ORIGINAL RESEARCH ARTICLE

$PM_{2.5}$ and PM_{10} exposure in selected animal feed processing facilities in Kiambu County, Kenya.

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ABSTRACT

The high demand for animal feed in major towns in Kenya has escalated the proliferation of animal feed manufacturing and uncontrolled animal feed facilities. This exposes the workers to grain dust, which is harmful to their respiratory health. The exposure levels have not been extensively studied and reported in Kenya. The goal of the study was to assess the exposure levels of grain dust to animal feed mill workers in Kiambu County, Kenya. The animal feed facilities were purposely sampled. The grain dust exposure levels in the study sites were monitored using a portable particulate matter sensor. SPSS was used to process and analyze the collected data. The mean PM_{10} of 53.72 µg/m^3 and $PM_{2.5}$ of 36.54 µg/m^3 exceeded the WHO Air Quality Guideline level of a 24-hour exposure time of 45 µg/m^3 for PM_{10} and $PM_{2.5}$, 15 µg/m^3. The study recommends continued implementation of the dust control measures within the animal feed manufacturing facilities and adherence to the set safety and health guidelines by the feed processors.

Key words: PM_{10}, $PM_{2.5}$, occupational, health, exposure, dust

1.0 Introduction

Occupational exposures to grain dust contribute to approximately 12% of deaths linked to chronic obstructive airway diseases (Iyogun, Lateef and Ana, 2019). 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 (Meo and Al-Drees, 2005; Subbarao, Mandhane and Sears, 2009). In Kenya, no public data exists where actual grain dust concentrations had been investigated in connection with lung health among workers in the animal feed industry; thus, little awareness and practice on safety and health standards had been made. The awareness of the standards positively impacts a safe work environment (Oluoch, Ndeda and Njogu, 2017).Thus, there was a need to assess exposure levels to grain dust. 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, Hussein and El-Sokkary, 2013). Exposure to grain dust in various quantities has been reported to cause either acute or chronic respiratory ailments (Health and Safety Executive, 2013).

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The WHO Air Quality guidelines provide strict standards for indoor exposure to particulate matter where grain dust falls into that category. During the global update in 2005, the annual mean concentrations, PM_{10} was 20 µg/m^3 and $PM_{2.5}$ was 10 µg/m^3 whereas, for 24-hour mean concentrations, PM_{10} was 50 µg/m^3 and $PM_{2.5}$ was 25 µg/m^3. This is because multiple epidemiological studies have found 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 outdoors (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 of 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 µg/m^3 and for $PM_{2.5}$ 5 µg/m^3 whereas 24-hour mean concentrations at, PM_{10} were 45 µg/m^3 and for $PM_{2.5}$ 15 µg/m^3 (Jarosinska, 2021; World Health Organization, 2021).

Due to the significant bio-contamination in their work environment, decreased pulmonary function has been reported in Egypt as a significant health concern for feed milling workers (Hameed, Shakour and Yasser, 2003). At a large 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, attributable to the animal feed dust (Baser *et al.*, 2003). 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. Because of exposure to grain dust, respiratory diseases 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 (Vandenplas, Toren and Blanc, 2003). These clinical symptoms are critical and may result in workplace absence, change of job, disability, and finally, work cessation. Therefore, the assessment of the level of exposure to grain dust was necessitated. 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. In Kiambu County, feed milling operators are majorly concentrated in urban areas, such as where there is an availability of infrastructure. These feed milling industries operate at various capacities, with the majority being small-scale operators. Occupation-related illnesses have been documented in various regions where workers are exposed to grain dust in industries that generate dust during production (Mohammadien, Hussein and El-Sokkary, 2013; Aiguomudu, 2018). The study aimed at evaluating the airborne grain dust levels at the selected animal feed mills in Kiambu County, Kenya. This study formed the basis for helping policymakers improve safety and health strategies in the animal feed industry.

2.0 Methodology

2.1 Study Study population and area

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, as shown in Figure 1. It had 35 registered feed

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milling manufacturers duly registered by the Association of Kenya Feed Manufacturers (AKEFEMA).

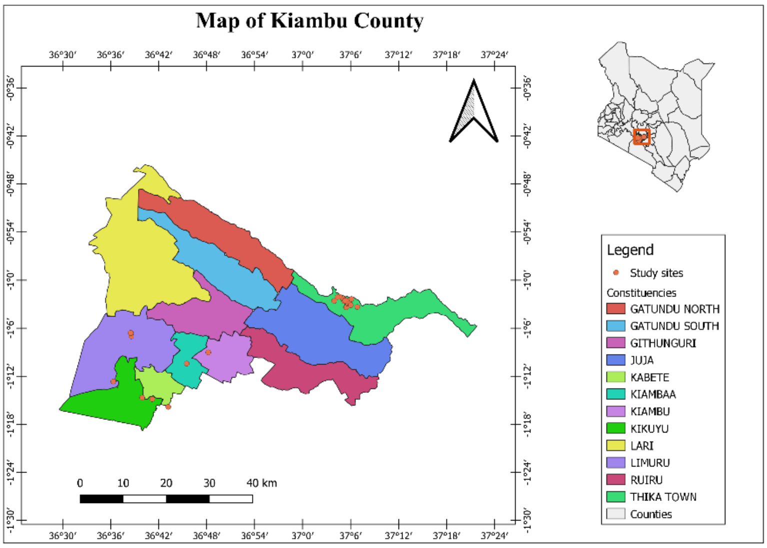

Figure 1: Map of the study area

2.2 Sample size determination

Fisher's formula recommends a characteristic interest of 50% to determine the sample size where 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 were to be certified by the Directorate of Occupational Safety and Health Services (DOSHS).

The researcher conducted PM_{10} and $PM_{2.5}$ sampling during the active production process at eight stationary sampling points of 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 (Smid *et al.*, 1992; Halstensen *et al.*, 2013).

2.3 Data collection methods

2.3.1 Grain dust exposure levels

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 a few feet toward the air inlet, air outlet, and source

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of dust. Where there was no clear source of dust, the sampling was done toward the air inlet and outlet. The sampling duration for every sampling point was ten minutes on average and four hours for each site. The PM_{10} and $PM_{2.5}$ for each static sampling point for the animal feed mills were determined. All sites were monitored in the morning and afternoon for three non-consecutive days to capture the peak activity periods. The results were expressed in micrograms per cubic meter of air. The data gathered was then compared to the applicable standards relating to exposure levels to dust. The manufacturers of the dust monitor provided a calibration certificate which was valid for the study.

2.4 Data Analysis and Presentation

The data collected was analyzed using descriptive statistics using SPSS (Statistical Package for Social Sciences, Version 20 and reported as means, standard deviation, and frequencies. The significance level was at $p<0.05$ or 95% confidence level. F test was performed to compare data attributes.

3.0 Results and discussions

3.1 Response rate

Seventeen animal feed millers were selected for the grain dust monitoring study. However, only twelve agreed to participate in the study. This was a 70.59% response rate. During the active production process, DOSHS and AKEFEMA registered at least twelve animal feed millers. However, the twelfth miller did not have a functioning grinding section.

3.2 Particulate matter concentration in animal feed mills.

Table 1 Frequency distribution of PM_{10} in various work sections in the target animal feed mill companies

	PM_{10} (µg/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

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 demonstrates that the grinding section makes the workers more vulnerable to grain dust exposure as compared to other work sections.

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Table 2 Frequency distribution of $PM_{2.5}$ in various work sections in the target animal feed mill companies

	$PM_{2.5}$ ($\mu g/m^3$)										
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

The minimum concentration of $PM_{2.5}$ was 10.88 $\mu g/m^3$ in the finished goods loading in company number 1, while the maximum was 327.47 $\mu g/m^3$ in the grinding section in company number 9. This reveals similar trend as compared to the findings in table 1 where the grinding section exposes the workers to the highest concentration of grain dust.

Table 3 Mean particulate concentration in the various work sections in the target animal feed mill companies

Work sections	PM_{10} (Mean ± SD)	$PM_{2.5}$ (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
Mean ± SD ($\mu g/m^3$)	53.72±71.32	36.54±41.56

The mean concentration of PM_{10} was 130.80 $\mu g/m^3$ whereas that of $PM_{2.5}$ was 82.61 $\mu g/m^3$ was highest in the grinding section. PM_{10} (27.95 $\mu g/m^3$) and $PM_{2.5}$ (20.79 $\mu g/m^3$) was also low at the administration offices.

The average mean PM_{10} (53.72 $\mu g/m^3$/0.05 mg/m^3) and $PM_{2.5}$ (36.54 $\mu g/m^3$/0.04 mg/m^3) results were comparable to those obtained by Aiguomudu (Aiguomudu, 2018). The study focused on assessing dust exposure and respiratory effects among bakery workers in Nigeria, where the average mean PM_{10} was 0.50 mg/m^3, and $PM_{2.5}$ was 0.07 mg/m^3. However, the study results were lower than those obtained in the animal feed manufacturing facility in Egypt (1.97 mg/m^3) (Hameed, Shakour and Yasser, 2003). This is because the authors carried out background sampling using gravimetric dust samplers with no internal fractionators. Similarly, the results were lower than those obtained in the grain and compound feed industry in Norway (1.00 mg/m^3) since the authors carried out personal sampling using gravimetric dust

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samplers (Halstensen *et al.*, 2013). 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 complex (Halstensen *et al.*, 2013). This study utilized stationary or fixed-point sampling. This underestimates the dust concentration compared to personal sampling in other case studies (Health and Safety Executive, 2000; Aiguomudu, 2018). Additionally, this study utilized 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 (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 (Liu *et al.*, 2017).

The mean PM_{10} (53.72 µg/m^3) and $PM_{2.5}$ (36.54 µg/m^3) concentrations exceeded the WHO Air Quality Guideline level of a 24-hour exposure time of 45 µg/m^3 for PM_{10} and $PM_{2.5}$ 15 µg/m^3. This is an occupational health risk to the workers. This study finding was similar to the results of a study conducted in Nairobi County whereby the particulate matter concentration in the ambient air was above the permissible limits (Mutua, Kanali and Njogu, 2016).

Table 4 Comparison of mean particulate matter concentrations between task environments in the target group

	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

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

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uniform. The grinding section's PM_{10} (130.80 μg/m^3) and $PM_{2.5}$ (82.61 μg/m^3) exposure levels 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), potentially predisposing workers at that section to more adverse health outcomes than workers at 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 4 mg/m^3 (4,000 μg/m^3). This study 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, Njogu and Magu, 2022). The level of grain dust exposure is dependent on the task and the location of the work station (Halstensen *et al.*, 2013).

4.0 Conclusion

The particulate matter mean concentration of PM_{10} was 53.72±71.32 μg/m^3 and $PM_{2.5}$ was 36.54±41.56 μg/m^3, which exceeded the WHO Air Quality Guideline level of a 24-hour exposure time of 45 μg/m^3 for PM_{10} and $PM_{2.5}$ 15 μg/m^3. The PM_{10} and $PM_{2.5}$ exposure levels at the grinding section were more than twice that of the PM_{10} and $PM_{2.5}$ means, which could predispose the workers at that section to more adverse health outcomes as compared to the other workstations.

5.0 Recommendation

The animal feed mill companies should ensure the grain dust exposure levels are maintained within the 10 mg/m^3 exposure limits as provided by The Factories and Other Places of Work Act (Hazardous Substances) Rules, 2007 (Government of Kenya, 2007).

The study recommends continued implementation of dust control measures within the animal feed manufacturing facilities and adherence to the set safety and health guidelines by the feed processors.

6.0 Acknowledgement

6.1 General acknowledgement

To uphold the idea of voluntary participation, the management of the facilities that make animal feed was asked for their informed consent. By outlining the goals and methods of the study, informed consent was ensured. The management was given the assurance that the information would only be utilized for academic reasons, which guaranteed confidentiality.

6.2 Declaration of interest

A research license was secured from the National Commission for Science, Technology, and Innovation, and ethical approval was received from the ethical review committee at Jomo Kenyatta University of Agriculture and Technology (NACOSTI).

6.3 Conflict of interest

None.

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