

EXPOSURE TO ULTRAFINE PARTICLES IN THE FOOD INDUSTRY

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ABSTRACT

Background: The air quality is essential to human health. In industrial environments, monitoring the environmental conditions of workplaces is particularly important. Ultrafine particles are particularly concerning due to their ability to penetrate the respiratory system and reach other organs through the bloodstream associated with various adverse effects. **Objectives:** The aim of this study was to assess workers' exposure to ultrafine particles and other atmospheric pollutants such as PM_{2.5}, PM₁₀, CO₂, and CO, temperature, and relative humidity, at different workstations in a food industry. **Results:** The results showed statistically significant differences between sectors and between shifts. The box forming machines had the highest average concentrations of ultrafine particles, not exceeding the recommended values considered high, while the agricultural department recorded higher levels of PM, considerably exceeding the recommended values. The correlations observed between UFP, HR, and temperature confirmed the influence of these environmental parameters. **Conclusions:** This study therefore concluded that the company's workers are exposed to worrying levels of airborne particles, reinforcing the need to implement mitigation strategies, such as adequate ventilation systems and continuous monitoring. These data contribute to recognizing the importance of assessing indoor air quality in industrial environments and implementing effective measures.

Keywords: Air Quality, Ultrafine Particles, Occupational Exposure, Food Industry.

1. INTRODUCTION

Ultrafine particles (UFP) are considered to be particles with a diameter $\leq 0.1 \mu\text{m}$, i.e., 100 nm. As early as 2005, there was considerable evidence on the toxicological effects of UFP, but it was stated that the epidemiological evidence was insufficient to recommend guidelines for UFP. Since then, the body of epidemiological evidence has grown, and two systematic reviews have evaluated scientific papers published between 1997 and 2017 to document the growing number of ongoing studies. The studies demonstrated short-term effects of exposure to PM, including mortality, visits to the doctor, hospital admissions, respiratory symptoms, and effects on pulmonary/systemic inflammation, heart rate variability, and blood pressure, as well as long-term effects on mortality and various types of morbidity. However, various PM size ranges and exposure thresholds were used, which prevented a complete comparison of results between studies. Therefore, a consensus was reached in the GDG (Global Development Group) that the epidemiological evidence was not yet sufficient to formulate PM exposure levels (WHO, 2021).

The distribution of PM is extremely variable in space and time, and PM concentration is considerably influenced by proximity to direct sources, such as motor vehicle traffic, being significantly higher in urban areas with high vehicle density. Meteorological factors such as temperature, solar radiation, and wind speed also affect the formation and dispersion of these particles, giving them great seasonal and daily variability (Sioutas C. *et al* 2005).

Air pollution originates from numerous natural and anthropogenic emission sources, with anthropogenic sources being the most prevalent globally since the beginning of industrialization. The combustion process is the main contributor to air pollution, particularly the combustion of fossil fuels and biomass for energy generation. Sources of outdoor combustion include land, air, and sea transport, industry, and energy production, as well as biomass burning, which includes forest fires and the burning of agricultural and urban waste (WHO, 2016; Soares, J. *et al*, 2023; Gregório, I. *et al*, 2024).

The main objective of the measurements is to ensure that adequate information on pollution levels is available. This information is essential for analyzing the increase in levels in more polluted areas, such as industrial locations, assessing the possible contribution of long-distance transport of air pollutants, informing the analysis of source distribution, and understanding specific pollutants such as PUFs (República, 2017).

Since this work is aimed at the food industry, it is important to regularly study air quality, both for the health of the population around these companies and for the workers who work there, as it is one of the main sources of pollution, as mentioned above.

Nanoparticles enter the human body in various ways, and the full extent of the damage they can cause to the health of exposed workers is still unknown. Although information on worker exposure and its health effects is very limited, it is crucial to implement basic prevention principles as soon as possible (Magalhães, 2024).

Poor indoor air quality has been associated with symptoms such as headaches, fatigue, difficulty concentrating, and irritation of the eyes, nose, throat, and lungs. In addition, some diseases have been linked to poor indoor air quality, such as asthma in more humid environments (OSHA, 2011; T.S.Filipe *et al*, 2013; de Carvalho, J.M. *et al*, 2020; Ana Ferreira *et al*, 2020; Ferreira, A. *et al* 2024a; Ferreira, A. *et al*, 2024b).

Currently, research on the effects of nanoparticles on health and safety is insufficient. Nanoparticles have very different properties compared to macroparticles, which requires a new approach to risk assessment. Studies indicate that once inside the body, nanoparticles can migrate to organs or tissues distant from the site of entry. Due to their biopersistence and bioaccumulation capacity, especially in the lungs, brain, and liver, nanoparticles pose a significant challenge. Although the basis for toxicity is not completely established, it appears that the ability to cause inflammation is one of the main mechanisms of impact (Magalhães, 2024).

Ultrafine particles (UFP), with a diameter of less than 100 nm, are mainly generated by combustion processes, such as vehicle and industrial emissions. Due to their small size, they can easily penetrate the respiratory tract, settling in the central regions of the lungs. This deposition promotes inflammation of the airways and aggravates chronic respiratory diseases such as asthma, bronchitis, and other lung diseases. In addition, UFPs can travel to other organs, affecting systems beyond the respiratory system (Leikauf G. *et al*, 2020).

Even short-term exposure has been shown to be harmful to health. PM has also been linked to neurological diseases and problems in fetal and cognitive development in children. Studies are not yet conclusive, as they are so recent, but they indicate a serious need for monitoring (FCT, 2019).

As mentioned above, airborne particles have been linked to diseases and deaths caused by heart or lung disease. The World Health Organization has gathered sufficient scientific evidence to state that the most harmful exposure to airborne particles is prolonged exposure to ultrafine particles (WHO, 2018).

Table 1: Reference values (WHO Guide Lines)

Pollutant	Recommended values
CO (ppm/8h)	30
CO ₂ (ppm/8h)	1000
T (°C)	22
HR (%)	65
UPF (partículas·cm ³ /24h)	<1000 low 1001-9999 Medium 8 > 10000 High
PM ₁₀ (µg·m ⁻³ /8 h)	10
PM _{2.5} (µg·m ⁻³ /8 h)	3

According to the reference values shown above, we can state that for exposure to CO for 8 hours, the recommended value is 30 ppm. For CO₂, the recommended values are 1000 ppm/8 hours. For PM, there are still no exposure limit values, however, there are values that classify whether the concentration of UFP is low or high over a 24-hour period. When the concentration is low, the values are <1000 particles/cm³, while when there are values >10000 particles/cm³, this indicates that exposure is high and that controlling UFP emission sources should be a priority. For PM₁₀, the exposure limit value for 8 hours is 10 µg/m³, and for PM_{2.5}, the value is 3 µg·m⁻³/8 h.

2. MATERIALS AND METHODS

This study was observational and analytical, with a cross-sectional timeline. In terms of knowledge level, the study falls under level III, descriptive-correlational.

For this research, I used the following guidelines as a basis: WHO global air quality guidelines and Methods for sampling and analysis of chemical pollutants in indoor air.

The study universe will be three locations where the employees of the company under study work in the agricultural area (raw potato reception), in flavoring, and in the box forming machine area. To be included in the research, the sample must meet the following inclusion criterion: the workers must work at the company under study. As exclusion criteria, we assume that workers who do not work at the company under study will be excluded from the study. The sampling method to be applied will be non-probabilistic and, in terms of technique, quota sampling. We will estimate the sample size based on the number of workers present at the company under study. As this is a prevalence (cross-sectional) study, the target population is finite (< 100,000 cases). The agricultural department is where the potatoes are received, sorted, and stored. It measures 243.5 m² and has two gates and two doors to the outside. In this area, the potatoes are received in big bags and in bulk. Both stages involve equipment that removes clods, soil, stems, and stones. The potatoes are then sent to another potato grading system, where they undergo a manual visual

inspection before being sent to the accumulators. These initial stages generate the highest volume of dust and waste, as the raw material comes from the field or warehouses without being washed. The systems that contribute most to dust are bulk unloading. The potatoes pass through the destoner and then the calibrator. In both pieces of equipment, there is a large release of solid dust into the ambient air as the potatoes with dry skin pass through. The area described is partially isolated from the rest of the factory in order to reduce the risk of contamination, however, workers are required to wear protective masks. In this area, there are two gates to the outside where air is renewed, in addition to daily cleaning per shift, which aims to mitigate contamination and for hygiene reasons.

The box forming machine section is an area where machines form boxes for packaging potato chip bags, covering an area of 148 m² and with one gate to the outside. In this area, there are 3 box forming machines that supply production, and this area is also isolated from the rest of the packaging due to the dust released by the cardboard during handling. Here, workers only place the cardboard sheets in the equipment according to the references to be produced and make the adjustments, after which it is an automatic process until the box is formed. There is one functional gate in this area, which usually remains closed, and there are no ventilation systems, which makes air renewal difficult.

The flavoring area covers 1259 m² with one gate and one door to the outside (always closed) and two more interior doors. It is located in the packaging area, but on a platform on the first floor, which occupies approximately half of the packaging area. In this area, the potatoes are flavored as soon as they come out of the fryer, where salt and flavorings (solid, powdered raw materials) are added. The French fries are transported from the fryer to the packaging equipment using impulse movement equipment. At the end of this transport route are the flavoring and packaging stations, divided by process lines, which allow up to 14 different flavors to be produced simultaneously, as each station has a salt or flavoring application system. According to the latest solid dust assessment, the VLE has not been exceeded, so it is not mandatory to wear a protective mask. Nevertheless, as a good practice, it is advisable to wear an FFP2 mask whenever processes involving aromas are being carried out. In addition, as a good practice, the health of workers is monitored through spirometry and consultation with the occupational physician. There are nine air extraction fans in this area. Due to the characteristics of the area (aroma handling), ventilation is provided indirectly through the packaging, using nine air ducts connected to the air cooling equipment, in order to maintain constant renewal of the ambient air.

The measurements will be taken at workstations in the company under study, with the aim of determining whether workers are exposed to ultrafine particles and, if so, identifying the health problems they may develop.

As a strategy to be implemented in data collection, we will take measurements with real-time reading equipment to assess the parameters that determine air quality: CO, CO₂, particulate matter (PM_{2.5} and PM₁₀), ultrafine particles, and meteorological parameters (temperature and relative humidity).

The following instruments were used to conduct the analytical assessment of the selected parameters. For the evaluation of CO, CO₂, VOC, temperature (T), and relative humidity (RH), a VelociCalc device (TSI, model 7575, serial number 7575-2148002) was employed. To measure concentrations of PM_{2.5} and PM₁₀, a Handheld 3016-IAQ device by Lighthouse Worldwide Solutions (serial number 402997233-2) was used. For ultrafine particle concentration, a P-Trak device (TSI, model 8525, serial number 8525-11170007) was used. All the equipment are real time measurements, and direct sampling.

To take measurements, we will take into account the layout of the space, the location of doors or gates and ventilation systems, the existence of sources of contamination, the number of people frequenting the spaces, and other factors that are identified as relevant. Measurements will be taken during the most representative period in terms of occupancy and time of use of the space, with the equipment placed as centrally as possible, at least 3 meters away from walls and other vertical surfaces and at the height of the respiratory tract of the population under study.

Air quality measurements will be taken for at least 30 minutes, with values taken every minute.

The statistical approach of the research project was carried out after the collection and subsequent processing and analysis of the data, with all the information being used to build a database in specialized software (IBM SPSS Statistics version 29.0.1.0).

3. RESULTS

Taking into account the objectives of this study, we intend to present the results obtained in different workplaces (flavoring, box forming, and agricultural departments), where various environmental variables were analyzed. Measurements were taken over three days, covering morning and afternoon shifts.

The results that will be highlighted aim to reveal the behavior of environmental variables as a function of working conditions and the physical environment, allowing the identification of possible risk factors or risk situations in the context of occupational exposure.

Table 2: Comparison of environmental parameters between workplaces

	Flavoring	Box formers	Agro Department	
	M ± DP			P-value
UFP	5358,60 ± 2045,30	6509,48 ± 2764,75	5036,55 ± 1234,44	< 0,001
PM _{2,5}	2815,61 ± 1569,10	7498,93 ± 7447,30	52543,26 ± 53444,66	< 0,001
PM ₁₀	879,96 ± 1690,07	1037,84 ± 1711,95	12885,03 ± 28600,13	< 0,001
CO ₂	440,42 ± 83,46	618,43 ± 514,05	594,01 ± 239,36	< 0,001
CO	0,046 ± 0,18	0,02 ± 0,10	0,0035 ± 0,02	< 0,001
HR (%)	56,49 ± 4,90	48,70 ± 9,70	55,39 ± 9,58	< 0,001
T (C°)	24,18 ± 1,05	25,14 ± 2,87	22,59 ± 2,36	< 0,001

Looking at table 2, we can see that a comparison of environmental variables between the three workplaces—flavoring, box forming, and agricultural department—was performed using the Kruskal-Wallis test.

Statistically significant differences ($p < 0.001$) were found for all variables analyzed:

- The concentration of UFP (ultrafine particles) was higher in the box formers (6509.48 ± 2764.75), followed by aromatization (5358.60 ± 2045.30) and lower in the agricultural department (5036.55 ± 1234.44).
- PM_{2.5} values were significantly higher in the agricultural department (52543.26 ± 53444.66), in contrast to box makers (7498.93 ± 7447.30) and flavoring (2815.61 ± 1569.10).

- For PM₁₀, the agricultural department again showed higher levels (12885.03 ± 28600.13), compared to box formers (1037.84 ± 1711.95) and aromatization (879.96 ± 1690.07).
- For CO₂ levels, the highest values were recorded in the box forming department (618.43 ± 514.05), followed by the agricultural department (594.01 ± 239.36) and were lower in the flavoring department (440.42 ± 83.46).
- CO values were minimal in all locations, although slightly higher in the flavoring department (0.046 ± 0.18) at certain times of the day, particularly in the morning.
- Relative humidity was lower in the box formers (48.70 ± 9.70) compared to flavoring (56.49 ± 4.90) and the agricultural department (55.39 ± 9.58).
- Finally, the temperature was higher in the box formers (25.14 ± 2.87), followed by aromatization (24.18 ± 1.05) and the agro department (22.59 ± 2.36).

These results show that there is a significant difference between workplaces, with the agro department standing out with high levels of PM_{2.5} and PM₁₀ and the box formers with high levels of UFP, temperature, and CO₂ concentrations.

Table 3: Comparison of environmental parameters between work shifts

	Morning	Afternoon	
	M ± DP		P-value
UFP	6158,47 ± 2488,65	4954,40 ± 1488,45	< 0,001
PM _{2,5}	11909,17 ± 49439,39	33011,17 ± 49439,39	< 0,001
PM ₁₀	2354,47 ± 5178,25	8359,29 ± 25548,60	< 0,001
CO ₂	503,87 ± 183,39	613,96 ± 465,11	< 0,001
CO	0,04 ± 0,16	0,00 ± 0,02	< 0,001
HR (%)	54,15 ± 10,10	52,67 ± 7,35	< 0,001
T (C°)	23,47 ± 2,46	24,62 ± 2,32	< 0,001

Analyzing table 3, the Mann-Whitney test was used to investigate possible differences in environmental conditions between work shifts.

The results showed statistically significant differences ($p < 0.001$) for the variables analyzed:

- The average concentration of UFP was lower in the morning shift (6158.47 ± 2488.65) than in the afternoon shift (4954.40 ± 1488.45).
- The averages for PM_{2.5} and PM₁₀ were also higher in the morning shift compared to the afternoon shift.
- The average CO₂ level was higher during the afternoon shift (613.96 ± 465.11), in contrast to the morning shift (503.87 ± 183.39).
- CO was slightly higher on average in the morning shift (0.04 ± 0.16) than in the afternoon shift (0.00 ± 0.02).
- Relative humidity was higher in the morning (54.15 ± 10.10) than in the afternoon (52.67 ± 7.35).

- Finally, the temperature was higher in the afternoon shift (24.62 ± 2.32) compared to the morning shift (23.47 ± 2.46).

These results indicate that the morning shift has a higher load of ultrafine particles, while the afternoon shift shows a higher concentration of CO₂.

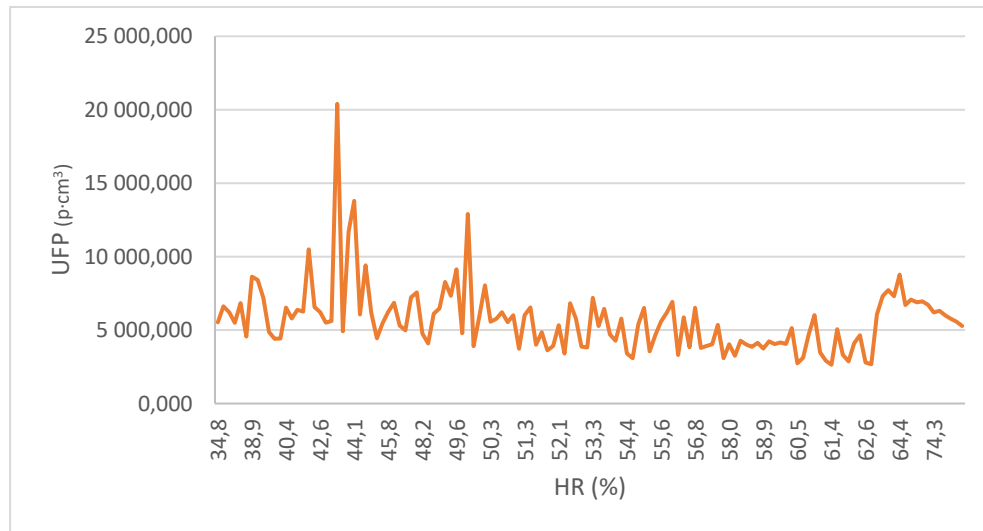


Figure 1: Correlation between UFP and RH (%)

In Figure 1, we can see the average concentrations of ultrafine particles as a function of relative humidity. We can highlight that, in general, the concentration of UFPs is higher at lower relative humidity intervals, namely between 35% and 48%. As relative humidity values increase, ultrafine particle concentrations tend to decrease and stabilize.

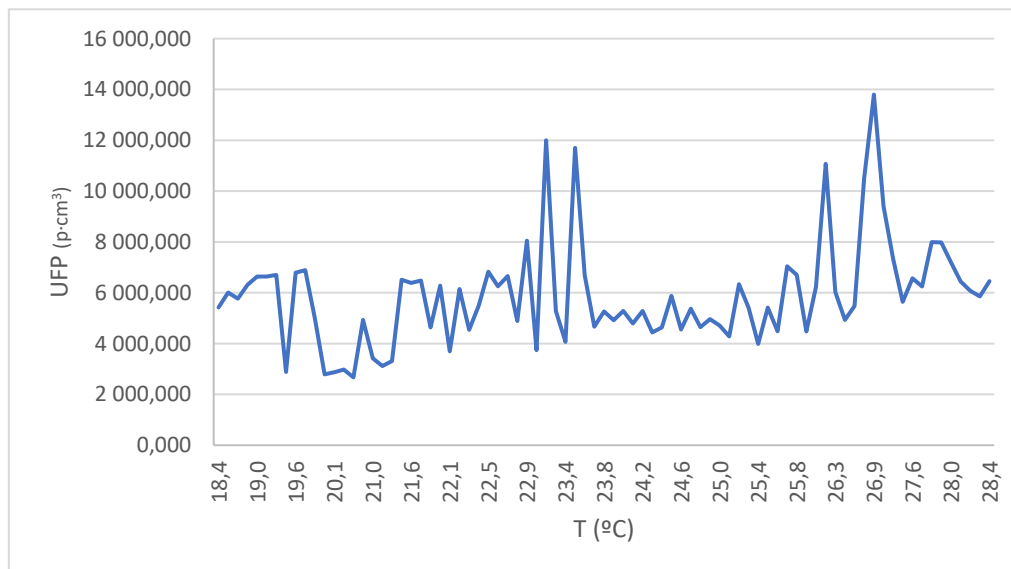


Figure 2: Correlation between UFP and T (°C)

The Figure above shows the relationship between UFP concentration and temperature. It is possible to see an increase in ultrafine particles as the temperature rises. Between 18°C and

22°C, UFP levels remain relatively low and stable; however, from 23°C to 27°C, an increase in UFP concentration can be observed.

Table 4: Comparison between recommended values and values obtained

Pollutant	Recommended values	Values obtained		
		Flavoring	Box formers	Agro Department
CO (ppm/8h)	30	0,046 ± 0,18	0,02 ± 0,10	0,0035 ± 0,02
CO ₂ (ppm/8h)	1000	440,42 ± 83,46	618,43 ± 514,05	594,01 ± 239,36
T (°C)	22	24,18 ± 1,05	25,14 ± 2,87	22,59 ± 2,36
HR (%)	65	56,49 ± 4,90	48,70 ± 9,70	55,39 ± 9,58
UPF (partículas·cm ³ /24h)	<1000 Baixo 1001-9999 Médio > 10000 Alto	5358,60 ± 2045,30	6509,48 ± 2764,75	5036,55±1234,44
PM ₁₀ (µg·m ⁻³ /8 h)	10	879,96 ± 1690,07	1037,84 ± 1711,95	12885,03 ± 28600,13
PM _{2,5} (µg·m ⁻³ /8 h)	3	2815,61 ± 1569,10	7498,93 ± 7447,30	52543,26 ± 53444,66

As mentioned above, there are still no exposure limit values for UFPs, but when the concentration is low, the values are <1000 particles/cm³, whereas when there are values >10000 particles/cm³, this indicates that exposure is high. According to Table 4, we can say that the UFP values obtained in each sector show that, although none of the locations exceeded the high exposure limit, all measurements in the sectors were moderate values.

For PM_{2.5} and PM₁₀, the values shown in the table exceeded the recommended values, with all locations recording values above the reference values, with the Agricultural Department posing the greatest risk to workers' health.

In the case of CO, RH, and CO₂, the measured values remained below the reference levels and therefore did not present a significant risk factor.

On the other hand, the temperature was above the recommended values, but this was not a cause for concern, given that the highest value exceeded only 3°C.

4. DISCUSSION

Based on the data presented and the analysis performed, it is possible to compile a set of results that can be discussed through research conducted on the subject in question.

As demonstrated in several studies the higher the relative humidity values, the greater the probability of UFP growth, which means that particles will increase in size as they absorb water vapor. This increase in size facilitates aggregation between particles, since larger particles are more likely to collide and bind together, and they tend to settle more quickly than individually. Consequently, in environments with lower relative humidity, there is a reduction in ultrafine particles suspended in the air due to agglomeration and deposition. In fact, in this study, according to Figure 1, which shows the correlation between UFPs and RH, there was a decrease in UFPs when there was an increase in relative humidity (Chen S., 2011).

A study was conducted in a steel production industry, where it was observed how temperature influenced the concentration and formation of ultrafine particles. According to the study, high temperatures promote the vaporization of particles, which condense to form large quantities of ultrafine particles, resulting in a high number of particles suspended in the air. On the other hand, lower temperatures favor the coagulation and aggregation of these particles, thus reducing the amount of UFP in the environment. That said, temperature is considered a factor in the variation of ultrafine particles in industrial environments. According to Figure 2, we can see that when there are high temperature values, there is a tendency for high UFP concentrations as well, and vice versa (Pili S., 2024).

According to research by Zender-Świercz (2024), the concentration of PM_{2.5} and PM₁₀ particles was reduced when compared to temperature and moderate when related to relative humidity. In this research, PM₁₀ particle concentrations were higher than PM_{2.5} because PM₁₀ particles are smaller, which makes them more volatile. However, according to the results obtained in all sectors, PM_{2.5} concentrations were higher than PM₁₀ concentrations (Zender-Swiercz E., 2024). According to the study *Health Effects of Fine Particulate Air Pollution: Lines that Connect*, exposure to PM_{2.5} and PM₁₀ particles has been the cause of several health problems. Exposure to these particles can aggravate respiratory diseases, including asthma, chronic bronchitis, and reduced lung function, in addition to increasing the likelihood of developing chronic obstructive pulmonary disease. From a cardiovascular perspective, prolonged exposure is linked to an increased risk of hypertension, arterial disease, myocardial infarction, and arrhythmias (Pope *et al.*, 2006).

PM_{2.5} particles are a concern for occupational health due to their ability to penetrate the respiratory system. According to NIOSH, these particles can reach the pulmonary alveoli, bypassing the body's defenses. Long-term exposure to PM_{2.5} particles has been linked to various health effects such as lung inflammation, stress, DNA damage, and potentially worsening chronic respiratory diseases such as asthma and bronchitis (NIOSH 2010).

According to the article *The Health Effects of Ultrafine Particles*, exposure to UFP has been linked to health problems in the cardiovascular and neurological systems. In the cardiovascular system, these particles contribute to systemic inflammation, endothelial dysfunction, and changes in coagulation mechanisms, which are factors that increase the risk of cardiovascular diseases such as hypertension. At the neurological level, it has been proven that UFPs can reach the brain through the olfactory nerve channel, where they are responsible for functional changes in the brain and nervous system. These effects show that UFPs are harmful to health, affecting not only the respiratory system but also distant organs and systems due to their ability to move throughout the body (Schraufnagel D., 2020).

According to the study *Determination of Occupational Exposure to Ultrafine Particles in Different Sectors of Activity*, which assessed workers' exposure to UFP in different sectors of activity, it was found that the levels of UFP measured in the workplace considerably exceeded the reference values suggested by the WHO. This result shows that workers are often exposed to high concentrations of particles that are harmful to health. This research also indicates that there are no exposure limit values for UFP, which represents a significant gap in current legislation and compromises the protection of workers' health. They also emphasize that workplaces need to be regularly monitored for UFP exposure and that monitoring and control measures need to be implemented. Comparing with the present study, it can be seen that workers at this company are also exposed to high levels of ultrafine particles (Moreira F., 2024).

One of the articles that serves as a guideline for this study highlights the importance of implementing appropriate procedures for monitoring indoor air quality in industrial environments, especially those where production generates particles. In the context of the food industry, where UFPs are significant, rigorous sampling and analysis techniques must be implemented in order to correctly assess the exposure to which workers are exposed. Such monitoring is essential for rigorous control of the environment and finding effective strategies, contributing to the protection of occupational health and improving conditions in the workplace (WHO, 2020).

To control workers' exposure to UFP, PM_{2.5}, and PM₁₀, it is necessary to monitor air quality and implement measures to mitigate the risk, for example, installing adequate ventilation, using exhaust fans, especially in this type of food industry as they work with frying oils at high temperatures, opting for certified equipment, using high-efficiency filters, such as HEPA filters, in heating, ventilation, and air conditioning systems can help reduce indoor air particles, hire a qualified professional to inspect and clean equipment, and finally, change air conditioning and ventilation filters according to the manufacturer's instructions (EPA, 2024).

5. CONCLUSIONS

This study has shown that workers in this food industry are exposed to high levels of airborne particles, namely PM_{2.5} and PM₁₀, which substantially exceed the WHO reference values mentioned above. Although the concentrations of ultrafine particles are below the limit considered to be high exposure, the values recorded show that they are exposed to moderate levels, which in the long term may pose significant risks to workers' health, both respiratory and cardiovascular. As previously presented, analysis of the data showed that the surrounding environment, such as temperature and humidity, directly influences UFP concentrations, and it is therefore essential to implement mitigation measures and strategies for the most critical areas of the company. This research therefore reinforces the importance of continuous monitoring of indoor air quality in industrial environments and contributes to raising awareness of occupational risks associated with exposure to ultrafine particles, especially in sectors such as the food industry, where this type of assessment is infrequent. There is also an urgent need to establish standards and regulatory measures to control pollution sources or use more efficient emission control technologies.

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