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Comprehensive analysis of particulate matter, gaseous pollutants, and microbiological contamination in an international chain supermarket☆

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A R T I C L E I N F O

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A B S T R A C T

Indoor environmental quality is of utmost importance since urban populations spend a large proportion of their life in confined spaces. Supermarkets offer a wide range of products and services that are prone to emitting several air pollutants. This study aimed to perform a comprehensive characterisation of the indoor and outdoor air quality in a multinational supermarket, encompassing not only criteria parameters but also unregulated pollutants of concern. Monitoring included measurements of comfort parameters, CO_2, multiple gaseous pollutants, particulate matter (PM_{10}) and bioburden. PM_{10}, volatile organic compounds (VOCs) and carbonyls were subject to chemical speciation. Globally, the supermarket presented CO_2, VOCs, and PM_{10} values below the limits imposed by international regulations. The PM_{10} concentration in the supermarket was 33.5 ± 23.2 μg/m^3, and the indoor-to-outdoor PM_{10} ratio was 1.76. Carbonaceous constituents represented PM_{10} mass fractions of 21.6% indoors and 15.3% outdoors. Due to the use of stainless-steel utensils, flour and fermentation processes, the bakery proved to be a pollution hotspot, presenting the highest concentrations of PM_{10} (73.1 ± 9.16 μg/m^3), PM_{10}-bound elements (S, Cl, K, Ca, Ti, and Cr) and acetaldehyde (42.7 μg/m^3). The maximum tetrachloroethylene level (130 μg/m^3) was obtained in the cleaning products section. The highest values of colony-forming units of bacteria and fungi were recorded in the bakery, and fruit and vegetable section. The most prevalent fungal species was *Penicillium* sp., corresponding to 56.9% of the total colonies. In addition, other fungal species/sections with toxicological or pathogenic potential were detected (*Aspergillus* sections *Aspergilli*, *Circumdati*, *Flavi*, *Mucor and Fusarium* sp.).

1. Introduction

Supermarkets play a crucial role in urban life by providing a diverse range of products to meet people's needs. These large self-service retail establishments are known for offering a wide variety of food and household items organised in aisles for customer accessibility. Additionally, supermarkets often provide various services such as bakeries, meat shops, fish shops, and restaurants, serving different consumer preferences. Given the significance of supermarkets in modern society, ensuring a high-quality indoor environment is essential for both employees and customers. Monitoring indoor air quality is a key strategy to improve environmental conditions within these spaces. Numerous studies in the literature have highlighted the profound impact of air quality on health and well-being (Kurt et al., 2016; Salthammer et al., 2016). In addition, a good indoor air quality management contributes significantly to creating a healthier and more comfortable environment for shopping, increasing the consumer's motivation to buy (Dang et al., 2021).

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Among the multitude of air pollutants present indoors, particulate matter is highlighted due to its complex nature and implications for human health (Adams et al., 2015). Despite being categorised as a single pollutant, particulate matter is a composition of various elements, encompassing carbon, metals, volatile organic compounds, microorganisms, and ions, each with its own unique characteristics and potential health effects (Mirante et al., 2013; Zeb et al., 2018). Studies have also shown that particulate matter is more relevant to serious cardiorespiratory health problems than other common indoor pollutants. The analysis of mortality risk factors from 1990 to 2015 revealed that in 2015, environmental particulate matter ranked fifth among the leading causes of death, alongside household air pollution. Together, they were estimated to have contributed to approximately 5.7 million to 7.3 million deaths (Cohen et al., 2017). Although many studies have indicated that the burden of disease is mainly due to the fine fraction of particulate matter ($PM_{2.5}$), recent research has demonstrated that coarse particles ($PM_{2.5\text{-}10}$) can exhibit equal or greater inflammatory effects compared to lower fractions (Jarvis et al., 2018; Kataoka et al., 2021; Schins et al., 2002; Tang et al., 2020). Systematic reviews and meta-analysis also revealed strong associations for short- and long-term $PM_{2.5\text{-}10}$ concentrations with mortality and hospital admissions (Adar et al., 2014; Orellano et al., 2020; Tian et al., 2020). Therefore, since PM_{10} encompasses coarse and fine particles, it is a strong indicator of overall toxicity and a more comprehensive measure of potential health impacts.

A simple search on the Scopus database, using the query terms "indoor air quality" AND "supermarket" in the fields of article title, abstract, keywords, and English language, yielded fifteen results until 2023. The Web of Science database, using the same query, yields ten results. This indicates a limited number of studies focusing on indoor air quality in supermarkets, with even fewer specifically addressing the characterisation of particulate matter. Given the limited number of studies with a focus on particulate matter in supermarkets, identifying primary emission sources poses a challenge. However, knowledge from existing research on indoor particulate matter emissions allows sources to be identified based on previous findings. Notably, indoor particulate matter exhibits a strong correlation with various activities conducted within enclosed spaces. Activities involving movement that disturb air currents, such as walking, sweeping, and vacuuming, are often associated with the resuspension of particulate matter, as evidenced by Vicente et al. (2020) and McCormack et al. (2008). Furthermore, most supermarkets have bakeries, which, according to Karjalainen et al. (2018), are establishments with high concentrations of particulate matter due to the use of flour. Infiltration can also contribute significantly to the concentration of particulate matter indoors, as documented by Stephens (2015).

To fill the gap in knowledge about air quality in a workplace frequented by the majority of the population, this study aimed to perform the first comprehensive multipollutant assessment of the air quality within a supermarket belonging to one of the largest chains in Portugal, and with representation in other countries in Europe and Latin America. Monitoring included continuous measurement of comfort parameters, particulate matter, various gaseous pollutants and CO_2 as a proxy for ventilation. Samples of particulate matter with an equivalent aerodynamic diameter of 10 μm or less (PM_{10}) were used for further analysis of carbonaceous and elemental composition. Passive sampling of volatile organic compounds (VOCs) was applied for the speciation of carbonyls and some aliphatic, aromatic, halogenated and terpenic hydrocarbons. In addition, microorganisms were collected in different sectors of the supermarket to assess welfare in this occupational environment.

2. Methodology

2.1. Sampling site

This research was conducted in a supermarket belonging to an international chain and involved the measurement of various indicators of indoor environmental quality. The study was carried out from March to April of 2022 in a supermarket located in the northeast region of Portugal. The supermarket is located in an industrial and commercial area surrounded by a variety of retail stores, including furniture and clothing shops, mechanics, car dealerships, locksmiths, building materials suppliers, electrical and lighting stores, agricultural supply shops, and marble and granite businesses. A local assessment revealed that the area is primarily comprised of commercial buildings, which do not significantly contribute to gaseous emissions (Alves et al., 2020). The area is located 3 km from the city centre, and is primarily accessed by car, with vehicular traffic - especially from employees and shoppers - being the main mode of transportation. Additionally, there is a consistent flow of heavy vehicles transporting products to and from the industrial area.

The supermarket offers a diverse range of products, including fruits and vegetables, household appliances, drinks, household cleaning products, perfumery, cosmetics, canned and packaged foods, frozen foods, snacks, meat and seafood, and pet products. Additionally, the store has a bakery, restaurant, meat and fish shop, florist, and pharmacy. It is open from Monday to Sunday, from 8:00 a.m. to 10:00 p.m. Fig. 1 illustrates the supermarket and its different sections, with the sampling locations being identified.

2.2. Sampling and instrumentation

The evaluation of the supermarket's indoor air quality involved the implementation of various methodologies, where three main components were employed. The first one comprises an air quality assessment system for simultaneous indoor and outdoor monitoring. Indoors, the system was deployed across five distinct areas within the supermarket: the bakery, near the meat shop, pet section, cleaning products section, and warehouse. The selection of these locations was determined following discussions with the establishment's director, considering factors such as homogeneity of the available space, as the variety of products and activities in the various sections of the supermarket are likely to impact air quality differently. Also, the ISO 16000-1:2004 standard (Indoor air -Part 1: General aspects of sampling strategy) states that in large rooms, it may be necessary to divide monitoring into subspaces. The outdoor monitoring system remained stationary throughout the duration of the monitoring campaign and was installed at the rear of the supermarket, next to the loading and unloading area, which is restricted to employees. This location was chosen for its relative isolation from the main entrance and parking lot. Additionally, the area offers enhanced security, allowing for continuous monitoring throughout the entire campaign without the need for constant supervision or the risk of tampering. By placing the equipment here, the influence of direct human activity and vehicle emissions from the parking lot was minimised, creating a more controlled environment for air quality monitoring. This monitoring phase spanned from March 8th to April 29th, 2022.

The indoor system consisted of: i) a 10 L/min low-volume sampler (FAI Instruments, SILENT Sequential Air Sampler) - later replaced by a 38.3 L/min sampler (ECHO PM, Tecora), due to the low concentration of particulate matter - for PM_{10} sampling on 47 mm quartz filters; ii) a particulate matter monitor (DustTrak DRX 8533, TSI); iii) an indoor air quality probe (WolfSense IQ-610, GrayWolf) for measuring $CO_{2,\ CO}$ and total volatile organic compounds (TVOCs); iv) a multigas analyser (Gasera ONE, Gasera) for measuring CH_4, CO_2, and NH_3; and v) a thermal comfort probe (DeltaOhm, HD32.3) for measuring temperature, relative air humidity and air speed. The outdoor system integrated a low volume sampler of 38.3 L/min (ECHO PM, Tecora) for PM_{10} sampling, a particle monitor (DustTrak DRX 8533, TSI) and a thermal comfort probe (DeltaOhm, HD32.1) for monitoring temperature and relative humidity. A total of 34 quartz filters were sampled, 17 outdoors and 17 indoors.

In addition to these systems, data were collected from gas analysers

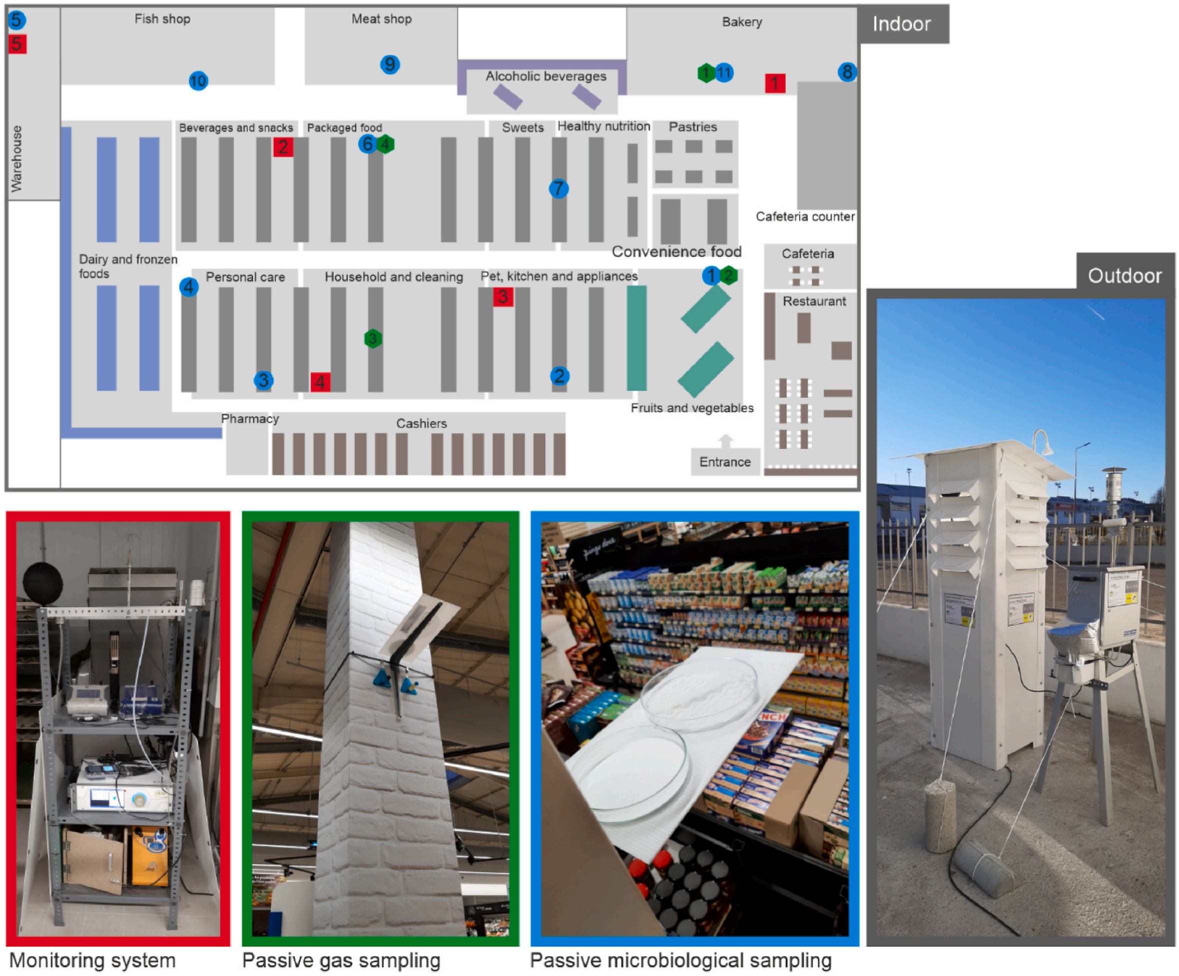

Fig. 1. Supermarket floor plan with sampling locations indicated. Different colours correspond to the different sampling components: red for the air quality and thermal comfort monitoring system, green for the volatile organic compound passive samplers, and blue for the microbiological samplers. On the right side is a picture of the outdoor system.

close to the study site, comprising a NO_X analyser (HORIBA, APNA-370) and an O_3 analyser (HORIBA, APOA-370). Data from a meteorological station were also used, including temperature and relative humidity, rainfall, solar radiation, wind speed and direction. The second component of this work was the passive sampling of gaseous pollutants on diffusive samplers - Radiello codes RAD145 and RAD165 for VOCs and carbonyls, respectively. Four samplers of each were installed between March 23rd and April 3rd, 2022, indoors, and one of each between March 23rd and April 6th, 2022, outdoors. Lastly, the third component of the monitoring was the passive collection of microorganisms at eleven points in the supermarket using electrostatic dust collectors (EDCs) with a diameter of 140 mm (Viegas et al., 2023). These consist of a circular cloth filter, which is transported to the site in a sealed Petri dish. Upon arrival, the Petri dish is opened, exposing the cloth to ambient air. Additionally, 110 mm quartz fibre filters were installed alongside the EDCs to assess the deposition of particulate matter. These filters remained exposed to dust fall from March 21st, 2022, to May 20th, 2022. After the exposure period, the samples were collected and transported to the laboratory, where the EDCs were extracted for subsequent analyses, and the quartz filters were frozen until weighing. Table S1 of the supplementary material summarises the sampling times and locations of each component.

It is worth noting that the different sections of the supermarket were not monitored simultaneously, as doing so would require multiple systems and result in an expensive monitoring campaign. On the other hand, multiple sampling systems would cause additional disturbances, mainly due to noise from sampling pumps. Thus, the monitoring system operated for 5 days in the bakery, 11 in the butcher's shop, 11 in the pet section, and 6 in the cleaning products section. The monitoring periods in each section varied for two reasons: i) in sections with low PM_{10} levels, it was necessary to accumulate mass on the same filter over two consecutive days to ensure the detection of certain metals and the quantification of organic and elemental carbon above the detection limit; ii) a compromise with supermarket manager was needed to obtain representative results for each section while minimising disturbance to customers and employees. In contrast, passive sampling for VOCs and microorganisms was conducted simultaneously across all areas, without distinguishing between occupancy and non-occupancy, as handling the diffusive tubes and EDCs could introduce contamination.

2.3. Analytical procedures

To ensure accurate analysis, quartz fibre filters were weighed on a high-precision microbalance (RADWAG, MYA 5/2Y/F) with an accuracy of 1 μg. Filter mass was calculated by averaging six readings after stabilisation in controlled conditions (20 °C, 50% relative humidity). PM_{10} concentrations determined from this gravimetric method were used for calibration of the particle monitors data (See Fig. S1 of the supplementary material). Since the particulate matter monitors and gravimetric particle samplers were installed side by side, the filters from the gravimetric reference equipment were used to validate and correct the readings of the optical monitors. The particle concentration from each sampled filter was compared with the average concentration measured by the monitor over the same sampling period. The indoor optical monitor was compared with the indoor gravimetric sampler, and the outdoor monitor with the outdoor gravimetric sampler, resulting in a correlation curve for each. As mentioned in Section 2.2, there was a change in the gravimetric sampler during the study, so two correlation curves were constructed for the indoor measurements to account for the different samplers used. Before the campaign, the WolfSense monitor underwent a thorough multipoint calibration. For the CO_2 probe, gas bottles with concentrations of 347 ppm, 803 ppm, and 2484 ppm were used. The CO probe was calibrated using pure nitrogen (N_2) for zeroing and a 7.9 ppm CO standard for span calibration. The TVOC probe was similarly calibrated, first using N_2 to establish the zero point, followed by isobutylene at concentrations of 96.1 ppm and 251 ppm. Additionally, the multi-gas analyser, GaseraOne, was calibrated at the manufacturer's facility.

A thermo-optical transmission technique was employed to quantify the carbonaceous content of the PM_{10} samples. This technique distinguishes between organic carbon (OC) and elemental carbon (EC) by sequentially heating small circular filter sections in an inert nitrogen atmosphere (100%) to volatilise the OC, followed by oxidation in a controlled atmosphere containing 4% oxygen and 96% nitrogen to determine EC. Both OC and EC are quantified in the form of CO_2 in a Fourier-Transform Infrared (FTIR) gas analyser. However, due to the limited sample mass collected on the filters, differentiation between OC and EC proved to be challenging. Consequently, only total carbon (TC) was determined.

X-ray fluorescence (XRF) analysis was used to determine the elemental composition of the quartz fibre filters, specifically targeting elements such as S, Cl, K, Ca, Ti, V, Cr, Mn, Fe, Ni, Cu, Zn, Br, Pb, and Sr. The analysis was conducted using an ARL Quant'X EDXRF spectrometer (Thermo Scientific Inc.). A detailed breakdown of the methodology can be found in Chiari et al. (2018).

The analysis of the diffusive tubes was conducted by Fondazione Salvatore Maugeri (Padova, Italy). To extract and analyse carbonyls, acetonitrile was employed as a desorption solvent followed by analysis using high-performance liquid chromatography (HPLC). For the determination of VOCs, thermal desorption coupled to gas chromatography-mass spectrometry (GC/MS) was used.

EDC samples were extracted with 20 mL of 0.9% NaCl with 0.05% Tween™ 80 by orbital shaking (250 rpm, 30 min, at room temperature) and seeded onto specific media. To identify fungi, malt extract agar (MEA) and dichloran-glycerol agar (DG18) were used, while tryptic soy agar (TSA) and violet red bile agar (VRBA) were the media applied for bacterial assessment.

After incubating the MEA and DG18 plates at 27 °C for 5–7 days for fungal growth, and incubating TSA and VRBA at 30 °C and 35 °C, respectively, for 7 days to identify Gram-negative bacteria, the bioburden densities were calculated. The identification of fungal species was performed microscopically using the tease mount or Scotch tape mount methods, with lactophenol cotton blue stain applied to facilitate observation of fungal structures. Fungal species/sections were identified microscopically through macro and microscopic characteristics, as described by Hoog et al. (2000). The specific procedures for these analyses are outlined in detail by Viegas et al. (2022, 2021).

2.4. Data analyses

Data collected from continuous equipment was used to create temporal profiles. Considering that the supermarket is open every day of the week, between 8:00 a.m. and 10:00 p.m., this period was taken to create daily profiles. Spearman's coefficients were calculated to examine the relationships between variables. The two-sided test with a significance level of 0.05, 0.01 and 0.001 was applied. In addition to the I/O (indoor/outdoor) ratio, the enrichment factor (EF) was also calculated for each element in relation to its concentration in the earth's crust, following Zoller et al. (1974) equations, to assess their origin. Equations are described in the supplementary material. For data processing and statistical analysis, Microsoft Excel and OriginPro from OriginLab were used.

The CO_2 decay method (Batterman, 2017) was applied to measure the ventilation rate of the building using the following equation:

$$AER = \frac{\ln\left((C_1 - C_R)/(C_0 - C_R)\right)}{t} \quad (1)$$

where AER is the air exchange rate in 1/h; C_0 and C_1 are the measured CO_2 concentrations in the period during which the decay of CO_2 is observed (usually at night, when people are not in the store); C_R is the reference CO_2 concentration (in this study, C_R represents the value at the lowest occupancy level); and t is the measurement time in hours between time 0 and 1.

3. Results and discussion

3.1. Meteorological parameters, indoor thermal comfort, gas concentrations and ventilation rate

As detailed in the methodology, in addition to air pollution monitoring, meteorological and thermal comfort parameters were also monitored. Table 1 displays the mean values for each of the supermarket sections studied for the working hours.

The lowest temperature and highest relative humidity values were measured in the warehouse. These results are explained by the fact that the warehouse has no heating, and the door is open for long periods to unload products. As for the other sections, the supermarket has a central air conditioning system, stabilising the temperature above 20 °C. For department stores, the standards CEN-EN 16798–1 and ISO 17772-1 suggest a temperature range between 15 and 23 °C in the winter season and from 22 to 26 °C in the summer season. In relation to relative humidity, it is recommended to maintain the values between 20 and 70%. Thus, it was observed that the supermarket has good thermal comfort conditions. Differences in temperature values between distinct sections of the supermarket can be due to several factors. The distribution of air within a space can be uneven due to the positioning of vents, windows, doors, or HVAC systems. Areas closer to these air sources may feel cooler or warmer depending on how air is distributed, leading to temperature variations across the space. Different parts of a room may have localised heat sources, such as lighting, electronic equipment, or occupants. These heat sources can create warmer zones, especially if concentrated in specific areas of the room. Sunlight can create temperature gradients in indoor spaces. Areas near windows or in direct sunlight tend to be warmer, while shaded areas or those farther from windows are cooler. Variations in wall insulation, the presence of thermal bridges, or the proximity to exterior walls can affect temperature. Some parts of a room may lose heat more quickly than others, resulting in cooler spots. Large furniture or partitions can block air movement, creating isolated areas where temperature is slightly different from the rest of the space due to restricted airflow or trapped heat.

Fig. 2 shows the daily profile of CO_2 in different areas of the supermarket. The meat shop, cleaning, and pet section all displayed similar CO_2 profiles, with levels increasing after supermarket opening at 8:00 a.m. In the cleaning section, the highest concentration was observed at 12:00 p.m., remaining stable until 6:00 p.m., after which it began to decrease due to the reduction in the number of consumers. The meat shop experienced a greater influx of customers in the afternoon, with CO_2 levels increasing after 2:00 p.m. CO_2 concentrations in the warehouse remained low due to the frequent opening of doors for restocking and unloading trucks. The bakery exhibited the most irregular pattern of CO_2 levels. Between 6:00 a.m. and 8:00 a.m., three peaks of CO_2 were observed. These occurred after the bakers opened the door of the

Table 1
Thermal comfort and meteorological parameters for each section.

Section	T in (°C)	T out (°C)	H in (%)	H out (%)	Wind Dir (°)	Wind Sp (m/s)	Prec (mm)	Rad (W/m^2)[a]
Bakery	22.8 ± 0.82	7.47 ± 2.39	32.4 ± 4.17	86.5 ± 9.72	–	–	–	–
Butchery	22.8 ± 0.74	11.7 ± 2.49	32.7 ± 4.07	67.6 ± 14.2	97.8 ± 27.8	3.02 ± 0.81	5.5	188 ± 31.5
Pet	24.2 ± 0.78	10.9 ± 3.77	24.2 ± 5.34	53.2 ± 18.0	86.0 ± 34.9	2.76 ± 0.83	2.4	366 ± 50.0
Cleaning	25.2 ± 0.91	15.7 ± 4.68	30.2 ± 3.07	58.5 ± 20.4	224 ± 39.3	2.14 ± 0.66	19.4	390 ± 42.4
Warehouse	15.9 ± 1.40	12.5 ± 4.19	41.6 ± 7.37	60.6 ± 17.4	246 ± 40.1	2.28 ± 0.73	5.5	349 ± 60.9

[a] Solar radiation was based on daytime, 06:00 a.m. to 7:00 p.m.

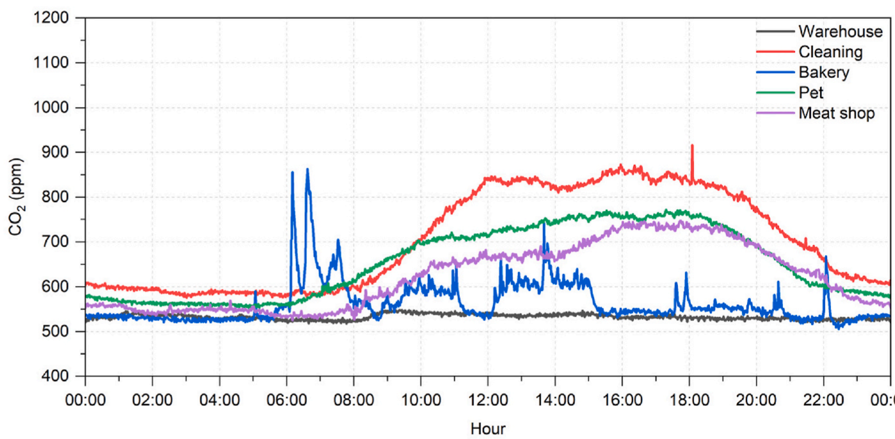

Fig. 2. CO_2 daily profile for the different sections in the supermarket.

refrigerator where they left the bread dough overnight, releasing the accumulated gases. No changes in CO_2 levels were observed during the use of the ovens for baking, as they are equipped with exhaust systems. Due to the exhaust system and less presence of people, the concentrations of CO_2 remained low, and after 3:00 p.m., when the main activities of the bakery were finished, the concentrations remained near 550 ppm.

In addition to possible interday variability, the differences in CO_2 concentrations in different sectors of the supermarket during nighttime, even when the store was closed, can be explained by several factors. Different sectors may have varying levels of ventilation or airflow. Areas with poor ventilation or less air circulation could experience higher CO_2 buildup, as the existing air (which may contain CO_2 from earlier activities) is not adequately refreshed. HVAC systems may not evenly distribute air throughout all areas, especially in larger spaces. Refrigeration and cooling units can affect air circulation patterns. In areas with refrigeration, the cooling process can limit air mixing, causing CO_2 to accumulate in pockets. Additionally, CO_2 is sometimes used as a refrigerant, and in case of minor leaks, concentrations could increase locally. Certain sectors might have stored organic products (e.g., fruits, vegetables) that continue to respire and release small amounts of CO_2 even after the store is closed. Structural elements, such as walls, shelves, or storage racks, can obstruct airflow, trapping air in certain areas. This lack of circulation can cause CO_2 levels to remain higher in certain sectors, while better-ventilated areas experience lower levels. If there was significant foot traffic or machinery operation (e.g., forklifts, cleaning equipment) before closing, CO_2 could still be present in some areas. Poor ventilation in those sectors may not have fully cleared the accumulated CO_2 before the nighttime measurements.

In addition to CO_2, other gaseous pollutants, such as ethanol, methane, and ammonia, were continuously monitored. Methane and ammonia concentrations remained similar in all locations, averaging 2.43 ± 0.48 ppm and 0.92 ± 0.44 ppm, respectively. Ethanol was detected at higher concentrations (3.75 ± 4.97 ppm) in the bakery, likely associated with emissions from yeast fermentation (Dzialo et al., 2017). Observations showed that ethanol concentrations rose after opening the fridge doors where the bread dough was fermenting, as observed for CO_2.

TVOCs and CO concentrations are shown in Fig. S2 of the supplementary material. As documented for CO_2, TVOCs showed the most irregular profile in the bakery. The peak recorded around 6:00 a.m. clearly reflected emissions from biological fermentation. TVOC concentrations correlated well with those of ethanol.

The average ventilation rate for the supermarket was calculated by taking the average value of different indoor areas, excluding the warehouse. The warehouse had high ventilation and was isolated. As a result, the CO_2 levels measured indoors (Fig. 2) were similar to those measured outdoors. The average ventilation rate for the supermarket was found to be 0.54 air changes per hour. Considering the average height of the store building as 8 m, the average ventilation rate is 1.2 $L/s.m^2$ (see Equation S2 of the Supplementary Material). The ASHRAE standard 62.1-2022, Ventilation and Acceptable Indoor Air Quality, sets a minimum ventilation rate for sales buildings of 0.6 $L/s.m^2$. This category is the closest to the store studied, which is characterised by a moderate level of occupant activity, and by having products with a potentially high impact on IAQ.

3.2. PM_{10} concentrations

On average, $PM_{2.5}$ accounted for 81% of PM_{10} concentrations indoors. The PM_{10} levels in each section are shown in Fig. 3. On-site observations, together with measurements, showed that the higher PM_{10} concentrations in the bakery are related to the use of flour, mainly during the kneading process, when it is manually placed on the table for the bakers to press the dough. A study by Marraccini et al. (2008) showed that chronic exposure to flour is correlated to various respiratory diseases, especially the well-documented baker's asthma (Baur et al., 1998). PM_{10} concentrations in the bakery were above the 24-h guideline value of 45 μg/m^3 recommended by the WHO (2021), and above the daily protection threshold of 50 μg/m^3 stipulated by the Portuguese legislation on indoor air quality - Ordinance No. 138-G/2021 (Presidency of the Council of Ministers, 2021).

The occupational exposure limit for flour is usually measured in terms of inhalable dust (≤100 μm) and is higher than that recommended

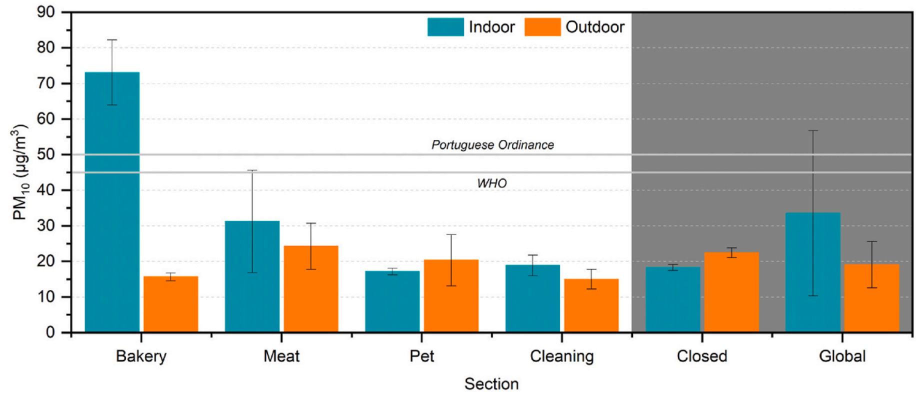

Fig. 3. PM_{10} average concentrations in each section and outdoor values. Health protection values according to the World Health Organisation (WHO, 2021) guidelines and the Portuguese regulation (Ordinance No. 138-G/2021) are marked in the graph. The part in white represents the concentrations in each section, while the grey part depicts the global average (average value considering all the sections) and the average during closed hours. The green bar refers to the concentrations monitored indoor for the different sections and the orange bar the corresponding outdoor concentration.

for PM_{10}. In the Recommendation from the Scientific Committee on Occupational Exposure Limits for Flour Dust (SCOEL, 2008b), it is argued that concentrations of inhalable dust lower than 1 mg/m^3 would protect most labourers from diseases. An article evaluating exposure of baker and pastry apprentices found an average exposure level for PM_{10} of 870 ± 700 μg/m^3 (Mounier-Geyssant et al., 2007), well above the concentrations reported here. However, the concentrations in that study may be higher due to the use of personal samplers. Another study using an environmental sampler (Ielpo et al., 2020) reported an average concentration of 90 ± 18 μg/m^3 for $PM_{2.5}$. Particulate matter concentrations can vary greatly in bakeries, depending on whether the processes are manual or mechanical. Considering the high PM_{10} levels observed in the bakery, resulting from the use of flour, wearing face masks would be an effective measure to safeguard the health of the bakers. Faridi et al. (2020) studying different commercial face masks to reduce particulate matter exposure, documented removal efficiencies from 3.5 to 68.1%. Although it is clear that masks can reduce the inhalation of PM_{10}, it is essential that prior research need to be conducted to prove the effectiveness of each brand. Another study by Shen et al. (2021) showed that another solution to reduce indoor PM_{10} exposure is the use of air purifiers. It should be noted, however, that the supermarket targeted in this study has an HVAC system.

Hwang and Lee (2018) assessed the contribution of different microenvironments to PM_{10} and $PM_{2.5}$ in Seoul, South Korea. The PM_{10} concentrations recorded in a supermarket were 35.4 ± 27.7 μg/m^3 in summer and 33.8 ± 18.2 μg/m^3 in winter. These values are in line with those of the present study (33.5 ± 23.2 μg/m^3). The authors also reported significantly higher winter PM_{10} levels in other environments, such as a restaurant (127 ± 205 μg/m^3), office (45.9 ± 53.6 μg/m^3), school (87.7 ± 73.0 μg/m^3), subway (78.8 ± 48.0 μg/m^3), and bus (78.8 ± 48.0 μg/m^3). In Lisbon, Portugal, Faria et al. (2020) conducted a study on children's exposure to particulate matter in schools and homes. They found higher PM_{10} concentrations in schools, with an average of 65.4 ± 38.9 μg/m^3, compared to homes, in which an average of 18.2 ± 13.3 μg/m^3 was obtained. Faria and co-workers attributed these elevated indoor PM_{10} levels to a combination of human activities, particle resuspension and infiltration from outdoors, most related to traffic emissions. These observations corroborate the findings of the current study, in which external factors such as outdoor air pollution and indoor resuspension of particles were identified as key contributors to IAQ. These comparisons highlight the variability in PM_{10} concentrations across different indoor environments.

Particulate matter daily profiles, based on the DustTrak concentrations after gravimetric correction, are shown in Fig. 4. Considering that the supermarket maintains the same opening hours throughout the week, the creation of daily profiles was based on all data from each section. To make the graph easier to read, Locally Estimated Scatterplot Smoothing (loess) was used to smooth the curves. The highest PM_{10} concentration was observed in the bakery, reaching a peak of 515 μg/m^3. As work in this section starts at 06:00 a.m., a rapid increase in particulate matter concentrations is noticed. Levels only decrease at 10:30 a.m. when the bakers have a lunch break. It is also worth noting that the highest concentrations, with an average of 123 μg/m^3, were recorded between 6:00 a.m. and 8:00 a.m., the most intensive production period. From 3:00 p.m., when production ends, and until 7:00 p.m., a decrease in the concentrations of particulate matter is observed. At this time, the bakers finish organising and cleaning the bakery. A study also using a DustTrak Aerosol Monitor Model 8530 (Rumchev et al., 2021) found that PM_{10} was the predominant fraction of particles, with a concentration of 181 μg/m^3 in the bread dough room, where the pastry was produced.

The meat section showed an inverse trend when compared to the others. An increase in PM_{10} concentrations between 8:00 p.m. and 10:00 p.m. was observed, at the time corresponding to the end of the working day. This phenomenon is possibly related to the cleaning of this section at the end of the shift. During this period, hot water is poured onto the floor and meat benches. This procedure can cause water atomisation and the generation of microdroplets, as happens with humidifiers. It has been documented that washing or humidification procedures with tap water generate mist, increasing the number and concentration of particulate matter, which contains high amounts of minerals originally present in the water (Guo et al., 2021).

At the cleaning and pet sections the concentrations of particulate matter before 08:00 a.m. are related to replenishment. The highest concentrations coincide with periods of greater public influx, during lunch hour and late afternoon. The pet section presented more variations in particulate matter levels than the cleaning section because it was closest to the entrance of the supermarket, where people tended to pass frequently. As some workers begin the shift at 5:00 a.m., mainly for replenishment, an increase in PM_{10} concentrations is observed until the supermarket opens at 08:00 a.m.

The highest concentrations of PM_{10} in the warehouse were recorded in the afternoon, between 1:00 p.m. and 4:00 p.m., a period during which trucks are unloaded. The other peaks at 5:30 p.m. and 7:30 p.m. were from the same source. Outdoors, the particle monitor registered an average concentration of 25.4 μg/m^3, which is slightly higher than that obtained by the gravimetric sampler (19.1 μg/m^3). The concentration begins to rise at 06:00 a.m. when people go to work. A second increase is recorded at 2:00 p.m. due to returning after lunch and again at 7:00 p.m. when most of the retailers close.

Substantial variations in outdoor and indoor PM_{10} concentrations were observed. From day to day, outdoor PM_{10} levels can vary

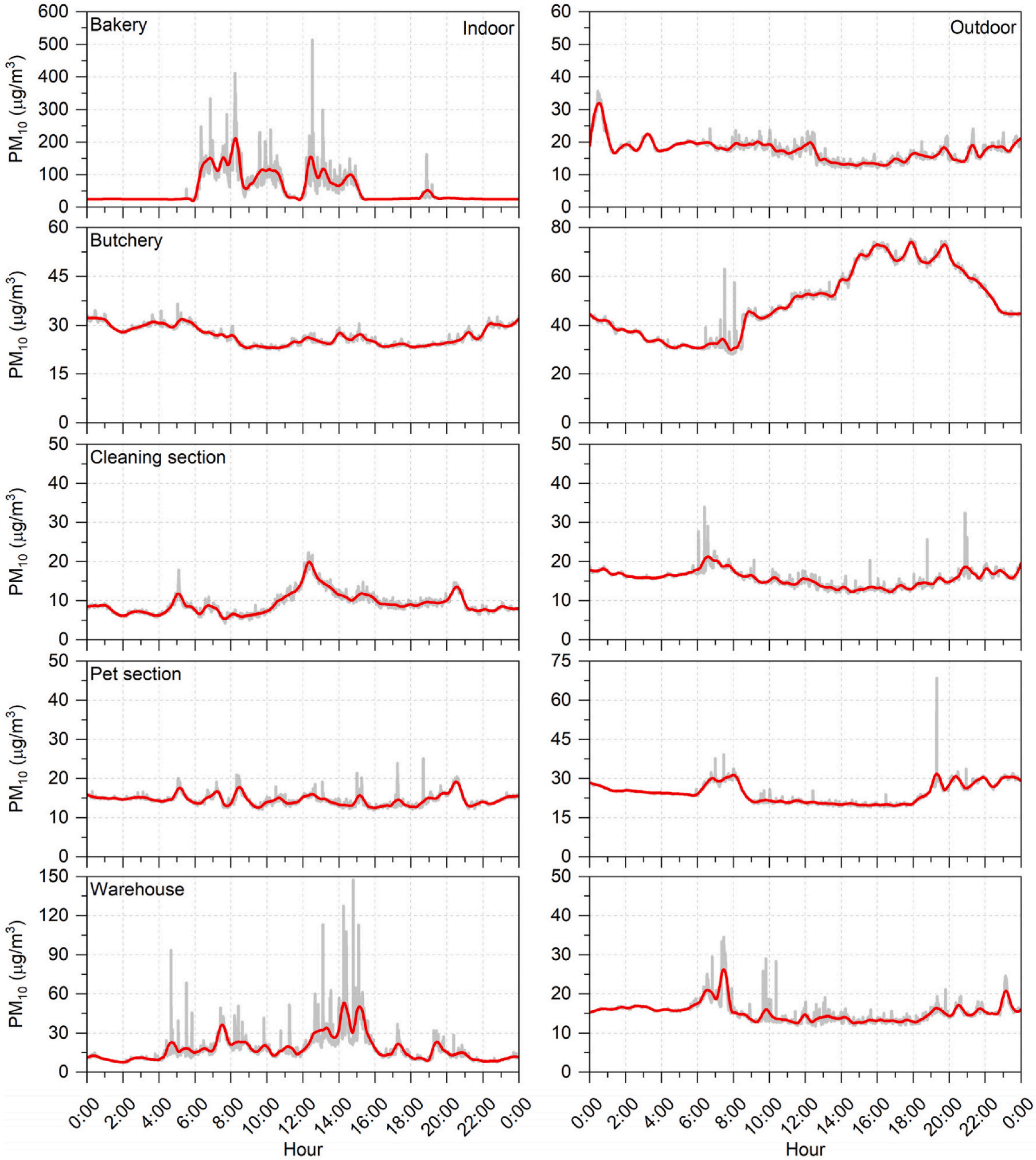

Fig. 4. PM_{10} daily profile for each of the supermarket sections studied and for outdoors, based on TSI DustTrak particle monitors. The grey line corresponds to the average data for each minute and the red line is the fitting using loess. The graphs on the left correspond to the indoor concentrations for each section, while the right side the corresponding outdoor concentrations for the same sections and time of monitoring.

significantly in the same location due to several environmental and anthropogenic factors, which include meteorological conditions, African dust intrusions, traffic patterns and other specific activities. A shift in wind direction can bring pollutants from different sectors or sources. High temperatures can increase the resuspension of particles, while temperature inversions can trap pollutants close to the ground, causing PM_{10} concentrations to rise. High humidity can lead to the formation of larger particles through condensation, affecting PM_{10} levels. Rain can temporarily reduce concentrations by washing particles out of the atmosphere. African dust episodes, such as those observed during the monitoring campaign, significantly raise PM_{10} levels. Variations in vehicle emissions or specific activities throughout the day (e.g., rush hours, nearby construction works, agricultural practices in the surroundings, etc.) can lead to fluctuations in PM_{10} concentrations. These factors interact dynamically, leading to considerable variation in outdoor PM_{10} concentrations, even within a small geographical area over short time periods. PM_{10} levels in a supermarket can show high variability due to several factors related to both indoor and outdoor conditions, as well as human activities within the building. Some key reasons include resuspension of dust and handling of products. High foot traffic from customers and staff can stir up dust particles from the floor, shelves, and other surfaces. This resuspended dust can contribute to fluctuating PM_{10} levels, particularly during peak shopping hours. Activities like restocking shelves, unpacking boxes, and moving products can generate additional particulate matter. Indoor PM_{10} concentration also depend on the air exchange with outdoors, the filtration efficiency of the HVAC system and local airflows. Air distribution inside the supermarket may be uneven, leading to variations in PM_{10} levels in different sections (e.g., near entrances, checkout areas, or air vents). Cleaning activities, especially dry sweeping, can disturb settled dust and increase airborne PM_{10} levels temporarily. Some cleaning processes, like floor polishing or waxing, can generate particulates and chemical aerosols, which may also contribute to PM_{10} levels. The interconnection of these factors can lead to significant variability in PM_{10} values throughout the day or even within different sections of the supermarket.

3.3. Correlations between variables

The correlations between the analysed variables are shown in Fig. 5. To perform the correlations, the entire dataset was used without distinguishing between locations. The data were adjusted to match the longest sampling period, which was associated with the gas analysers that recorded hourly data. The primary variables, indoor PM_{10} and outdoor PM_{10}, were organised in the initial rows.

Correlation coefficients are usually divided into five classes: 0.00–0.10 negligible correlation, 0.10–0.39 weak correlation, 0.40–0.69 moderate correlation, 0.70–0.89 strong correlation, 0.90–1.00 very strong correlation (Schober et al., 2018). Indoor particulate matter showed weak correlations with most of the significant variables. Of these, the highest positive correlation was found with outdoor particulate matter with a Spearman's correlation coefficient of 0.38. This shows that the outdoor environment has low influence on indoor particulate matter concentrations, and that the supermarket has a good air conditioning system. In contrast, the highest moderate negative correlation was with ozone (−0.4). This result was similar to that documented by Chen et al. (2019), who found a negative relationship between ozone and $PM_{2.5}$ during winter.

TVOCs showed a strong correlation (0.81) with ethanol, indicating that a greater share of the total concentration of volatile compounds is due to this alcohol. In addition, CO_2 displayed strong correlations with TVOCs (0.73) and ethanol (0.74), showing that these gaseous compounds increase with the number of people, since the main source of CO_2 is the exhalation of customers and workers. CO_2 strongly correlated (0.86) with temperature, likely because the supermarket's heating system is turned on during working hours.

Outdoors, as expected, the highest correlation was found between NO_X and NO_2 (0.98), reflecting their majority origin in road traffic. PM_{10} out showed moderate correlation (0.43) with NO_X, indicating that part of the particulate matter derives from vehicular emissions.

3.4. Carbonaceous content of PM_{10}

Fig. 6 shows the carbonaceous content in each section. On average, TC accounted for PM_{10} mass fractions of 21.6% indoors, and 15.3% outdoors. Ielpo et al. (2020) reported $PM_{2.5}$ combined mass fractions of organic carbon, elemental carbon and levoglucosan in a bakery of 23.8%. The highest TC concentration (19.3 μg/m^3) was found in the bakery, with an I/O of 5.95. Also, it was the section with the highest TC mass fraction, accounting for 26.7% of the PM_{10} concentrations. The meat, pet, and cleaning sections showed similar concentrations, with TC (I/O ratio) contents of 3.89 (1.17), 4.04 (1.47) and 3.95 (1.84) μg/m^3, respectively. Furthermore, the meat and pet sections presented lower PM_{10} concentrations than those recorded outdoors, but higher TC percentages. TC accounted for PM_{10} mass fractions of 16.4% in the meat section and 24.4% in the pet section, but the corresponding outdoor values were 13.6% and 14.4%.

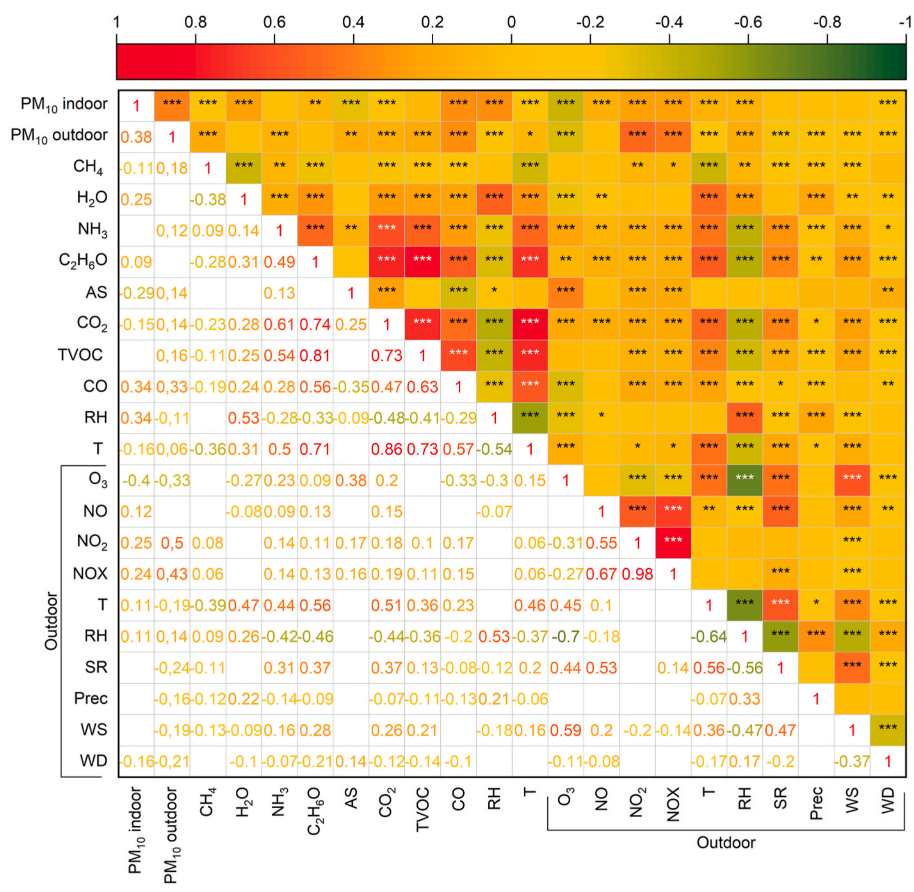

Fig. 5. Spearman correlation matrix for indoor and outdoor variables. The correlations with no significant level were excluded. AS – air speed, RH – relative humidity, T - temperature, SR – solar radiation, Prec – precipitation, WS – wind speed, WD – wind direction.

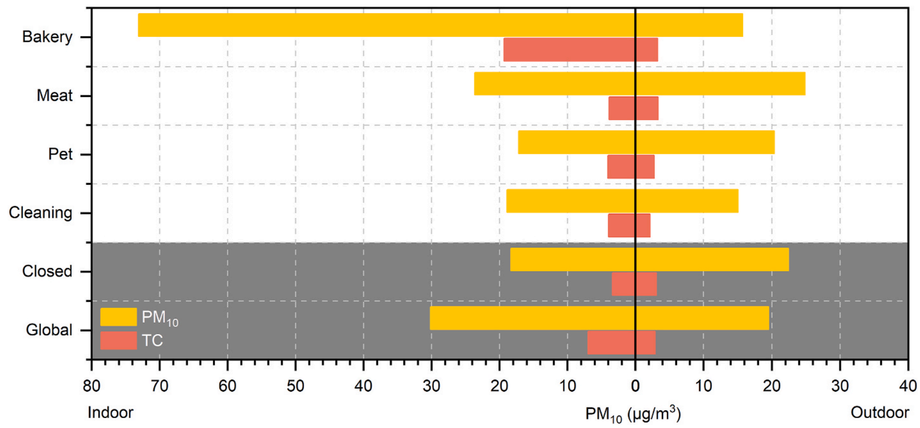

Fig. 6. Carbonaceous content of indoor and outdoor samples. The upper part in white represents the concentrations in each section, while the grey part depicts the global average (average value considering all the sections) and the average during closed hours. The left part of the graph corresponds to the indoor concentrations of each section and the right part of the graph the corresponding outdoor concentrations.

3.5. PM_{10}-bound elements

The elements analysed in this study were divided into major - those with a concentration of more than 100 ng/m^3 – and minor - those with a concentration of less than 100 ng/m^3. The concentrations can be seen in Fig. 7. Of the different environments studied, the bakery stood out for presenting the highest concentrations of S, Cl, K, Ca, Ti, Cr and Mn. An I/O ratio of 2.31 was obtained for sulphur in the bakery, suggesting the contribution from indoor sources. Bread fermentation is a possible source, given that yeasts can generate various products, including alcohols, carbonyls, phenols, esters, and compounds containing sulphur (Dzialo et al., 2017). Cl presented an I/O ratio of 0.67 and showed to be extremely enriched (EF = 84.5 indoors; EF = 192 outdoors). In the other sectors, the levels of S and Cl did not differ much. The main outdoor source of Cl is biomass burning, but long-range transport of sea salt cannot be ruled out (Cipoli et al., 2023). Inside, in addition to the infiltration of particles from outside, the presence of Cl is mainly due to the use of chlorinated cleaning products. Also in the bakery, Ca and K are

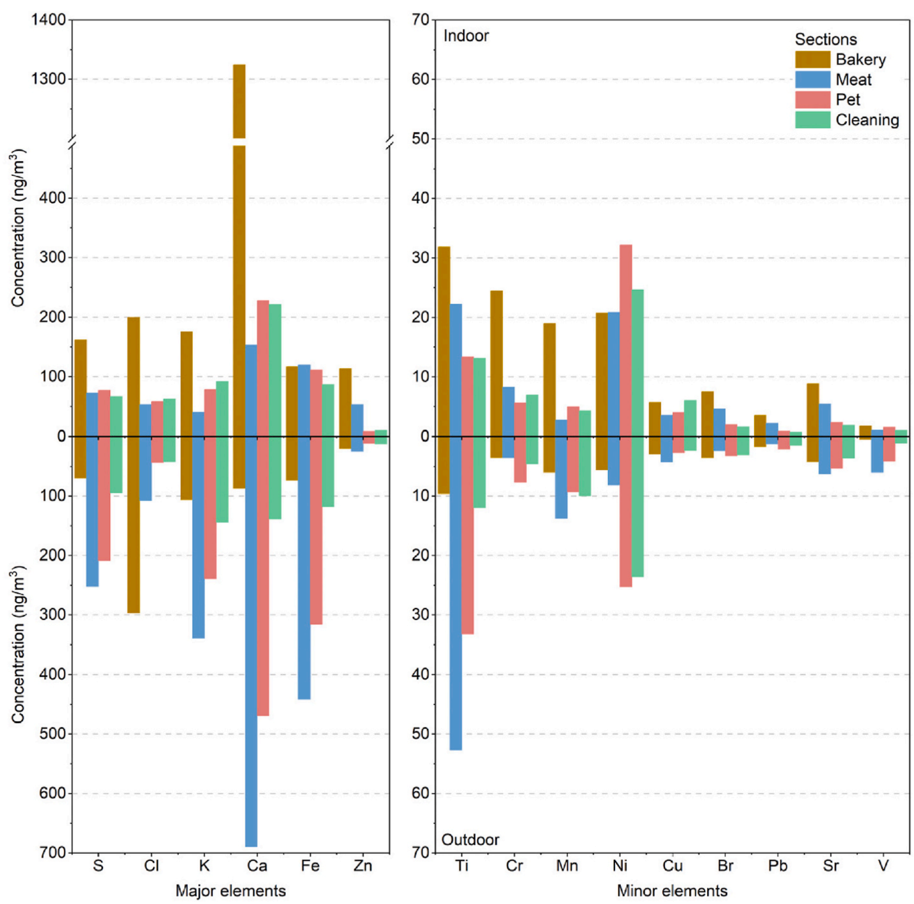

Fig. 7. Concentrations of PM_{10}-bound elements in different supermarket sections and average concentrations. Elements not displayed in the graph were below the method detection limit. The upper part of the graph shows the indoor concentrations for each section and the lower part the corresponding outdoor concentrations for the same sampling time as indoors.

more related to the composition of wheat flour, which may have a high content of these elements (Akin et al., 2020; Fernández-Canto et al., 2022). I/O ratios of 1.66 and 15.2 were obtained for Ca and K, respectively in this section. The Scientific Committee on Occupational Exposure Limits (SCOEL, 2008a) sets a limit for calcium oxide (CaO) of 1 mg/m^3 for 8-h. Converting the Ca concentration in the bakery to CaO yields a value of 1853 ng/m^3, which is far below the occupational exposure limit.

Zn in the bakery had an EF of 580 and an I/O ratio of 5.55, indicating that its concentration is due to some in situ processes. This element can have several emission sources. The most likely is wheat flour, which can be enriched with Zn (Wang et al., 2020). In addition, Zn can be released from galvanised products (John et al., 2007). Similar to calcium, the exposure limit for Zn is in the form of zinc oxide (ZnO). The concentration in the bakery was 114 ng/m^3, which corresponds to 142 ng/m^3 of ZnO. This value is below the exposure limit set by OSHA (2023) of 5 mg/m^3 for respirable dust (particles less than 10 μm in diameter).

Cr, Mn, and Ni are known to be common elements released by stainless steel into the environment (Cediel-Ulloa et al., 2021). Several surfaces and utensils made of stainless steel represent possible sources of these metals in the supermarket, which were mostly found in the bakery. Chromium (Cr) poses the highest potential risk to human health among the different elements of this study, particularly in its hexavalent form (Cr(VI)), which is classified as a Group 1 carcinogen (carcinogenic to humans) by the International Agency for Research on Cancer(IARC, 2012). However, in this study total chromium concentrations were obtained, which include all forms of Cr. The highest Cr concentration was detected in the bakery, where a concentration of 56.5 ng/m^3 was achieved in one of the PM_{10} filters. Sheehan et al. (1992) reported that Cr (VI) represents approximately 21% of the total airborne chromium in indoor samples. Applying this proportion, a concentration of 19.2 ng/m^3 of Cr(VI) was estimated for the bakery. According to the U.S. Environmental Protection Agency's (EPA) Integrated Risk Information System (IRIS) (EPA, 2024), the reference concentration (RfC) for chromium (VI) is set at 30 ng/m^3. While the concentrations observed in this study are below the EPA's RfC, the presence of Cr(VI), even at low levels, highlights a potential concern for long-term exposure.

For outdoor environments, elements such as Ti, Cu, Cr, Ni, Zn, Fe, and Pb are mainly originated in non-exhaust vehicle emissions like tyre and brake wear (Adamiec et al., 2016; Alves et al., 2018). Ti also occurs in most soils and rocks, so part of its contribution to PM_{10} is due to geogenic dust. Ti was moderately enriched in indoor particles (EF = 2.7) and presented an I/O of 3.31. Possible indoor sources include the constant movement of workers, causing resuspension, and also the titanium present in the flour and metal alloys.

3.6. *Volatile organic compounds & carbonyls*

Concentrations of VOCs are displayed in Table 2. Some VOCs, such as 1,4-dichlorobenzene, acrolein, butanal and trichloroethylene, showed indoor and outdoor concentrations lower than the detection limits. As expected, limonene and α-pinene, common terpenes found in cleaning products (Angulo et al., 2021; Ciriminna et al., 2014), presented higher concentrations in the section that sells these products. Acetaldehyde, classified as possible carcinogenic to humans (Group 2 B) by the IARC (International Agency for Research on Cancer) (IARC, 1999), reached its highest level in the bakery, with an I/O ratio of 35. Its source is mostly related to the process of alcoholic fermentation, as shown in other studies (Miligi et al., 2023; Ochs et al., 2015). The acetaldehyde concentration was lower than the United States Office of Environmental Health Hazard Assessment threshold that sets a chronic exposure limit of 140 μg/m^3 averaged over a year (OEHHA, 2020). The same organisation sets a 8-h average exposure limit of 300 μg/m^3. However, it should be taken into account that, in this study, VOC sampling was not subdivided into occupancy and non-occupancy periods. Consequently, the concentrations to which workers and customers are exposed during working hours may be higher than those reported. Benzaldehyde, benzene, ethylbenzene, formaldehyde, isopentanal, m,p-xylene, naphthalene, o-xylene, pentanal, propanal and styrene showed similar concentrations across the sections. Hexanal attained its highest concentration (15.9 μg/m^3) in the bakery, possibly related to lipid oxidation during fermentation (Pico et al., 2020).

Tetrachloroethylene presented an average I/O ratio of 97, meaning that its concentrations are substantially higher indoors. This VOC, also known as tetrachloroethene or perchloroethylene (PERC), is a common solvent used in dry cleaning and a degreaser agent. Also, it is found in stain removers, wood cleaners and fabric finishes (Nijhuis et al., 2010). IARC classified tetrachloroethylene as probably carcinogenic to humans (Group 2 A) (IARC, 2014). Given the uncertainty of the effects on humans, exposure limits can vary widely. In Europe, the Scientific Committee on Occupational Exposure Limits recommended an occupational exposure limit of 138 mg/m^3 for an 8-h working day (SCOEL, 2009). Much more conservative, the WHO set a guideline value of 250 μg/m^3, although the need for a detailed risk assessment of

Table 2
Concentrations of volatile organic compounds, including carbonyls, for each section and average indoor/outdoor ratios.

VOC (μg/m^3)	Bakery	Fruit and vegetables	Cleaning	Meat	Outdoor	Average I/O
1,4-Dichlorobenzene	<0.03	<0.03	<0.03	<0.03	<0.023	–
Acetaldehyde	42.7	12.7	10.5	10.5	1.2	16
Acrolein	<0.29	<0.29	<0.29	<0.29	<0.22	–
α-Pinene	6.1	8.2	18	13	<0.081	140[a]
Benzaldehyde	0.44	0.52	0.54	0.50	0.19	2.6
Benzene	0.54	0.52	0.45	0.47	0.8	0.6
Butanal	<1.0	<1.0	<1.0	<1.0	<0.8	–
Ethylbenzene	0.68	0.86	0.99	0.81	0.22	3.8
Formaldehyde	3.9	4.9	5.0	4.6	1.1	4.2
Hexanal	15.9	13.0	13.7	12.6	<0.5	28[a]
Isopentanal	1.2	0.9	0.9	0.7	0.2	4.6
Limonene	10	15	36	20	0.28	72
m,p-Xylene	2.0	2.6	3.0	2.4	0.66	3.8
Naphthalene	0.23	0.23	0.26	0.26	0.1	2.5
o-Xylene	1.0	1.4	1.5	1.3	0.32	4.1
Pentanal	1.8	2.0	2.0	1.9	<0.4	4.8[a]
Propanal	2.3	2.5	2.7	2.4	0.6	4.1
Styrene	0.31	0.41	0.55	0.46	0.057	7.6
Tetrachloroethylene	60	100	130	99	1	97
Toluene	16	26	24	23	3.1	7.2
Trichloroethylene	<0.024	0.048	0.072	0.024	<0.019	–

[a] I/O ratio considering the detection limit.

tetrachloroethylene has been recognised (WHO, 2000). The concentrations found in this study in all sections were below the WHO guideline, ranging from 60 μg/m^3 in the bakery to 130 μg/m^3 in the cleaning section. However, the values were greater than the indoor concentrations reported by other studies. In dwellings in Paris (France), an average annual concentration of 2.8 μg/m^3 was obtained, ranging from 0.6 to 124 μg/m^3 (Roda et al., 2013). The authors argued that the main factors influencing the concentration of tetrachloroethylene were the proximity to dry cleaning facilities and the use of degreasing agents during manual work and repair. Another study in California (USA) detected a concentration of 1 μg/m^3 in a grocery store, 5.6 μg/m^3 in a furniture shop and 0.2 μg/m^3 in an apparel store (Chan et al., 2015). The suggested hypothesis for the relatively high tetrachloroethylene levels in the present study is that, in the same building where the supermarket is located, there is a laundry offering wet and dry cleaning. Both are connected by a main aisle leading to the building entrance. The lowest concentration was observed in the bakery (60 μg/m^3), which is the sector furthest from the supermarket entrance and the least influenced by emissions from other stores in the same building. Toluene showed higher concentrations in the fruit and vegetables, cleaning, and meat sections.

When compared to the study by Amodio et al. (2014), which investigated VOC concentrations in a shopping mall in Bari, Italy, using diffusive samplers, several differences in pollutant levels were observed. Amodio's study found higher concentrations of VOCs in the storehouses, with α-pinene and camphene as the dominant compounds. The elevated VOC levels in storehouses were attributed to poor air exchange and the large volume of stored materials. In the supermarket environment, Amodio et al. (2014) reported an average toluene concentration of 13.5 μg/m^3, which is lower than the 22.2 μg/m^3 found in this study. Additionally, tetrachloroethylene concentrations in Amodio's study were significantly lower at 4.0 μg/m^3 compared to the much higher average concentration of 97.2 μg/m^3 detected in this study. Limonene was also found at lower levels (3.1 μg/m^3) in the Bari supermarket, whereas the concentrations of benzene (1.8 μg/m^3), ethylbenzene (3.1 μg/m^3), m, p-xylene (3.3 μg/m^3), styrene (0.9 μg/m^3), and 1,4-dichlorobenzene (0.1 μg/m^3) were higher than those recorded in this study.

3.7. Microorganisms in settleable dust

The total fungi colony forming units (CFU) in two culture media (MEA and DG18) can be found in Fig. 8, together with the deposition rates for each section. *Penicillium* was the most common genera, followed by *Cladosporium* and *Trichoderma*. These three genera accounted for 86.2% of total fungi. The highest fungal contamination was observed in the fruit and vegetable section, both in MEA and DG18, with values of 20.6 and 26 CFU/m^2/day, respectively. Also in this section, the most prevalent were *Cladosporium* sp. in MEA and *Penicillium* sp. in DG18, with concentrations of 13.0 and 15.1 CFU/m^2/day, respectively. A study by Jeddi et al. (2014) found a predominance of these species in ready-to-eat salads and fresh-cut vegetables products. Viegas et al. (2023) monitored 21 groceries in Spain and Portugal, also documenting the highest microorganism concentrations in the fruit and vegetable sections. This could be explained by the origin and handling of the products, as well as the high flow of consumers. Detailed information about the concentrations in each section can be found in Table S3 of the supplementary material.

In addition to the most prevalent genera, other fungal species/sections were also observed and should be highlighted due to their toxicological potential (*Aspergillus* sections *Aspergilli*, *Circumdati* and *Flavi*). Furthermore, some species from the WHO priority list of fungal agents with pathogenic potential (WHO, 2022) were also identified, such as Mucorales (*Mucor* genera) and *Fusarium* sp. (*Fusarium verticilloides*), both belonging to the high-priority group on the list. Thus, if there is no safe level of exposure to pathogenic microorganisms, their presence should be null (Górny et al., 2020).

The highest bacteria CFU value was registered in the bakery (Fig. S3 of the supplementary material), where a deposition rate of 29.2 CFU/m^2/day was obtained, corresponding to 45% of the TSA total colonies. For VRBA, bacterial growth was only observed in the samples of the bakery entrance, meat and fish sections. Proper hygiene in these specific areas (e.g., washing followed by disinfection) and ventilation are critical to minimise cross-contamination sources and prevent indoor bacterial contamination (Viegas et al., 2023). The concentration for TSA in the fruit and vegetable section and warehouse were 3.25 and 4.33 CFU/m^2/day, respectively, lower than the values (>10 CFU/m^2/day) reported by Viegas et al. (2023) for the same sections, also using EDCs.

4. Conclusions

In this study, detailed multiparametric monitoring of the indoor and outdoor air quality of a hypermarket was carried out. The assessment not only covered regulated physicochemical and biological parameters, but also the chemical composition of the particulate matter.

Since the supermarket operates with an air conditioning system year-round and experiences no significant changes in daily activities or operations, the results of this study provide a baseline of the supermarket's air quality across all seasons. Nevertheless, numerous factors, both meteorological and related to various indoor and outdoor activities, can introduce variability in pollutant concentrations. Therefore, this study should be considered exploratory, and it is recommended to repeat the monitoring over longer periods and across different seasons.

Among the various supermarket sections examined, the bakery emerged as the most critical due to high particulate matter levels. The findings of this study revealed that bakers are frequently exposed to PM_{10} concentrations above the WHO health protection guideline, being recommended in this section the use of a face mask. However, the choice of the appropriate model should be made with caution as the PM_{10}

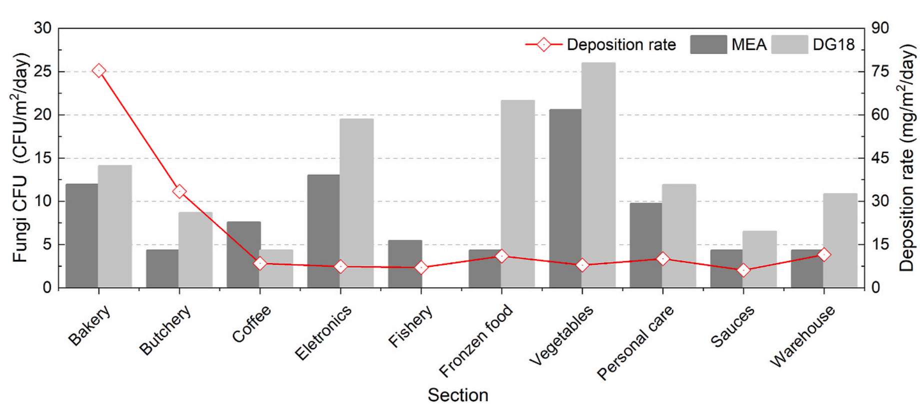

Fig. 8. Fungal colony forming units and dust deposition rates. MEA: malt extract agar, DG18: dichloran glycerol.

removal efficiencies of commercial masks can vary greatly. Prevalent volatile organic compounds, such as acetaldehyde and tetrachloroethylene, were linked to supermarket activities, with potential contributions from emissions originating from neighbouring shops. Also, biological fermentation during bread making, was shown to be one of the sources of hexanal, acetaldehyde and ethanol. Fungal contamination was predominant in the fruit and vegetable section, while the bakery exhibited the highest bacterial levels. These sections should be intervened with proper sanitary measures to avoid cross-contamination and dissemination through all the facilities.

This study is significant as it focuses on a supermarket belonging to a large retail chain known for offering its own product line. The standardisation of products means that the results are not only relevant to this specific location but can also be applied to other branches. Furthermore, the stores share similar design and operational characteristics, including double-door systems at entrances, air conditioning systems, and facilities such as restaurants and bakeries. These similarities establish the findings as a baseline for indoor air quality across different stores.

This work forms part of a broader initiative aimed at understanding air quality in diverse retail stores, with a specific focus on particulate matter. By providing small and large retailers with valuable information on the sources of pollution, this initiative seeks to improve environmental quality in retail spaces. Given that air quality may exhibit some seasonality because of meteorology and variations in the contribution of the various emission sources, it is recommended that similar monitoring campaigns be repeated at other times of the year. It would also be advantageous, with the permission of commercial establishments, to obtain data on occupancy rates and customer attendance, with the aim of correlating these data with the concentrations of certain pollutants.

CRediT authorship contribution statement

Leonardo Furst: Writing – review & editing, Writing – original draft, Methodology, Data curation, Conceptualization. **Yago Cipoli:** Writing – review & editing, Methodology, Data curation. **Nuria Galindo:** Writing – review & editing, Resources, Methodology. **Eduardo Yubero:** Writing – review & editing, Resources, Methodology. **Carla Viegas:** Writing – review & editing, Resources, Methodology, Funding acquisition. **Pedro Pena:** Writing – review & editing, Methodology. **Teresa Nunes:** Writing – review & editing, Resources, Methodology. **Manuel Feliciano:** Writing – review & editing, Supervision, Resources, Methodology, Conceptualization. **Célia Alves:** Writing – review & editing, Supervision, Resources, Project administration, Funding acquisition, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.envpol.2024.125236.

Data availability

Data will be made available on request.

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