

OCCUPATIONAL EXPOSURE TO AIRBORNE FLOUR DUST ACROSS INDUSTRIAL MILLING WORKSTATIONS

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ABSTRACT

Background: Occupational exposure to flour dust is associated with respiratory diseases such as occupational asthma, rhinitis, conjunctivitis, and exposure levels in bakeries and milling industries frequently exceed recommended occupational exposure limits. **Objective:** This study evaluated occupational exposure to flour dust in an industrial milling facility in northern Portugal, identifying high-risk workstations, determine the effective dust concentration and proposing preventive measures. **Methodology:** A cross-sectional study was conducted in three high-exposure workstations (bakery, mix–weighing, and mix–bagging). Personal air sampling was performed on different days and time periods following NP EN 689 principles. Total and respirable dust were collected using NIOSH Methods 0500 and 0600. **Results:** All workstations exceeded the occupational exposure limit (0.5 mg/m³). The highest total dust exposure occurred in the mix–weighing sector (mean 19.18 mg/m³; 10.37–27.56 mg/m³), followed by the bakery (mean 4.69 mg/m³; 0.55–12.55 mg/m³) and mix–bagging (mean 0.84 mg/m³; 0.32–1.17 mg/m³). Worst-case modelling showed that FFP1 masks did not ensure safe exposure levels, FFP2 masks provided partial protection, and only FFP3 masks consistently reduced effective concentrations below the exposure limit. **Conclusions:** Flour dust exposure remains significantly above recommended limits, highlighting the need for regular monitoring, engineering controls, and appropriate respiratory protection.

Keywords: Flour Dust, Occupational Exposure, Milling industry, Respiratory Health, Occupational Hygiene.

1. INTRODUCTION

Occupational exposure to flour dust has long been associated with the development of respiratory diseases, including occupational asthma, rhinitis, and conjunctivitis, with adverse health effects documented since the eighteenth century (Martinelli *et al.*, 2020). Workers in bakeries and milling facilities are particularly exposed during activities such as bagging, mixing, maintenance, and cleaning, where exposure may occur either directly or indirectly. The risk of occupational disease depends on several factors, including dust concentration and composition, duration of exposure, and individual variability in immune response (Dewangan & Patil, 2015).

Epidemiological evidence indicates that the most common health outcomes associated with flour dust exposure include asthma, conjunctivitis, rhinitis, and dermal reactions, with baker's asthma representing the most frequent and severe manifestation of occupational allergy (Page, 2010; Page *et al.*, 2013). Rhinitis often precedes the development of asthma, and conjunctival and skin symptoms may also occur (Stobnicka & Górny, 2015). Atopy, defined as a genetic predisposition to allergic diseases, is a recognized risk factor, and symptoms may develop months or even years after the initial exposure, with risk increasing as exposure concentrations rise (Baur *et al.*, 1998; Moghaddasi *et al.*, 2014). Wheat flour and other cereal flours are among the principal causes of occupational asthma in workers employed in bakeries and milling industries (Sander *et al.*, 2001; Stobnicka & Górny, 2015).

Flour is a complex organic particulate matter composed of various milled cereals, frequently combined with additives intended to improve product quality. Handling of these materials during milling operations can significantly increase airborne dust concentrations, and several international studies have reported exposure levels exceeding recommended occupational exposure limits (OELs), highlighting the need for systematic exposure assessment and effective control measures (Kirkeleit *et al.* 2017; Martinelli *et al.*, 2020; Rumchev *et al.*, 2021). For clarity, it is important to distinguish between *flour dust*, generated during milling and processing operations, and *grain dust*, which originates from harvesting and grain handling; the present study focuses exclusively on flour dust exposure (Karpinski, 2003; Moghaddasi *et al.*, 2014; Stobnicka & Górny, 2015).

In this context, the present study aimed to evaluate occupational exposure to wheat flour dust among workers in an industrial milling facility in northern Portugal.

2. MATERIALS AND METHODS

2.1 STUDY DESIGN AND SETTING

A cross-sectional observational study was conducted in a flour milling industry located in northern Portugal. The factory employs 80 workers, distributed across the different stages of the wheat flour and semolina production process, which is illustrated in Figure 1.

Three workstations were selected where workers were suspected to be more highly exposed to flour dust, namely: Bakery; Mix – Weighing; Mix – Bagging. The activities carried out at each workstation were as follows:

- **Bakery:** located on the second floor, where workers receive bags containing samples of different types of flour, which are evaluated by analyzing the dough and its development.
- **Mix – Weighing:** located on the factory ground floor, where operators work with additives, performing their weighing.
- **Mix – Bagging:** also located on the ground floor, on bagging line no. 3, where the treated (additivated) flour is bagged.

All sectors are separated by solid walls, preventing the mixing of airborne dust between the different departments.

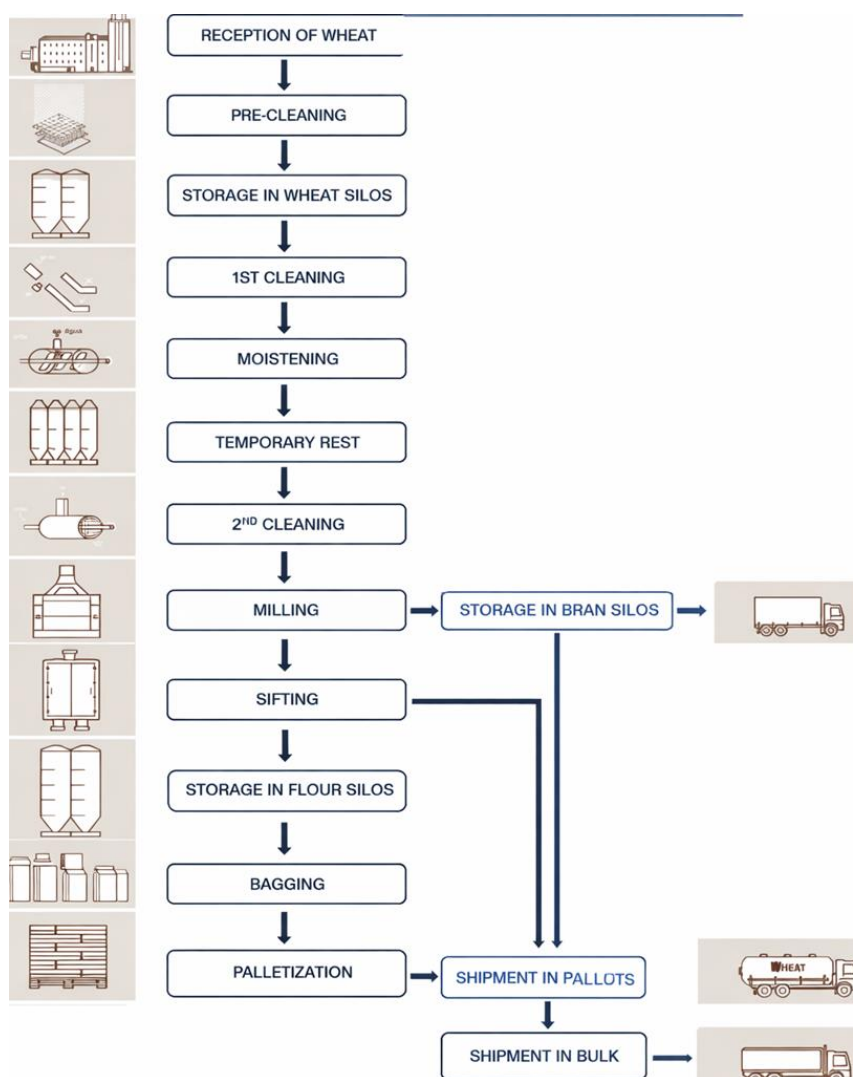


Figure 1: Stages of the flour and semolina production process.

2.2. FLOUR DUST SAMPLING AND ANALYSIS

Personal active air sampling was conducted at three workstations within a flour milling facility: bakery, mix–weighing, and mix–bagging. Total dust fraction (TD) was measured in all workstations, while respirable dust fraction (RD) was assessed exclusively in the mix–weighing area due to the handling of fine-particle additives incorporated into flour.

In accordance with the exposure assessment principles described in NP EN 689:2018+AC:2021, measurements were performed on different days of the week and at different time periods to account for day-to-day and task-related variability, recognizing that single measurements may not adequately represent actual exposure patterns.

Active air sampling and gravimetric analysis of total and respirable dust fractions were carried out following National Institute for Occupational Safety and Health (NIOSH) Methods 0500 and 0600, respectively (NIOSH, 1994; NIOSH, 1998). Personal sampling pumps (SKC Universal Sample Pump, model PCXR8) were connected to filter cassettes and, for respirable dust, to a cyclone separator. Polyvinyl chloride (PVC) membrane filters (37 mm, 5 µm pore size) were used.

Sampling duration was 60 minutes. This duration was established based on airflow rate requirements and minimum air volume specifications of the NIOSH gravimetric methods. At the selected flow rates (1.5 L/min for total dust and 2.5 L/min for respirable dust), the sampling period ensured sufficient mass collection for reliable gravimetric determination. Airflow rates were calibrated before and after sampling using a primary flow calibrator (DryCal® DC-Lite, Bios International), and filter weighing was performed with a high-precision microbalance (sensitivity 0.001 mg), in accordance with method requirements.

All measurements were conducted as personal task-based sampling during active operational periods, aiming to characterize exposure intensity associated with specific work activities rather than full-shift time-weighted averages. Therefore, results should be interpreted as representative of task-related exposure scenarios.



Figure 2: Pumps calibration/verification process.

Measured concentrations were calculated according to the following formula:

$$Ca = \frac{(W2 - W1) - (B2 - B1)}{V} \times 10^3$$

where:

Ca = dust concentration measured in the workplace (mg/m³);

V = air volume (L);

W₁ = tare weight of the filter before sampling (mg);

W₂ = post-sampling weight of the filter containing the sample (mg);

B₁ = mean tare weight of the blank filters (mg);

B₂ = mean post-sampling weight of the blank filters (mg).

The measured concentrations were compared with the Portuguese occupational exposure limit (OEL) for flour dust (0.5 mg/m³), as established in NP 1796:2014. This OEL refers to the inhalable fraction, which is considered the most appropriate metric for assessing exposure to flour dust due to its known effects on the upper and lower airways.

No specific OEL is established for the respirable fraction of flour dust. In the absence of a dedicated limit value, respirable dust measurements were included as a complementary indicator of fine particle exposure, particularly in the mix–weighing sector where flour additives are

handled. It is likely that a substantial proportion of the respirable fraction originates from additive particles rather than flour itself.

Although the general OEL for particles not otherwise classified (PNOC) is 3 mg/m³ for the respirable fraction, direct comparison with this value may not fully reflect the toxicological properties of flour dust or additives. Therefore, respirable dust results were interpreted cautiously and primarily used to characterize particle size distribution and potential alveolar deposition risk, rather than as a strict regulatory compliance assessment.

2.3. EFFECTIVE CONCENTRATION USING RESPIRATORY MASKS

Although it is the last protection measure to be applied, considering the general principles of prevention established by law, in the context of the present study one of the widely adopted measures is the use of Personal Protective Equipment (PPE), namely respirator masks worn by workers, Category III, intended to protect against the inhalation of dust. There are three levels of protection: Filtering Facepiece 1 (FFP1), FFP2, and FFP3. These masks are standardized throughout the European Union in accordance with Standard EN 149:2001+A1:2009.

Masks with a higher level of protection provide greater filtration efficiency and can therefore be used against more hazardous substances and in environments with higher contamination concentrations. Table 1 below presents the description of the mask types. The effective concentration (C_e) represents the concentration of dust effectively inhaled by the worker after considering the filtration efficiency of the respiratory mask. It was calculated using the following formula:

$$C_e = C_a \times (1 - \text{mask efficiency})$$

where:

C_e = effective concentration of airborne dust reaching the respiratory tract (mg/m³);

C_a = dust concentration measured in the workplace (mg/m³).

Mask efficiency = filtration efficiency of the respiratory mask, expressed as a decimal value (e.g., 0.80 for 80% efficiency). This formula assumes that the respiratory protective equipment reduces the airborne concentration inhaled by the worker proportionally to its filtration efficiency.

Table 1: Description of the mask types.

FFP1	FFP2	FFP3
Minimum filtration efficiency: 80% (filters 80% of airborne contaminants).	Minimum filtration efficiency: 94% (filters 94% of airborne contaminants).	Minimum filtration efficiency: 99% (filters 99% of airborne contaminants).
Low filtration efficiency – does not ensure protection against infectious agents.	Moderate filtration efficiency – suitable for medium- to high-risk situations.	High filtration efficiency – recommended for high-risk situations, such as aerosol-generating activities.
Suitable for contaminant concentrations up to 4 times the OEL.	Suitable for contaminant concentrations up to 10 times the OEL.	Suitable for contaminant concentrations up to 20 times the OEL.

2.4. DATA ANALYSIS

Occupational exposure measurements were analysed in accordance with the statistical framework underlying NP EN 689:2018+AC:2021, which assumes that occupational exposure data follow a log-normal distribution. Therefore, measured concentrations were log-transformed prior to statistical analysis. For each workstation and dust fraction, the geometric mean (GM) and geometric standard deviation (GSD) were calculated. The estimated 95th percentile (P95) of the exposure distribution was determined, representing the upper bound of expected exposure under the log-normal assumption. In addition, the probability of exceeding the occupational exposure limit (OEL = 0.5 mg/m³) was estimated using the cumulative distribution function of the normal distribution applied to log-transformed data. This approach allows quantification of the likelihood that true exposure exceeds the limit value, rather than relying solely on arithmetic confidence intervals. Given the limited number of measurements collected per workstation (n = 3), the statistical estimates should be interpreted as indicative of exposure patterns and exceedance likelihood. The results are not intended to constitute a full formal compliance assessment according to the complete decision procedure described in NP EN 689 but provide a robust characterization of exposure magnitude and variability consistent with its statistical assumptions.

3. RESULTS

For each workstation and analyte under study, personal samples were collected on three different days and at different times to ensure representativeness.

3.1 FLOUR DUST CONCENTRATION (C_A)

Table 2 presents the results obtained from the measurements carried out at the different workstations.

Table 2: Flour dust concentrations (C_a).

Workstation	Concentration by day	Mean±SD
	(mg/m ³)	
Mix - Bagging	1.17	0.84±0.45
	1.04	
	0.32	
Mix - Weighing (TD)	27.56	19.18±8.6
	19.60	
	10.37	
Mix - Weighing (RD)	1.87	1.47±0.42
	1.03	
	1.50	
Bakery	12.55	4.69±6.8
	0.55	
	0.98	

Note: SD = standard deviation.

From Table 2, it can be observed that the workstation with the highest concentrations is the Mix – Weighing sector. At this workstation, workers are exposed to different particle size fractions, and both total dust and respirable dust samples were collected. The analysis showed that workers are more highly exposed to total dust, with a mean concentration of 19.18 mg/m³, and recorded maximum and minimum values of 27.56 mg/m³ and 10.37 mg/m³, respectively.

It should be noted that, according to the data presented in Table 3, all sectors showed concentration values exceeding the recommended OEL of 0.5 mg/m³. The sector with a mean concentration closest to the OEL was Mix – Bagging, with an average of 0.84 mg/m³. However, variability was observed in the results, with the highest value reaching 1.17 mg/m³ on a day with higher bagging activity, followed by 1.04 mg/m³ on a day with longer breaks and lower activity, while the lowest value (0.32 mg/m³) was recorded on a day when it was observed that the worker operated at a slower pace. The Bakery sector generally presented values close to the recommended limit. Nevertheless, a value substantially higher than the OEL (12.55 mg/m³) was also found, contributing to a mean concentration of 4.69 mg/m³. The remaining values were lower because, during the sampling period, workers did less demanding tasks, such as dough kneading or minor cleaning activities. Regarding the Mix – Weighing sector, for respirable dust, a mean concentration of 1.47 mg/m³ was measured.

To ensure consistency with the statistical framework underlying NP EN 689:2018+AC:2021, exposure data were treated as log-normally distributed. Concentrations were log-transformed prior to analysis, and geometric mean (GM), geometric standard deviation (GSD), and the estimated 95th percentile (P95) of the exposure distribution were calculated for each workstation and dust fraction. In addition, the probability of exceeding the occupational exposure limit (OEL = 0.5 mg/m³) was estimated assuming a log-normal distribution. Given the limited number of samples per workstation, results should be interpreted as indicative of exposure patterns and likelihood of exceedance rather than as a formal compliance assessment according to the full EN 689 decision strategy. The results are presented in Table 3.

Table 3: Log-normal exposure statistics and estimated probability of exceeding the OEL for flour dust by workstation.

Workstation / (Fraction)	GM (mg/m ³)	GSD	P95 (mg/m ³)	Prob. (C >) OEL	Compliance (NP EN 689 approach)
Mix–Bagging (TD)	0.73	2.05	2.37	0.701	Non-compliant (high exceedance probability)
Mix–Weighing (TD)	17.76	1.64	40.17	~1.000	Non-compliant
Mix–Weighing (RD)	1.42	1.35	2.34	0.9997	Non-compliant
Bakery (TD)	1.89	5.28	29.22	0.788	Non-compliant (high variability)

Note: GM = geometric mean; GSD = geometric standard deviation; P95 = estimated 95th percentile assuming log-normal distribution ($P95 = GM \times GSD^{1.645}$); OEL = occupational exposure limit (0.5 mg/m³). Prob. (C > OEL) estimated under the log-normal model. “Compliance” is reported qualitatively (given the small sample size, n=3) and should be interpreted as indicating a high likelihood of exceedance rather than a full EN 689 compliant decision procedure.

The log-normal analysis confirms a high likelihood of OEL exceedance across all assessed workstations. The mix–weighing sector (total dust) presented the highest exposure burden, with an estimated geometric mean of 17.76 mg/m³ and a P95 of 40.17 mg/m³, corresponding to an

almost certain probability of exceeding the OEL. Similarly, respirable dust concentrations in the same sector showed a probability of exceedance above 99%.

Although the mix–bagging sector exhibited lower geometric mean concentrations, the estimated probability of exceeding the OEL remained substantial (70.1%), indicating that exposure control cannot be considered adequate. The bakery workstation showed pronounced variability (GSD = 5.28), reflecting the occurrence of short-term peak exposure events, and an estimated exceedance probability of 78.8%.

Overall, the log-normal modelling approach provides a more appropriate characterization of occupational exposure variability and confirms that flour dust concentrations are consistently above recommended limits, reinforcing the need for enhanced engineering controls and preventive measures.

3.2 EFFECTIVE CONCENTRATION USING PPE (C_e)

Table 4 presents the effective concentration to which workers are exposed, assuming the correct use of PPE. The dust concentration (C_a) used corresponded to the worst-case scenario observed (i.e., the highest concentration measured at each workstation).

Table 4: Effective concentration (C_e) considering masks efficiency.

Dust concentration (C_a)	Sector	Worst scenario (mg/m ³)		OEL ≥	OEL ≥	OEL ≥
Mask efficiency	FFP1 = 0,80	Mix – Bagging TD	1.17			
	FFP2 = 0,94	Mix - Weighing	27.56	FFP1	FFP2	FFP3
	FFP3 = 0,99	– TD				
Effective concentration (C_e)		Mix - Weighing – RD	1.87			
$C_e = C_a \times (1 - \text{mask efficiency})$		Bakery – TD	12.55			

The analysis of table 4 shows that, in the MIX – Bagging sector, the use of FFP1 masks is sufficient to ensure worker protection, since the inhaled fraction remains within the recommended OELs. In the case of the Bakery, under the worst observed scenario, adequate protection requires the use of FFP3 masks in order to ensure the highest level of protection.

Regarding the MIX – Weighing sector, for respirable dust sampling, the data indicate that the use of FFP1 masks is effective. However, for total dust sampling carried out in the same sector, the results show that only the use of FFP3 masks ensures adequate protection.

Based on these observations and in comparison, with the practices observed on site, it can be verified that the MIX – Bagging and MIX – Weighing sectors already correctly implement the use of PPE. In contrast, in the Bakery sector—where workers do not use masks—the implementation of FFP3 masks is recommended on days with higher workloads and FFP2 masks on days with lower work intensity.

4. DISCUSSION

All assessed workstations presented flour dust concentrations exceeding the recommended exposure limit. The highest total dust exposure was observed in the mix–weighing sector, with a mean concentration of 19.18 mg/m³ and values ranging from 10.37 to 27.56 mg/m³, consistent with previous findings in similar industrial settings (Matos & Cardoso, 2024; Martinelli *et al.*, 2020). In the bakery, total dust concentrations showed marked variability, with a mean of 4.69 mg/m³ and a range between 0.55 and 12.55 mg/m³, indicating the occurrence of short-term peak exposure events commonly associated with manual handling and cleaning activities (Moghaddasi *et al.*, 2014). The mix–bagging sector presented the lowest exposure levels; however, concentrations still exceeded the OEL, with a mean of 0.84 mg/m³ and values ranging from 0.32 to 1.17 mg/m³. Respirable dust concentrations were assessed in the mix–weighing sector, yielding a mean value of 1.47 mg/m³, with measured concentrations ranging from 1.03 to 1.87 mg/m³. The observed variability highlights the importance of considering not only mean exposure levels but also maximum values, as peak exposures may significantly increase respiratory health risks, particularly in sensitised workers (Stobnicka & Górny, 2015). Elevated variability (high CV values) and exceedance factors substantially above the occupational exposure limit confirm the presence of consistently high exposure levels, especially in the mix–weighing workstation, emphasizing the need for improved exposure control strategies. Based on the worst-case exposure scenarios (maximum measured concentrations in each workstation), effective inhaled concentrations were calculated considering the use of FFP1, FFP2, and FFP3 respiratory protective masks, applying their respective filtration efficiency factors. In the mix–weighing sector, effective concentrations reached 5.51 mg/m³ with FFP1 masks, 0.37 mg/m³ with FFP2 masks, and 0.23 mg/m³ with FFP3 masks. In the bakery, effective concentrations were 1.65 mg/m³, 0.11 mg/m³, and 0.07 mg/m³ for FFP1, FFP2, and FFP3 masks, respectively. In the mix–workstation sector, lower effective concentrations were observed (0.28 mg/m³, 0.13 mg/m³, and 0.01 mg/m³, respectively). These results demonstrate that FFP1 masks are insufficient to ensure safe exposure levels, particularly in the mix–weighing and bakery sectors where effective concentrations remained well above the occupational exposure limit. Although FFP2 masks provided partial protection, they did not consistently guarantee compliance under peak exposure conditions. Only FFP3 masks consistently reduced effective concentrations below occupational exposure limits (Matos & Cardoso, 2024). Although respiratory protective equipment was used in some sectors, the results emphasize the need for correct selection and use of respiratory protective equipment, combined with collective preventive measures such as local exhaust ventilation, to effectively control flour dust exposure and prevent occupational respiratory diseases.

5. LIMITATIONS OF THE STUDY

The number of personal measurements collected per workstation was limited, which restricts the statistical power and precludes a full formal compliance assessment according to the complete NP EN 689 decision strategy. Although log-normal modelling was applied in accordance with the statistical assumptions of the standard, the limited dataset should be interpreted as indicative of exposure magnitude and exceedance likelihood rather than definitive compliance classification. Additionally, respirable dust was assessed only in the mix–weighing sector, and no specific OEL exists for respirable flour dust. Therefore, comparisons with the established limit value should be interpreted cautiously. Finally, the chemical composition of flour additives handled in the mix–

weighing sector was not specifically characterized. As additive particles may present distinct toxicological or sensitizing properties, future studies should incorporate chemical and allergenic characterization to provide a more comprehensive exposure and risk assessment.

6. CONCLUSIONS

This study demonstrates that workers in the milling industry are exposed to flour dust concentrations well above recommended occupational limits, particularly in additives weighing and bakery activities. The findings highlight the importance of regular exposure monitoring, improved ventilation and extraction systems, task reorganization, regular cleaning and changing of working and protective clothes should be considered, proper facilities to wash hands (or take a shower) when leaving the workplace should be provided, education and training of workers and appropriate use of personal protective equipment (should be used as the last possible prevention measure). Addressing both average exposure levels and short-term peak concentrations is essential to reduce respiratory health risks and improve occupational health in milling environments.

Future research should broaden exposure assessment approaches by incorporating the analysis of microbiological and allergenic components associated with flour dust, including microbial contamination, bioaerosol load, allergen characterization, and potential mycotoxin presence. Integrating these parameters with classic occupational exposure may provide a more comprehensive evaluation of occupational health risks and support the development of more effective preventive and risk-management strategies in milling workplaces.

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