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Metabolic syndrome risk factors among mill workers exposed to noise and respirable dust

Marzieh Belji Kangarlou[1,2], Elaheh Saleh[3] & Alireza Dehdashti[3,4]✉

This 15-year prospective cohort study aimed to examine the impact of occupational exposure to noise and respirable flour dust on the incidence of metabolic syndrome (MetS) and its components among 379 flour mill workers in Iran. The cohort was divided into an exposed group ($n = 232$), comprising workers with chronic exposure to noise and dust, and a non-exposed group ($n = 147$), including administrative and supervisory staff with minimal exposure. Annual measurements of noise and dust followed NIOSH guidelines, and cumulative exposures were calculated over time. MetS and its components were assessed based on ATP III criteria using clinical and biochemical markers such as fasting blood sugar (FBS), triglycerides (TG), HDL cholesterol, and blood pressure. The results revealed that prolonged exposure to flour dust was associated with borderline increases in the risk of hypertension and hypertriglyceridemia, while noise exposure did not show significant associations with MetS or its components. Significant risk factors for MetS components included body mass index (BMI), age, and type 2 diabetes mellitus (T2DM). Age was a strong predictor of hyperglycemia (HR = 1.08, 95% CI: 1.02–1.14, $p = 0.007$), and baseline TG levels were significantly associated with hypertriglyceridemia (HR = 1.003, 95% CI:1.001–1.004, $p = 0.001$). Stratified analyses highlighted increased risks of MetS components among workers with extended working hours and rotational shifts. These findings emphasize the need for workplace interventions to reduce cumulative exposure risks. Future research should investigate potential mechanisms and synergistic effects of multiple occupational hazards.

Keywords Occupational exposure, Noise, Dust, Metabolic syndrome, Flour mill workers, Cohort study

Overview of metabolic syndrome (MetS) and its public health significance

Metabolic Syndrome (MetS), characterized by a group of interconnected risk factors including obesity, hypertension, hyperglycemia, hypertriglyceridemia, and low high-density lipoprotein cholesterol (HDL), represents a formidable public health challenge worldwide[1]. Globally, the prevalence of MetS ranges from 20 to 25% in the adult population, with some regions reporting even higher rates[2]. Recent systematic reviews have shown that in certain Middle Eastern countries, the prevalence can reach up to 45% among working-age adults, making it a critical occupational health concern[3].

The prevalence of MetS is on the rise and its association with an increased risk of cardiovascular diseases and type 2 diabetes mellitus (T2DM) emphasizes the importance of understanding its etiology and identifying risk factors that can be modified to reduce risk[4,5]. While the exact reasons for MetS are not completely known, it is believed to result from a combination of genetic and environmental factors[6,7]. Although lifestyle factors such as diet and physical activity have been extensively studied[8–10], evidence suggests that occupational exposures to chemical and physical agents in the work environment may influence in the development of MetS and its components[11,12].

Environmental and occupational risk factors for MetS

Recent comprehensive analyses have demonstrated that exposure to environmental pollutants, particularly air pollution and noise, can trigger metabolic disruption through various pathophysiological mechanisms[13,14]. A 2024 systematic review revealed that chronic exposure to ambient air pollution is associated with a 1.5-fold

[1]Department of Occupational Health and Safety, Faculty of Medical Sciences, Tehran University of Medical Sciences, Tehran, Iran. [2]Department of Occupational Health and Safety, Student Research Committee, Semnan University of Medical Sience, Semnan, Iran. [3]Social Determinants of Health Research Center, Semnan University of Medical Sciences, Semnan, Iran. [4]Department of Occupational Health and Safety, Faculty of Health, Semnan University of Medical Sciences, Semnan, Iran. ✉email: dehdashti@semums.ac.ir

increased risk of MetS, particularly in occupational settings where exposure levels are typically higher[15]. Studies have explored the potential links between exposure to chemical agents such as heavy metals[16,17], organic solvents[12], and pesticides[18], as well as physical agents like noise and shift work, and the risk of individual components of MetS[19,20]. However, several knowledge gaps persist in our understanding of this association. Most of these studies have focused on single exposures or single outcomes, without considering the possible interactions or combined effects on metabolic health[11,17,19].

Although we know the associations between workplace exposures and metabolic outcomes, the precise dose-response relationships, threshold levels, and exposure durations associated with increased risk remain unclear[21,22]. Flour mill workers are exposed to fine flour dust, which contains organic compounds that can trigger inflammatory responses and oxidative stress and contribute to metabolic health disturbances. Additionally, the mechanical processes involved in flour milling generate high noise levels that further amplify stress and systemic inflammation[23].

Potential mechanistic pathways of noise and dust exposure on metabolic syndrome

The interaction between noise and dust exposure, particularly fine particulate matter (PM2.5), has been hypothesized in the literature to exert additive or synergistic effects on the risk of metabolic syndrome (MetS) through their combined impact on inflammation and oxidative stress. However, this study did not specifically assess the interaction effects between these exposures. Instead, it focused on the individual associations of noise and dust with MetS risk. The interaction between noise and dust exposure, particularly fine particulate matter ($PM_{2.5}$), may have additive or synergistic effects on the risk of metabolic syndrome (MetS) due to their combined impact on inflammation and oxidative stress[24]. Research indicates that simultaneous exposure to these environmental stressors can intensify systemic inflammation, as evidenced by increased levels of C-Reactive Protein (CRP) associated with both noise and PM2.5 exposure[24,25]. Noise exposure amplifies stress responses, potentially heightening sensitivity to inflammatory agents like dust particles, leading to endothelial dysfunction and metabolic dysregulation[26,27]. Furthermore, particulate matter may disrupt the lung-gut axis, contributing to gut microbiota dysbiosis[28]. Studies have shown that co-exposure to noise and PM2.5 significantly elevates the risk of MetS, with hazard ratios indicating a greater risk than single exposures alone[24,27].

Noise exposure alone has been associated with increased blood pressure, elevated blood glucose, higher triglycerides, and decreased HDL levels, all of which are key components of MetS[29]. When combined with dust exposure, these stressors may induce a compounded effect on metabolic homeostasis by activating inflammatory pathways and promoting oxidative stress[30]. Thus, the interaction between noise and dust exposure presents a reasonable biological pathway that needs further exploration to better understand the potential role of workplace exposures in the pathogenesis of MetS.

Rationale for the study and study objectives

Given the above evidence, there is a critical need to investigate the combined effects of noise and dust exposure on metabolic health. the mechanistic pathways by which workplace exposures influence metabolic health remain inadequately explored, especially for multiple concurrent exposures that may act synergistically. Although individual effects of these exposures have been studied, there is limited research on how they interact to influence MetS, especially within occupational settings where such dual exposures are common[31].

Flour mills represent a unique workplace setting due to the simultaneous presence of two significant occupational hazards chronic noise exposure from machinery and respirable flour dust. While previous studies have linked noise or dust exposure individually to adverse health outcomes, few have focused on their potential combined impact on metabolic syndrome (MetS). Furthermore, existing research often overlooks the interplay between occupational exposures and metabolic changes, such as lipid profile disturbances and other biochemical markers that contribute to MetS development. Additionally, this study examines cumulative exposure assessments, allowing for a better understanding of dose-response relationships and long-term health effects. By employing a prospective cohort design and collecting detailed exposure data over 15 years, our study provides a comprehensive view of how chronic workplace exposures contribute to metabolic disturbances.

The primary objective of this study was to assess the relationship between simultaneous noise and respirable dust exposure and the incidence of MetS among flour mill workers. Specifically, the study aimed to evaluate the individual contributions of these occupational exposures to metabolic health disturbances. We hope to uncover the mechanistic pathways through which noise and dust exposure might influence metabolic health, thereby informing workplace safety guidelines and contributing to the establishment of occupational exposure limits that better reflect real-world conditions in industrial settings.

Research hypotheses

H1: Continuous levels of noise and dust exposure are positively associated with the incidence and prevalence of MetS and its components among flour mill.

H2: The association between continuous occupational exposure to noise and dust and MetS is modified by demographic factors (age, sex, marital status, BMI, working hours, and level of education), family history of selected medical conditions (diabetes, hypertension), and lifestyle factors (smoking habits, physical activity).

H3: The effects of continuous occupational exposure to noise and dust on MetS are mediated by various baseline biochemical measurements including Fasting Blood Sugar (FBS), Triglycerides (TG), High-Density Lipoprotein (HDL), Low-Density Lipoprotein (LDL), Systolic Blood Pressure (SBP), and Diastolic Blood Pressure (DBP).

Materials and methods
Study setting
The study investigated multiple flour mills located in Iran, focusing on occupational exposure to flour dust and noise. These mills engage in the industrial processing of wheat and other grains to produce flour for commercial use. The working environment in these facilities is characterized by high levels of flour dust and noise, particularly in areas near grinding, sieving, and packaging equipment. Typical workstations include grain storage, cleaning and grinding, sifting, and final packaging units.

Recruitment campaigns and data collection
This prospective cohort study followed a group of 379 flour mill workers exposed to noise and dust from 2007 to 2022. The study design aimed to investigate the association of noise and dust exposure on the incidence of metabolic syndrome or its components by following workers over time and comparing those exposed to noise and dust with those who were not. Participants' baseline health and exposure data were collected, and subsequent follow-ups were conducted at regular intervals to assess changes in health status. The study comprised three recruitment campaigns during which detailed health outcomes measurements were performed. Initial recruitment (2007): Participants underwent baseline assessments, including demographic, anthropometric, and biochemical evaluations. Mid-study evaluation (2015): Follow-up exposure measurements and health assessments were conducted to identify emerging MetS cases. Final evaluation (2022): Comprehensive measurements were repeated to capture long-term exposure effects and final health outcomes. The study timeline is illustrated in Fig. 1.

The control group consisted of 147 workers in administrative or supervisory roles within the same flour mills, where occupational exposure to noise and dust was minimal. These participants were matched with exposed workers based on key demographic factors (age, gender, BMI, and employment duration) to minimize potential confounding. The selection of this control group was intentional to ensure that both groups shared similar work environments, socio-economic contexts, and access to healthcare, thus reducing variability unrelated to exposure. Noise exposure levels for control participants did not exceed 85 dB, and respirable dust concentrations were below 0.25 mg/m^3, as determined through personal air monitoring and area sampling. Workers in the control group primarily performed office-based tasks, which minimized their exposure to the occupational hazards studied. Importantly, participants who occasionally entered high-exposure areas for job-related tasks were excluded from the control group to maintain its integrity.

While this control group design helps isolate the effects of noise and dust, it is acknowledged that differences in job roles (physical activity levels, task-related stress) may introduce residual confounding. However, these

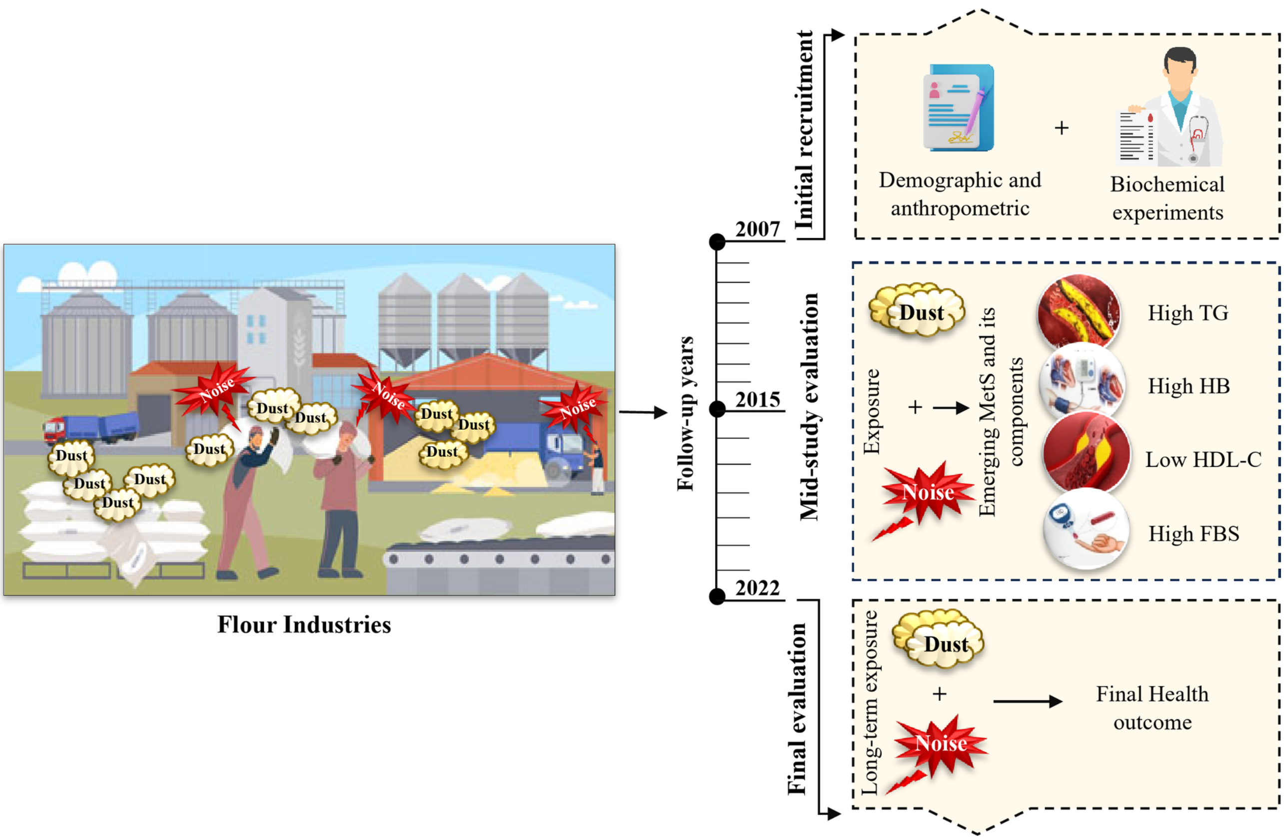

Fig. 1. The average noise and flour dust exposure trend in the mill workshops from 2007 to 2022.

differences are less noticeable than if the control group had been selected from a completely different work environment.

Inclusion and exclusion criteria

Flour mill workers aged 18 years or older who provided written informed consent were eligible to participate. To ensure that the study cohort captured only new cases of MetS during the follow-up, certain exclusion criteria were applied at baseline. Participants were excluded if they lacked follow-up data ($n = 17$) to avoid bias due to missing time-to-event information. Workers with prior occupational exposure to noise and dust in jobs outside the flour mills ($n = 76$) were excluded to isolate the specific effects of flour mill exposures.

Additionally, workers with a history of pre-existing cardiovascular symptoms (e.g., chest pain, diagnosed cardiovascular disease) ($n = 123$) were excluded to minimize confounding, as these conditions are independently associated with MetS. Workers diagnosed with hypertension, hyperglycemia, hypertriglyceridemia, low HDL cholesterol, or MetS before the study ($n = 14$) or within the first year of follow-up ($n = 5$) were also excluded. This step ensured the study focused on the incidence of MetS rather than exacerbation of pre-existing conditions.

Regarding diabetes, workers with a family history of type 2 diabetes mellitus (T2DM) were not excluded. Instead, family history was included as a key variable to investigate its role as a modifier in the association between occupational exposures and MetS. This approach allowed us to study potential genetic predispositions without narrowing the study cohort unnecessarily (Fig. 2).

Baseline assessment

A comprehensive questionnaire was used to collect data on demographics (age, gender, education, marital status), work-related factors (working hours, shift work patterns), lifestyle habits (smoking status, physical activity levels), and personal and family medical history. Anthropometric measurements (height, weight) were conducted by a trained researcher using standardized instruments. Systolic blood pressure (SBP), and Diastolic blood pressure (DBP) was measured twice using a validated automated sphygmomanometer after participants rested for at least 5 min in a seated position. Fasting Blood Sugar (FBS), triglycerides (TG), high-density lipoprotein (HDL) cholesterol, and low-density lipoprotein (LDL) cholesterol levels were determined using standardized laboratory methods from blood samples collected after an overnight fast.

Cumulative exposure assessment

Cumulative exposure for noise and flour dust was calculated for each participant by integrating exposure intensity and duration over the follow-up period.

Noise exposure

We measured noise exposure levels in decibels (dB) using a sound statistical analyzer (TES-1358) that complies with ANSI and NIOSH guidelines. Personal sampling was conducted for each worker by positioning the sound level analyzer close to the ear to capture individual exposure levels accurately. Weekly measurements were conducted to calculate the 8-hour time-weighted average (TWA) noise levels for each worker. Noise exposure measurements were repeated annually throughout the follow-up period to track temporal changes in individual exposure levels.

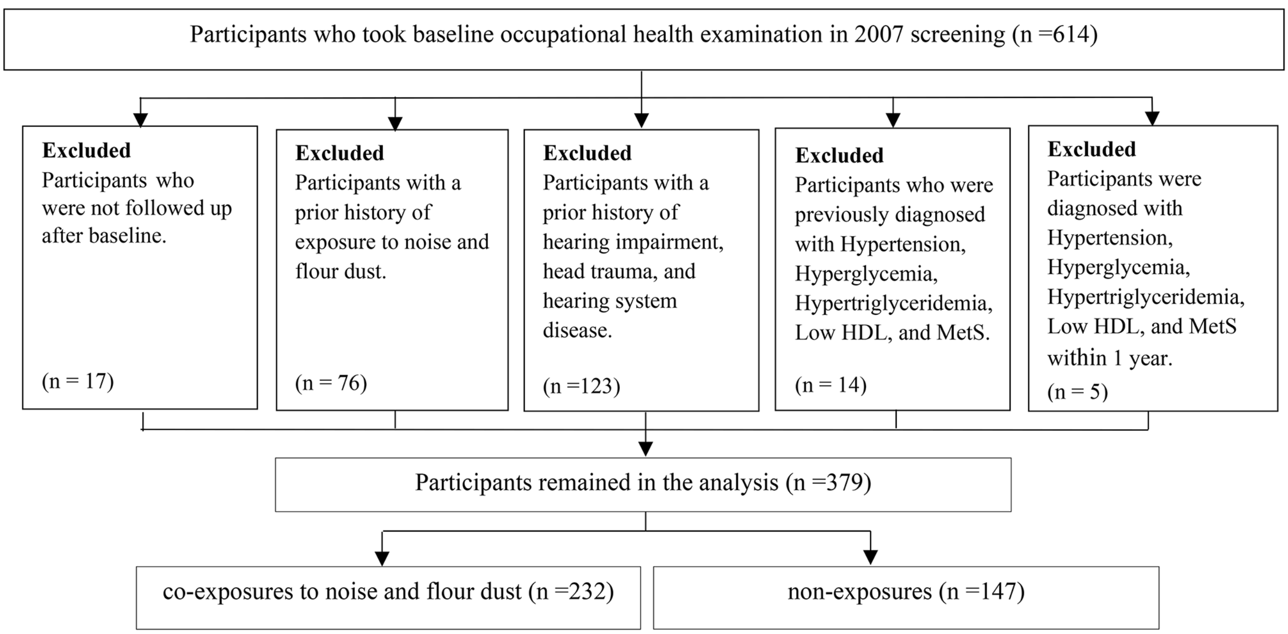

Fig. 2. The average noise and flour dust exposure trend in the mill workshops from 2007 to 2022.

We measured noise exposure levels in decibels (dB) using a sound statistical analyzer (TES-1358) that complies with ANSI and NIOSH guidelines. Personal sampling was conducted for each worker by positioning the sound level analyzer close to the ear to capture individual exposure levels accurately. Exposure thresholds were defined based on NIOSH-recommended limits for occupational noise exposure (e.g., 85 dB (A) over an 8-hour time-weighted average)[32]. Weekly measurements were conducted to calculate the 8-hour time-weighted average (TWA) noise levels for each worker. Exposure was classified into three categories—low (< 85 dB), moderate (> 85–90 dB), and high (> 90 dB), based on the intensity of noise levels observed at their primary workstations. Noise exposure measurements were repeated annually throughout the follow-up period to track temporal changes in individual exposure levels. Cumulative noise exposure was calculated by integrating both noise levels and duration of exposure over the follow-up period. For the primary analyses, noise exposure was ultimately dichotomized into two categories: non-exposed (< 85 dB) and exposed (≥ 85 dB). This binary classification was chosen to align with occupational safety thresholds (NIOSH-recommended limits) and to simplify the interpretation of exposure-response relationships. Sensitivity analyses using the semi-quantitative classification (low, moderate, and high) were conducted to confirm the strength of the binary approach.

Flour dust exposure

The sampling and measurement of airborne dust exposure were conducted using the personal air sampling method, following the National Institute for Occupational Safety and Health (NIOSH) Method 0600[33]. The collected dust samples were analyzed using gravimetric method and the airborne dust concentration was measured in milligram per cubic meter. Monthly sampling and analysis were conducted to track temporal changes and cumulative exposure levels for each worker over the follow-up period. We positioned personal air samplers near workers' breathing zones, provided individualized exposure measurements. In this study, exposure levels to flour dust among participants were assessed and compared to local established occupational exposure limits (OELs) aligned with ACGIH standards. we considered the ACGIH's TLV of 0.5 mg/m^3 as a benchmark to categorize exposure levels among the workers. participants' exposure levels were classified into the following categories: Low exposure level below 0.25 mg/m^3; Moderate exposure level between 0.25 mg/m^3 and 0.5 mg/m^3; High exposure level above 0.5 mg/m^3, exceeding the recommended TLV, indicating a high risk of respiratory irritation and sensitization for these workers. Cumulative exposure was calculated for each participant to account for both concentration and duration. For the primary analyses, flour dust exposure was dichotomized into two categories: non-exposed (< 0.25 mg/m^3) and exposed (≥ 0.25 mg/m^3). This binary classification was based on the ACGIH-recommended threshold limit value (TLV) of 0.5 mg/m^3 for respirable dust. Sensitivity analyses were performed using the semi-quantitative exposure classification to validate the binary approach.

Definition of MetS and its components

All participants were screened for MetS according to the definition of the National Cholesterol Education Program (NCEP) Adult Treatment Panel (ATP III)[34]. MetS was defined as the presence of three or more of the components The health outcomes assessed in this study were: (1) fasting plasma glucose level (FPG) ≥ 100 mg/dl or on therapy of anti-diabetes medicine. Blood samples were collected after an overnight fast, and FPG levels were determined using standardized laboratory methods. (2) blood pressure level ≥ 140/90 mmHg or on therapy for hypertension. Blood pressure was measured twice, with participants seated and resting for at least 5 min, using a validated automated sphygmomanometer. (3) serum triglycerides level ≥ 150 mg/dl or therapy of statins. Blood samples were processed and analyzed following standardized protocols. and (4) serum HDL-Cholesterol (HDL-C) level < 40 mg/ dl in men and < 50 mg/dl. HDL-C levels were measured using standardized laboratory assays.

Statistical analysis

Baseline characteristics and descriptive statistics

Descriptive analyses were conducted to compare the baseline characteristics of participants across exposure groups (non-exposed vs. exposed to flour dust and noise). Frequencies and percentages were calculated for categorical variables, and means with standard deviations (SD) were reported for continuous variables. The chi-square test was used to assess differences in proportions for categorical variables, while independent t-tests were used to compare means of continuous variables between exposure groups.

Regression models

Our study used Cox proportional hazards models to assess the association between occupational exposures and metabolic outcomes. Cox proportional hazards regression was used for participants with complete time-to-event data to estimate hazard ratios (HRs) and 95% confidence intervals (CIs). For the primary regression analyses, noise and flour dust exposures were included as binary variables, categorized as exposed and non-exposed. Stratified analyses were performed to assess whether associations between noise and dust exposure and MetS differed across these subgroups. Interaction terms between noise and dust exposure were included in the models to investigate their association with the incidence of MetS and its individual components. To evaluate the strength of the results, sensitivity analyses were conducted using alternative exposure thresholds and semi-quantitative exposure classifications (low, moderate, high) for both noise and dust. Covariates included demographic, work-related, and lifestyle factors. Hazard ratios (HRs) were calculated for increase in noise and dust exposure. All analyses were performed using Stata Vr.17.

Ethics

This study was a registered research project (A-10-88-25) conducted in accordance with the ethical standards and regulations as approved by the Research Ethics Review Committee of Semnan University of Medical

Sciences (Approval No: IR.SEMUMS.REC.1401.088). All experimental protocols were reviewed and approved by this committee prior to the initiation of the study. Permission to collect data and access the work environment was also obtained from the management of the flour mill company. Informed consent was obtained from all participants prior to their inclusion in the study. Participants were provided with detailed information regarding the aims and procedures of the research and were assured of their right to withdraw from the study at any time without any consequences. The confidentiality and privacy of all participants were strictly maintained throughout the research process.

Results

Baseline characteristics

Table 1 presents the baseline characteristics of participants in the non-exposed ($n = 147$) and exposed ($n = 232$) groups. Significant differences were observed between the groups in terms of baseline age distribution ($p = 0.003$), educational status ($p < 0.001$), and working hours ($p < 0.001$). Exposed workers were more likely to have extended working hours (97.50% vs. 2.50%) and engage in rotational shift work (97.10% vs. 2.90%) compared to the non-exposed group. No significant differences were observed for baseline BMI ($p = 0.738$), smoking status ($p = 0.057$), or family history of hypertension ($p = 0.514$). The majority of workers younger than 30 years were found in the exposed group (81.82%), while a higher percentage of workers aged 50 years and above were present in the non-exposed group (68.97%).

Health and biochemical parameters

Regarding baseline clinical measures, there was a statistically significant difference in fasting blood sugar (FBS) levels ($p = 0.049$), with the exposed group having a slightly higher mean FBS (90.05 mg/dL) compared to the non-exposed group (88.21 mg/dL). Other baseline biochemical parameters, such as triglycerides (TG), high-density lipoprotein (HDL), low-density lipoprotein (LDL), and blood pressure measures (systolic and diastolic), did not show significant differences between the exposed and non-exposed groups. This lack of significance implies that, at baseline both groups share similar lipid profiles and blood pressure levels, suggesting that any potential occupational impact on these parameters might develop over a more extended exposure period.

Exposure levels to noise and flour dust

The breathing zone exposure to respirable flour dust was estimated using the NIOSH method and ranged from 1.32 to 28.53 mg/m^3 with an annual average concentration of 23.95 mg/m^3 across the cohort. The mean and Standard Deviation (SD) intensity of noise exposure was in each sub-cohort were 89.09 ± 2.04 (85.70–94.75) dB (A). Additionally, the trend of changes in the means of noise and flour dust measured during the study is shown in Fig. 3. The findings presented in Table 2 indicate the significant differences in noise and dust exposure levels between the exposed and non-exposed groups over the 15-year study period. The exposed group consistently experienced higher mean noise levels (≥ 89 dB) and respirable dust concentrations (≥ 23.95 mg/m^3) with a substantial proportion of workers falling into moderate and high-exposure categories. However, the non-exposed group consistently exposed to significantly lower noise (< 65 dB) and dust levels (< 0.20 mg/m^3) remaining below occupational exposure limits throughout the study.

Primary associations between noise and dust exposure and MetS

Hypertension

Table 3 shows the results of Cox models for hypertension risk factors. Respirable dust exposure showed a hazard ratio (HR) of 1.01 (95% CI: 0.99–1.02) with a p-value of 0.080, indicating no statistically significant association with hypertension risk in this cohort. Significant associations were observed for weight (HR = 1.02, 95% CI: 0.99–1.05, $p = 0.038$) and BMI (HR = 1.04, 95% CI: 0.94–1.15, $p = 0.046$), indicating their role in contributing to hypertension risk. Noise, family history of FHT2DM and sex, showed no significant associations. However, the confidence intervals for some of these variables are wide, indicating uncertainty in the estimates.

Hyperglycemia

Table 4 shows baseline T2DM was associated with an increased risk of hyperglycemia (HR = 3.07, 95% CI: 0.22–4.29, $p = 0.040$). However, the wide confidence interval, which includes 1.0, suggests uncertainty in this estimate. Also, age was significantly associated with hyperglycemia risk (HR = 1.08, 95% CI: 1.02–1.14, $p = 0.007$). Noise exposure showed a borderline association with hyperglycemia (HR = 1.02, 95% CI: 1.20–1.04, $p = 0.062$), indicating further investigation.

Hypertriglyceridemia

Table 5 shows higher baseline LDL levels (HR = 1.008, 95% CI: 1.002–1.013, $p = 0.005$), triglycerides (TG) (HR = 1.003, 95% CI: 1.001–1.004, $p < 0.001$), and T2DM (HR = 14.57, 95% CI: 3.017–70.328, $p = 0.001$) were significant predictors of hypertriglyceridemia. No significant associations were observed for noise exposure or respirable dust exposure levels compared to the low exposure group.

Low HDL-Cholesterol

Table 6 reveals that higher baseline levels of HDL cholesterol (HR = 0.959, 95% CI: 0.932–0.986, $p = 0.003$) were significantly protective against low HDL-C risk. Other variables, including physical activity, family history of hypertension, noise, respirable dust exposure, and exposure group, were not significantly associated with low HDL-C risk.

Characteristics	Total, No. (%) (*n* = 379)	Non-exposed (*n* = 147)		Flour dust and noise-exposed (*n* = 232)		*P*-value
		Freq (*n*)	%	Freq (*n*)	%	
Baseline age						0.003
< 30	55 (14.52)	10	18.18	45	81.82	
30–39	132 (34.82)	58	43.94	74	56.06	
40–49	134 (35.36)	39	29.10	95	70.90	
≥ 50	58 (15.30)	40	68.97	18	31.03	
Baseline educational statues						< 0.001
Lower Diploma	176 (46.44)	142	80.60	34	19.40	
Diploma	105 (27.70)	71	67.50	34	32.50	
Academic	98 (25.86)	19	18.90	79	81.10	
Marital Status						0.131
Single	42 (11.10)	24	56.30	18	43.70	
Married	337 (88.90)	124	46.70	213	63.30	
Baseline smoking status						0.057
Yes	337 (88.90)	42	12.50	295	87.50	
No	42 (11.10)	18	42.18	24	57.82	
Baseline working hours						< 0.001
Regular working 40 h/ week	168 (44.40)	142	84.40	26	15.60	
Extended working 40 h/ week	211 (55.60)	5	2.50	206	97.50	
Baseline shift work						< 0.001
Fixed daylight shift	295 (77.80)	147	50.00	147	50.00	
Rotational shift	84 (22.20)	2	2.90	82	97.10	
Baseline T2DM						0.150
Yes	5 (1.40)	0	0.00	5	100.0	
No	374 (98.60)	232	62.03	142	37.97	
Baseline family history of T2DM						0.039
Yes	47 (12.50)	29	61.10	18	38.90	
No	332 (87.50)	119	35.70	213	64.30	
Baseline family history of hypertension						0.514
Yes	39 (10.40)	18	46.70	21	53.30	
No	340 (89.60)	129	37.95	211	62.05	
Baseline physical activity						0.299
Yes	79 (20.80)	37	46.70	42	53.30	
No	300 (79.20)	109	36.30	191	63.70	
Baseline BMI (Kg/m2) (Mean ± SD)	26.03 ± 4.62	26.37 ± 6.27		25.82 ± 3.19		0.738
Baseline FBS (mg/dL) (Mean ± SD)	89.33 ± 11.34	88.21 ± 13.17		90.05 ± 10.01		0.049*
Baseline TG (mg/dL) (Mean ± SD)	135.88 ± 108.49	135.46 ± 158.49		136.15 ± 58.88		0.157
Baseline HDL (mg/dL) (Mean ± SD)	44.48 ± 13.63	44.46 ± 9.48		44.49 ± 15.76		0.304
Baseline LDL (mg/dL) (Mean ± SD)	64.49 ± 47.15	65.43 ± 44.46		63.9 ± 47.23		0.720
Baseline SBP (mg/dL) (Mean ± SD)	118.44 ± 12.09	116.02 ± 14.87		119.97 ± 9.73		0.089
Baseline DBP (mg/dL) (Mean ± SD)	79.22 ± 5.50	78.43 ± 5.99		79.73 ± 5.13		0.113

Table 1. Frequency and percentage of participants characteristics in exposed and non-exposed and the relevant p-value at baseline in flour mill workers (2007–2022). Note: Values for continuous variables are presented as mean ± standard deviation (SD). P-values for categorical variables were calculated using chi-square tests, and p-values for continuous variables were calculated using independent t-tests. Abbreviations: T2DM = Type 2 Diabetes Mellitus, BMI = Body Mass Index, FBS = Fasting Blood Sugar, TG = Triglycerides, HDL = High-Density Lipoprotein, LDL = Low-Density Lipoprotein, SBP = Systolic Blood Pressure, DBP = Diastolic Blood Pressure.

Metabolic syndrome

The results in Table 7 indicate that baseline T2DM was strongly associated with metabolic syndrome risk, with participants showing a 16.58-fold higher risk (HR = 16.58, 95% CI: 1.826–150.570, $p = 0.013$). Respirable dust exposure levels showed a borderline significant association, with the high exposure group approaching significance compared to the low exposure group ($p = 0.096$). No significant associations were found for noise exposure levels.

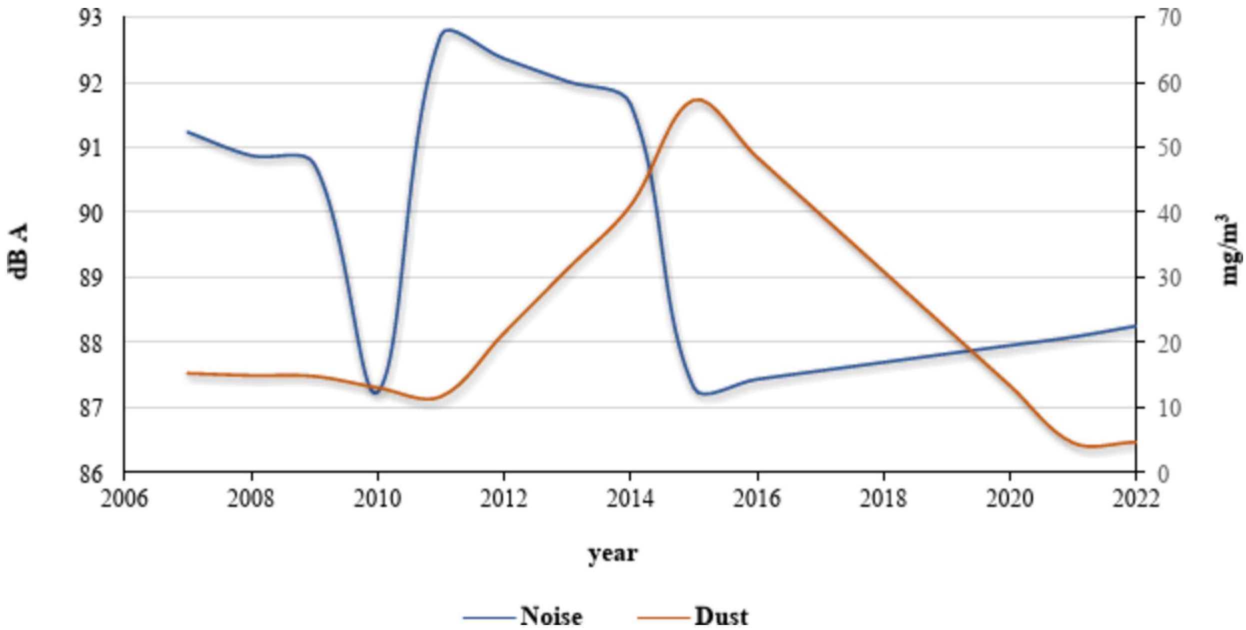

Fig. 3. The average noise and flour dust exposure trend in the mill workshops from 2007 to 2022.

Time period	Work environment agents	Exposure group	Exposure level (mean ± SD)	Range	Exposure categories (%)	Number of subjects (*n*)
2007 (Baseline)	Noise (dB)	Exposed	89 ± 2	85–94	Moderate (85–90 dB): 31.03% High (> 90 dB): 27.58%	*n* = 360
		Non-exposed	61 ± 2	57–64	Low (< 85 dB): 41.37%	*n* = 254
	Dust (mg/m^3)	Exposed	23.95 ± 5.67	1.32–28.53	Moderate (0.25–0.5 mg/m^3): 34.48% High (> 0.5 mg/m^3): 24.13%	*n* = 360
		Non-exposed	0.12 ± 0.02	0.09–0.17	Low (< 0.25 mg/m^3): 41.37%	*n* = 254
2015 (Mid-study)	Noise (dB)	Exposed	90 ± 2	86–95	Moderate (85–90 dB): 36.23% High (> 90 dB):28.98%	*n* = 180
		Non-exposed	65 ± 2	58–72	Low (< 85 dB): 34.78%	*n* = 172
	Dust (mg/m^3)	Exposed	24.50 ± 6.00	2.00–30.0	Moderate (0.25–0.5 mg/m^3): 37.68% High (> 0.5 mg/m^3): 27.53%	*n* = 180
		Non-exposed	0.13 ± 0.08	0.07–0.21	Low (< 0.25 mg/m^3): 34.78%	*n* = 172
2022 (Final Follow-Up)	Noise (dB)	Exposed	90 ± 2	87–96	Moderate (85–90 dB): 39.17% High (> 90 dB): 20.61%	*n* = 232
		Non-exposed	67 ± 2	61–72	Low (< 85 dB): 40.20%	*n* = 147
	Dust (mg/m^3)	Exposed	25.00 ± 6.50	2.50–32.00	Moderate (0.25–0.5 mg/m^3): 20.61X% High (> 0.5 mg/m^3): 39.17%	*n* = 232
		Non-exposed	0.16 ± 0.05	0.09–0.23	Low (< 0.25 mg/m^3): 40.20%	*n* = 147

Table 2. Summary of noise and dust exposure levels and number of subjects by groups (exposed and non-exposed) across time periods (2007–2022). Exposed: Workers operating in areas with high noise (> 85 dB) and dust (> 0.25 mg/m^3). Non-exposed: Workers in administrative or supervisory roles with low noise and dust exposure (≤ 85 dB, < 0.25 mg/m^3).

Stratified analyses by working conditions

Table 8 presents the hazard ratios (HRs) and 95% confidence intervals (CIs) for metabolic syndrome (MetS) and its components, stratified by these variables. Among workers with extended working hours high levels of exposure were significantly associated with MetS (HR: 1.38, 95% CI: 1.08–1.76, $p = 0.01$) and hypertriglyceridemia (HR: 1.50, 95% CI: 1.15–1.95, $p = 0.02$). These findings suggest that prolonged exposure duration increases the metabolic effects of occupational hazards particularly on lipid profiles. For hypertension, workers exposed to high levels of noise and dust for over 40 h per week also showed a significantly increased risk (HR: 1.35, 95% CI: 1.04–1.75, $p = 0.02$), while a similar association was observed for hyperglycemia (HR: 1.42, 95% CI: 1.11–1.82, $p = 0.01$). However, the risk for these outcomes was generally lower and less statistically significant among workers with ≤ 40 h of weekly exposure, highlighting the importance of exposure duration in influencing metabolic health outcomes.

Variables	Hypertension model [a]				
				95% CI	
	HR	Z	*P*-Value	Lower	Upper
Weight	1.02	0.86	**0.038**	0.99	1.05
FHT2DM	0.73	−0.67	0.505	0.28	1.90
Sex	0.58	−0.97	0.332	0.19	1.77
BMI	1.04	0.74	**0.046**	0.94	1.15
Noise	1.01	0.50	0.618	0.99	1.02
Respirable dust	1.01	1.75	0.080	0.99	1.02

Table 3. Results from Cox models for the association of risk factors and hypertension in flour mill workers (2007–2022). [a] Model for baseline weight, baseline FHT2DM, sex, baseline BMI, average noise, and average flour dust.

Variables	Hyperglycemia model [b]				
				95% CI	
	HR	Z	*P*-Value	Lower	Upper
Weight	1.02	0.97	0.322	0.98	1.06
T2DM	3.07	0.84	**0.040**	0.22	4.29
Age	1.08	2.69	**0.007**	1.02	1.14
Noise	1.02	1.87	0.062	1.20	1.04
Respirable dust	0.85	−1.78	0.076	0.72	1.02

Table 4. Results from Cox models for the association of risk factors and hyperglycemia in flour mill workers (2007–2022). [b] Model for baseline weight, baseline T2DM, baseline age, average noise, and average flour dust.

Variables	Hypertriglyceridemia model [C]				
				95% CI	
	HR	Z	*P*-Value	Lower	Upper
Wight	1.02	1.26	0.207	0.99	1.04
Sex	1.14	0.28	0.777	0.45	2.88
LDL	1.01	2.80	**0.005**	1.00	1.01
TG	1.01	3.71	**0.0001**	1.00	1.01
BMI	1.03	0.69	0.490	0.94	1.13
T2DM	14.60	3.33	**0.001**	3.01	70.3
Noise	1.20	−0.15	0.884	0.99	1.01
Respirable Dust	1.01	1.00	0.320	0.99	1.01

Table 5. Results from Cox models for the association of risk factors and hypertriglyceridemia in flour mill workers (2007–2022). [C] Model for baseline wight, sex, baseline LDL, baseline Triglyceride, baseline BMI, baseline T2DM, and average noise, average flour dust.

Among rotational shift workers, high exposure levels were significantly associated with an elevated risk of hypertriglyceridemia (HR: 1.65, 95% CI: 1.25–2.18, $p = 0.01$). Also, rotational shift workers exposed to high levels of noise and dust showed elevated risks for hyperglycemia (HR: 1.50, 95% CI: 1.15–1.96, $p = 0.03$) and hypertension (HR: 1.42, 95% CI: 1.07–1.89, $p = 0.01$), suggesting that shift work may exacerbate the metabolic effects of occupational exposures. In comparison, workers on fixed daylight shifts showed lower hazard ratios across all outcomes. Significant associations were observed only for hypertriglyceridemia (HR: 1.35, 95% CI: 1.02–1.79, $p = 0.03$) and hyperglycemia (HR: 1.33, 95% CI: 1.02–1.73, $p = 0.03$) at high exposure levels. These trends suggest that working conditions may modify the risk of metabolic health disturbances.

Interaction effects of exposure intensity and duration

We examined the interaction between exposure intensity (low, moderate, high) and duration (short-term vs. long-term) for noise and dust exposure, assessing their combined impact on the risk of MetS and its components. Cox proportional hazards models with interaction analyses revealed significant combined effects of dust exposure intensity and duration on hypertension (HR = 1.92, 95% CI: 0.92–2.76) and hypertriglyceridemia (HR = 2.05, 95% CI: 0.83–3.17). These findings show that prolonged and high-intensity dust exposure amplifies the risk of

Variables	Low HDL-cholesterol model [d]				
				95% CI	
	HR	Z	*P*-Value	Lower	Upper
PA	1.81	1.55	0.121	0.85	3.81
HDL	0.96	−2.94	**0.003**	932	0.98
FHH	0.34	−1.76	0.079	0.10	1.13
Noise	1.01	0.22	0.828	0.99	1.00
Respirable Dust	1.09	−1.14	0.256	0.97	1.00

Table 6. Cox models data for the association of physical activity, family history of hypertension, noise, dust, and exposure group with the risk of low HDL-cholesterol in flour mill workers (2007–2022). [d] Model for baseline Physical Activity PA, baseline HDL-C, baseline FHH, average noise, and average flour dust.

Variables	Metabolic syndrome model [e]				
				95% CI	
	HR	Z	*P*-Value	Lower	Upper
Weight	1.02	1.90	0.057	0.99	1.05
FHT2DM	2.34	1.65	0.100	0.85	6.48
T2DM	16.5	2.49	**0.013**	1.82	15.09
Noise	1.00	0.12	0.904	0.98	1.01
Respirable Dust	1.00	1.66	0.096	0.99	1.01

Table 7. Cox model results for the association of weight, family history of type 2 diabetes, type 2 diabetes, noise, dust, and exposure group with the risk of metabolic syndrome in flour mill workers (2007–2022). [e] model for baseline weight, baseline FHT2DM, baseline T2DM, average noise, and average flour dust.

Stratifying variable	Exposure group	MetS	Hyperglycemia	Hypertension	Hypertriglyceridemia	Low HDL
		HR (95%CI); P-value				
Working hours						
≤ 40 h/week	Low	Reference	Reference	Reference	Reference	Reference
	Moderate	1.10 (0.88–1.38); *p* = 0.25	1.12 (0.89–1.42); *p* = 0.28	1.14 (0.90–1.44); *p* = 0.22	1.18 (0.92–1.50); *p* = 0.18	1.09 (0.84–1.41); *p* = 0.32
	High	1.25 (0.97–1.62); *p* = 0.08	1.30 (1.01–1.67); *p* = 0.04	1.28 (0.99–1.65); *p* = 0.06	1.33 (1.01–1.75); *p* = 0.03	1.15 (0.88–1.50); *p* = 0.21
> 40 h/week	Low	Reference	Reference	Reference	Reference	Reference
	Moderate	0.18 (0.93–1.49); *p* = 0.16	1.22 (0.95–1.56); *p* = 0.12	1.25 (0.97–1.61); *p* = 0.08	1.29 (0.99–1.69); *p* = 0.05	1.18 (0.91–1.53); *p* = 0.14
	High	1.38 (1.08–1.76); *p* = 0.01	1.42 (1.11–1.82); *p* = 0.01	1.35 (1.04–1.75); *p* = 0.02	1.50 (1.15–1.95); *p* = 0.02	1.30 (0.98–1.73); *p* = 0.07
Shift type						
Fixed daylight shift	Low	Reference	Reference	Reference	Reference	Reference
	Moderate	1.12 (0.89–1.41); *p* = 0.26	1.15 (0.90–1.47); *p* = 0.20	1.13 (0.88–1.46); *p* = 0.30	1.20 (0.92–1.56); *p* = 0.18	1.14 (0.85–1.52); *p* = 0.25
	High	1.28 (0.99–1.65); *p* = 0.06	1.33 (1.02–1.73); *p* = 0.03	1.30 (0.99–1.70); *p* = 0.05	1.35 (1.02–1.79); *p* = 0.03	1.22 (0.89–1.66); *p* = 0.18
Rotational shift	Low	Reference	Reference	Reference	Reference	Reference
	Moderate	1.25 (0.96–1.63); *p* = 0.09	1.28 (0.98–1.68); *p* = 0.07	1.22 (0.92–1.62); *p* = 0.14	1.37 (1.03–1.83); *p* = 0.02	1.19 (0.89–1.60); *p* = 0.21
	High	1.45 (1.12–1.88); *p* = 0.05	1.50 (1.15–1.96); *p* = 0.03	1.42 (1.07–1.89); *p* = 0.01	1.65 (1.25–2.18); *p* = 0.01	1.38 (1.01–1.89); *p* = 0.04

Table 8. Stratified analysis by working hours and shift type for the association between occupational exposure and MetS. Hazard ratios (HR) and 95% confidence intervals (CI) estimated using Cox proportional hazards regression.

these outcomes compared to low-intensity, short-term exposure. However, interaction effects between noise intensity and duration were not significant for most MetS components, indicating that noise exposure might not have a strong independent or interactive effect on MetS within this cohort. This finding suggests that dust exposure, particularly at high intensity and over prolonged periods, is a more critical factor in the development of MetS-related outcomes among flour mill workers.

Statistical adjustments and sensitivity analyses

The sensitivity analyses revealed that the associations between noise and dust exposure with MetS components remained consistent across different exposure thresholds, suggesting that the risk estimates were strong to potential misclassification biases. For instance, hazard ratios (HRs) for hypertension remained significantly elevated with high dust exposure levels, reinforcing the association with dust as a risk factor for hypertension. However, the associations between noise exposure and hypertension, as well as other MetS components, remained non-significant across exposure thresholds, highlighting that noise might not be a primary factor in this cohort for these specific outcomes.

The cumulative exposure analysis showed that workers with prolonged and high-intensity dust exposure had elevated HRs for hypertension, hyperglycemia, and hypertriglyceridemia, although statistical significance varied among MetS components. These findings emphasize that cumulative exposure may offer more insights into chronic health effects than single-point measurements supporting the reliability of our exposure categorization approach.

Connecting results to hypotheses

Hypothesis 1 The findings partially support our hypothesis that occupational exposures, particularly respirable dust, contribute to hypertension and hypertriglyceridemia risk.

Hypothesis 2 The stratified analyses demonstrated that working conditions, such as rotational shifts and extended working hours, modify the impact of occupational exposures on metabolic outcomes.

Hypothesis 3 While biochemical indicators like LDL and TG were significantly associated with hypertriglyceridemia, formal mediation analyses were not conducted, leaving this as a potential area for future research.

Discussion

This study had important findings for the proposed hypothesis: first, mill workers' exposure to higher levels of noise and dust increased the incidence of MetS and its components than those without exposure levels. However, the increase was not significant. Second, the study found that the association between occupational exposure to noise and dust with MetS components was modified by weight, age, BMI, and T2DM. Lastly, the study found that the effects of occupational exposure to noise and dust on MetS were mediated by biochemical measurements of TG, HDL, and LDL.

New understandings from this study

While previous studies have explored the health impacts of noise or dust exposure independently, this study looks towards a comprehensive evaluations of their combined effects on metabolic syndrome (MetS). Flour mills offered a setting where workers are chronically exposed to both high noise levels and respirable dust, making them an ideal population for studying these interactions.

One of the novel aspects of this study is the use of cumulative exposure metrics for both noise and dust, which provided a more detailed assessment of occupational exposure intensity and duration over time. This approach not only strengthened the reliability of our findings but also enabled us to explore potential dose-response relationships.

Furthermore, our study uniquely examined how these exposures may influence lipid metabolism by identifying associations with biochemical markers such as TG, HDL, and LDL. While these associations do not establish causality, they offer new hypotheses regarding the biological pathways linking occupational exposures to metabolic disturbances.

Also this study highlights our identification of effect modifiers, such as age, BMI, and working hours, which highlight how individual and work-related factors may amplify the health risks associated with noise and dust exposure.

By focusing on a high-risk occupational group with prolonged exposure to dual hazards, our study could inform the development of more comprehensive workplace safety guidelines. Current occupational exposure limits often consider noise and dust in isolation; however, our findings emphasized the need for integrated risk assessments and control measures that account for the cumulative and interactive effects of multiple exposures. This work emphasized the importance of prioritizing occupational health policies that mitigate the long-term metabolic risks faced by workers in flour mills and similar industries.

Comparison of ATP III and other definitions of MetS

The ATP III definition was selected for this study because it is one of the most widely used definitions in epidemiological and clinical research, providing consistency and comparability with previous studies in occupational health[35]. Unlike the International Diabetes Federation (IDF) definition, which requires central obesity as a mandatory criterion, ATP III uses a more flexible approach by allowing any three of the five components to define MetS. This flexibility is particularly relevant in populations where obesity may not always be the dominant risk factor for MetS, such as in occupational cohorts. In contrast, the World Health Organization (WHO) and European Group for the Study of Insulin Resistance (EGIR) definitions emphasize insulin resistance as a key component, which requires more specialized testing and may not be practical for large-scale cohort studies such as ours[36].

Associations with hypertension and other MetS components

Our first hypothesis suggested that continuous occupational exposure to noise and respirable dust would increase the risk of MetS and its individual components among flour mill workers. While the overall association between high levels of exposure and MetS was not statistically significant, we observed notable trends in certain MetS components, particularly hypertriglyceridemia and hypertension. While the associations for noise exposure with hypertension were not statistically significant, the role of respirable dust warrants attention, as it exhibited consistent positive trends. These results align with existing evidence linking occupational exposures, particularly dust, to elevated blood pressure, likely due to systemic inflammation or oxidative stress caused by inhalable particles[25].

Our second hypothesis explored how demographic and lifestyle factors modify the relationship between occupational exposure to noise and dust and the risk of MetS and its components. The findings supported this hypothesis, highlighting the influence of individual characteristics such as age, BMI, extended working hours and rotational shift work on metabolic health outcomes. Older workers and individuals were more susceptible to MetS and its components when exposed to occupational hazards. Specifically, workers with higher BMI exposed to both noise and dust showed a greater risk of hypertriglyceridemia.

We found a positive association between the risk of hypertension with weight, BMI, and respirable dust exposure. However, the confidence intervals were wide, reflecting some uncertainty in the estimates. The lack of significance in certain variables might be attributed to the relatively small sample size or other confounding factors. Nevertheless, these results align with previous research that has linked occupational exposures to an increased risk of hypertension[27,37]. The study found no significant association between noise exposure and hypertension, which contradicts some previous studies reporting such a link[19,38]. This discrepancy may be due to the unique characteristics of the flour mill workplace or variations in exposure levels across different industries. This study also indicated that individual characteristics, such as age, BMI, smoking status, and physical activity, modify the association between occupational exposure to noise and dust and MetS. In our study, older workers or those with higher BMI looked more susceptible to the health effects of exposure. These findings are consistent with previous research suggesting that individual characteristics can influence the response to occupational exposures[37].

Biochemical indicators as potential mechanisms

Our third hypothesis explored whether the association between occupational exposure to noise and dust and MetS is mediated by biochemical markers. Our findings showed that noise and dust exposure may be associated with changes in biochemical indicators, including TG, HDL, and LDL which are known risk factors for MetS. High TG levels were particularly associated with exposure to both noise and dust, with workers in the high-exposure group showing significantly increased risks of hypertriglyceridemia. These results are in line with studies reporting alterations in lipid metabolism as a response to chemical exposure[39]. While these associations are consistent with the literature, we emphasize that no formal mediation analysis was conducted in this study and therefore, it cannot be concluded that these biochemical markers mediated the relationship between occupational exposures and MetS. Instead, these findings highlight potential pathways that warrant further investigation.

Risk factors for hyperglycemia and hypertriglyceridemia

This study identified age and T2DM as important risk factors for hyperglycemia, consistent with existing literature that has established age and T2DM as significant contributors to hyperglycemia and MetS[40,41]. The probable explanation for our results is that older adults are at higher risk for developing type 2 diabetes due to the combined effects of genetic, lifestyle, and aging influences. These factors contribute to hyperglycemia through reduced β-cell insulin secretory capacity and tissue sensitivity to insulin[42]. Additionally, weight and work-related noise exposure showed a positive, albeit non-significant, association with hyperglycemia. This suggests that these factors may play a role in hyperglycemia risk but require further investigation with larger sample sizes to draw definitive conclusions.

Regarding hypertriglyceridemia, TG and T2DM were identified as strong risk factors. These findings are consistent with the literature linking dyslipidemia to T2DM and poor lipid profiles with metabolic abnormalities[43,44]. Family history of specific diseases also reflects genetic susceptibility, which may contribute to fasting plasma triglyceride levels and metabolic disturbances[45]. While this study found associations between noise and dust exposure and alterations in TG, HDL, and LDL levels, further research is needed to confirm whether these biochemical changes act as intermediaries in the development of hypertriglyceridemia or MetS. Formal mediation analyses would provide a more robust understanding of the mechanistic pathways involved.

Furthermore, this study found associations between noise and dust exposure and alterations in HDL and LDL levels. These findings are consistent with the study by Kim et al. (2022) and suggest that hypertriglyceridemia may play a role in the development of MetS among workers exposed to noise and dust[11]. The mechanisms underlying this association may involve a reduction in HDL and an increase in atherogenic small-dense LDL levels[43,46]. However, further research is needed to confirm these mechanisms and explore other potential pathways. The lack of significant associations between hypertriglyceridemia risk and other variables, including noise, dust, and exposure group, may be attributed to complex interactions between multiple factors contributing to lipid metabolism and hypertriglyceridemia development.

Working hours and shift patterns

This study found no statistically significant associations between working hours or shift patterns and the risk of MetS or its components, these variables are recognized as important occupational factors that may influence metabolic health. Rotational shift work has been associated with circadian rhythm disruption, which can impair glucose metabolism[47]. Shift work and the risk for metabolic syndrome among healthcare workers: A systematic review and meta-analysis), while extended working hours may contribute to stress and unhealthy lifestyle behaviors[48]. While our stratified analyses did not detect significant interactions between these variables and MetS outcomes, future research should explore these relationships further in larger cohorts or with more detailed assessments of work schedules and their cumulative impacts.

Conclusions

In conclusion, this study contributes valuable insights into the potential associations between occupational exposure to noise and dust and metabolic health outcomes in flour mill workers. The findings highlight the importance of age, T2DM, LDL, TG, and HDL levels in influencing metabolic outcomes. However, several factors, such as BMI, weight, noise, and dust exposure, showed suggestive associations, necessitating further investigation with larger cohorts to elucidate their roles fully. Overall, this research emphasizes the significance of preventive strategies and health interventions targeting occupational exposures and metabolic health, with the ultimate goal of promoting well-being and reducing the burden of metabolic disorders in the workforce.

The implications of this research extend beyond the specific cohort of flour mill workers. Understanding the complex relationship between occupational exposures and MetS can inform occupational health policies and practices globally. Implementing proactive measures to reduce noise and dust exposure in workplaces could potentially contribute to the prevention and management of MetS and associated health conditions. Additionally, the identification of effect modifiers emphasizes the need for tailored intervention strategies based on individual characteristics, promoting a more personalized approach to occupational health and risk management. Overall, this study provides valuable insights into the potential health effects of occupational exposures, contributing to the advancement of knowledge in the field of occupational health and metabolism-related diseases.

Limitations

This study has several limitations. First, the exclusion of participants with pre-existing MetS or its components, while necessary to reduce reverse causality, may limit the generalizability of our findings to populations with pre-existing health conditions. Second, the exclusion of participants lacking follow-up data could result in selection bias if these participants differed systematically from those retained in the study, Although, no significant differences were observed in baseline characteristics. Third, the exclusion of workers with prior noise and dust exposure ensures accurate exposure assessments but may limit applicability to populations with more varied occupational histories. Despite these potential biases, our matched control group and sensitivity analyses strengthen the internal validity of our findings. Fourth, the sample size may have affected the statistical power, potentially contributing to the lack of significance in some associations. Larger cohorts may be needed to detect more subtle effects. Finally, exposure assessment, although objective, may have been subject to measurement error, potentially attenuating observed associations. Overall, our findings provide evidence for potential risk factors for MetS and components. However, the confidence intervals for some of these individual and occupational factors indicate uncertainty, and thus further research is needed to confirm these findings.

Data availability

The datasets generated or analyzed during the current study are available from the corresponding author upon request.

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Author contributions
M.B.K: Conceptualization, Investigation, Methodology, Resources, Writing - Original Draft, Writing - Review & Editing. E.S: Formal analysis, Data Curation, Software. A.D: Conceptualization, Investigation, Methodology, Writing - Original Draft, Writing - Review & Editing, Supervision, Project administration. All authors read and approved the final manuscript.

Declarations

Competing interests
The authors declare no competing interests.

Additional information
Correspondence and requests for materials should be addressed to A.D.