaire had both open- and closed-ended questions, which addressed specific research questions of this study. The questionnaire for this study was divided into two sections. The first section captured socio-demographic information of the population, such as gender, age, designation, and work experience. The second section gathered information on the practises and respiratory health of the workers. The respondents were requested to respond based on their knowledge of existing rules and regulations regarding occupational safety and health; the existence of safety and health systems within the workplace; and their respiratory health assessment. The questionnaires offered anonymity, thus encouraging the respondents to answer.

A walk-through survey was conducted through the business unit to record the existing working conditions and to corroborate the findings on the workers' safety and health practices. This was done using an observation checklist (Appendix III) that took into account direct observations of the safety risks, safety controls, and use of personal protective equipment.

Interviews were used to obtain data from the senior management about the company's profile to support the survey findings.

3.5.2 Determination of grain dust exposure levels (PM_{10} and $PM_{2.5}$)

The study used continuous or real-time methods that used optical particulate matter sensors (Temtop, US). The sensors are convenient, lightweight, and have low energy consumption (Badura et al., 2018). Additionally, their quick turnaround times on measurements make them viable for this study due to the numerous sampling points. During sampling, the air inlet channel of the device faced the direction of the air inflow, and the device was placed near the breathing zones of the workers but away from any blockages, fresh air inlets, and strong wind currents (Health and Safety Executive, 2000). Sampling was performed thrice for each sampling point that was two to three feet towards the air inlet, air outlet, and at the source of dust. Where there was no clear source of dust, the sampling was done towards the air inlet and outlet. The sampling duration for every sampling point was ten minutes weighted averages and four hours for each sampling point (Health and Safety Executive, 2000). The PM_{10} and $PM_{2.5}$ measurements were taken for each static sampling point for the animal feed mills for three months. Each study location was monitored in the morning and afternoon for three non-consecutive days to capture the peak activity periods and complete activity cycles. The results were expressed in micrograms per cubic metre of air. The data gathered was compared to the applicable standards relating to exposure levels to dust (World Health Organization, 2006).

3.5.3 Pulmonary Function tests

The study used spirometry due to the availability of the equipment and expertise within Kenya. A pre-screening questionnaire (Appendix IV) was administered to the eligible workers and the control group before the test to have an accurate population sample. This helped to identify and exclude individuals who did not fulfil the inclusion criteria. The screening process resulted in a final population sample of eighty-one (81) respondents from the target group, as well as a comparable number from the control group.

The researcher was trained on instrument handling and standard operating procedures by a spirometry technician. The target group was matched with the control group in terms of age, gender, height, and weight.

The worker's height was measured using a portable stadiometer, Seca. The participants were to remove any head protective gear, stand steadily against the wall, and face straight. The headpiece was then lowered and rested steadily on the participant's head, whereby the reading was measured and recorded.

The body weight of the participants was measured using a calibrated digital scale, Seca, with a maximum capacity of 200 kg on even ground. The scale was calibrated daily using reference test weights for the minimum and maximum load capacities, and the reading was recorded once the instrument stabilized. The test was repeated five times, and the mean values were taken. The location selected for calibration was thermally stable and free from magnetic or electrostatic fields. The participants were to remove any footwear before each weighing cycle and a reading was taken once the scale stabilized.

The spirometry tests were performed on each of the stratified randomly sampled feed milling workers. A clean, calibrated, and portable spirometer (Contec SP-10) was used to take the measurements. The workers loosened any tight clothing to achieve the best results. Once the device was on, the testing option was selected, and the worker had to inhale, seal the lips around the mouthpiece, and forcefully exhale all the air in the least time possible until they could not expel any more air. The device then displayed the results in the form of measured and predicted values. The predicted values were popularised values referenced using a set of variables such as gender, age, height, and ethnicity. The predicted values were evaluated using known standards that provide the benchmark for interpreting spirometry results. The test was performed in a well-aerated location and in a standing position (Quanjer et al., 1993).

Various lung function parameters were recorded, which are the Forced Vital Capacity (FVC), Forced Expiratory Volume quantified at the first second (FEV_1), FEV_1/FVC ratio, and $FEF_{25-75\%}$. The test results were acceptable if there was no false start, coughing in the first second, and exhalation lasted for at least six seconds. A minimum of three test trials were done to ensure the results were reproducible. The two highest values for the indicators should agree within 150 mL (0.15 L) after three successful runs (Centers for Disease Control and Prevention., 2013). All lung function measurements were done during the day shift between 1000–1700 hours to reduce any diurnal variation that occurs as a response to the circadian rhythm (Dimich & Sterling, 1981).

For interpretation of the spirometry results, the measured value was compared with the reference or predicted value. Normal lung function was considered when the FVC and FEV_1 test scores were more than or equal to 80% of the reference value, and the FEV_1/FVC ratio was more than or equal to 70% of the reference value. If the test scores were less than the normal values, this represented a lung function abnormality, either restrictive or obstructive. Obstructive lung disease was determined when FVC and FEV_1 test scores were less than 80% of the reference value and the FEV_1/FVC ratio was less than 70% of the reference value. This causes the FEV_1 to be lower than the normal values. Restrictive lung disease facilitates the FVC to be lower than the normal values, and it was considered when FVC and FEV_1 test score was less than 80% of the reference value, and FEV_1/FVC ratio was more than 70% of the reference value (Barreiro & Perillo, 2004; Ponce et al., 2022).

3.6 Reliability and validity of the research instruments

The researcher explained to the respondents the intentions of the research study before administering the same and followed up with phone calls or additional tests to ensure the success of the study. A pilot test was conducted with the two management staff, five middle-level employees, and thirteen operational level employees who were the target to ensure that the instruments met the set objectives as part of ensuring the reliability and validity of the data and results of the study.

The manufacturers of the dust monitor provided a calibration certificate (Appendix V) which was valid for the study.

The calibration of the spirometer was done using a 3-litre precision calibration syringe before the first session and after every full data log. The calibration interface would be selected on the spirometer's display screen, the syringe would then be attached to the spirometer, and the syringe volume would be fed into it steadily until the device displayed "REPEAT." Another feeding loop was performed, after which, if the calibration was successful, the device would display "OK!" and the display would return to its previous set interface.

Other measures of reliability and validity include peer-review of the tool and the results and the use of different approaches in data collection, as already explained.

3.7 Data validation

Prior to the data analysis, all questionnaires were checked for incompleteness, duplication, and inconsistencies. The data collected using various instruments was edited and coded to get the relevant data for the study. This involved checking for errors, resolving discrepancies, and identifying missing information.

3.8 Data processing and analysis

Quantitative data collected from questionnaires,observation checklists, particulate matter sampling, and lung function tests were analysed using descriptive statistics using SPSS (Statistical Package for Social Sciences) and reported as percentages, means, standard deviation, and frequencies. The information was also displayed by the use of frequency tables and charts. Content analysis was used to analyse the data collected from the openended questions. The study’s statistical significance level was at $p<0.05$ or 95% confidence level. A Chi-square test for independence was used to compare the association of significance between two categorical variables. The student’s t-test was used to compare the means between a categorical and continuous variable. An F test was carried out to compare whether a group of variables are jointly significant. This offered a systematic and qualitative description of the objectives of the study.

Additionally, a binary logistic regression model was performed to establish the relationship between specific predictor variables and the dependent variables to predict the lung function outcome.

3.8 Ethical consideration

The potential respondents were not coerced into taking part in this study; as such, the principle of voluntary participation was followed by ensuring informed consent was obtained from the feed mill workers and the management (Appendix VI). The participants were guaranteed their confidentiality by assuring them that the information provided was used only for academic purposes and accessed only by authorization. An ethical approval was obtained from Jomo Kenyatta University of Agriculture and Technology's Ethical Review Committee (Appendix VII) and a research license was obtained from the National Commission for Science, Technology, and Innovation (NACOSTI) (Appendix VIII).

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Response rate

Out of the 355 questionnaires administered by the interviewers to the 35 animal feed millers, 292 questionnaires from 31 animal feed mill companies were duly completed. This was an 82.25% participation rate from the respondents.

Seventeen animal feed millers were selected for the grain dust monitoring study and spirometry test; however, only twelve agreed to participate in the study. This was a 70.59% response rate. Mugenda and Mugenda (1999) state that a response rate of 50% is adequate for statistical reporting. Dust monitoring was performed in twelve animal feed millers where they were duly registered by DOSHS and AKEFEMA during the active production process, cumulatively 96 sampling points. However, the twelfth miller did not have a functioning grinding section.

A total of 81 animal feed mill workers from the twelve feed millers were matched with 81 workers from the three milk-processing companies on age, gender, weight, and height by applying frequencies. This was a 100% participation rate.

Overall, these participation rates indicate a high level of engagement and cooperation from the participants in the study. The study was able to match workers from animal feed mills and milk-processing companies on important demographic factors, allowing for meaningful comparisons to be made between the two groups. Additionally, the study met the adequacy threshold for statistical reporting by achieving a response rate of 50%.

4.2 Socio-demographic characteristics

4.2.1 Socio-demographic data of the feed mill workers

Table 4.1 presents the results of the socio-demographic characteristics of the feed mill workers in Kiambu County, Kenya. The table has information on the gender distribution, age, educational levels, work experience, job categories, and smoking status of the workers.

Table 0.1: Socio-demographic data of the feed mill workers (n = 292)

Characteristics	Frequency	Percentage
Gender		
Male	258	88.36%
Female	34	11.64%
Age group (years)*		
18-29	170	58.22%
30-39	91	31.16%
40-49	21	7.19%
50-59	10	3.42%
Level of education		
Primary	57	19.52%
Secondary	140	47.95%
Tertiary	95	32.53%
Years of experience in the animal feed industry		
Less than 1 year	51	17.47%
1-5 years	159	54.45%
6-10 years	61	20.89%
11-15 years	15	5.14%
16 years and above	6	2.05%
Job role/department		
Administration	59	20.21%
Machine operator/attendant	195	66.78%
Engineer	4	1.37%
Manager/Supervisor	34	11.64%
Smoking history		
Smokers	23	7.88%
Non-smokers	265	90.75%
Ex-smokers	4	1.37%

*Mean (±SD) of the age group: 30.54 (±7.397) years

From table 4.1, there were more males in the study than females, comprising 88.36%, attributed to the high level of physical labour involved. It can be deduced that this sector is male-dominated. This study finding was consistent with the results of a study conducted in Norwegian grain industries on the cross-shift respiratory response to bioaerosol exposure of the grain dust, where the male respondents were 94% while the female respondents were 6% (Straumfors et al., 2016).

The respondents within the age group 18-29 were the highest in number, followed by the age group 30-39, and 10.5% were comprised of the age groups 40-49 and 50-59. The mean age was 30.54 years in this study concurs with the study in Western Turkey, whose mean age was 32 years for the 108 animal feed industry workers (Baser et al., 2003).

Approximately half of the respondents had done secondary school education (47.95%), while nearly a fifth had primary school education (19.52%), and more than a third had tertiary education (32.53%). There were high literacy levels among the respondents, which could be used as an opportunity by the management of the animal feed facilities to provide continuous training to improve their workers' knowledge of the dust control measures. This study finding was not consistent with the findings of a study done to assess the prevalence of respiratory symptoms and lung function of the flour mill workers in Ilorin, Nigeria, which showed that 26.7% of the workers had no formal education, 0.9% attended primary school, 11.9% went to secondary school, and 36.6% had tertiary education (Tosho et al., 2015). The disparity may be a result of the study focusing on flour mill workers and the differing adult literacy rates between Kenya (78%) and Nigeria (59.6%) (UNESCO, 2013).

Regarding work experience, more than half of the respondents (54.45%) had between one and five years of experience, while those with six years or more of work experience accounted for 28.08%. The majority of the respondents had between one and five years of experience, implying that there was a high personnel turnover ratio that would amplify the healthy worker effect and reduce the animal feed facilities' capacity to retain workers with good knowledge of and practices for the dust control measures. This study finding differed from the results of the studies in Nigeria by Iyogun et al. (2019) and Tosho et al. (2015), attributed to the differing labour markets in Kenya and Nigeria. Iyogun et al. (2019) reported that about 75% of the grain miller workers had worked for more than 5 years, whereas Tosho et al. (2015) found that 55.4% of the flour mill workers had worked for more than 5 years.

Two-thirds of the respondents were machine operators or attendants classified as operational-level employees (66.78%). The middle-level employees comprised a fifth of the respondents, including the administration (20.21%) and the engineers (1.37%). The management, who were the managers/supervisors, consisted of 11.64% of the respondents. This shows that the bulk of the respondents were operational-level employees, indicating that they may have more direct involvement in the production process, which involves a lot of manual handling of the materials. The smaller percentage of middle-level and management employees suggests that decision-making may be concentrated in a smaller group of individuals within the processing facility. These study findings were consistent with the study conducted in the animal feed facilities in the Netherlands, where the majority of the sampled production workers were operators and general workers (Smid, Heederik, Mensink, et al., 1992).

A few respondents (7.88%) were current smokers. This finding suggests that smoking may not be a significant confounding factor in the study's results on the impact of grain dust exposure on pulmonary function of the workers.

4.2.2 Socio-demographic data of the matched groups for spirometry test.

Table 4.2 displays the socio-demographic characteristics of the matched target group, which consists of animal feed mill workers, and the control group, which consists of workers from milk-processing companies in Kiambu County, Kenya. The table presents the frequency distribution of key socio-demographic variables, which are gender, age group, education level, and work experience, for both groups.

Table 0.2: Socio-demographic data of the matched target group and control group.

	Target group n=81		Control group n=81			
Characteristics	**Frequency**	**%**	**Frequency**	**%**	**χ^2 value**	**P-value**
Gender						
Male	71	87.65%	71	87.65%	0.000	1.000
Female	10	12.35%	10	12.35%		
Age group (years)						
20-29	41	50.62%	41	50.62%	0.000	1.000
30-39	28	34.57%	28	34.57%		
40-49	9	11.11%	9	11.11%		
50-59	3	3.70%	3	3.70%		
Level of education						
Primary	15	18.52%	22	27.16%	13.313	0.001
Secondary	36	44.44%	49	60.49%		
Tertiary	30	37.04%	10	12.35%		
Work experience						
Less than 1 year	10	12.35%	12	14.81%	12.593	0.013
1-5 years	43	53.09%	25	30.86%		
6-10 years	19	23.46%	21	25.93%		
11-15 years	7	8.64%s	12	14.81%		
16 years and above	2	2.47%	11	13.58%		

From table 4.2, both gender and age were matched for the target group and the control group; thus, it was not a statistically significant difference (($\chi 2= 0.000$, *df= (1, 3)*, (*p=1.000*). Both the target group and the control group had more males than females, constituting 87.65% for both of them.

Nearly half (44.44%) of the target group and two-thirds (60.49%) of the control group had secondary school education. More than a third (37.04%) of the animal feed workers and more than a tenth (12.35%) of the control group had tertiary education. There was a statistically significant difference in the level of education between the animal feed mill workers and the milk processing workers ($\chi 2= 13.313$, *df=2*, *p=.001*). This suggests that there may be differences in the educational requirements for these two types of jobs, which could have implications for the recruitment and training of workers in these industries.

Workers with 1–5 years of work experience within the industry from both groups comprised nearly half (42%) of the total, and they were the leading number of respondents. Workers with 6–10 years' work experience comprised almost a quarter (24.7%) of both groups. The difference in work experience between the two groups was statistically significant ($\chi 2= 12.593$, $df=2$, $p=.013$). This implies that the control group operated in a more favourable work environment compared to the target group since more than half of the group had more than 6 years of work experience.

The study findings on gender and age group were consistent with the study findings conducted among 196 flour mill factory workers in Hawassa city, southern Ethiopia, to evaluate the prevalence of chronic respiratory symptoms, pulmonary function, and associated factors whereby both the target group and the control group had more males than females, and more than half (51%) of respondents in both groups were aged 20 to 29 years (Lagiso et al., 2020).

The study findings on the level of education differed from the study findings conducted in Ethiopia that showed that almost three quarters (73.6%) of the workers had primary education, 18.4% attended secondary school, and 8% had more than secondary education (Lagiso et al., 2020). The disparity may be a result of the study focusing on flour mill workers and the differing adult literacy rates between Kenya (78%) and Ethiopia (48.6%) (UNESCO, 2013).

The study findings on the work experience differed from the study conducted among 315 animal feed mill workers in fourteen animal feed mills in the Netherlands to assess the association between organic dust exposure, respiratory symptoms, and chronic pulmonary function changes. The study observed that most of the workers had been employed in the industry for an average of 13.7 years (Smid et al., 1994). This could be attributed to the different labour laws in Kenya and the Netherlands and the employer-employee relationship in the different facilities.

Figure 4.1 presents the job description of the matched target group consisting of 81 animal feed mill workers in Kiambu County, Kenya. The figure provides a breakdown of the different job roles or categories within the animal feed mills, including managers, supervisors, machine operators, and administration workers. The figure also indicates the percentage of workers in each job category, providing insights into the composition of the workforce in the animal feed mill industry in the study area.

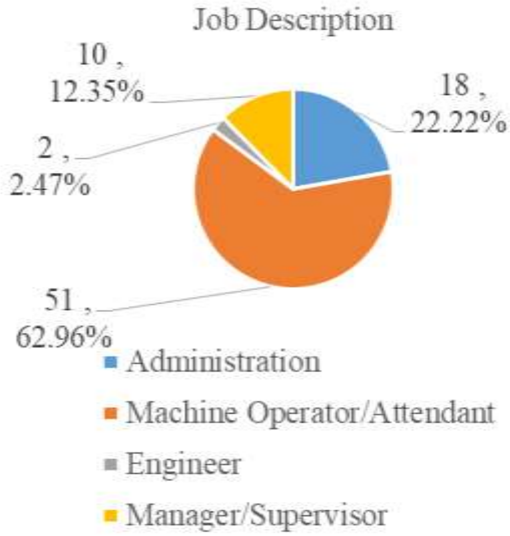


Figure 0.1: Job description of the matched target group n=81

From figure 4.1, the findings show that nearly two-thirds of the respondents were machine operators or attendants. More than a fifth of the workers were in the administration. More than a tenth (12.35%) were managers or supervisors, and engineers accounted for 2.47%. This shows that there is a diverse range of job roles within the animal feed mill industry in Kiambu County, Kenya, with a significant proportion of workers involved in machine operation and administration.

Figure 4.2 provides information on the job description of the matched control group, which consists of 81 workers from three milk-processing companies in Kiambu County, Kenya. The figure gives a breakdown of the work sections that were assigned to the workers.

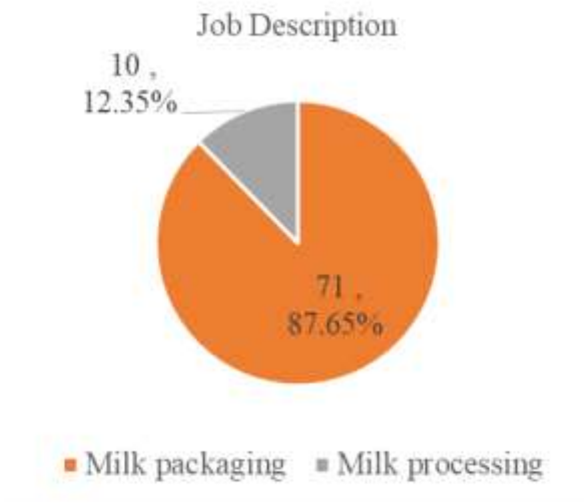


Figure 0.2: Job description of the matched control group n=81

From figure 4.2, the majority of the workers (87.65%) were from the milk packaging section. Milk packaging is a crucial aspect of milk pasteurisation. The workers were responsible for ensuring that the milk was properly packaged and labelled before it was distributed to consumers.

Figure 4.3 displays the distribution of daily work hours of the matched target group of 81 animal feed mill workers. The figure provides an insight into the typical working hours of the workers in the animal feed milling industry, which is essential for assessing their occupational exposure to grain dust and health effects such as decreased pulmonary function.

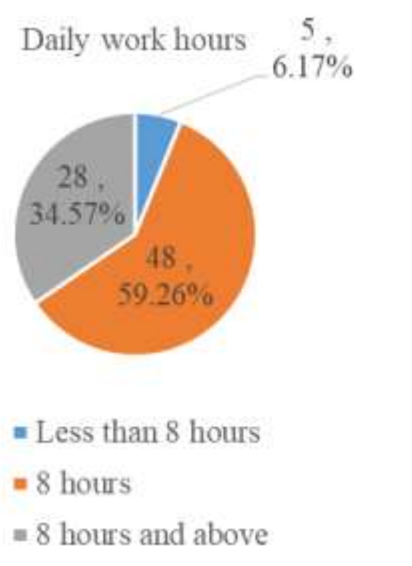


Figure 0.3: Daily work hours of the matched target group n=81

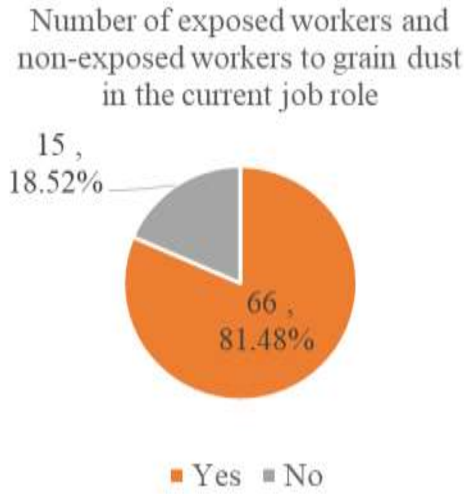
From figure 4.3, nearly 94% of the target group worked 8 hours or more than 8 hours per day. This indicates that the majority of the selected animal feed mill workers in Kiambu County work long hours, which may increase their exposure to grain dust and potentially affect their pulmonary function.

Figure 4.4 displays the daily work hours of the matched control group, consisting of 81 workers from three milk-processing companies in Kiambu County, Kenya. The figure provides information on the duration of work hours for the control group, which can be compared to the work hours of the target group in Figure 4.3.

Figure 0.4: Daily work hours of the matched control group n=81

From figure 4.4, the majority (87.65%) worked more than 8 hours a day. This was in contrast to the exposed group, where only 34.57% worked more than 8 hours a day. This finding suggests that the mill workers in Kiambu County, Kenya, are likely experiencing better working conditions in terms of daily work hours compared to the matched control group.

Figure 4.5 presents data on the number of animal feed mill workers who were exposed and not exposed to grain dust in their current job role. The figure helps to highlight the proportion of workers who are exposed to grain dust in their daily work, as well as the number of workers who are not exposed. This information can be used to develop appropriate interventions to reduce the risk of respiratory problems among the exposed workers.



n=81

Figure 0.5: Exposure to grain dust in the current job role of the matched target group

From figure 4.5, more than four-fifths of the target group's work duties involved handling grain dust. This high level of exposure to grain dust may have a significant impact on the pulmonary function of the animal feed mill workers in Kiambu County, Kenya.

4.3 Dust management system measures implemented at the animal feed mills.

Table 4.3 provides information on the reported dust management control measures by workers at animal feed companies in Kiambu County, Kenya. The table presents the frequency and percentage of workers who reported the use of different dust control measures, including personal protective equipment (PPE) and administrative controls. The information provides insights into the current practices in the industry and inform potential areas for improvement to reduce dust exposure and improve worker health and safety.

Table 0.3: Reported dust management control measures at the animal feed companies in Kiambu County

	Frequency			
Dust management control measures	**N**	**%**	**N**	**%**
	Yes		No	
Availability of dust management policy statement	4	1.37%	288	98.63%
Availability of dust management system or program	38	13.01%	254	86.99%
Work injury Benefit Act (WIBA) insurance policy awareness by the workers	92	31.51%	200	68.49%
Training on safe dust management procedures and rules	48	16.44%	244	83.56%
Training on the grain dust hazards	10	3.42%	282	96.58%
Air sampling measurements to determine the exposure to dust	0	0.00%	292	100.00%
Awareness of the exposure limits to the grain dust within the scope of the work	0	0.00%	292	100.00%
Availability of the safety signs indicating highly dusty areas	4	1.37%	288	98.63%
Training on the usage of the Personal Protective Equipment (PPE)	40	13.70%	252	86.30%
Provision of the Personal Protective Equipment (PPE)	8	2.74%	284	97.26%

From table 4.3, the percentage availability of both dust management policies and systems to the workers was less than 15%. On WIBA insurance awareness, 31.51% of the workers were aware of it. The proportion of workers trained on dust management procedures was 16.44%, grain dust hazards (3.42%) and usage of PPE (13.70%), showing that the vast majority were not trained. None of the workers was aware of the air sampling measurements or the exposure limits. The percentage of workers who were aware of the available safety signage was 1.37%.

The majority of the workers were neither trained nor aware of the various elements of dust management procedures. This indicates a concerning lack of awareness and implementation of dust management policies and systems among workers in animal feed companies in Kiambu County, which increases the risk of occupational diseases or other effects related to grain dust exposure.Continuous training is needed to promote a safety culture in the workplace. It is particularly alarming that none of the workers were aware of air sampling measurements or exposure limits and low percentage of workers aware of WIBA insurance, a mandatory workers' compensation insurance in Kenya. This suggests a lack of monitoring of grain dust and potential overexposure to grain dust and a need for better communication and enforcement of workers' rights and protections.

These study findings were supported by a study conducted in bakeries located in the United Kingdom, where 40% of the fifty-five bakeries conducted some form of training on flour dust for employees during their job orientation, and 27% of the bakeries were aware of the occupational exposure limits (Elms et al., 2005). This was similarly found in a study in Ethiopia where only a third of the flour mill workers and a third of the office workers received safety and health training (Mekonnen et al., 2021).

Only 2.74% of the workers reported having been provided PPE by their companies. Without proper PPE, workers may be at increased risk of respiratory diseases caused by exposure to dust in the workplace. The low provision of PPE could also indicate a lack of commitment to workplace safety and health by the employers, which can have a negative impact on the morale and productivity of workers. The importance of PPE is very vital since it is the last resort when minimising the exposure to grain dust. This was consistent with the study conducted by Adeoye et al. (2015) to evaluate the awareness of occupational hazards among sawmill workers in Osun State, Nigeria. The study findings were that employers rarely provided them, and when they did, they were not long-lasting.

Table 4.4 presents the observed dust management control measures at the animal feed companies in Kiambu County, Kenya. The table outlines the frequency and percentage of each dust management control measure that was observed during the visits to the animal feed companies. The control measures covers the administrative controls, engineering controls, and personal protective equipment (PPE). The table provides insight into the implementation of dust management control measures in the animal feed industry in Kiambu County and highlights areas where improvements in the implementation of dust management controls may be necessary.

Table 0.4: Observed dust management control measures at the animal feed companies in Kiambu County

	Frequency			
Dust management control measures	**N**	**%**	**N**	**%**
	Yes		No	
Fully operational ventilation systems	22	70.97%	9	29.03%
Segregation of work processes	5	16.13%	26	83.87%
Structural dust controls (manual or automated) apart from ventilation systems	5	16.13%	26	83.87%
Warning signs indicating a hazardous atmosphere	0	0.00%	31	100.00%
MSDS for production inputs and outputs	0	0.00%	31	100.00%
Workspaces free from dust	0	0.00%	31	100.00%
Obstructions near the air inlets and outlets within the workplace	16	51.61%	15	48.39%
Sources of air contaminants within the workplace	31	100.00%	0	0.00%
Visible mould on the raw materials and finished products	0	0.00%	31	100.00%
Shaking the bags during emptying	31	100.00%	0	0.00%
Workers tipping the bags into the feeding inlet while facing away	31	100.00%	0	0.00%
Dust stirred during cleaning	31	100.00%	0	0.00%
Workspaces cleaning during the production in case of spillages	5	16.13%	26	83.87%
Routine cleaning schedules for the production floor	5	16.13%	26	83.87%
Workers wearing dust protective gear such as masks and respirators properly during all production processes	0	0.00%	31	100.00%

From table 4.4, nearly three quarters (70.97%) of the animal feed production facilities had some form of general and local exhaust ventilation with no visible mould on the raw materials and finished products in the 31 millers. This shows that there is a general compliance within the animal feed sector in the provision of proper ventilation systems as required by the Occupational Safety and Health Act, 2007. These study findings were comparable with the study done to evaluate the control measures of fifty-five bakeries in England, Scotland, and Wales. It was observed that 86% of them had a certain kind of mechanical ventilation, with 28% having local exhaust ventilation (Elms et al., 2005). Despite this, there was no animal feed millers' workspace that was free from dust.

None of the animal feed millers had warning signage and Material Safety Data Sheets (MSDS) for the inputs and products. This contravenes the Occupational Safety and Health Act, 2007 and the Factories and Other Places of Work Act (Hazardous Substances) Rules, 2007 that state that the employer shall make available MSDS for all hazardous substances into which the grain dust falls.

Only 16.13% of the feed millers controlled the dust using other engineering and administrative controls such as segregation of the work processes, structural dust control systems such as dust collectors, and routine cleaning procedures. This is because the initial cost of setting up the engineering controls is higher compared to the administrative controls. This causes the management of the animal feed facilities to be reluctant about installing them and focus on profit maximization. These study findings were similar to those observed in the study conducted to assess the control measures among bakery workers in Edo Central Senatorial District, Nigeria, where structural controls and local exhaust ventilation were scarcely available (Aiguomudu, 2018).

During the production in all millers, workers tipped the bags into the feeding inlet while facing away and shook the bags when emptying, stirring dust in the ambient air. During the cleaning process, dust was generated in all the millers. More than half of the workplaces had obstructive objects near the air inlets and outlets within the workplace.

It was observed that no worker wore the dust protective gear properly. These study findings were similar to those of a study conducted in the Western Australian Wheatbelt to assess the personal exposure to dust of farm workers, and it was observed that no workers wore respiratory protective gear when working outside the vehicle's enclosure (Rumchev et al., 2019). Similar findings were observed by Adeoye et al. (2015), whose study evaluated the awareness of occupational hazards among sawmill workers in Osun

State, Nigeria. It was observed that the reported usage frequency of personal protective equipment was nil except for facemasks, gloves, and goggles, whereby the percentage of workers using them frequently was 2%, 5%, and 10%, respectively. This low usage of PPE was attributed to non-availability (Adeoye et al., 2015). In addition, low usage may be attributed to the health belief model, where workers might only take action when they perceive a hazard to cause harm or injury to them (Abdollahzadeh & Sharifzadeh, 2021). According to the Occupational Safety and Health Act, 2007, the employers have to ensure they provide protective gear for their workers within the workplace. If this is done accordingly, it can help in reducing exposure levels to workers.

Similarities between reported and observed dust control measures indicate an increased risk of grain dust exposure to the workers.

4.4 Particulate matter concentration in the animal feed mills.

Table 4.5 presents the results of the levels of PM_{10} in various work sections in the target animal feed mill companies in Kiambu County, Kenya. The table shows the results of the PM_{10} measurements taken at different locations in the animal feed mills, including the grinding, mixing, grain elevators, and transport areas.

Table 0.5: Levels of PM_{10} in various work sections in the target animal feed mill companies

	PM_{10} ($\mu g/m^3$)										
Animal Feed Mills No.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Work sections											
Administration offices	17.99	23.97	29.57	24.03	29.73	14.83	30.57	29.63	33.47	24.77	48.93
Finished goods loading	15.20	22.70	31.70	33.93	34.13	48.00	25.47	30.53	22.20	57.13	111.33
Grain elevators/Storage areas	307.33	18.70	47.17	33.33	18.60	53.93	35.13	24.90	21.00	58.40	103.27
Grinding	385.50	97.13	43.67	36.17	105.87	98.03	23.90	30.97	515.00	49.13	53.47
Mixing	33.90	43.33	48.27	52.93	19.90	54.70	40.87	35.07	78.73	23.97	108.73
Raw materials reception	19.00	38.37	29.20	41.33	38.57	36.60	30.93	43.77	48.30	73.60	47.60
Transport areas	19.97	26.80	37.47	42.17	40.53	25.00	24.57	35.35	17.20	49.93	24.03
Weighing	26.85	46.53	69.40	33.30	28.30	84.83	25.23	29.67	59.13	42.77	50.63

From table 4.5, the minimum concentration of PM_{10} was 15.20 µg/m^3 in the finished goods loading in company number 1, while the maximum was 515.00 µg/m^3 in the grinding section in company number 9. This shows that the grinding section makes the workers more susceptible to grain dust exposure compared to other work sections, leading to more severe respiratory health issues as compared to the other workers. The high concentration of PM_{10} in the grinding section was due to the method of operation that involved the breaking down of grains into smaller particles, resulting in more airborne grain dust. The insufficient dust management control measures in the grinding section was a contributing factor to the high levels of PM_{10}.

Table 4.6 presents the results of the levels of $PM_{2.5}$ in various work sections in the target animal feed mill companies in Kiambu County, Kenya. The table shows the results of the $PM_{2.5}$ measurements taken at different locations in the animal feed mills, including the grinding, mixing, grain elevators, and transport areas.

Table 0.6: Levels of $PM_{2.5}$ in various work sections in the target animal feed mill companies

	$PM_{2.5}$ (µg/m^3)										
Animal Feed Mills No.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Work sections											
Administration offices	12.86	18.60	20.87	16.37	21.10	10.90	21.47	24.63	30.73	17.20	34.00
Finished goods loading	10.88	16.17	22.60	27.03	31.43	37.15	18.13	25.67	15.70	39.33	71.30
Grain elevators/Storage areas	164.67	13.40	32.73	25.33	13.37	35.50	24.83	21.90	14.90	40.20	68.60
Grinding	202.57	64.60	30.60	27.37	69.90	68.80	17.13	26.30	327.47	33.83	40.13
Mixing	27.20	30.10	32.77	43.07	14.33	36.70	28.57	28.93	51.97	17.17	68.73
Raw materials reception	13.65	26.90	20.70	32.10	27.07	31.37	21.97	34.40	33.43	49.70	33.03
Transport areas	14.90	19.20	25.73	29.93	28.27	18.13	17.43	31.30	12.20	34.70	16.37
Weighing	19.20	32.33	46.77	30.87	20.17	57.67	18.00	25.27	39.57	30.13	35.40

From table 4.6, the minimum concentration of $PM_{2.5}$ was 10.88 µg/m^3 in the finished goods loading in company number 1, while the maximum was 327.47 µg/m^3 in the grinding section in company number 9. This shows a similar trend compared to the findings in table 4.5, where the grinding section exposes the workers to the highest concentration of grain dust.

Table 4.7 presents the mean particulate matter concentration in the various work sections in the target animal feed mill companies.

Table 0.7: Mean particulate matter concentration in the various work sections in the target animal feed mill companies

	PM_{10} (Mean ± SD) μg/m^3	**$PM_{2.5}$ (Mean ± SD) μg/m^3**
Work sections		
Administration offices	27.95±8.94	20.79±6.98
Finished goods loading	39.30±26.67	28.67±16.77
Grain elevators/Storage areas	65.62±83.91	41.40±43.85
Grinding	130.80±163.07	82.61±96.14
Mixing	49.13±25.48	34.50±15.51
Raw materials reception	40.66±13.87	29.48±9.32
Transport areas	31.18±10.44	22.56±7.63
Weighing	45.15±19.47	32.31±12.23
Mean ± SD (μg/m^3)	53.72±71.32	36.54±41.56

From table 4.7, the mean concentration of PM_{10} was 130.80 μg/m^3 whereas that of $PM_{2.5}$ was 82.61 μg/m^3 was highest at the grinding section. The administration offices had the lowest levels of PM_{10} (27.95 μg/m^3) and $PM_{2.5}$ (20.79 μg/m^3).

The average mean PM_{10} (53.72 μg/m^3 or 0.05 mg/m^3) and $PM_{2.5}$ (36.54 μg/m^3 or 0.04 mg/m^3) results in this study were similar to the findings obtained in bakery workers in Nigeria whereby there was no statistical difference between the means ($p>.05$). The study focused on assessing dust exposure and respiratory effects among bakery workers, where the average mean PM_{10} was 0.50 mg/m^3, and $PM_{2.5}$ was 0.07 mg/m^3. (Aiguomudu, 2018).

However, the present study results were significantly lower than those derived from the animal feed manufacturing facility in Egypt which was 1.97 mg/m^3 ($p<.05$) (Hameed et al., 2003). This is because Hameed et al. (2003) performed background sampling using gravimetric dust samplers with no internal fractionators. Similarly, the results were significantly lower than those obtained in the grain and compound feed industry in Norway which was 1.00 mg/m^3 ($p<.05$) since Halstensen et al. (2013) carried out personal sampling using gravimetric dust samplers. These samplers tested total inhalable dust, which is not size-selective compared to the particulate matter sensors that measured the dust concentration according to its aerodynamic particle size.

However, differences in the sampling, analysis, and instrumentation methods in the multiple studies make the comparison of the results complicated (Halstensen et al., 2013). This study utilised stationary or fixed-point sampling. This underestimates the dust concentration compared to personal sampling in other case studies (Aiguomudu, 2018; HSE, 2000). Additionally, this study operated a low-cost, light-scattering-based portable particulate matter (PM) sensor, which can exhibit a non-linear response compared to the gravimetric reference methods applied in other studies (Kelly et al., 2017; Nguyen et al., 2021). This response is experienced over various ranges of particulate matter concentration and could be a result of the low sensitivity of the particulate matter sensors (Li et al., 2018).

The mean PM_{10} (53.72 $\mu g/m^3$) and $PM_{2.5}$ (36.54 $\mu g/m^3$) concentrations exceeded the WHO Air Quality Guideline level of a 24-hour exposure time of 45 $\mu g/m^3$ for PM_{10} and for $PM_{2.5}$ 15 $\mu g/m^3$. This is an occupational health risk to the workers.

Table 4.8 provides a comparison of the mean particulate matter concentrations between different task environments in the animal feed processing mills in Kiambu County, Kenya. The table aims to identify the sections of the animal feed processing mills with the highest particulate matter concentrations. The results can be used to determine the most hazardous task environments and to identify measures that can be implemented to reduce worker exposure in the animal feed processing industry.

Table 0.8: Comparison of mean particulate matter concentrations between task environments in the animal feed processing mills

	PM_{10} (µg/m^3)	$PM_{2.5}$ (µg/m^3)
Work sections	**Mean ± SD**	**Mean ± SD**
Administration offices	27.95±8.94	20.79±6.98
Finished goods loading	39.30±26.67	28.67±16.77
Grain elevators/storage areas	65.62±83.91	41.40±43.85
Grinding	130.80±163.07	82.61±96.14
Mixing	49.13±25.48	34.50±15.51
Raw materials reception	40.66±13.87	29.48±9.32
Transport areas	31.18±10.44	22.56±7.63
Weighing	45.15±19.47	32.31±12.23
F value	2.717	2.846
P-value	0.014	0.011

From table 4.8, there was a statistically significant difference in the mean concentration of PM_{10} ($F(7) = 2.717, p = .014$) and $PM_{2.5}$ ($F(7) = 2.846, p = .011$) between the different task environments in the animal feed mill companies. The PM_{10} mean concentration was highest at the grinding section (130.80 µg/m^3), followed by grain elevators/storage areas (65.62 µg/m^3), mixing (49.13 µg/m^3) sections, and the rest of the work sections were closely uniform.

The $PM_{2.5}$ mean concentration was highest at the grinding section (82.61 µg/m^3), and in subsequent order, the grain elevators/storage areas (41.40 µg/m^3) and the rest of the unit stations were nearly uniform.

The PM_{10} (130.80 µg/m^3) and $PM_{2.5}$ (82.61 µg/m^3) exposure levels at the grinding section were more than twice that of the PM_{10} mean (53.72 µg/m^3) and $PM_{2.5}$ mean (36.54 µg/m^3), which could predispose the workers at that section to more adverse health outcomes compared to the other workstations. This is because previous studies have shown a relationship between grain dust exposure and deterioration of lung function, as well as a growing prevalence of respiratory symptoms at levels below 1.72 mg/m^3 (1,720 µg/m^3) (Hameed et al., 2003). This study's finding is similar to a study carried out in apparel processing factories in Kenya whereby the $PM_{2.5}$ concentration in the sewing department was higher than in the office department (Otieno et al., 2022). The level of grain dust exposure is dependent on the task and the location of the work station (Halstensen et al., 2013; Straumfors et al., 2021).

4.5 Anthropometric data for the target group and control group.

Table 4.9 compares the mean age, weight, and height of the target and control groups in the study. The target group consists of animal feed mill workers who are exposed to grain dust in their workplace, while the control group consists of workers from milk-processing companies who are not exposed to grain dust. The table provides a summary of the demographic characteristics of the two groups. The comparison of these characteristics between the two groups is important in evaluating the impact of grain dust exposure on the health of animal feed mill workers.

Table 0.9: Comparison of mean age, weight, and height of the target and control group

Characteristics	Target group	Control group	t value	p-value
Age (years)				
Mean ± SD	32.02±7.64	32.48±7.62	0.381	0.704
Weight (Kg)				
Mean ± SD	70.81±9.32	71.22±9.35	0.284	0.777
Height (cm)				
Mean ± SD	172.11±7.29	172.90±7.97	0.659	0.511

From table 4.9, the study sought to match the ages, weights, and heights of the target and the control groups. From the findings, there was no statistically significant difference in their mean values.

The mean age for the target group (32.02 years) and control group (32.48 years) were comparable with the findings of Baser et al. (2003), who focused on animal feed dust exposure on its workers and reported a mean age of 32 years for the target group and 30 years for the control group.

The mean weight of the target group (70.81 Kg) and the control group (71.22 Kg) contradicts with the study in the Norwegian grain and animal feed production industry by Straumfors et al. (2016), where the mean weight of the exposed workers was 90 Kg while that of the referents was 83 Kg. This was attributed to the differing average weights in Kenya and Norway, whereby Kenya, being in the African region, has a mean weight of 60.7 Kg, and Norway, being in the European region, has a mean weight of 70.8 Kg, according to a study conducted by Walpole et al. (2012).

The mean height of the target group (172.11 cm) and the control group (172.90 cm) was in agreement with the results of the study on bioaerosol exposure and respiratory response in the grain and feed workers, where the mean height of the exposed workers was 179 cm, and that of the control group was 176 cm (Straumfors et al., 2016).

4.6 Pulmonary function of the target group and control group.

Table 4.10 presents the results of the lung function parameters among the target and control groups in the study. The purpose of this table is to compare the lung function parameters between the target and control groups and determine if there is any significant difference between the groups. The results of the lung function tests are important in determining the lung function status of the workers in the animal feed processing mills and their exposure to grain dust.

Table 0.10: Lung function parameters among target and control groups

Parameter	Target group	Control group		
	Mean ± SD	**Mean ± SD**	**t value**	**P-value**
FEV_1 (%)	82.64±21.17	108.06±11.86	9.429	0.000
FVC (%)	88.44±21.76	95.47±13.32	2.478	0.014
FEV_1/FVC (%)	95.42±20.76	113.72±5.91	7.628	0.000
FEF_{25-75} (%)	80.60±30.69	100.81±10.74	5.594	0.000

From table 4.10, the mean predicted lung function values: FEV_1 (%)±SD (82.64±21.17), FVC (%)±SD (88.44±21.76), FEV_1 /FVC (%)±SD (95.42±20.76), and FEF_{25-75} (%)±SD (80.60±30.69) were lower for the animal feed mill workers than the control workers for all the parameters. The differences were significant for FEV_1, FVC, FEV_1/FVC, and FEF_{25-75} between the target and the control groups ($p<.05$). The results show that working in an animal feed mill may have a negative impact on lung function, as evidenced by the lower values of FVC, FEV_1, FEV_1/FVC, and FEF_{25-75} in the workers compared to the control group.

These study findings were consistent with the study conducted in Turkey by Baser et al. (2003), where the mean pulmonary function test values (predicted %) of the workers were FVC±SD (85.23±12.06), FEV_1±SD (88.73±13.09) and FEF_{25-75}±SD (88.42±25.94). These values were significantly lower than those of the control group and were attributed to grain dust exposure to workers in the animal feed facilities ($p<.05$).

However, a study carried out by Straumfors et al. (2016) in Norwegian grain and feed facilities had contrasting findings where there was no difference in the lung function parameters between the workers and the control group. The possible factors attributed to this are minimised acute effects due to tolerance built over long periods of exposure and healthy worker effect (Straumfors et al., 2016).

Table 4.11 presents the lung function classification among the target and control groups in Kiambu County, Kenya. Lung function tests were performed on the participants to determine the lung function classification based on the predicted values for FVC, FEV_1, and FEV_1/FVC. The classification categories were normal, restrictive, and obstructive. This table provides valuable information on the prevalence of lung function impairments among workers in animal feed processing mills.

Table 0.11: Lung function classification among the groups

	Target group n=81		**Control group n=81**			
Lung function classification	**Frequency**	**%**	**Frequency**	**%**	**x^2 value**	**P-value**
Normal	37	45.7%	72	88.9%	35.773	0.000
Obstructive	10	12.3%	0	0.0%		
Restrictive	34	42.0%	9	11.1%		

From table 4.11, the prevalence of normal lung function was higher in the control group companies than in the target group (88.9% versus 45.7%). Obstructive lung abnormalities were observed only among the target group and none in the control group. The differences were statistically significant ($p<.001$). This suggests that there is an association between exposure to grain dust and obstructive lung diseases.

These study findings were similar to studies carried out to assess the respiratory effects among bakery workers in Edo Central Senatorial District, Nigeria, where the prevalence of obstructive lung disease was observed among the bakery workers and none among water company workers who formed the control group (Aiguomudu, 2018).

Table 4.12 presents the prevalence of respiratory symptoms in the target group, which is composed of 292 workers from animal feed processing mills in Kiambu County. The table provides information on the percentage of workers who reported experiencing various respiratory symptoms such as cough and phlegm production.

Table 0.12: Prevalence of respiratory symptoms in the target group (n=292)

Characteristics	Frequency	%
Chronic bronchitis	2	0.68%
Pneumonia	19	6.51%
Hay fever	8	2.74%
Other: Breathing difficulty	2	0.68%
Other: Cold allergy	2	0.68%
Cough first thing in the morning during cold periods	36	12.33%
Cough during the rest of the day or at night working hours	21	7.19%
Phlegm first thing in the morning during cold periods	40	13.70%
Phlegm during the rest of the day or at night working hours	23	7.88%
Phlegm on most days or night working hours as much as 3 months in a year	23	7.88%
Phlegm first thing in the morning	25	8.56%
Increased cough and phlegm lasting for 3 weeks or more in a year	14	4.79%
Shortness of breath when hurrying on level ground	23	7.88%
Shortness of breath with other people of your age on level ground	2	0.68%
Shortness of breath walking at your own pace on the level ground	6	2.05%
Breathless to leave the house or on dressing or undressing	2	0.68%
Wheezy or whistling chest	12	4.11%
Whistling sounds improve when you are away from work	6	2.05%

Characteristics	Frequency	%
Stuffy, itchy, running nose	157	53.77%
Watery, itchy eyes	89	30.48%

From table 4.12, the most prevalent symptom among the respondents was a stuffy, itchy, and running nose (53.77%), followed by watery and itchy eyes (30.48%), phlegm first thing in the morning during cold periods (13.70%), and cough first thing in the morning during cold periods (12.33%). These study findings were consistent with the study undertaken among animal feed workers in the Netherlands to assess the lung function changes and occupation-related symptoms associated with grain dust and endotoxin. The most commonly recorded symptom among the animal feed workers was sneezing (21%), followed by nasal irritation (15%) and cough (9%). These symptoms were significantly higher compared to those of the control group ($p<.01$) (Smid et al., 1994).

Similarly, in Denizli, Western Turkey, a study assessed the prevalence of chronic occupational respiratory symptoms in animal feed workers. The prevalence of respiratory symptoms among the workers was cough (12%), dyspnea (5.6%), and sinusitis (8.3%). The prevalence of the irritation symptoms in the exposed group was pruritus of the eyes (11.1%), skin lesions (7.4%), and nose symptoms (8.3%) (Baser et al., 2003).

Table 4.13 presents the predictors of respiratory symptoms and associated factors in the matched target group of 81 workers in animal feed processing mills. This table aims to provide an understanding of the factors that contribute to the occurrence of respiratory symptoms among workers who are exposed to grain dust in their work environment. The table includes variables such as age, gender, education level, and duration of employment. Binary logistic regression analysis was used to ascertain the effects of socio-demographic and occupational variables on the prevalence of respiratory symptoms in the animal feed workers (target group). The results are presented as odds ratios (OR) with 95% confidence intervals (CI) and p-values to indicate the significance of the association.

Table 0.13: Predictors of respiratory symptoms and associated factors in the matched target group

Variables	At least one respiratory symptom		Crude Odds ratio (95% CI)	P-value
	Yes	No		
Gender				
Male	44	27	Reference	
Female	8	2	2.84 (0.33-24.28)	0.341
Age				
20-29	30	11	Reference	
30-39	17	11	0.20 (0.04-0.96)	0.045
≥ 40	5	7	0.10 (0.01-0.64)	0.016
Education level				
Primary	11	4	Reference	
Secondary	23	13	0.45 (0.09-2.10)	0.308
Tertiary	18	12	0.26 (0.04-1.61)	0.147
Work experience				
Less than 1 year	3	7	Reference	
1-5 years	32	11	6.86 (1.24-38.00)	0.027
6-10 years	12	7	5.65 (0.79-40.50)	0.085
11 years and above	5	4	5.10 (0.40-65.49)	0.211
Daily working hours				
Less than 8 hours	4	1	Reference	
8 hours	26	22	0.41 (0.03-4.80)	0.475
8 hours and above	22	6	1.76 (0.13-24.46)	0.674
Exposure to dust at the current job role				
No	43	23	Reference	
Yes	9	6	2.20 (0.39-12.30)	0.371

(n=81)

From, table 4.13, the likelihood of getting respiratory symptoms was higher in the age group 30–39 ($p=.045$) compared to the age group ≥ 40 ($p=.016$), which was significant. This could be that older workers may have developed greater immunity or tolerance to grain dust due to longer exposure over time, while younger workers may still be building up their tolerance. Additionally, older workers may have had more opportunities to get medical care, which could protect them against respiratory symptoms.

A similar trend was observed in the work experience variable. Although insignificant for workers with more than 6 years of work experience, a negative relationship between work experience and the probability of getting respiratory symptoms was observed.

Workers with 1-5 years of experience (*OR=6.86*, *p=.027*) had higher odds than those with 6-10 years (*OR=5.65*, *p=.085*) and more than 11 years (*OR=5.10*, *p=.211*). The chances of getting respiratory symptoms had a significant positive association with workers working between 1 to 5 years (*OR=6.86*, *p=.027*). This may suggest that workers with more experience have had time to adapt to the working conditions and have developed some level of immunity to the grain dust in their workplace. Also, "healthy worker effect" may have influenced these results. This effect refers to the tendency of workers to remain employed in a job if they are healthy enough to work, leading to a selection of healthier workers over time. As a result, the workers in this study may have been healthier than the general population of workers, and this could have impacted the results. The other predictor variables were insignificant (*p>.05*).

The study findings were consistent with a study in the Netherlands on the dust and endotoxin related respiratory effects in the animal feed industry where the prevalence of the severe respiratory symptoms declined with the increasing years of exposure attributed to the "healthy worker effect" (Smid, Heederik, Houba, et al., 1992). This phenomenon was similar to another study conducted in Ethiopian flour mills where the chances of respiratory symptoms for workers with 6–9 years of work experience was twice that of workers with more than 10 years. This was attributed to the healthy worker effect (Lagiso et al., 2020).

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The majority of the workers had not been trained in dust management processes such as dust management procedures, grain dust hazards, and the usage of PPE. The majority of the workers reported having not been provided with PPE by the companies. Though the majority of the workers self-provided their own PPE, it was observed that no worker wore the dust protective gear properly.

The majority of the animal feed production facilities had some form of general and local exhaust ventilation, although there was no animal feed millers' workspace that was free from dust. A minority (16.13%) of the feed millers controlled the dust using other engineering and administrative controls such as segregation of the work processes, structural dust control systems such as dust collectors, and routine cleaning procedures.

The particulate matter mean concentration of PM_{10} was 53.72±71.32 $\mu g/m^3$ and $PM_{2.5}$ was 36.54±41.56 $\mu g/m^3$, which exceeded the WHO Air Quality Guideline level of a 24-hour exposure time of 45 $\mu g/m^3$ for PM_{10} and for $PM_{2.5}$ 15 $\mu g/m^3$.

The mean predicted lung function values for animal feed mill workers were significantly lower than the control workers for all the parameters, attributed to grain dust exposure to workers in the animal feed facilities ($p<.05$). The most prevalent symptom among the respondents was a stuffy, itchy, and running nose. Obstructive lung abnormalities were found among the target group and none in the control group. The differences were statistically significant. ($p<.001$). This suggests that there is an association between exposure to grain dust and obstructive lung diseases.

5.2 Recommendations

(i) Animal feed companies should develop a dust management system that includes improving existing control measures and developing appropriate control measures where none exist, as well as plans and strategies for controlling grain dust emissions, limiting exposure, and monitoring the effectiveness of the system. Regular reviews and updates to the system, along with management commitment and the allocation of adequate resources, are essential to maintaining an effective dust management system.

(ii) The animal feed mill companies should provide continuous training on the risks associated with exposure to grain dust, safe operating procedures, and suitable protective gear to their workers. On the other hand, the workers should adhere to the set safety and health guidelines and wear the appropriate personal protective equipment at all times. This will promote awareness of the grain dust hazards and help stimulate a safety and health culture. This is per The Occupational Safety and Health Act, 2007 and The Factories and Other Places of Work Act (Hazardous Substances) Rules, 2007 which constitute part of the regulations that DOSHS should ensure they comply with in order to promote the safety and health of the workers.

(iii) The animal feed mill companies should ensure the implementation of the annual grain dust monitoring and its exposure levels are maintained within the acceptable exposure limits as provided by the WHO Air Quality Guidelines and The Factories and Other Places of Work Act (Hazardous Substances) Rules, 2007. This will aid in determining the effectiveness of the controls in place.

(iv) Animal feed companies should engage qualified experts to regularly monitor and assess the levels of grain dust in their facilities and provide recommendations for improvement.

(v) The animal feed facilities should develop an exposure control plan that includes strategies for reducing exposure levels, such as improvements to ventilation and work practices, and procedures for monitoring and maintaining exposure levels.

(vi) The animal feed mill facilities should ensure their workers undergo pre-employment and period medical examinations as part of their health surveillance to assist in the early detection of abnormal lung function. Proper interventions that have been taken at an early stage decrease the severity of pulmonary diseases. This is provided by The Factories and

Other Places of Work Act (Hazardous Substances) Rules, 2007, and The Factories and Other Places of Work (Medical Examination) Rules, 2005.

(vii) The animal feed processing companies should create a respiratory protection program that includes procedures for selecting, fitting, and maintaining dust masks, as well as training workers on their proper use.

5.3 Areas for further research

(i) Further studies can be carried out to evaluate the effectiveness of structural control measures such as Local Exhaust Ventilation in reducing grain dust exposure in the animal feed manufacturing facilities in Kenya.

(ii) Grain dust monitoring using gravimetric samplers can be undertaken in the studied animal feed manufacturers and a comparison between gravimetric, and real-time dust monitors evaluated.

(iii) Characterization of the bio-contaminants in the grain dust and their effects on the respiratory health of the animal feed mill workers in Kenya should be done on a regular basis.

REFERENCES

Abdollahzadeh, G., & Sharifzadeh, M. S. (2021). Predicting farmers' intention to use PPE for prevent pesticide adverse effects: An examination of the Health Belief Model (HBM). *Journal of the Saudi Society of Agricultural Sciences*, *20*(1), 40–47. https://doi.org/10.1016/J.JSSAS.2020.11.001

Abdulsalam, S. T., Adeshina Abdus-salam, I., & Tope Arinde, J. (2015). Occupational Health Works in a Flour Mill in Ilorin, North Central, Nigeria. *International Journal of Research & Review (Www.Gkpublication.In)*, *2*(3), 67. www.ijrrjournal.com

Adeoye, O. A., Adeomi, A. A., Abodunrin, O. L., Olugbenga-Bello, A. I., & Abdulsalam, S. T. (2015). Awareness of Occupational Hazards and Health Problems among Sawmill Workers in Osun State, Nigeria. *International Journal of Research & Review (Www.Gkpublication.In)*, *2*(1).

Aiguomudu, M. (2018). Assessment of Exposure to Flour dust, Respiratory Effects and Control measures among Bakery workers in Edo Central Senatorial District, Edo State, Nigeria. In *Public Health*. Irrua Specialist Teaching Hospital.

Alemseged, E. A., Takele, A. K., Zele, Y., Abaya, S. W., Kiros, K. G., Mehari, M., Bezabh, Y. A., Atsbaha, A. H., Awoke, T. Y., & Goyteom, M. H. (2020). Assessment of chronic respiratory health symptoms and associated factors among flour mill factory workers in addis ababa, ethiopia, 2019: A cross-sectional study. *Journal of Asthma and Allergy*, *13*, 483–492. https://doi.org/10.2147/JAA.S273820

Amaral, S. S., de Carvalho, J. A., Costa, M. A. M., & Pinheiro, C. (2015). An overview of particulate matter measurement instruments. *Atmosphere*, *6*(9), 1327–1345. https://doi.org/10.3390/atmos6091327

American Conference of Governmental Industrial Hygienists. (1972). Threshold Limit Values for Substance in Workroom Air. *Adopted by ACGIH for 1972*.

American Conference of Governmental Industrial Hygienists. (1997). *Threshold Limit*

Values and Biological Exposure Indices. American Conference of Governmental Industrial Hygienists.

Auma, J. O., Omondi, I. A., Mugwe, J. G., Rao, E. J. O., Lukuyu, B. A., & Baltenweck, I. (2018). *USAID - Kenya Crops and Dairy Market Systems (KCDMS): Feed and fodder value chain assessment report*. https://hdl.handle.net/10568/100637

Badura, M., Batog, P., Drzeniecka-Osiadacz, A., & Modzel, P. (2018). Evaluation of low-cost sensors for ambient PM2.5 monitoring. *Journal of Sensors*, *2018*, 16. https://doi.org/10.1155/2018/5096540

Barreiro, T. J., & Perillo, I. (2004). An Approach to Interpreting Spirometry. *American Family Physician*, *69*(5), 1107–1115.

Baser, S., Fisekci, F. E., Ozkurt, S., & Zencir, M. (2003). Respiratory Effects of Chronic Animal Feed Dust Exposure. *Journal of Occupational Health*, *45*(5), 324–330. https://doi.org/10.1539/joh.45.324

Basu, S., & Debnath, A. K. (2019). Main Equipment. In *Power Plant Instrumentation and Control Handbook*. https://doi.org/10.1016/b978-0-12-819504-8.00002-0

Bi, T., Zhang, J., Strohl, K. P., & Han, F. (2021). Hypercapnia and Hypoxemia in a Young Woman. *Annals of the American Thoracic Society*, *18*(3), 527–533. https://doi.org/10.1513/ANNALSATS.202006-699CC/SUPPL_FILE/DISCLOSURES.PDF

Caseiro, C., Dias, J. N. R., de Andrade Fontes, C. M. G., & Bule, P. (2022). From Cancer Therapy to Winemaking: The Molecular Structure and Applications of β-Glucans and β-1, 3-Glucanases. *International Journal of Molecular Sciences 2022, Vol. 23, Page 3156*, *23*(6), 3156. https://doi.org/10.3390/IJMS23063156

Centers for Disease Control and Prevention. (2013). *National Health and Nutrition Examination Survey (NHANES): respiratory health spirometry procedures manual*.

Chaudhuri, R., Thompson, M. A., Pabelick, C., Agrawal, A., & Prakash, Y. S. (2018). Obesity, mitochondrial dysfunction, and obstructive lung disease. In *Mechanisms and Manifestations of Obesity in Lung Disease* (pp. 143–167). https://doi.org/10.1016/B978-0-12-813553-2.00007-5

Cramer, M. E., Wendl, M. J., Sayles, H., Duysen, E., & Achutan, C. (2017). Knowledge, Attitudes, and Practices for Respiratory and Hearing Health among Midwestern Farmers. *Public Health Nursing*, *34*(4), 348–358. https://doi.org/10.1111/phn.12306

Demeke, D., & Haile, D. W. (2018). Assessment of Respiratory Symptoms and Pulmonary Function Status among Workers of Flour Mills in Addis Ababa, Ethiopia: Comparative Cross-Sectional Study. *Pulmonary Medicine*, *2018*. https://doi.org/10.1155/2018/9521297

der Poel, A. F. B. va., Abdollahi, M. R., Cheng, H., Colovic, R., den Hartog, L. A., Miladinovic, D., Page, G., Sijssens, K., Smillie, J. F., Thomas, M., Wang, W., Yu, P., & Hendriks, W. H. (2020). Future directions of animal feed technology research to meet the challenges of a changing world. *Animal Feed Science and Technology*, *270*, 114692. https://doi.org/10.1016/J.ANIFEEDSCI.2020.114692

Dimich, H. D., & Sterling, T. D. (1981). Ventilatory function changes over a workshift. *British Journal of Industrial Medicine*, *38*(2), 152–155.

Elms, J., Robinson, E., Rahman, S., & Garrod, A. (2005). Exposure to flour dust in UK bakeries: Current use of control measures. *Annals of Occupational Hygiene*, *49*(1). https://doi.org/10.1093/annhyg/meh074

Falcon-Rodriguez, C. I., Osornio-Vargas, A. R., Sada-Ovalle, I., & Segura-Medina, P. (2016). Aeroparticles, composition, and lung diseases. In *Frontiers in Immunology*. https://doi.org/10.3389/fimmu.2016.00003

Fiorelli, A., Poggi, C., Ardò, N. P., Messina, G., Andreetti, C., Venuta, F., Rendina, E. A., Santini, M., Loizzi, M., Serra, N., Sollitto, F., & Loizzi, D. (2019). Flow-

Volume Curve Analysis for Predicting Recurrence After Endoscopic Dilation of Airway Stenosis. *The Annals of Thoracic Surgery*, *108*(1), 203–210. https://doi.org/10.1016/J.ATHORACSUR.2019.01.075

Fisher, L. D. (1998). Self-designing clinical trials. *Statistics in Medicine*, *17*(14), 1551–1562.

Government of Kenya. (2005). The Factories and Other Places of Work (Medical Examination) Rules. *WorkSafe Kenya*, 1–12. https://www.worksafekenya.com/downloads/Medical-Examination-Rules-2005.pdf

Government of Kenya. (2007a). The Factories and Other Places of Work (Hazardous Substances) Rules. *WorkSafe Kenya*, 1–61. https://www.worksafekenya.com/downloads/Hazardous-Substances-Rules_-2007.pdf

Government of Kenya. (2007b). The Occupational Safety and Health Act; Act No. 15 of 2007. *Kenya Law Reports*, *2010*(15). http://kenyalaw.org/kl/fileadmin/pdfdownloads/Acts/OccupationalSafetyandHealth(No.15of2007).pdf

Gupta, N., & Anjum, N. (2020). *Extrusion technology and its application in food processing: A review*. https://doi.org/10.22271/tpi.2020.v9.i2d.4367

Hafen, B. B., & Sharma, S. (2022). Oxygen Saturation. *Oxygen Saturation - StatPearls - NCBI Bookshelf (Nih.Gov)* , 4–9. https://www.ncbi.nlm.nih.gov/books/NBK525974/

Hagan, D. H., & Kroll, J. H. (2020). Assessing the accuracy of low-cost optical particle sensors using a physics-based approach. *Atmospheric Measurement Techniques*, *13*(11), 6343. https://doi.org/10.5194/AMT-13-6343-2020

Halstensen, A. S., Heldal, K. K., Wouters, I. M., Skogstad, M., Ellingsen, D. G., & Eduard, W. (2013). Exposure to grain dust and microbial components in the Norwegian grain and compound feed industry. *The Annals of Occupational Hygiene*, *57*(9), 1105–1114. https://doi.org/10.1093/annhyg/met032

Hameed, A. A. A., Shakour, A. A., & Yasser, H. I. (2003). Evaluation of bio-aerosols at an animal feed manufacturing industry: A case study. *Aerobiologia*, *19*(2), 89–95. https://doi.org/10.1023/A:1024441106818

Hantzidiamantis, P. J., & Amaro, E. (2022). Physiology, Alveolar to Arterial Oxygen Gradient. *StatPearls*. https://www.ncbi.nlm.nih.gov/books/NBK545153/

Hardy, R. (1980). *FAO/UNDP Training Course in Fish Feed Technology* (Vol. 80, Issue 11).

Haschek, W. M., Rousseaux, C. G., Wallig, M. A., Bolon, B., & Ochoa, R. (2013). Haschek and Rousseaux's Handbook of Toxicologic Pathology. In *Haschek and Rousseaux's Handbook of Toxicologic Pathology*. https://doi.org/10.1016/C2010-1-67850-9

Health and Safety Executive. (2000). General methods for sampling and gravimetric analysis of respirable and inhalable dust. In *Methods for Determination of Hazardous Substances no. MDHS 14/3.* Health and Safety Executive Books Sudbury, UK. www.hse.gov.uk/pubns/mdhs

Health and Safety Executive. (2013). Grain dust. *Guidance Note*, *66*, 1–12. http://www.hse.gov.uk/pubns/eh66.pdf

Heffler, E., Carpagnano, G. E., Favero, E., Guida, G., Maniscalco, M., Motta, A., Paoletti, G., Rolla, G., Baraldi, E., Pezzella, V., Piacentini, G., & Nardini, S. (2020). Fractional Exhaled Nitric Oxide (FENO) in the management of asthma: a position paper of the Italian Respiratory Society (SIP/IRS) and Italian Society of Allergy, Asthma and Clinical Immunology (SIAAIC). *Multidisciplinary Respiratory Medicine*, *15*(1). https://doi.org/10.4081/MRM.2020.36

Held, A., & Mangold, A. (2021). Measurement of Fundamental Aerosol Physical Properties. *Springer Handbooks*, 535–565. https://doi.org/10.1007/978-3-030-

52171-4_18/COVER

Huss, A., Cochrane, R., Muckey, M., & Jones, C. (2018). Animal Feed Mill Biosecurity: Prevention of Biological Hazards. In *Food and Feed Safety Systems and Analysis*. https://doi.org/10.1016/B978-0-12-811835-1.00004-X

Huynh, C., Whitmore, G. A., Vandemheen, K. L., FitzGerald, J. M., Bergeron, C., Boulet, L. P., Cote, A., Field, S. K., Penz, E., McIvor, R. A., Lemière, C., Gupta, S., Mayers, I., Bhutani, M., Hernandez, P., Lougheed, M. D., Licskai, C. J., Azher, T., Ainslie, M., … Aaron, S. D. (2022). Derivation and validation of the UCAP-Q case-finding questionnaire to detect undiagnosed asthma and COPD. *European Respiratory Journal*, *60*(3). https://doi.org/10.1183/13993003.03243-2021

Iyogun, K., Lateef, S. A., & Ana, G. R. E. E. (2019). Lung Function of Grain Millers Exposed to Grain Dust and Diesel Exhaust in Two Food Markets in Ibadan Metropolis, Nigeria. *Safety and Health at Work, 10*(1), 47–53. https://doi.org/10.1016/j.shaw.2018.01.002

Jeebhay, M. F. (2000). Health and safety legislation and worker's compensation for allergic diseases of occupational aetiology. *Current Allergy and Clinical Immunology, 13(3),* 4–8.

Jeon, K.-J., Ryu, D. Y., & Jung, Y.-W. (2000). A Study on Dust Control Characteristics inside a Test Dome in the Port of Inchon. *Journal of Korean Society for Atmospheric Environment*, *16*, 47–57.

JJ, L., C, T., D, D., & SL, L. (2018). Physiology, Residual Volume. *StatPearls*. http://europepmc.org/books/NBK493170

Kellerer, C., Jankrift, N., Jörres, R. A., Klütsch, K., Wagenpfeil, S., Linde, K., & Schneider, A. (2019). Diagnostic accuracy of capnovolumetry for the identification of airway obstruction - Results of a diagnostic study in ambulatory care. *Respiratory Research*, *20*(1), 1–10. https://doi.org/10.1186/S12931-019-1067-1/TABLES/4

Kelly, K. E., Whitaker, J., Petty, A., Widmer, C., Dybwad, A., Sleeth, D., Martin, R., & Butterfield, A. (2017). Ambient and laboratory evaluation of a low-cost particulate matter sensor. *Environmental Pollution*, *221*, 491–500.

Kelsey, J., Whittemore, A., Evans, A., & Thompson, W. (1996). *Methods in observational epidemiology*. *2*, 332–335.

Kenya Markets Trust. (2016). Animal feed study: mapping animal feed manufacturers and ingredient suppliers in Kenya. *Kenya Market Trust*, 1–74.

Kheiralipour, K., Al-ansari, N., & Sissakian, V. K. (2018). Dust determination methods and instrumentations. *2nd International Conference on Dust, Ilam, Iran, 25-27 April 2018.*, 1–8.

Kuchuk, A. A., Basanets, A. V., & Louhelainen, K. (2000). Bronchopulmonary pathology in workers exposed to organic fodder dust. *Annals of Agricultural and Environmental Medicine*, *7*(1), 17–23.

Lagiso, Z. A., Mekonnen, W. T., Abaya, S. W., Takele, A. K., & Workneh, H. M. (2020). Chronic respiratory symptoms, lung function and associated factors among flour mill factory workers in Hawassa city, southern Ethiopia: "comparative cross-sectional study." *BMC Public Health*, *20*(1). https://doi.org/10.1186/s12889-020-08950-9

Langton, D., Bennetts, K., Noble, P., Plummer, V., & Thien, F. (2020). Bronchial thermoplasty reduces airway resistance. *Respiratory Research*, *21*(1), 1–8. https://doi.org/10.1186/S12931-020-1330-5/FIGURES/5

Li, J., Li, H., Ma, Y., Wang, Y., Abokifa, A. A., Lu, C., & Biswas, P. (2018). Spatiotemporal distribution of indoor particulate matter concentration with a low-cost sensor network. *Building and Environment*, *127*, 138–147. https://doi.org/10.1016/J.BUILDENV.2017.11.001

Liebers, V., Brüning, T., & Raulf, M. (2020). Occupational endotoxin exposure and health effects. *Archives of Toxicology*, *94*(11), 3629–3644. https://doi.org/10.1007/s00204-020-02905-0

Lukuyu, B., Franzel, S., Ongadi, P. M., & Duncan, A. J. (2011). Livestock feed resources: Current production and management practices in central and northern rift valley provinces of Kenya. *Livestock Research for Rural Development*, *23*(5), 112.

Lyu, F., Thomas, M., Hendriks, W. H., & van der Poel, A. F. B. (2020). Size reduction in feed technology and methods for determining, expressing and predicting particle size: A review. In *Animal Feed Science and Technology* (Vol. 261). https://doi.org/10.1016/j.anifeedsci.2019.114347

Mack, S. M., Madl, A. K., & Pinkerton, K. E. (2019). Respiratory Health Effects of Exposure to Ambient Particulate Matter and Bioaerosols. *Comprehensive Physiology*, *10*(1), 1. https://doi.org/10.1002/CPHY.C180040

Mario Morais-Almeida, M., Miguel Barbosa, M., & Claudia Sousa, M. (2022). Telemedicine in the Management of Chronic Obstructive Respiratory Diseases: An Overview. *Exon Publications*, 131–144. https://doi.org/10.36255/EXON-PUBLICATIONS-DIGITAL-HEALTH-RESPIRATORY-DISEASES

Martinez-Pitre, P. J., Sabbula, B. R., & Cascella, M. (2022). Restrictive Lung Disease. *Preoperative Assessment: A Case-Based Approach*, 101–106. https://doi.org/10.1007/978-3-030-58842-7_16

Medical Research Council Committee on the Aetiology of Chronic Bronchitis. (1960). Standardized questionnaire on respiratory symptoms. *British Medical Journal*, *2*(5213), 1665. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2098438/

Meijster, T., Tielemans, E., & Heederik, D. (2009). Effect of an intervention aimed at reducing the risk of allergic respiratory disease in bakers: Change in flour dust and fungal alpha-amylase levels. *Occupational and Environmental Medicine*. https://doi.org/10.1136/oem.2008.042564

Mekonnen, T. H., Dessie, A., & Tesfaye, A. H. (2021). Respiratory symptoms related to flour dust exposure are significantly high among small and medium scale flour mill workers in Ethiopia: a comparative cross-sectional survey. *Environmental Health and Preventive Medicine*, *26*(1), 1–10. https://doi.org/10.1186/S12199-021-01019-Y/TABLES/5

Meo, S. A., & Al-Drees, A. M. (2005). Lung function among non-smoking wheat flour mill workers. *International Journal of Occupational Medicine and Environmental Health*, *18*(3), 259–264.

Mhetre, M., Patil, Y., & Abhyankar, H. K. (2018). Design and evaluation of turbine spirometer: A new approach. *Lecture Notes in Networks and Systems*, *7*, 587–594. https://doi.org/10.1007/978-981-10-3812-9_60/COVER

Modi, P., & Cascella, M. (2020). Diffusing Capacity Of The Lungs For Carbon Monoxide. *StatPearls*. http://europepmc.org/books/NBK556149

Mohammadien, H. A., Hussein, M. T., & El-Sokkary, R. T. (2013). Effects of exposure to flour dust on respiratory symptoms and pulmonary function of mill workers. *Egyptian Journal of Chest Diseases and Tuberculosis*, *62*(4), 745–753. https://doi.org/10.1016/j.ejcdt.2013.09.007

Molaie, S., & Lino, P. (2021). Review of the Newly Developed, Mobile Optical Sensors for Real-Time Measurement of the Atmospheric Particulate Matter Concentration. *Micromachines 2021, Vol. 12, Page 416*, *12*(4), 416. https://doi.org/10.3390/MI12040416

Mugenda, O. M., & Mugenda, A. G. (1999). Research Methods: Quantitative & Qualitative Approaches. In *Olive M. Mugenda and Abel G. Mugenda* (Vol. 1). African Centre for Technology Studies.

Munguti, J. M., Kirimi, J. G., Obiero, K. O., Ogello, E. O., Sabwa, J. A., Kyule, D. N., Liti, D. M., & Musalia, L. M. (2021). Critical Aspects of Aquafeed Value Chain in the Kenyan Aquaculture Sector- A Review. *Sustainable Agriculture Research*, *10*(2), 87. https://doi.org/10.5539/sar.v10n2p87

Murgia, N., Gambelunghe, A., dell'Omo, M., & Muzi, G. (2020). COPD. In *Reference Module in Biomedical Sciences*. Elsevier. https://www.sciencedirect.com/science/article/pii/B9780128012383114977

Ngo, N. D., & Jang, J. (2021). Long-Term Measurement of PM2.5 Mass Concentration Using an Electrostatic Particle Concentrator-Based Quartz Crystal Microbalance Integrated with Carbon Dioxide Aerosol Jets for PM Sensing in Remote Areas. *IEEE Access*, *9*, 90715–90726. https://doi.org/10.1109/ACCESS.2021.3090401

Ngo, N. D., Lee, J., Kim, M. W., & Jang, J. (2019). Measurement of PM2.5 Mass Concentration Using an Electrostatic Particle Concentrator-Based Quartz Crystal Microbalance. *IEEE Access*. https://doi.org/10.1109/ACCESS.2019.2955377

Nguyen, N. H., Nguyen, H. X., Le, T. T. B., & Vu, C. D. (2021). Evaluating Low-Cost Commercially Available Sensors for Air Quality Monitoring and Application of Sensor Calibration Methods for Improving Accuracy. *Open Journal of Air Pollution*, *10*(1), 1–17. https://doi.org/10.4236/ojap.2021.101001

Nitter Moazami, T., Hirsch Svendsen, K., Buhagen, M., & Bramming Jørgensen, R. (2022). *Comparing PM2.5, respirable dust, and total dust fractions using real-time and gravimetric samples in a human exposure chamber study*. https://doi.org/10.21203/rs.3.rs-1810629/v1

Noble, C. A., Vanderpool, R. W., Peters, T. M., McElroy, F. F., Gemmill, D. B., & Wiener, R. W. (2001). Federal reference and equivalent methods for measuring fine particulate matter. *Aerosol Science and Technology*. https://doi.org/10.1080/02786820121582

Nordgren, T. M., & Charavaryamath, C. (2018). Agriculture Occupational Exposures and Factors Affecting Health Effects. *Current Allergy and Asthma Reports*, *18*(12), 65.

https://doi.org/10.1007/S11882-018-0820-8

Oluoch, I., Ndeda, J. O. H., & Njogu, P. (2017). Effect of Occupational Safety and Health Awareness on Work Environment in the Water Service Industry within Kisumu County - Kenya. *IOSR Journal of Environmental Science, Toxicology and Food Technology*, *11*(06), 35–41. https://doi.org/10.9790/2402-1106013541

Omanga, E., Ulmer, L., Berhane, Z., & Gatari, M. (2014). Industrial air pollution in rural Kenya: Community awareness, risk perception and associations between risk variables. *BMC Public Health*. https://doi.org/10.1186/1471-2458-14-377

Otieno, O. A., Njogu, P. M., & Magu, D. (2022). Occupational Safety and Health Hazards in Apparel Processing Factories Posed by Respirable PM2.5 in Export Processing Zone, Machakos County, Kenya. *Open Journal of Safety Science and Technology*, *12*(02), 43–50. https://doi.org/10.4236/ojsst.2022.122004

Ou, C., Hang, J., & Deng, Q. (2020). Particle Deposition in Human Lung Airways: Effects of Airflow, Particle Size, and Mechanisms. *Aerosol and Air Quality Research*, *20*(12), 2846–2858. https://doi.org/10.4209/AAQR.2020.02.0067

Patashnick, H., & Rupprecht, E. G. (1991). Continuous pm-10 measurements using the tapered element oscillating microbalance. *Journal of the Air and Waste Management Association*. https://doi.org/10.1080/10473289.1991.10466903

Pompey, J., & Abraham-Settles, B. (2019). Clarifying the confusion of arterial blood gas analysis: Is it compensation or combination? *American Journal of Nursing*, *119*(3), 52–56. https://doi.org/10.1097/01.NAJ.0000554035.74335.59

Ponce, M. C., Sankari, A., & Sharma, S. (2022). Pulmonary Function Tests. *StatPearls*. https://www.ncbi.nlm.nih.gov/books/NBK482339/

Poole, J. A., Quirce, S., Siracusa, A., Carmona, M. J. C., Johnson, A. N., Malo, J.-L., & Bernstein, D. I. (2021). Airway Diseases Due to Organic Dust Exposure. *Asthma in the Workplace*, 293–302.

https://doi.org/10.1201/9781003000624-23

QGIS Development Team. (2022). *QGIS Geographic Information System*. Open Source Geospatial Foundation. http://qgis.org

Quanjer, P. H., Tammeling, G. J., Cotes, J. E., Pedersen, O. F., Peslin, R., & Yernault, J. C. (1993). Lung volumes and forced ventilatory flows. *European Respiratory Journal, Supplement*, 5–40. https://doi.org/10.1183/09041950.005s1693

Radovanovic, D., Pecchiari, M., Pirracchio, F., Zilianti, C., D'Angelo, E., & Santus, P. (2018). Plethysmographic loops: A window on the lung pathophysiology of COPD patients. *Frontiers in Physiology*, *9*(MAY), 484. https://doi.org/10.3389/FPHYS.2018.00484/BIBTEX

Ruiter, S., Bard, D., Ben Jeddi, H., Saunders, J., Snawder, J., Warren, N., Gorce, J.-P., Cauda, E., Kuijpers, E., & Pronk, A. (2023). Exposure Monitoring Strategies for Applying Low-Cost PM Sensors to Assess Flour Dust in Industrial Bakeries. *Annals of Work Exposures and Health*, *67*(3), 379–391. https://doi.org/10.1093/ANNWEH/WXAC088

Rumchev, K., Gilbey, S., Mead-Hunter, R., Selvey, L., Netto, K., & Mullins, B. (2019). Agricultural dust exposures and health and safety practices among western Australian Wheatbelt farmers during harvest. *International Journal of Environmental Research and Public Health*. https://doi.org/10.3390/ijerph16245009

Rumchev, K., Zhao, Y., & Lee, A. (2021). Case Report: Occupational Dust Exposure Among Bakery Workers in Perth, Western Australia. *Frontiers in Public Health*, *9*, 723154. https://doi.org/10.3389/FPUBH.2021.723154

Seddon, J., Contreras, S., & Elliott, B. (2019). *5 Under-recognized Impacts of Air Pollution*. World Resource Institute.

Shao, W., Zhang, H., & Zhou, H. (2017). Fine particle sensor based on multi-angle light scattering and data fusion. *Sensors (Switzerland)*, *17*(5).

https://doi.org/10.3390/S17051033

Shukla, K., & Aggarwal, S. G. (2022). A Technical Overview on Beta-Attenuation Method for the Monitoring of Particulate Matter in Ambient Air. *Aerosol and Air Quality Research*, *22*(12), 220195. https://doi.org/10.4209/AAQR.220195

Smid, T., Heederik, D., Houba, R., & Quanjer, P. H. (1992). Dust- and Endotoxin-related Respiratory Effects in the Animal Feed Industry. *American Review of Respiratory Disease*, *146*(6), 1474–1479. https://doi.org/10.1164/ajrccm/146.6.1474

Smid, T., Heederik, D., Houba, R., & Quanjer, P. H. (1994). Dust- and endotoxin-related acute lung function changes and work-related symptoms in workers in the animal feed industry. *American Journal of Industrial Medicine*, *25*(6), 877–888. https://doi.org/10.1002/ajim.4700250611

Smid, T., Heederik, D., Mensink, G., Houba, R., & Boleij, J. S. M. (1992). Exposure to dust, endotoxins, and fungi in the animal feed industry. *American Industrial Hygiene Association Journal*, *53*(6), 362–368. https://doi.org/10.1080/15298669291359780

Sobczak, P., Mazur, J., Zawiślak, K., Panasiewicz, M., Zukiewicz-Sobczak, W., Królczyk, J., & Lechowski, J. (2019). Evaluation of dust concentration during grinding grain in sustainable agriculture. *Sustainability (Switzerland)*. https://doi.org/10.3390/su11174572

Stobnicka, A., & Górny, R. L. (2015). Exposure to flour dust in the occupational environment. *International Journal of Occupational Safety and Ergonomics*. https://doi.org/10.1080/10803548.2015.1081764

Straumfors, A., Eduard, W., Heldal, K. K., Skogstad, M., Barregård, L., & Ellingsen, D. G. (2018). Pneumoproteins and markers of inflammation and platelet activation in the blood of grain dust exposed workers. *Biomarkers*.

Straumfors, A., Heldal, K. K., Eduard, W., Wouters, I. M., Ellingsen, D. G., & Skogstad, M. (2016). Cross-shift study of exposure-response relationships between bioaerosol exposure and respiratory effects in the Norwegian grain and animal feed production industry. *Occupational and Environmental Medicine*, *73*(10), 685–693.

Straumfors, A., Mundra, S., Foss, O. A. H., Mollerup, S. K., & Kauserud, H. (2021). The airborne mycobiome and associations with mycotoxins and inflammatory markers in the Norwegian grain industry. *Scientific Reports*, *11*(1), 9357.

Subbarao, P., Mandhane, P. J., & Sears, M. R. (2009). Asthma: Epidemiology, etiology and risk factors. *Canadian Medical Association Journal*, *181*(9), E181–E190. https://doi.org/10.1503/cmaj.080612

Tasić, V., Jovašević-Stojanović, M., Vardoulakis, S., Milošević, N., Kovačević, R., & Petrović, J. (2012). Comparative assessment of a real-time particle monitor against the reference gravimetric method for PM 10 and PM 2.5 in indoor air. *Atmospheric Environment*. https://doi.org/10.1016/j.atmosenv.2012.02.030

Thakur, A. K., Kaundle, B., & Singh, I. (2020). Mucoadhesive drug delivery systems in respiratory diseases. *Targeting Chronic Inflammatory Lung Diseases Using Advanced Drug Delivery Systems*, 475–491. https://doi.org/10.1016/B978-0-12-820658-4.00022-4

Tosho, A. S., Adeshina, A. I., Salawu, M. O., & Tope, J. A. (2015). Prevalence of Respiratory Symptoms and Lung Function of Flour Mill Workers in Ilorin, North Central Nigeria. *International Journal of Research & Review (Www.Gkpublication.In)*, *2*(3), 55–56.

Tulchinsky, T. H., & Varavikova, E. A. (2014). *The New Public Health*. Academic Press.

U.S. Environmental Protection Agency. (2003). Grain Elevator and Processes. In *Emission Factors/ AP-42* (Vol. 1, Issue 5). U.S. EPA.

UNESCO. (2013). Adult and Youth Literacy: National, regional and global trends, 1985-2015. UIS Information paper. In *Adult and Youth Literacy: National, regional and global trends, 1985-2015. UIS Information paper* (Issue June 2013). UNESCO

Institute for Statistics. https://doi.org/10.15220/978-92-9189-133-7-en

Van Woensel, J., Goeminne, P., & Valcke, Y. (2021). A case of hypercapnic respiratory failure. *Breathe*, *17*(1), 1–9. https://doi.org/10.1183/20734735.0217-2020

Vonderbank, S., Gibis, N., Schulz, A., Boyko, M., Erbuth, A., Gürleyen, H., Bastian, A., & Kassel, M. (2020). Hypercapnia at Hospital Admission as a Predictor of Mortality. *Medicine*, *2020*, 12–173. https://doi.org/10.2147/OAEM.S242075

Walpole, S. C., Prieto-Merino, D., Edwards, P., Cleland, J., Stevens, G., & Roberts, I. (2012). The weight of nations: An estimation of adult human biomass. *BMC Public Health*, *12*(1), 1. https://doi.org/10.1186/1471-2458-12-439

Wang, C. C., Prather, K. A., Sznitman, J., Jimenez, J. L., Lakdawala, S. S., Tufekci, Z., & Marr, L. C. (2021). Airborne transmission of respiratory viruses. *Science*, *373*(6558).

Ward, M. M. (2019). Chapter 12 - Comorbidities∗. In P. Mease & M. A. Khan (Eds.), *Axial Spondyloarthritis* (pp. 183–202). Elsevier.

West, J. B., Wang, D. L., & Kim Prisk, G. (2018). Measurements of pulmonary gas exchange efficiency using expired gas and oximetry: Results in normal subjects. *American Journal of Physiology - Lung Cellular and Molecular Physiology*, *314*(4), L686–L689. https://doi.org/10.1152/AJPLUNG.00499.2017/ASSET/IMAGES/LARGE/ZH50031873990003.JPEG

Wisnivesky, J., & De-Torres, J. P. (2019). The global burden of pulmonary diseases: Most prevalent problems and opportunities for improvement. *Annals of Global Health*, *85*(1). https://doi.org/10.5334/aogh.2411

World Health Organization. (2006). *Air quality guidelines : global update 2005 : particulate matter, ozone, nitrogen dioxide, and sulfur dioxide.* World Health Organization.

World Health Organization. (2010). WHO guidelines for indoor air quality: selected pollutants. In *Bonn, Germany: in puncto druck+ medien GmbH*. https://doi.org/10.1186/2041-1480-2-S2-I1

World Health Organization. (2019). WHO | Air pollution. In *World Health Organization*.

World Health Organization. (2021). *WHO global air quality guidelines: particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide*. World Health Organization. https://apps.who.int/iris/handle/10665/345329

Yamane, T. (1967). *Elementary sampling theory* (1st ed.). Prentice Hall.

Yawn, B. P., Mintz, M. L., & Doherty, D. E. (2021). Gold in practice: chronic obstructive pulmonary disease treatment and management in the primary care setting. *International Journal of COPD*, *16*, 289–299. https://doi.org/10.2147/COPD.S222664

Zamani, A., Khanjani, N., Bagheri Hosseinabadi, M., Ranjbar Homghavandi, M., & Miri, R. (2019). The effect of chronic exposure to flour dust on pulmonary functions. *Https://Doi.Org/10.1080/10803548.2019.1582853*, *27*(2), 497–503. https://doi.org/10.1080/10803548.2019.1582853

Zhang, Y., Lou, W., & Liao, M. (2018). Research on Dust Concentration Measurement Technique Based on the Theory of Ultrasonic Attenuation. *Journal of Physics: Conference Series*. https://doi.org/10.1088/1742-6596/986/1/012026

APPENDICES

Appendix I: List of Feed Millers in Kiambu County

Name of Feed Miller	Location	Number of employees			
		Top	Middle	Operational	Total
Chania Feeds Limited*	Thika	25	50	125	200
Jubilee Feed Industries Limited*	Thika	5	18	27	50
Njuca Feeds Limited	Thika	3	5	12	20
May Feeds Limited*	Thika	5	10	35	50
Pwani Feeds Limited*	Thika	7	17	56	80
Ohami Millers Limited*	Thika	5	15	30	50
Trust Feeds Limited	Thika	5	-	45	50
Legorn Feeds International*	Thika	7	10	53	70
Afri-Vet feeds Limited	Thika	2	8	20	30
Bedson EA Limited	Thika	2	7	30	39
Thika Farmers Group Limited	Thika	15	50	135	200
Aroma Suppliers Limited	Thika	1	-	9	10
Treasure Industries Limited*	Thika	6	13	111	130
Tosha Products (K) Limited*	Limuru	10	50	200	260
Jupiter Manufacturers Limited	Limuru	2	8	40	50
Ngenia Feeds Limited*	Limuru	4	12	54	70
Sifa Feeds Limited	Limuru	2	7	91	100
Turbo Feeds Limited*	Limuru	1	4	35	40
Tuvune Feeds Limited	Limuru	16	90	194	300
Limuru Dairy Farmers Co-operative Limited*	Limuru	10	29	61	100
Masters Manufacturers (K) Limited*	Limuru	2	10	38	50
Jakarada Feeds Limited*	Limuru	2	-	18	20
Bora Feeds/ Mukurweini Wakulima Dairy Feeds	Limuru	10	40	250	300
Silmart investments*	Thika	3	2	25	30
Economy Farm Products (K) Limited*	Limuru	5	10	80	95
Limuru Posho Mills*	Limuru	4	-	11	15
Prosper Industries*	Thika	5	10	75	90
Milele Feeds Limited*	Thika	12	15	40	67
Optyvit Millers	Kiambu	1	-	9	10
Much Feeds Limited	Kiambu	2	-	10	12
Jumbo Feeds Limited	Ruiru	4	9	32	45
Stock Feed Enterprises	Thika	8	16	169	193
County Style Feeds*	Thika	5	15	80	100

Name of Feed Miller	Location	Number of employees			
		Top	Middle	Operational	Total
Fuga Enterprise Limited	Uthiru	2	-	8	10
Preshama Feeds Limited	Kikuyu	10	45	145	200
TOTAL		**208**	**575**	**2,353**	**3,136**

*DOSHS registered animal feed company

Appendix II: Questionnaire for the workers

	Date:		
	Study Identification No.		

The objective of this questionnaire is to gather information about the current dust management systems within your workplace. I humbly request your active participation in answering the provided questions. If there is a question you are not willing to answer, kindly let me know so that we can ignore it. Your valuable feedback, together with those of other survey respondents, will aid in improving the health and safety of workers in this industry. We will ensure utmost confidentiality, and prior written consent will be required to share information externally.

a) Tick appropriately (× or ✓) in the blank spaces provided.
b) Please do not provide your name.

A. DEMOGRAPHICS

1	**Respondent's gender**	Male	
		Female	
2	**What is your age?**	________________________ years	
3	**What is your highest level of education?**	Never attended school or nursery school	
		Primary	
		Secondary	
		Tertiary	
		Declined to answer	

B. OCCUPATIONAL HISTORY

5	**How long have worked in the animal feed industry?**	Less than 1 year			
		1-5 years			
		6-10 years			
		11-15 years			
		16 years and above			
6	**Which department do you work in?**	Administration			
		Machine Operator/Attendant			
		Engineer			
		Manager/Supervisor			
		Other___________________ _________ ____________________			

7	**How long have worked in your current workstation?**	Less than 1 year			
		1-5 years			
		6-10 years			
		11-15 years			
		16 years and above			
8	**How many hours in a day do you work in a day?**	Less than 8 hours			
		8 hours			
		8 hours and above			
9	**Does your current job role expose you to grain dust?**	Yes		No	

C. DUST MANAGEMENT

10	**Is there a dust management policy statement within the company?**	Yes		No	
11	**If yes, is it available to you?**	Yes		No	
12	**If yes, do you know what it entails? Tick appropriately all that apply.**	Duties of the employer and employees.			
		Safety and Health Committees.			
		Safety and Health Audits.			
		The procedure of notification on incidents, accidents and occupational diseases.			
		Other___________________________ ___________________________________			
		None of the above.			
13	**Is there a dust management system or program within the company?**	Yes		No	
14	**If yes, is it available to you?**	Yes		No	
15	**If yes, do you know what it entails? Tick appropriately all that apply.**	Management commitment			
		Employee training			
		Risk assessment and controls.			
		Accident investigation			
		Program evaluation			
		Other___________________________ ____ _________________			
		None of the above			

16	**Who is in charge of dust management within the company? Tick appropriately all that apply.**	Owner/Occupier			
		Safety and Health Officer			
		Safety and Health Management System that accords duties and responsibilities to the employees and the management			
		(Some of) the supervisors have been provided with an additional task to ensure safety and health within their workstations.			
		The employee is solely responsible for adhering to the set safety regulations.			
		Other__________________________ __________________________________			
		None of the above			
17	**How is dust management training conducted? Tick appropriately all that apply.**	Initial and annual training by the Safety and Health Officer.			
		New employees are taught safety by experienced employees during on-job training.			
		Safety Officer(s)/Supervisors hold regular safety meetings with the workers through presentations.			
		The Safety and Health Committee provide regular safety and health training to the workers through presentations.			
		Self-taught training.			
		Other__________________________ ____________________________________			
		None of the above			
18	**Averagely, how many hours of safety training do you obtain annually?**	_______________________ _______hours			
19	**Are you aware of the Work injury Benefit Act (WIBA) insurance policy within the company?**	Yes		No	
20	**Have you been trained on safe dust management procedures and rules involving your type of work?**	Yes		No	
21	**If yes, do you follow the work procedures while carrying your daily work routine?**	Yes		No	
22	**Have you been trained on the grain dust hazards**	Yes		No	

	that affect your line of work at the workplace?				
23	**If yes, does the company perform air sampling measurements to determine the exposure to grain dust?**	Yes		No	
24	**If yes, are you aware of the exposure limits to the grain dust within the scope of your work?**	Yes		No	
25	**Are there safety signs for identifying highly dusty areas within the scope of your work?**	Yes		No	
26	**Have you been trained on how to use Personal Protective Equipment (PPE) for your line of work?**	Yes		No	
27	**Does the company provide PPE for your line of work?**	Yes		No	
28	**If yes, name the PPEs**	____________________________________			
29	**Do you have PPEs that are reusable?**	Yes		No	
30	**If yes, name the PPEs**	____________________________________			
31	**How do you store your PPE?**	Designated cabinet/drawer			
		Other___________________________ ____________________________________			
		None of the above			

D. HEALTH

32	**How would you rate your general health?**	Excellent			
		Very good			
		Good			
		Fair			
		Poor			
33	**In the past year, how many times have you been admitted to the hospital overnight or longer?**	None			
		________________________ ___times			

34	**In the past year, how many times did you consult a medical doctor or healthcare practitioner (do not count the times while admitted to the hospital)?**	None			
		________________________ ___times			
35	**Have you ever been diagnosed with asthma since you started working here?**	Yes		No	
36	**Have you ever been informed by a doctor that you had chronic bronchitis?**	Yes		No	
37	**Have you ever been informed by a doctor that you had pneumonia?**	Yes		No	
38	**Have you ever been informed by a doctor that you had hay fever since you started working here?**	Yes		No	
39	**Have you ever been informed by a doctor that you had chest tuberculosis (TB)?**	Yes		No	
40	**Have you ever had any other chest illnesses as mentioned by a doctor?**	Yes		No	
41	**If yes, please specify.**	________________________ ____________			
		________________________ ____________			
42	**Have you ever had any other chest injuries as mentioned by a doctor?**	Yes		No	

RESPIRATORY CONDITIONS AND ALLERGY

COUGH

Note: Ignore an occasional cough

43	**Do you usually cough first thing in the morning (on getting up*) in the cold months of the year?**	Yes		No	

44	**Do you usually cough at all during the rest of the day or night working hours?**	Yes		No	

PHLEGM

Count phlegm with first smoke or on first going out of doors. Exclude phlegm from the nose. Count swallowed phlegm.

45	**Do you usually bring up any phlegm/sputum/mucus from your chest first thing in the morning (on getting up*) in the cold months of the year?**	Yes		No	
46	**Do you usually bring up any phlegm/sputum/mucus from your chest during the day (or at night*) in the cold months of the year?**	Yes		No	
47	**Do you bring up phlegm like this on most days or night working hours for as much as three months each year?**	Yes		No	
48	**Do you usually bring up phlegm at all on getting up or first thing in the morning?**	Yes		No	

EPISODES OF COUGH AND PHLEGM

49	**Have you had periods or episodes of (increased) cough and phlegm lasting for 3 weeks or more each year?**	Yes		No	

BREATHLESSNESS

50	**Are you troubled by shortness of breath when hurrying on level ground?**	Yes		No	

51	**Do you get short of breath walking with other people of your age on level ground?**	Yes		No	
52	**Do you have to stop for breath when walking at your own pace on level ground?**	Yes		No	
53	**Are you too breathless to leave the house or too breathless on dressing or undressing?**	Yes		No	

WHEEZING

54	**Does your chest ever sound wheezy or whistling?**	Yes		No	
55	**Does this whistling sound improve when you are away from work for some days?**	Yes		No	

WEATHER

56	**Does the weather affect your chest?Only record "YES" if adverse weather definitely and regularly causes chest symptoms**	Yes		No	
57	**Does the weather make you short of breath?**	Yes		No	
58	**What kind of weather?**	____________________________ ____________			
		____________________________ ____________			

OTHER SYMPTOMS & ALLERGIES

During the past 12 months, have you had any episodes of:

59	**Stuffy, itchy, running nose?**	Yes		No	
60	**Watery, itchy eyes?**	Yes		No	

E. TOBACCO USE

Cigarette use

61	**Do you smoke cigarettes now?**	Yes		No	
62	**Have you ever smoked as much as one cigarette a day for as long as a year?**	Yes		No	
63	**Have you been regularly smoking one or more cigarettes a day for at least one year?**	Yes		No	
64	**Did you ever smoke one or more cigarettes a day regularly in the past but have quit smoking at least one year before the study?**	Yes		No	

Thank you for your valuable time in answering these questions.

Appendix III: Observation Checklist

	Date:		
	Study Identification No.		
	QUESTION	**YES**	**NO**
1	Are there warning signs indicating a hazardous atmosphere?		
2	Are the workspaces free of dust?		
3	Are there fully operational ventilation systems that are general ventilation and Local Exhaust Ventilation?		
4	Are there any obstructions near the air inlets and outlets within the workplace?		
5	Are there sources of air contaminants within the workplace?		
6	Are the workers wearing dust protective gear such as masks and respirators?		
7	Is the temperature and humidity within the acceptable range?		
8	Is there visible mould on the raw materials and finished products?		

Appendix IV: Spirometry Prescreen Questionnaire

	Date:		
	Study Identification No.		
	QUESTION	**YES**	**NO**
1	In the last 6 weeks, have you had major surgery or been hospitalized?		
2	In the last 4 weeks, have you had a heart attack?		
3	Are you under a doctor's care for high blood pressure?		
4	In the last 3 weeks, have you had a respiratory infection (e.g., chest cold, pneumonia, bronchitis, coronavirus)?		
5	In the last hour, have you smoked tobacco?		
6	In the last hour, have you eaten a heavy meal?		
7	In the last hour, have you used an albuterol rescue inhaler (Proair, Proventil)?		
8	Have you had more than 2 cups of caffeinated coffee, tea, or cola (total) in the last 6 hours?		
9	Are you wearing any tight clothing that interferes with your ability to breathe deeply?		
10	Are you wearing dentures?		

Appendix V: Calibration certificate

广东省电子电器研究所
Guangdong Electronic and Electric Institute

CNAS
CALIBRATION
CNAS L0307

126

校准证书
Calibration certificate

证书编号 Certificate No.: CGEL030720170921064　第 1 页 共 3 页 Page 1 of 3

委托方 Client: 乐控（上海）环境技术有限公司

仪器名称 Description: 空气品质检测仪　型号规格 Model/Type: M1000

制造者 Manufacturer: 乐控（上海）环境技术有限公司　编号 Serial No.: 16007000011

委托方地址 Add.of Client: 上海市浦东新区基隆路1号汤臣国际贸易大楼817

本次校准所使用的主要测量标准
Standards of measurement used in the calibration

名称 Description	证书编号 Certificate No.	编号 Serial No.	有效期至 Due date
甲醛检定装置	DBB2017046693	3523645	2018-04-09
PM2.5标准粒子	DBB2016128647	9473189	2017-12-10

本次校准所依据技术文件 Reference documents for the calibration: JJG 1022-2016/JJF1172-2007

校准地点 Place of calibration: 本所实验室　温度 Temperature: 23 ℃　相对湿度 Relative Humidity: 60 %

发证单位（专用章）Issued by (stamp)

批准人 Approved by: 林树

核验 Inspected by: [signature]

校准 Calibrated by: 刘巨虎

校准日期 Cal. Date: 2017 年 Year 09 月 Month 21 日 Day

建议下次校准日期 Due Date: 2018 年 Year 09 月 Month 20 日 Day

Appendix VI: Informed Consent Form

Introduction

I am Virginia Kimanzi, a MSc student at Jomo Kenyatta University of Agriculture and Technology pursuing a Master's Degree in Occupational Safety and Health and conducting this study that entails the assessment of the effect of exposure to grain dust on pulmonary function of selected animal feed mill workers in Kiambu County, Kenya.

Procedures

You are requested to fill out a questionnaire. The questionnaire consists of parts (A, B, C, and D) and will take you approximately 30 minutes. Questions will include details about your demographics, occupational history, dust management awareness and health.

Risks/Discomforts

Participation in this study has minor risks. However, you may experience emotional distress when answering a few questions.

Benefits

There are no direct gains for the participants. However, it is expected that your participation will assist the researcher to come up with recommendations on occupational safety and health issues for workers in the animal feed industry.

Confidentiality

All information provided will be treated as confidential and will only be presented as group data with no identifiable information. All data, including questionnaires, will be maintained in a secure location, and only those directly involved with the research will have access to them. After the research is completed, the questionnaires will be destroyed.

I consent to serve as a participant in the study titled…………………………………………………………………………………………….

The nature and objective of the research procedure and the known risks and discomfort involved have been explained to me. The investigator is permitted to proceed on the condition that I may terminate my services at any time I so desire. I have read, understood, and obtained a copy of the above consent and wish to engage in this study of my own free will and volition. I believe that reasonable safeguards have been taken to minimize both known and potentially unknown risks.

Participant's signature ………………………………………….……..…….

Date …………………

Signature ……………………………... Date…………………………….

Appendix VII: Ethical Review Committee approval letter

JOMO KENYATTA UNIVERSITY OF AGRICULTURE AND TECHNOLOGY
P.O BOX 62000(00200) NAIROBI, Tel:(067) 58700001-4
(Office of the Deputy Vice Chancellor, Research Production and Extension Division)

JKUAT INSTITUTIONAL ETHICS REVIEW COMMITTEE

REF: JKU/2/4/896B

Date: 26th August 2021

VIRGINIA VIMA KIMANZI
Institute of Energy and Environmental Technology (IEET), JKUAT

Dear Ms. Kimanzi,

RE: ASSESSMENT OF EFFECT OF EXPOSURE TO GRAIN DUST ON PULMONARY FUNCTION OF SELECTED ANIMAL FEED MILL WORKERS IN KIAMBU COUNTY, KENYA

This is to inform you that JKUAT Institutional Ethics Review Committee has reviewed and approved your above research proposal. Your application approval number is **JKU/IERC/02316/0175.** The approval period is **26th August 2021** to **25th August 2022**.

This approval is subject to compliance with the following requirements;

i. Only approved documents including (informed consents, study instruments, MTA) will be used
ii. All changes including (amendments, deviations, and violations) are submitted for review and approval by JKUAT IERC.
iii. Death and life threatening problems and serious adverse events or unexpected adverse events whether related or unrelated to the study must be reported to JKUAT IERC within 72 hours of notification
iv. Any changes, anticipated or otherwise that may increase the risks or affected safety or welfare of study participants and others or affect the integrity of the research must be reported to JKUAT IERC within 72 hours
v. Clearance for export of biological specimens must be obtained from relevant institutions.
vi. Submission of a request for renewal of approval at least 60 days prior to expiry of the approval period. Attach a comprehensive progress report to support the renewal.
vii. Submission of an executive summary report within 90 days upon completion of the study to JKUAT IERC.

Prior to commencing your study, you will be expected to obtain a research license from National Commission for Science, Technology and Innovation (NACOSTI) https://oris.nacosti.go.ke and also obtain other clearances needed.

Yours sincerely

Dr Patrick Mburugu
Chair, JKUAT IERC

INSTITUTIONAL ETHICS REVIEW COMMITTEE
26 AUG 2021
APPROVED
JKUAT

JKUAT is ISO 9001:2015 and ISO 14001:2015 certified
Setting Trends in Higher Education, Research, Innovation and Entrepreneurship

Appendix VIII: NACOSTI research license

REPUBLIC OF KENYA

NATIONAL COMMISSION FOR SCIENCE,TECHNOLOGY & INNOVATION

Ref No: **491122**

Date of Issue: **13/September/2021**

RESEARCH LICENSE

This is to Certify that Ms.. Virginia Kimanzi of Jomo Kenyatta University of Agriculture and Technology, has been licensed to conduct research in Kiambu on the topic: ASSESSMENT OF EFFECT OF EXPOSURE TO GRAIN DUST ON PULMONARY FUNCTION OF SELECTED ANIMAL FEED MILL WORKERS IN KIAMBU COUNTY, KENYA for the period ending : 13/September/2022.

License No: **NACOSTI/P/21/12907**

491122

Applicant Identification Number

Director General
NATIONAL COMMISSION FOR SCIENCE,TECHNOLOGY & INNOVATION

Verification QR Code

NOTE: This is a computer generated License. To verify the authenticity of this document, Scan the QR Code using QR scanner application.