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糕餅烘焙作業環境粉塵及化學性有害物暴露調查

Exposure to Flour Dust

and Hazardous Chemicals in Bakeries

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中文摘要

近年來，順應台灣民眾飲食習慣的改變，糕餅烘焙產業之成長極為快速；而依據流行病學研究結果顯示，麵包師傅患有職業性氣喘比例約為 5%-20%，再加上其他眼、鼻等症狀的高發生率，致使其相關的勞工安全衛生議題備受重視。

目前國內對於糕餅烘焙業勞工健康、工作環境、空氣中粉塵及揮發性有機物質的研究資料極為有限，而為了關心與促進此工作場所的勞工健康，本研究藉由：(1) 整理國內連鎖糕餅製作產業資料、國內外有關連鎖糕餅製作作業勞工呼吸道有害物暴露之職業安全衛生相關文獻；(2) 訪視整理連鎖糕餅業，進行勞工安全衛生項目資料調查與整理；(3) 糕餅製作環境空氣中常見或危害較甚物種辨識及定量；及(4) 問卷調查等工作執行，進而了解其危害因子、並提出安全衛生改善或管理建議。

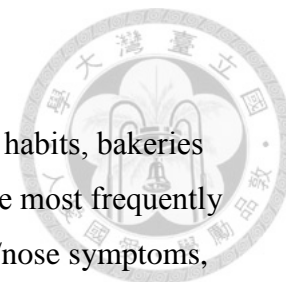
本研究以主動採樣幫浦，搭配 IOM 粉塵採樣器、並聯矽膠採樣管、XAD-2 採樣管進行烘焙業空氣中 9 項有害物質採樣，流量分別設為 2000 mL/min、100 mL/min 及 35 mL/min，採樣時間為 5 小時。採樣後，氣狀樣本經溶劑脫附，使用氣相層析質譜儀進行分析。

本研究除了完成 15 間糕餅烘焙業者的現場訪視之外，另完成 5 家業者的空氣採樣，共計 66 個空氣樣本，182 筆空氣濃度。此外，本研究亦搭配總揮發性有機物、粉塵直讀式儀器等進行採樣；結果顯示可吸入性粉塵平均濃度為 0.27 mg/m³，範圍為 0.01-0.83 mg/m³，有 23% 之採樣點高於 ACGIH 之 TLV-TWA(0.5 mg/m³)，顯示粉塵暴露為烘焙業之重要職業衛生議題。另一方面，丁二酮、2,3-戊二酮、乙醯乙醇、2,3-己二酮、2,3-庚二酮、乙醛及呋喃甲醛等也皆存在於烘焙業空氣中；其中部份樣本之乙醛濃度可達一般室內空氣濃度之 37-83 倍。與非操作區相比，工作區之總揮發性有機物濃度可達 21 倍，顯示工作流程中空氣中有害物的濃度在廠區中有累積的現象。

建議糕餅烘焙業應加強室內空調換氣率，訂立烘焙業職業安全衛生相關之工作規範，注意可吸入性粉塵暴露情形，以降低員工的可能健康風險。

關鍵字：糕餅烘焙業、空氣採樣、可吸入性粉塵、乙醛、人工香精

Abstract



In correspondence with a transition trend of Taiwanese' eating habits, bakeries become a fast growing industry. High prevalent Baker's Asthma, the most frequently reported occupational asthma since the 20th century, as well as eye/nose symptoms, make occupational health a critical issue in the bakeries. Currently, the studies about workers' health, working environment, dust and airborne concentrations of the associated chemicals in the bakeries of Taiwan are limited. Hence, to improve occupational health, the objectives of this research were to: (1) perform a comprehensive collection of information regarding bakery; (2) perform a comprehensive literature survey on occupational safety and health regarding bakery and related workplace; (3) identify hazardous airborne materials and perform air sampling and analysis in the bakery; and (4) perform walk-through surveys at the bakeries and administrate questionnaires for the workers.

In this study, the walk-through surveys have been carried out for 15 different bakeries. Field air samplings were performed at 5 out of the 15 bakeries. The average concentration of inhalable dust was found to be 0.27 mg/m^3 , with a range of $0.01\text{-}0.83 \text{ mg/m}^3$. Among the samples, 23% of them were higher than the ACGIH TLV-TWA (0.5 mg/m^3), in terms of the concentration of inhalable dust. The findings indicate that inhalable dust is an important air pollutant for workers in the bakeries.

In addition, diacetyl, acetoin, 2,3-pentanedione, 2,3-hexanedione, 2,3-heptanedione, furfural, and acetaldehyde were also found in the bakeries with various levels. In one of the samples, it was observed that the concentration of acetaldehyde was 37-83 times higher than the general indoor environment. On the other hand, the concentration of total VOCs in the working area can be 21 times higher than other non-working areas. The results suggest that the hazardous airborne substances might be accumulated in the bakeries.

To lower the levels of exposures, bakeries should improve the ventilation and air exchange rate. It is also important to implement work rules, in terms of occupational safety and health, for the baking industry, and to monitor the exposures of inhalable dust and total VOCs.

Keywords: bakeries, air sampling, inhalable flour dust, acetaldehyde, food flavoring

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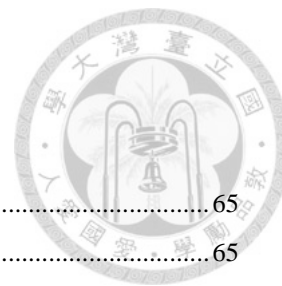


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Chapter 1 Introduction



According to the Nutrition and Health Survey from the Food and Drug

Administration in Taiwan, a transition trend of food source has been found. Compared to 1993~1996, it was indicated that an increasing proportion of people tend to have more convenient food, such as bread, sandwiches, and hamburgers, as the source of carbohydrate in 2005~2008. [1] ; In correspondence with the trend, the annual value of production reached 50 billion in 2010, according to the Food Industry Research and Development Institute.[2]

With case report started from the 20th century, Baker's asthma has been a very frequently reported occupational disease, and exposure to flour dust was recognized as the primary cause to trigger allergic reaction.[3][4][5]

In order to enhance the diversity, smell, and taste of products, raw materials used in baking workplaces became more complicated, including widely used food additives, such as the food flavoring which caused severe occupational health events in the U.S.[6]. Furthermore, the necessary mixing, blending, and heating process increased the concentrations of airborne hazards, including dust and organic volatile compounds, which may pose potential health risks toward workers in the bakeries.

1.1 Baking industry in Taiwan



According to the Taiwan Chain Stores and Franchise Association, the number of brands and the number of baking chain stores increased rapidly in recent 10 years.

(Table 1)[7] As shown in Table 2, the total number of factories and the number of workers grew fastly (i.e., 910 enterprise units and 20,428 workers in 2011 with 40 billion revenues).[8] Moreover, accumulated people had certificates of baking were 228,677 in 2014. [9]

The Taiwan Bakery Association reported that there are 4,588 companies taking part in the business association. Compared to the number of total chain stores in Taiwan, it was obvious that the independent bakeries and online shopping companies may also play an important role in this industry.[10] On the other hand, the Taipei Bakery Association showed that the number of baking retail stores and the combinative coffee shops has exceeded 9000, and 10,000, respectively. [2]

1.2 Health Effects and Potential Hazards in Bakeries

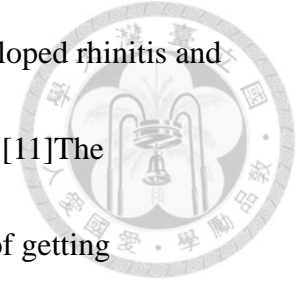


1.2.1 Exposure to Flour Dust

In the baking process, workers need to weigh and sieve flour, sugar, and other baking powder before mixing with eggs, food flavoring, yeast, and butter. At the same time, they prepare different stuffings with butter, food flavoring, and sugar. Dough would then be divided, shaped, and fermented under different temperature and humidity. Finally, workers would bake dough with different temperatures after applying oil on the dough and baking plates.

It was indicated that 5-19% of adults' asthma results from occupational exposure. With case report started from the 20th century, bakers' asthma is one of the most frequently reported occupational asthma. [11] The symptoms include cough, shortness of breath, wheezing, and chest tightness.[4] Significant correlation was reported between asthmatic symptoms and positive skin prick allergy tests to wheat flour, rye flour, and soy bean flour. Therefore, exposure to flour dust and other allergens in bakeries was generally recognized as the primary risk factor.[2][3][12]As a result, both the American Conference of Industrial Hygienists (ACGIH) and the Cal/OSHA had set the Occupational Exposure Limits (OELs) of 0.5 mg/m^3 for the inhalable flour dust. [4]

In Finnish, France, Australia, USA, and Germany, the prevalences for Baker's asthma ranged from 4% to 10%, and were about 14-23% for rhinitis. [2][3][4][13][14]



In a two-year follow-up study toward new apprentices, 41.2% developed rhinitis and the cumulative incidence of asthma-like symptoms reached 20.5%. [11]The epidemiological research in Germany maintained that bakers' risk of getting obstructive lung disease was 50 times higher than the average risk of other professions.

[3]

In 2003, a research that included 70 industrial and traditional bakeries was conducted in Belgium. The average concentration of inhalable flour dust reached 2.10 mg/m³ in traditional bakeries, and 1.06 mg/m³ in industrial bakeries. [15] R Baatjies et al. (2007) pointed out that bakers in charge of making dough and operating mixing machine had the highest exposure to flour dust, which was 0.904 mg/m³. [16] In 2010 and 2013, the survey carried out by the National Institute for Occupational Safety and Health (NIOSH) found out that the median concentration was up to 8.21mg/m³, and workers in high exposure group were more likely to undergo wheezing, runny nose, itchy eyes, and watery eyes. [4][17]In conclusion, the research showed that the concentration of inhalable flour dust ranged from 0.125 to 8.21mg/m³. (Table 3) Furthermore, Burdorf A et al. (1994) reported that in the total mass of inhalable dust, 39% is thoracic subfraction, and 19% is respirable subfraction. [17][18] [20][21] Even though great attention has been raised regarding the exposure to flour dust in many countries, there is no regulation toward exposure to flour dust at workplaces in Taiwan.

[20]



1.2.2 Exposure to Food Flavoring

It was reported elsewhere that over 540 kinds of volatile organic compounds were released naturally during the baking process, and additional food flavoring was used to enhance the smell and aroma. [23][24] M. I. Rincon-Delgadillo et al. (2012) and other baking ingredient stores indicated that flavoring substances were widely added in variable products commonly used in the bakeries, such as sour cream, cottage cheese, and margarine.[25][26] The detected concentration reached 22,000 μ g/g in the products.

[27]

In 1958, the USFDA started the "GRAS" program. Through examining toxicological data, many food additives and flavoring substances were classified as "Generally Recognized as Safe (GRAS)".[28][29][30] However, as pointed out by the US Department of Labor, while the flavorings may be safe when eaten, the health effects via inhalation is unknown since the exposure routes other than ingestion were not considered. [6]

In 2000, NIOSH started the investigations regarding the microwave popcorn manufacturing facilities and food flavoring plants, since several former workers were diagnosed with a severe, rare lung disease, bronchiolitis obliterans. Current workers

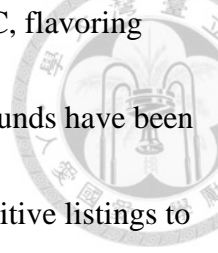
also had fixed airway obstruction which indicated lung function abnormalities.

Diacetyl, which was extensively used to produce a variety of food flavoring, was identified as the most common air contaminants and was considered as the primary risk factor. [6][31][32]

As shown in Table 4, it was found that the concentration of total volatile organic compounds in flavoring manufacturing plant reached 100,000 ppb in 2007. As for diacetyl and acetoin, the concentrations of 0.002-0.235ppm were determined. [33] In 2012, the US OSHA detected diacetyl in 8-hr TWA of 4.31 ppm and short-term concentration of 50.95 ppm, which exceeded the ACGIH TWA (0.01 ppm) as well as the STEL (STEL, 0.02 ppm) in the flavoring industry. [34][35]

Apart from diacetyl, up to 150 volatile organic compounds (VOCs) was detected, including acetoin, 2,3-pentanedione, acetic acid, furfural, and acetaldehyde. [6][33] In animal studies, the above compounds were found to influence important macromolecules such as DNA, structural proteins, and enzymes, especially for furfural and acetaldehyde. [36][37][38][39]

Some flavorings plants started to use less hazardous diacetyl substitute, including diacetyl trimer, 2,3-pentanedione, 2,3-hexanedione, and 2,3-heptanedione. However, in 2012, the US OSHA alerted that the toxicities of the substitutes may be similar to diacetyl because of the similar functional α -diketone group. [6][32]

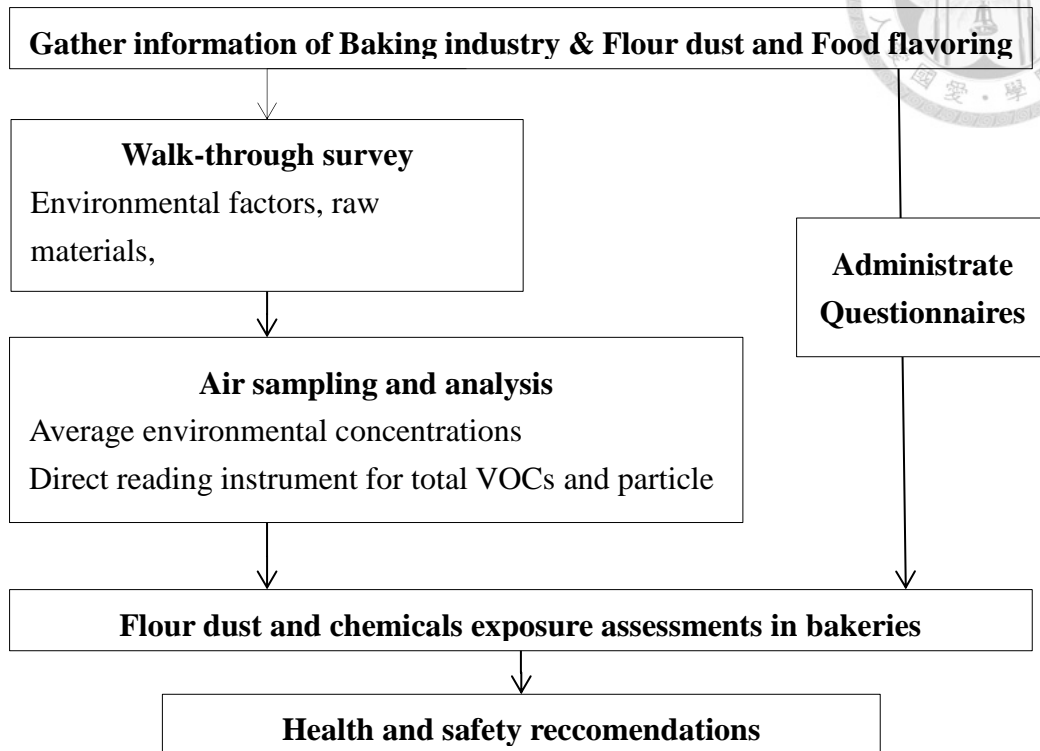


During mixing, blending, and heating process under 200-300°C, flavoring substances volatilized and high air concentrations of various compounds have been observed. [6][32] Food and Drug Administration in Taiwan have positive listings to regulate food additives in Taiwan, but there is no regulation or recommendation toward industry dealing with flavoring substances.[40][41] In addition, baking workplaces in Taiwan tended to be crowded and poorly ventilated, and the long term overexposure to flour dust and flavoring substances may be even risky for the workers.[42]

1.2.3 Research Objective

As mentioned in the research background, the information of chemical and flour dust exposure in bakeries in Taiwan was limited. Therefore, the aims of this study were to: 1) describe the environmental characteristics related to occupational hazards; 2) identify and measure the air concentrations of flour dust and chemicals in bakeries; 3) administrate health questionnaire to collect the information on worker's health status.

1.2.4 Research Framework



Chapter 2 Materials and Methods



2.1 Selecting Bakeries

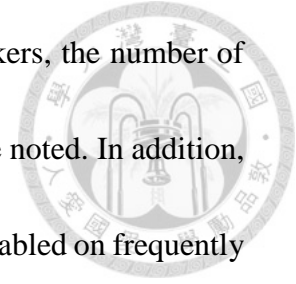
In Taiwan, stores selling baking products can be categorized into baking retail stores, chain stores, combinative coffee shops, convenient stores, supermarkets, and online shopping platforms. The common retail store has its factory/kitchen in the same building. (前店後廠)[43] Some of the chain retail stores are only dealing with selling, packaging, heating or baking of the semifinished products and leave its central factories or kitchens in charge of producing.

Through telephone inquiries and administrative documents, 15 bakeries were included in the study, and air sampling was conducted in 5 of the 15 bakeries, which were scattered in Taipei City, New Taipei City, Taoyuan City, Hsinchu City, Changhua City, and Kaohsiung City.

2.2 Walk-through Survey

During walk-through surveya, field information were recorded based on bakeries owners' and workers' reports, or researcher's observation, including environmental factors, working conditions, raw materials and personal protective equipments used.

For instance, the surface areas of the bakeries, the number of workers, the number of branches, the ventilation system, and the operating procedures were noted. In addition, in order to gather the information of food flavoring, the ingredients labeled on frequently used materials were recorded by cameras.



2.3 Selecting Hazardous Chemicals

According to the literature reported elsewhere, the Flavor and Extract Manufacturers Association (FEMA) identified 34 "high priority" flavoring substances which potentially posed respiratory risk. Among them, diacetyl, acetoin, 2,3-pentanedione, 2,3-hexanedione, and 2,3-heptanedione were chosen to be monitored the airborne concentrations. (Table 5) [32][44]

Research in recent years further recognized that wheat lipid transfer protein, lactoserum, and rye were potential allergens in the bakeries, and it is reported that the concentrations of flour dust corresponded to the amount of allergens. [45][46][47][48] Therefore, inhalable flour dusts were chosen to measure by the IOM multidust sampler.

2.4 Sampling and Analytical Methods



2.4.1 Instruments and reagents

- ✧ Ethanol: 99.9%, A.C.S. Reagent, J.T. Baker.
- ✧ Toluene: 99.9%, Gradient Grade for Liquid Chromatography, Merck.
- ✧ 2,3-Pentanedione, analytical standard, Aldrich.
- ✧ Acetoin, analytical standard, Aldrich.
- ✧ 2,3-Hexanedione, analytical standard, Aldrich.
- ✧ 2,3-Heptanedione, analytical standard, Aldrich.
- ✧ Diacetyl, analytical standard, Aldrich.
- ✧ Acetaldehyde, analytical standard, Aldrich.
- ✧ Furfural, analytical standard, Aldrich.
- ✧ XAD-2 treated with 2-HMP: SKC Cat. No. 226-118.
- ✧ Silica gel tube: SKC Cat. No. 226-183.
- ✧ Sampling pump: GilAir Plus, SENSIDYNE.
- ✧ Gas chromatography column: DB-5MS, length 60 meters, I.D. 0.32 mm, Film 0.25 μ m, J&W Scientific.
- ✧ Gas chromatography column: Rtx-Volatiles, length 60 meters, I.D. 0.32 mm, Film 1.5 μ m, RESTEK.
- ✧ Gas chromatography mass spectrometry: Agilent 6890GC, Agilent.
- ✧ IAQ Monitor: AirBoxx IAQ Monitor, KD Engineering.
- ✧ Flow rate calibrator: BIOS Defender 510-M, DryCal Technology.
- ✧ IOM sampler with MultiDust Foam Disc: SKC Cat. No. 225-70A.

2.4.2 Sampling Methods



Air sampling methods in this study were adopted from both the National Institute for Occupational Safety and Health (NIOSH) and the US OSHA, which were OSHA 1013, NIOSH 2538, NIOSH 2529, and NIOSH 2539. [49][50][51] During sampling, two Gilair plus personal sampling pumps were connected to the IOM sampler and the sorbent tubes, respectively. Silica gel tube and the XAD-2 tube were connected to the pump in parallel.

Diacetyl, acetoin, 2,3-pentanedione, 2,3-hexanedione, and 2,3-heptanedione were sampled by two silica gel tubes connected in series to a sampling pump which was calibrated at a flow rate of 100 mL/min. (Figure 1) [52] In addition, 2-(hydroxymethyl) piperidine treated XAD-2 tubes were used to measure furfural and acetaldehyde under 35 mL/min of flow rate. (Figure 2) Meanwhile, Inhalable flour dust and respirable flour dust were sampled by using IOM sampling heads with Teflon® filters (pore size 1.0 micro with) and MultiDust Foam Discs under 2000 mL/min of flow rate. (Figure 3)

2.4.3 Direct Reading Instruments

In order to gather the concentration profiles of VOCs and particle mass, ppb RAE3000 was used to monitor the total VOCs and AEROCET 531 was used to measure PM₁, PM_{2.5}, PM₇, PM₁₀, and TSP.(Figure 4Figure 5)

2.4.4 Sampling Strategies

At each bakery, air samples were taken at four different sites, including weighing area, baking area, dough making/decorating area, and office/counter. The samplers were placed at bakers' breathing zone height (1.3-1.5 meters). The sampling duration was 5 hours. Two field blanks and more than one lab blanks were prepared for each sampling and analysis. The flow rates were calibrated before and after sampling.

Task-based personal sampling of inhalable flour dust was carried out at one bakery on a worker in charge of weighing flour dust and food flavoring dust, and the task lasted for 42 min, approximately. As shown in Figure 6, the sampler was put on the worker's chest.

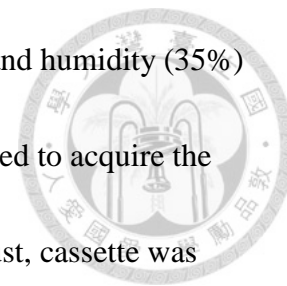
2.4.5 Sample Pretreatments

After sampling, the adsorbent tubes were covered by lids, sealed with parafilm, shipped to laboratory, and then stored in the fridge. Before desorbing, sorbent was poured into a 4 mL vial. Xad-2 sorbent was desorbed by 2 mL toluene followed by 60 mins ultrasonic bath. As for silica gel tube, 2 mL ethanol:water (95:5) was used followed by mechanical shaking for 60 minutes. Finally, supernatant was transferred to a new 1.8 mL vial for analysis and storage. [49][50]

As for the IOM sampler, Teflon® filters and IOM multidust foam discs were



conditioned over 24 hours in a chamber under temperature (20°C) and humidity (35%) control. Pre-weigh and post-weigh the whole cassette were conducted to acquire the mass of inhalable dust. In order to acquire the mass of respirable dust, cassette was weighed for the second run after removing the multidust foam disc. [51]



2.5 Analytical Methods

2.5.1 Instrumental Analysis and calibration curves

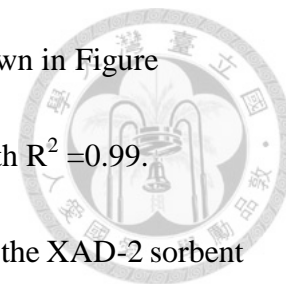
Gas chromatography with mass spectrometry (GC-MS) was applied to analyze the samples. Diacetyl, 2,3-pentanedione, acetoin, 2,3-hexanedione, and 2,3-heptanedione were separated by a RTX-Volatiles column. To analyze acetaldehyde and furfural, a DB-5MS column was used. Detailed information listed in Table 6 including oven program, injection setting and inlet temperature.

The mass spectrometry was operated in electron ionization at 70 eV and quantitative analysis was conducted by selected ion monitoring (SIM) mode. (Table 7) The chromatograms of analytes were shown in Figure 7Figure 8.

2.5.2 Calibration Curve

The chemical standard solutions were used to verify and develop the analytical

method. The calibration curves with concentration ranges were shown in Figure 9, Figure 10, Figure 11, and Figure 12, and good linearity was indicated with $R^2 = 0.99$. Acetaldehyde and furfural standard stock solutions were injected on the XAD-2 sorbent to prepare calibration curve. In addition, because the mass of acetaldehyde in front and back sorbent sections were different, two different calibration curves were performed and applied.



2.5.3 Determination of the mass of analytes in the air

After acquiring the mass of analytes on the sorbent from calibration curve, the air concentrations could be derived from the following calculation.

$$C = (W_f + W_b - B_f - B_b) / V$$

C : the mass of analytes in the air (mg/m^3)

V : air volume sampled (m^3)

W_f : the mass in the sample front sorbent (mg)

W_b : the mass in the sample back sorbent (mg)

B_f : the mass in the average media blank front sorbent (mg)

B_b : the mass in the average media blank back sorbent (mg)

2.5.4 Method Detection Limit (MDL)

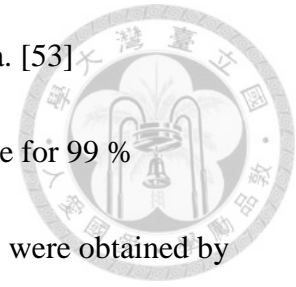
According to the method of US Environmental Protection Agency (EPA), the

method detection limit (MDL) was calculated by the below formula. [53]

$MDL = (\text{standard deviation of replicate analysis}) \times (\text{student's } t \text{ value for } 99 \% \text{ confidence level with } n-1 \text{ degrees of freedom})$; standard deviations were obtained by

repeating the lowest concentrations of calibration curves for seven times.

If under the 100 % desorption efficiency conditions, the detectable air concentrations for in this study were calculated by detectable air concentrations = $MDL \times \text{desorption volume} / \text{air volume sampled}$ (Table 8)



Chapter 3 Results



3.1 Walk-through survey

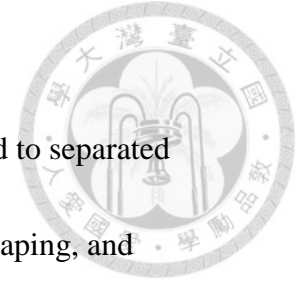
This study visited 15 baking workplaces, including 8 factories, 4 traditional retail stores, 1 retail store with online shopping platform, and 2 chain retail stores. The information of working environment, types of orders, and personal protective equipments used were collected.

3.1.1 Environmental information

Apart from traditional retail stores, a number of the chain retail stores located at commercial area with limited working space. Hence, the stores were only in charge of packaging and selling breads, while there were central kitchens/factories operated at different locations. For the stores far from the factories, half-finished frozen doughs were delivered to the retail stores followed by the decorating/baking tasks.

As shown in Table 9, the size of factories tended to be larger. Most of the workplaces were not equipped with local exhaust ventilation systems. In addition, standing fans with larger flowing rate were equipped at two workplaces, which may lead to the resuspension of flour dust.

3.1.2 Number of Workers and Types of Orders



There were usually more workers in factories and workers tended to separated further into small groups, such as, flour weighing/mixing, dough shaping, and packaging; therefore, workers in factories may repeat the same tasks all day in similar working area, which was a crucial factor to exposure profile.

In addition, the bakers in chain retail stores may expose to high concentration of flavoring substances, because they repeated baking semi-finished dough all day in crowded kitchen. Futhermore, as shown in Table 10, the workload may be variable due to the catering and lunch box orders, which were deeply related to the extra work hours and usage of different types of raw material. Some factories did shift working especially on sepcial festivals such as mother's day

3.1.3 Personal Protection Equipment

The wearing of working suit in baking worplace considered more about protecting the food safty, therefore, workers need to wear clean working shoes, strip cap, and working suits to enter factories. At dough making area, most workers did not wear gloves because it was inconvenient during blending dough by arms. (Table 11)

3.2 Air sampling and analysis



Air sampling was conducted at 5 baking workplace, which located in Taipei City, New Taipei city, Hsinchu City, and Taoyuan City.

3.2.1 Factory 1

This is a well-known brand with 30 branches in Taiwan. The factories is 4000 m², and the sampling sites located in the working area on the second and third floor, as show in Figure 13. The first round of baking tasks was at 4 -10 am in 2F, and the second run baking process finished at 1:00 pm in 3F. There were around 30 workers at the sampling day

The air conditioner was on, and there was ventilation system connected to ovens only on the third floor, the ventilation system is 1.5 m above the tunnel ovens. There were 4 sampling sites at weighing room (A), 2F baking room (B), 3F baking room (C), and office in which sometimes microbial experiments were conducted and was next door to the weighing room (D).

As shown in Table 12, the concentrations of inhalable flour dust (0.55 mg/m³) exceeded TLV-TWA of 0.5 mg/m³, and the other one (0.41 mg/m³) exceeded 1/2 TLV-TWA. Ketones were detected at four sites and with higher concentration in weighing room. Even though it was lower than 1/10 PEL, the concentration of

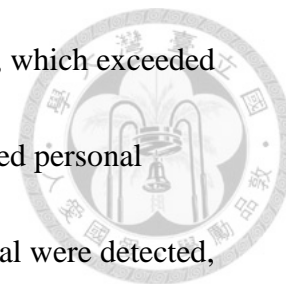
acetaldehyde was much higher, especially in weighing room room. (Table 12) Because the baking task ended before the time we stopped sampling, so if we adjusted the sampling time according to working time, the workers' exposure concentration may be 3-5 times higher than detected.

As for the result of direct-reading instrument, Figure 14 indicated that the total VOCs reached 5000ppb, which was 21 times higher than non-working area (1F). Moreover, the VOCs concentration opposite trends in 2F and 3F revealed that VOCs may accumulate in the working area during baking process; for instance, the concentration in 2F was higher in the morning when the first run of baking task finished.

3.2.2 Factory 2

This was an industrial bakery which provided cakes for supermarkets and convenient stores. The facories was 1653 m²; Shaping and decorating was conducted on the first floor, and baking area was on the second floor. The task started at 8 am, and finished around 6 pm. There were 45 workers on the sampling day. The air conditioner was on, and there was ventilation systems connected to the tunnel ovens. There were 4 sampling sites at weiging room (A), 2F baking tunnel ovens (B), 3F cake decorating area (C), and office (D). (Figure 15)

The highest concentrations of inhalable dust were 0.82 mg/m^3 , which exceeded TLV-TWA of 0.5 mg/m^3 , and the concentration of 42 mins task-based personal sampling was 0.83 mg/m^3 . (Table 13) Both acetaldehyde and furfural were detected, and the highest concentration of acetaldehyde measured around tunnel ovens.



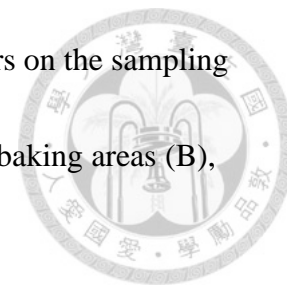
The TVOCs direct reading instrument showed the ventilation system on the second floor needed to be improved. After entering the factory, the TVOCs concentration rose fastly, the highest concentration of TVOCs was 8,678 ppb, 21 times higher than concentration in office. (Figure 16) As shown in Figure 17 Figure 18, the particle mass concentration in flour-weighing room and oil-sprayed room were much higher than the concentration in office; total suspended particles were measured 0.697 and 9.47 mg/m^3 , respectively.

3.2.3 Retail store 3

This is a well-known traditional bakery in central Taiwan, with the surfaces of 331 m^2 . The stores mainly produced traditional cakes and moon cake. The materials were simple and no food flavorings were used during the process. The flexible amount of production depended on the selling condition. It was not the busy season for the store on the sampling day.

All windows and doors were open when air sampling was conducted, and there

were ventilation systems connected to ovens. There were 11 workers on the sampling day, and 4 sampling sites located at weighing and theiving area (A), baking areas (B), working table (C), and counter (D). (Figure 19)



Higher concentration of flour dust was detected around ovens and working table, which were higher than 1/2 TLV-TWA. The concentration of 2,3-heptanedione was higher beside counter, it may result from the cooling and packaging tasks conducted there.(Table 14)

This store is the only one without the detectable acetaldehyde, and coincided on the low direct-reading TVOCs concentrations, which were all lower than 400 ppb. As for total particle mass shown in Figure 20, the concentration peaked at 0.278 mg/m³ during pouring flour dust.

3.2.4 Retail store 4

This was not only a retail store but also a popular online shopping brand. With the surfaces of 116 m², the store was on the first floor and cakes and breads were produced on the basement floor. They normally started to bake at 10 am, and there were 6 workers on the sampling day.

The only ventilation device was a window fan and the basement was crowded. The 4 sampling sites were set up near weighing and mixing area (A), ovens(B), heating

area (C), and warehouse(D). (Figure 21)

The concentrations of inhalable dust at A, B, C sampling sites exceeded 1/2 TLV-TWA, the concentration at baking area reached 0.77 mg/m^3 . Workers did not wear any mask, and due to the poor air circulation in basement, it was also hot in the afternoon. Higher acetaldehyde concentration detected at heating area and warehouse. (Table 15)



3.2.5 Retail store 5

This was a chain store of a famous brand located in Taipei City, with the surfaces of 149 m^2 . Breads was sold on the first floor, and a small proportion of bread was produced on the second floor. The ventilation system were connected to ovens and air circulation was pretty good on the second floor. The 4 sampling sites were set up near working table (A), working table (B), counter (C), and stairs(D). (Figure 22)

The concentrations of inhalable dust were the lowest among 5 bakeries. Acetoin and acetaldehyde were detected at all sampling sites. (table 16) Most of breads were produced by their central factories in New Taipei City, and shipped to this chain store for selling. So there were lots of breads and cakes put besides counter and waited to be packaged and placed on shelves. This was probably the reason why the concentrations of TVOCs would be higher on the first floor than the second floor, which was over

2000ppb, 4-5 times the outdoor concentrations. (Figure 23)



3.3 Health Questionnaire

Questionnaires were designed based on respiratory disease questionnaire created by American Thoracic Society administrated and NIOSH's plants investigation questionnaire in 2009. [52][54] Participants' demographic data, disease history , health status, and on-job symptoms were recorded. (appendix 1)

Highlights of the results

1. The participants' demographic data is listed in Table 17. The percentage of male and female is similar.
2. The average work years in baking industry were 7.15 years, 77.9% workers needed to work at least 10 hours per day. And 92.6% workers had (less than) 6 days vacations per monthes. (Table 17)
3. 26.4% and 8.8% workers had smoking and drinking habit, respectively. 19% workers believed they were less healthy than people at the same age. (Table18)
4. 10.2% had hands/face skin disease, 20.5% had tendinitis/ arthritis, and 36.7% had nose or skin allergy. (Table18)
5. About asthmatic symptoms, 14.7% had a cough over 3 monthes, 23.5% had

shortness of breath, 2.9% still have asthma. (Table18)

6. During the work in past 12 months, 8.8% workers often had eye/nose/throat symptoms, and 10.2% often had Runny nose and stuffy nose.(Table19)
7. In the past 12 monthes, 3-10% workers often/always had skin issues, and 20% for musculoskeletal symptoms. (Table 20)
8. In the past 12 monthes, 23.4% worker thought the workplaces were too hot, and only 45% workers thought the ventilation were good. (Table 20)
9. As shown in Table 21, apart from calculated the prevalence of symptoms, participants were divided into two groups based on their tasks. High exposure group were in charge with weighing flour, mixing ingredients, and cake making, and low exposure group were responsible for shaping dough, packaging, and decorating. After grouping, prevalences of asthma-like symptoms of the two groups were derived, and Pearson's Chi-squared tests were conducted to test the significance of odds ratio in RStudio. (appendix 2) The result indicated that odds ratio = 3.2, p-value = 0.02, which meant the prevalence of asthmatic group in high exposure group was significant higher than that in low exposure group.



Chapter 4 Discussion



4.1 Walk-through survey in 10 bakeries

Environmental factors differed a lot in various kinds of bakeries. All tasks were conducted in the same room in traditional retail stores, so the highest concentrations of flour dust were not necessary near the flour handling sites due to wind flow. Even though industrial bakeries may have better local ventilation systems connected to the ovens, the circulating air conditioning and the large amount of baking tasks may still lead to high concentrations of hazardous chemicals.

As shown in Table 22, since food flavorings are added into diverse raw material in the bakeries, more research will be needed to explore the influence to workers' health, including skin symptoms for workers in charge of shaping and decorating dough.

The usage of personal protection equipment varied from stores to stores, and the purpose of wearing mask was to follow the food safety regulation, but not to protect workers' health. The most commonly used was surgical mask, which may not be practical to protect workers from the exposure to flour dust and chemicals.

For those workers in charge of cooking and controlling oven temperature, the heat exposure and skin burns issues were also critical. Naomi Sharon et al. (2008) indicated that long term exposure to heat during monitoring baking process may result

in the damage of the lens epithelial cells. [55]



4.2 Inhalable flour dust and Hazardous Chemicals

4.2.1 Concentrations of flour dust

Among the 5 bakeries conducted air sampling, 23% of the samples with concentration exceeded the ACGIH TLV-TWA for flour dust of 0.5 mg/m^3 [48] ; 46.2% of the samples exceeded 1/2 TLV-TWA ; 73% of the samples exceeded 1/10 TLV-TWA.

(Table 23) However, there were only 7 out of 15 workplaces requested workers to wear mask. In addition, masks offered by most of the companies were very thin and there was no regulation to remind workers of changing mask periodically.

Considering the frequently occurred skin/nose allergic and respiratory symptoms, exposures to flour dust were the most crucial issue in the industry, in terms of occupational safety and health.

Furthermore, the Figure 25 indicated that the clear job and working area division caused the different patterns of inhalable flour dust among dissimilar bakeries. In factory 1 and factory 2, the high inhalable dust concentrations were only detected at the weighing area.

The concentration ranges of the inhalable flour dust were $0.01\text{-}0.83 \text{ mg/m}^3$ in this research, while $0.125\text{-}93 \text{ mg/m}^3$ was determined from other studies. [4][15][16] The

highest proportion of respirable dust is 36% detected in factory 2, which is higher than 19% indicated in Burdorf A. et al. (1994)[17]

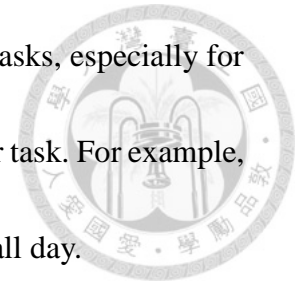


4.2.2 Concentrations of Acetaldehyde and Ketones

As shown in Figure 26, P. Lovreglio et al. (2009) reported the average residential concentration of acetaldehyde was 0.010 mg/m^3 in Italy [56], and S. Uchiyama et al. (2015) found that it was 0.022 mg/m^3 in Japan. [57] The highest concentration of acetaldehyde determined was 0.83 mg/m^3 in this research, which was around 37-83 times higher than the residential concentration. In addition, J.H. Cheng et al. (2015) found that the highest concentration of acetaldehyde was 0.086 mg/m^3 among 6 different types of restaurants. Hence, the highest concentration detected in the bakeries in this study was ten times higher than the concentrations found in the restaurants previously. [58]

Apart from acetaldehyde, ketones were also identified in bakeries. All ketones were detected in low air concentrations, which were similar to the finding reported by two researches conducted in baking mix plants by G. Day et al. in 2009 and 2011. (Table 24) However, according to field observation, workers in industrial bakeries

might still expose to large amount of food flavoring during some tasks, especially for the industrial ones, since every worker was in charge of a particular task. For example, workers in weighing room may expose to food flavoring dust for all day.

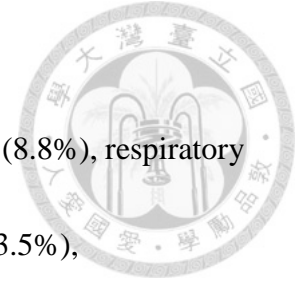


On the other hand, the Figure 27 showed the average concentrations of ketones in working and non-working area. For some ketones were detected in relatively higher concentrations at non-working area, it may resulted from the cooling and packaging tasks conducted beside counter in the retail stores.

4.2.3 direct-reading instruments

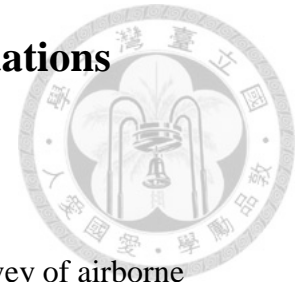
As for the result from direct-reading instruments, the concentration of total volatile organic compounds reached 5000 ppb-8000 ppb, which was 21 times higher than non-working areas, such as the office. With air conditioner running, the TVOCs concentration of 3000 ppb was still detected in the office of factory 1, where no operation was conducted. The concentration of 3000 ppb was 13 times higher than the rooms out of the floor where factory 1 located. The above finding pointed out that the exchange rate of the air conditioner needed to be improved.

4.3 Results of Health Questionnaire



The health questionnaire indicated the high prevalence of eyes (8.8%), respiratory (8-23.5%), allergic symptoms (36.7%), asthmatic symptoms (5.8-23.5%), musculoskeletal (20%), and skin symptoms (3-10%). G.Y. Hur et al. (2007) also reported high prevalence (17%) of upper and lower respiratory symptoms in Korean bakeries. Keeping the same standing posture, repeated action, and heavy lift may be the reason why 20% of the workers usually had musculoskeletal disorders. Some workers expressed that being contact to flour dust, oil-sprayed, and yeast resulted in eyes and skin symptoms, and the denser smell in bakeries was from cooking fume and cheese.

Chapter 5 Conclusions and Recommendations

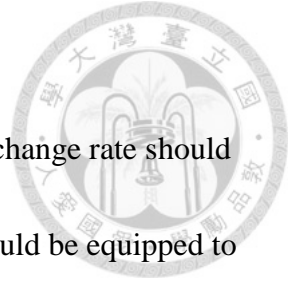


5.1 Conclusions

To the best of our knowledge, this study provided the first survey of airborne hazards in the baking workplaces in Taiwan. The concentration range of inhalable dust was 0.01-0.83 mg/m³, and 23% of the samples collected were higher than the ACGIH TLV-TWA (0.5mg/m³). As to the other chemicals, such as aldehydes and ketones, the concentrations were all well below PEL-TWA. However, the high TVOCs direct-reading concentrations at workplaces indicated that the ventilation system needed to be improved.

Moreover, some repeated tasks in the factories might be risky, especially for workers in weighing room and oil-sprayed area where they exposed to high concentrations of flour dust and food flavoring particle.

The results of questionnaire also stated that the prevalence of on job health symptoms were relatively high, including respiratory, skin, nose, and musculoskeletal symptoms. The exposure of the flour dust was suspected to play an important role for the causes.



5.2 Recommendations

1. To reduce the accumulation of hazardous chemicals, the air exchange rate should be increased, while ventilation systems connected to ovens should be equipped to lower down the temperature of the surrounding area

2. To provide suitable personal protection equipments, while workers with asthma history should be transferred to tasks with lower flour dust exposure

Activated carbon masks and dust masks could be provided at different working areas. Workers with asthma history and respiratory symptoms should avoid tasks in weighing and mixing room, and should be transferred to shaping, decorating, and packaging areas.

3. To cover the basket during weighing, sieving, and pouring flour dust. And weighing flour could be done on the table, since it can reduce airborne flour dust if the tools were closer to the containers. Local exhaust ventilation system is also recommended in the flour weighing room.

4. To improve the efficiency of the local exhaust ventilation system, when cooking and frying are conducted indoors, to prevent the accumulation of the cooking fume

5. Using glove is advised to avoid skin irritation when performing cleaning job with detergents



Appendix

Appendix 1 Health Questionnaires

臺灣糕餅烘焙業者健康問卷調查

主辦單位：勞動部勞動及職業安全衛生研究所

研究單位：國立臺灣大學環境衛生研究所

您好！這份問卷是想了解您工作時的基本健康狀況
為了增進您的健康，以及提供往後烘焙業職場安全衛生的建議
我們希望透過這份問卷了解烘焙業者工作情形、員工健康狀況

感謝您耐心回答下列問題
問卷結果僅供研究用途，結果也會以整體數據而非個人資料呈現
希望透過這個研究，我們能幫助你們工作同時也能保護身體健康

問卷為匿名方式，敬請放心填寫！

若填寫上有任何建議或問題，可註記在題目旁或空白處，

或聯絡 台大環境衛生所 張佩婷 小姐

E-mail:r03844003@ntu.edu.tw

手機:0912206577

非常感謝您的幫忙，願意撥空接受我們的問卷調查！



一、基本資料

1. 年齡: _____
2. 性別: _____
3. 身高: _____公分；體重: _____公斤
4. 學歷: 國小 國中 高中職 大學專科 碩士以上

二、工作型態

1. 工作店家名稱: _____
2. 全職或兼職: 全職 兼職
3. 職別: 烘焙師(傅) 學徒 收銀員 廚房人員 麵包搬運送貨員 其他: _____
4. 您總共在本店/廠工作: _____年_____月
5. 您總共在烘焙業工作: _____年_____月
6. 每週需工作幾天: _____天，或者月休_____天
7. 通常_____點上班~_____點下班，每周約加班_____小時

➤ 每日大約工作內容 (請填數字。若同時進行多個工作，大略填寫主要工作即可)

- 1:秤、篩麵粉,糖粉,發粉 2:使用麵粉攪拌機 3:手揉麵團 4:控制麵包發酵 5:切割、整形麵團 6:西點、蛋糕製作 7:控制烤箱溫度 8:裝飾加料 9:出爐、冷卻 10:包裝、運送出貨 11:結帳 12:炸豬油、烹煮 13:清洗用具、環境

- 08 點之前: _____
08~12 點: _____
下午 1~5 點: _____
下午 5~9 點: _____

三、日常作息及一般健康狀況

1. (1)請問您有**抽菸**的習慣嗎?

- 有 以前有，現在已戒菸 從來沒有(請跳第 2.題)

(2)請問您 現在/以前有吸菸時 的**吸菸量**?

- 每天半包 每天一包 每天 1.5 包
每天 2 包 每天 2.5 包以上

(3)請問您 到現在/以前有吸菸時 **總共抽菸幾年**?

總共_____年

2. 請問您現在是否有**喝酒**的習慣?

- 有，每周約喝_____毫升(cc)，哪一種酒: _____酒
沒有



3. 請問您有沒有**運動**的習慣?

有，每周_____小時 沒有

4. 請問您覺得最近一年來，與同年齡的人相比，自己**健康狀況**如何?

很好 還不錯 普通 較差 很差

5. 您現在或曾經被**醫生診斷**有以下疾病嗎?(請勾選)

		無	曾經有，已治好	現在有，治療中
(1)	心臟病			
(2)	糖尿病			
(3)	高血壓			
(4)	肌腱炎			
(5)	關節炎			
(6)	脊椎、椎間盤疾患			
(7)	鼻炎			
(8)	肺炎、氣管炎			
(9)	肺氣腫			
(10)	手、臉部皮膚病			
(11)	月經失調			

6. 您有被醫生診斷出**鼻子過敏、皮膚過敏**嗎? 有 沒有(跳第 7.題)

若有:

(1)小時候就有過敏體質嗎? 有 沒有

7. 您最近有**咳嗽**症狀嗎? 有 沒有(跳到第 8.題)

若有:

(1)曾經連續咳嗽三個月或更久嗎? 有 沒有

(2)休假時，咳嗽的情形怎麼樣? 相同 改善 更常咳嗽

8. 快速行走或爬緩坡時，會有**呼吸急促**難以調節的情況嗎? 有 沒有(跳第 9.題)

若有:

(1)與同年齡人相比，情況有沒有比較明顯? 有 沒有

(2)曾有需要停止前進以緩和呼吸的情況嗎? 有 沒有

9. 過去 12 個月，呼吸時是否曾有哮喘、喘鳴(咻咻)聲響? 有 沒有(跳第 10.題)

若有:

- | | | |
|--------------------------|-----------------------------|---|
| (1)沒有感冒時有發生過這種情況嗎? | <input type="checkbox"/> 有 | <input type="checkbox"/> 沒有 |
| (2)放假時，喘鳴的情形怎麼樣? | <input type="checkbox"/> 相同 | <input type="checkbox"/> 改善 <input type="checkbox"/> 更常喘鳴 |
| (3)哪一年、哪一個月開始有喘鳴(咻咻)聲響的? | ____年____月 | |

10. 曾經被醫生診斷為「氣喘」嗎? 有 沒有(跳到第 11.題)

若有:

- | | |
|---------------------|---|
| (1)最近一次得到氣喘是哪年、哪月? | ____年____月 |
| (2)當時有在烘焙業嗎? | <input type="checkbox"/> 沒有 <input type="checkbox"/> 有，當時已經在烘焙業工作____年/月(圈選) |
| (3)現在還有「氣喘」嗎? | <input type="checkbox"/> 有 <input type="checkbox"/> 沒有 |
| (4)現在還有用藥嗎(吃藥、噴劑)? | <input type="checkbox"/> 有 <input type="checkbox"/> 沒有 |
| (5)放假時，氣喘的情形怎麼樣? | <input type="checkbox"/> 相同 <input type="checkbox"/> 改善 <input type="checkbox"/> 更常氣喘 |
| (6)小時候有氣喘症狀嗎? | <input type="checkbox"/> 有 <input type="checkbox"/> 沒有 |
| (7)有哪一原料較容易引起氣喘症狀嗎? | <input type="checkbox"/> 有，什麼原料?_____ |
| | <input type="checkbox"/> 沒有 |

11. 過去 12 個月，工作時以下症狀出現頻率、下班後情形?(請勾選)

		沒有	很少	偶爾 (1次/ 月)	常常 (每周 多次)	總是 (幾乎 每天)	放假、下班後 左方症狀 會改善嗎? (無症狀免答)
眼睛症狀							
(1)	眼睛乾、癢、流眼淚						<input type="checkbox"/> 會改善 <input type="checkbox"/> 差不多 <input type="checkbox"/> 情況更糟
(2)	眼睛刺激、痠痛						
(3)	眼睛持續有異物感						
(4)	眼睛發紅、有血絲						
呼吸道症狀							
(5)	鼻子喉嚨乾癢						<input type="checkbox"/> 會改善 <input type="checkbox"/> 差不多 <input type="checkbox"/> 情況更糟
(6)	鼻子喉嚨刺激、刺痛						
(7)	流鼻水、鼻塞						
(8)	打噴嚏、咳嗽						
(9)	有痰、有異物感						
(10)	胸悶、喘不過氣						
(11)	呼吸急促、喘鳴						



➤ 進行下列工作時會有眼睛、呼吸道不舒服的感覺嗎?

會，請勾選

- 秤、篩麵粉、蛋糕粉 攪拌雞蛋、麵粉、打蛋糕
使用香草粉、香精 揉、整形麵糰 發酵 控制烤箱溫度
麵包出爐、冷卻 清洗動作 炸豬油、烹煮
包裝、運送、結帳 其他:_____

均不會

12. 過去 12 個月，工作時以下症狀出現頻率、下班後情形?(請勾選)

		沒有	很少	偶爾 (1次/ 月)	常常 (每周多 次)	總是 (幾乎每 天)	放假、下班後 左方症狀 會改善嗎? (無症狀免答)
皮膚症狀							
(1)	燒、燙傷						<input type="checkbox"/> 會改善 <input type="checkbox"/> 差不多 <input type="checkbox"/> 情況更糟
(2)	脫皮、紅腫						
(3)	皮膚癢、乾燥、疼痛						
(4)	不明疹子、溼疹						
(5)	手掌、手指頭皮膚裂開						
肌肉骨骼症狀							
(6)	手腕、手臂肌肉痠痛						<input type="checkbox"/> 會改善 <input type="checkbox"/> 差不多 <input type="checkbox"/> 情況更糟
(7)	脖子、肩膀僵硬痠痛						
(8)	背部肌肉痠痛						
(9)	腿部肌肉痠痛						
其他症狀							
(10)	滑倒、跌倒						<input type="checkbox"/> 會改善 <input type="checkbox"/> 差不多 <input type="checkbox"/> 情況更糟
(11)	頭暈、頭痛、嗜睡						
(12)	疲倦無力、動作不協調						
(13)	沮喪、焦慮						
(14)	噁心想吐						



➤ 接觸下列什麼原料時會有皮膚不舒服的感覺？

會，請勾選

- 麵粉、麥粉、麵糰 打發蛋白 香草粉、香精 酵母
優格、起司、奶油抹醬 烤盤油、植物油、豬油 清潔劑
醃漬類水果、果醬 酒類 冷凍麵團 其他:_____

均不會

➤ 進行哪一項工作時會較明顯有肌肉痠痛的感覺？

會，請勾選

- 搬運、秤、篩麵粉 攪拌雞蛋、麵粉、打蛋糕 搬運、送貨
揉製、整形麵糰 麵包烘烤前、後搬動烤盤 使用麵包夾
進烤箱前蛋糕製模 清理物品、地面、桌面 其他:_____

均不會

四、工作環境描述

		沒有	很少	偶爾	常常	總是
(1)	烘烤時，廚房太熱以致大量流汗					
(2)	廚房通風狀況「較差」的頻率如何？					
(3)	廚房空氣品質「較差」的頻率如何？					
(4)	您戴口罩頻率如何？					
烘烤過程，空氣中有以下哪些物質較多、味道較濃嗎？						
(4)	麵粉、麥粉、蛋糕預拌粉					
(5)	油煙					
(6)	乳酪、起司、酥皮味					
(7)	布丁、克林姆、奶油味、奶粉					
(8)	雞蛋牛奶、蛋白霜					
(10)	香草、焦糖、黑糖、咖啡等調味料					
(11)	芋頭、紅豆、青蔥等其他餡料					

Appendix 2. RStudio code and output for Pearson's Chi-squared test



```
> exposure<-c("high", "low")
> allergy<-c("yes","no")
> data<-c(27,11,13,17)
> table<-expand.grid(exposure=exposure, allergy=allergy)
> table<-cbind(table,count=data)
> result<-xtabs(count~exposure+allergy, table)
> result
      allergy
exposure yes no
high     27 13
low      11 17
> chisq.test(result)

      Pearson's Chi-squared test with Yates' continuity correction

data:  result
X-squared = 4.2353, df = 1, p-value = 0.03959

> oddsratio(27,11,13,17, conf.level=0.95)
      Disease Nondisease Total
Exposed      27         13    40
Nonexposed   11         17    28
Total        38         30    68

      odds ratio estimate and its significance probability

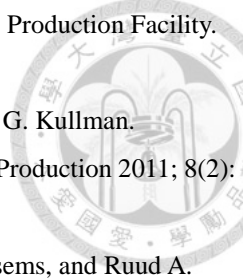
data:  27 11 13 17
p-value = 0.02207
95 percent confidence interval:
 1.173211 8.781674
sample estimates:
[1] 3.20979
```

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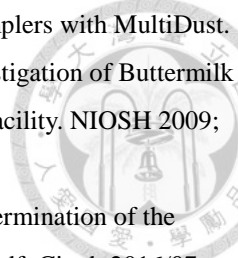
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Table 1 Number of chain baking stores and brands in Taiwan

year	Number of brands	Nuber of stores
2006	45	677
2010	55	779
2011	83	1234

Table 2 The total number of factories and workers

year	Number of factories	Number of workers	Revenues (thousand dollars)
2001	551	12,661	29,262,656
2006	418	13,710	30,318,140
2011	910	20,428	40,470,764

Table 3 Sampling methods and results in different reasearch

	Analyte	Sampling method	Concentration
P. Bulat et al., 2003	inhalable dust Industrial and traditional Bakeries	PAS-6 sampling heads Teflon filters	0.56-2.10 mg/m ³
J. Elms et al., 2004	inhalable dust Small to large bakeries	IOM samplers glass fiber filters	2.2-4.7 mg/m ³
R Baatjies et al., 2007	inhalable dust Bakeries in supermarket	PAS-6 sampling heads Teflon filters	0.125-0.904 mg/m ³
E. H. Page et al., 2010	inhalable dust Commercial bakery	IOM samplers Teflon® filters	0.235-65 mg/m ³
E. H. Page et al., 2013	inhalable dust Breeding plant	IOM samplers Teflon® filters	0.22-93 mg/m ³



Table 4 Air sampling and surveys at food flavoring workplaces

Reference	Sampling target	Results
M. Huey et al. 2012.	Air sampling at different working areas in food flavoring plants	Diacetyl TWA: 4.31ppm; STEL: 50.95ppm higher concentration around mixing machine
G. Day et al. 2011.	Air sampling and raw material survey at working areas in baking mix plants using diacetyl substitutes	diacetyl substitutes: 2,3-pentanedione, 2,3-hexanedione, 2,3-heptanedione, and acetoin 2,3-pentanedione TWA: 78ppb personal sampling: 91ppb
M. I. Rincon-Delgadillo et al. 2012.	FEMA priority compounds in cheese, margarine, oil spreads	Highest concentration in products ($\mu\text{g/g}$): Acetoin: 130,000 Diacetyl: 22,000 Acetic acid: 290,000 Propanoic acid: 22,000
R. Kanwal et al. 2007.	Air sampling and lung function test in food flavoring plants	Powdered flavoring production: TVOC concentrations >100,000 ppb Diacetyl, and acetoin: 0.002-0.223ppm Acetaldehyde: 0.0001-0.271ppm
G. A. Day et al. 2009.	Air sampling and raw material survey at working areas in baking mix plants using diacetyl substitutes	The inhaled risk of flavoring dust is unknown but may be important

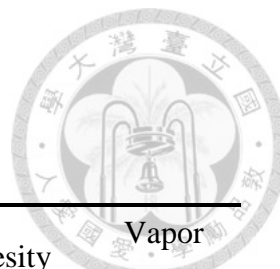


Table 5 Properties of the analytes

	CAS NO.	Molecular weight (g/mol)	Boiling point (°C)	Melting point (°C)	Density (g/cm ³ @ 20 °C)	Vapor pressure (mm Hg @ 25 °C)
Diacetyl	431-03-8	86.09	88	3	0.99	56.8
Acetoin	513-86-0	88.1	148	15	1.005	2.7
2,3-pentanedione	123-54-6	100.12	138	-23	0.972	2.96
2,3-hexanedione	3848-24-6	114.14	128	-30	0.934	10
2,3-heptanedione	96-04-8	128.17	176	149.7	0.92	3.97
Acetaldehyde	75-07-0	44.05	21	-123.5°C	1.52	757
Furfural	98-01-1	96.09	161.85	-36.15	1.16	75



Table 6 GC-MS conditions of analytes

Chemicals	Column	Front inlet / inject volume	Programs
Diacetyl, acetoin, 2,3-pentanedione, 2,3-hexanedione, 2,3-heptanedione	RTX-Volatiles 60 m × 0.32 mm ID × 1.50 μm	Splitless / 1 μL	90 °C for 9 mins ; 5 °C/min to 130 °C ; 60 °C/min to 240 °C
Acetaldehyde, furfural	DB-5MS 60 m × 0.32 mm ID × 0.25 μm	Splitless / 5 μL	100 °C ; 20 °C/min to 310 °C

Table 7 Retention times and selected ions of GC-MS

	Retention time (mins)	Quantitative ions (m/z)	Qualitative ions (m/z)
Diacetyl	4.55	86	87
2,3-pentanedione	6.63	57	100
Acetoin	7.69	88	55
2,3-hexanedione	10.06	71	114
2,3-heptanedione	14.60	57	85
Acetaldehyde	4.30	126	140, 141
Furfural	6.50	193	163, 193



Table 8 Detection limit of target analytes

Analytes	Instrument Detection Limit (ng/ μ L)	detectable air concentrations (mg/m ³)
Diacetyl	0.074	0.0024
2,3-pentanedione	0.082	0.0027
Acetoin	0.081	0.0027
2,3-hexanedione	0.147	0.0049
2,3-heptanedione	0.081	0.0026
Acetaldehyde	0.043	0.0040
Furfural	0.008	0.0010

Table 9 Walk through survey toward 10 baking workplaces

	Factory A	Factory B	Factory C	Factory D	Factory E	Factory F	Retail store G	Retail store H	Retail store I	Retail store J	Factory 1	Factory 2	Retail store 3	Retail store 4	Retail store 5
Size (m ²)	430	826	99	496	331	198	50	83	66	50	4000	1653	331	116	149
Air conditioner	v	v	v	v	v	-	-	v	only in store, not in kitchen		v	v	-	-	-
Mechanical ventilations	-	Connect to ovens	-	1m above ovens	Connect to ovens	Connect to ovens	-	-	-	Connect to ovens	Connect to 1/2 ovens	Connect to ovens/ tunnel ovens	Connect to ovens	-	Connect to ovens
Natural ventilation	Door with curtain	-	Standing fan window fan	-	Door with curtain	Open window fan	Open window	Open door	Window	Open door	-	-	-	-	-
Machine															
Blending	v	v	v	v	v	v	v	-	v	v	v	v	v	v	v
Shaping	v	v	v	v	v	v	v	-	-	v	v	v	-	-	-
Fermenting	v	v	v	v	v	v	v	v	-	v	v	v	v	v	v
Ovens	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
Grinding	-	-	-	-	-	-	v	-	-	-	-	-	-	-	-

Table 10 Orders and products in ten bakeries


	Factory A	Factory B	Factory C	Factory D	Factory E	Factory F	Retail store G	Retail store H	Retail store I	Retail store J	Factory 1	Factory 2	Retail store 3	Retail store 4	Retail store 5
Numbers of workers	27	60-70	6	11	47	6	7	7	2	8	30	45	11	6	7
Orders															
Branch store	v	v	v	v	v		v	v	v	v	v	v	-	-	v
Lunch box	v	v	v	v			v			v	v	v	-	-	v
Catering (party)	v	v		v						v	v	v	-	-	-
Products															
Bread	v	v	v	v	v	v	v	v		v	v	-	v	v	v
Cake	v	v	v	v	v		v	v	v	v	v	v	v	v	v
Cookie	v	v		v	v		v			v	v	-	-	v	-
Chinese cookie	v			v	v			v		v	v	-	v	-	-

Table 11 Personal protective equipment in 10 bakeries

	Factory A	Factory B	Factory C	Factory D	Factory E	Factory F	Retail store G	Retail store H	Retail store I	Retail store J	Factory 1	Factory 2	Retail store 3	Retail store 4	Retail store 5
Strip	-	v		v	v	v	v				v	v			v
Cap															
Mask	-	v		v	v	v	v				v	v			-
Glove	Cake (latex)	-	-	-	-	-	-	-	-	-	-	-	-	-	-
working suit	v	v		v	v	v	v				v	v			v
Working shoes	v	v		v	v	-	-				v	v			-



Table 12 Factory 1 concentrations of analytes

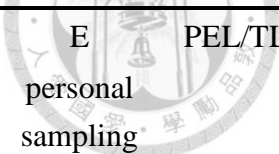


sampling sites	A		B	C	D	PEL/TLV-TWA
	weighing room		2F baking	3F baking	office	
	mg/m ³					
Inhalable dust	0.55	0.41	0.01	*	*	0.5(ACGIH)
Respirable dust	0.17		0.07	0.01	0.07	-
Diacetyl	0.00335		0.00287	<0.0024	<0.0024	-
2,3-pentanedione	0.00276		<0.0027	<0.0027	<0.0027	-
Acetoin	<0.0027		<0.0027	<0.0027	<0.0027	-
2,3-hexanedione	0.00802		<0.0049	<0.0049	<0.0049	-
2,3-heptanedione	0.0091		<0.0026	<0.0026	<0.0026	-
Acetaldehyde	0.8316		0.7525	0.0689	0.5899	180
Furfural	<0.001		<0.001	<0.001	<0.001	7.9

- no PEL-TWA value

* lower than pre-weighing

Table 13 Factory 2 concentrations of analytes



sampling sites	A		B	C	D	E	PEL/TLV-TWA
	weighing room		tunnel ovens	cake decorating	office	personal sampling*	
mg/m ³							
Inhalable dust	0.82	0.76	*	0.05	0.13	0.83	0.5(ACGIH)
Respirable dust	0.3		*	*	*	*	-
Diacetyl	<0.0024	<0.0024	<0.0024	<0.0024	<0.0024	-	-
2,3-pentanedione	<0.0027	<0.0027	<0.0027	<0.0027	<0.0027	-	-
Acetoin	<0.0027	<0.0027	<0.0027	<0.0027	<0.0027	-	-
2,3-hexanedione	<0.0049	<0.0049	<0.0049	<0.0049	<0.0049	-	-
2,3-heptanedione	<0.0026	<0.0026	<0.0026	<0.0026	<0.0026	-	-
Acetaldehyde	0.0594	0.0747	0.0563	0.0003	0.0003	-	180
Furfural	0.0660	<0.001	<0.001	<0.001	<0.001	-	7.9
- no PEL-TWA value			* lower than pre-weighing				

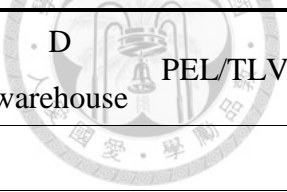
Table 14 Retail store 3 concentration of analytes

sampling sites	A		B	C	D	PEL/TLV-TWA
	theiving area		baking ovens	working table	counter	
mg/m ³						
Inhalable dust	0.1	0.02	0.49	0.38	0.09	0.5(ACGIH)
Respirable dust	*		*	*	*	-
Diacetyl	<0.0024		<0.0024	<0.0024	<0.0024	-
2,3-pentanedione	<0.0027		<0.0027	<0.0027	<0.0027	-
Acetoin	<0.0027		<0.0027	<0.0027	<0.0027	-
2,3-hexanedione	<0.0049		<0.0049	<0.0049	<0.0049	-
2,3-heptanedione	0.0115		0.0036	0.0099	0.0195	-
Acetaldehyde	<0.004		<0.004	<0.004	<0.004	180
Furfural	<0.001		<0.001	<0.001	<0.001	7.9

- no PEL-TWA value

* lower than pre-weighing

Table 15 Retail store 4 concentration of analytes



sampling sites	A		B	C	D	PEL/TLV-TWA
	mixing area		ovens	heating	warehouse	
	mg/m ³					
Inhalable dust	0.26	0.52	0.77	0.38	0.18	0.5(ACGIH)
Respirable dust	*		0.13	0.08	0.02	-
Diacetyl	<0.0024	<0.0024	<0.0024	<0.0024	<0.0024	-
2,3-pentanedione	<0.0027	<0.0027	<0.0027	<0.0027	<0.0027	-
Acetoin	<0.0027	<0.0027	<0.0027	<0.0027	<0.0027	-
2,3-hexanedione	<0.0049	<0.0049	<0.0049	<0.0049	<0.0049	-
2,3-heptanedione	<0.0026	<0.0026	<0.0026	<0.0026	<0.0026	-
Acetaldehyde	0.0929	0.0833	0.1458	0.1350	0.1350	180
Furfural	<0.001	<0.001	<0.001	<0.001	<0.001	7.9

- no PEL-TWA value

* lower than pre-weighing

Table 16 Retail store 5 concentration of analytes

sampling sites	A		B	C	D	PEL/TLV-TWA
	working table		working table	counter	stairs	
				mg/m ³		
Inhalable dust	0.15	0.11	*	*	0.26	0.5(ACGIH)
Respirable dust	*		*	*	*	-
Diacetyl	<0.0024		<0.0024	<0.0024	<0.0024	-
2,3-pentanedione	<0.0027		<0.0027	<0.0027	<0.0027	-
Acetoin	0.0054		0.0059	0.0045	0.0075	-
2,3-hexanedione	<0.0049		<0.0049	<0.0049	<0.0049	-
2,3-heptanedione	<0.0026		<0.0026	<0.0026	<0.0026	-
Acetaldehyde	0.2801		0.4314	0.1072	0.1373	180
Furfural	<0.0010		<0.0010	<0.0010	<0.0010	7.9

- no PEL-TWA value

* lower than pre-weighing

Table 17 Demographic characteristics of study subjects (n=68)

Age (years)	32.61(15-61)*
Gender No. (%)	
Male	39(57.3)
Female	29(42.6)
Weight(kg)	62.49(40-95)*
Height(cm)	166.62(144-185)*
BMI(kg m⁻²)	
<18.5	9(14.2)
18.5-24	35(55.5)
>24	19(30.1)
Education No. (%)	
≤6 years	3(4.4)
6-9 years	6(8.9)
9-12 years	36(53.7)
12-16 years	22(32.8)
Time working in bakeries	7.15(1-40)*
day off per month No.(%)	
4 days	12(17.6)
6 days	51(75)
8 days	3(44.1)
Working hours per day (hours)	
over 10	53(77.9)
8~10	14(20.5)
<8	1(1.4)

*Mean (min-max)



Table 18 Lifestyle and general health descriptions (n=68)

Smoking status No. (%)	
Smoker	18(26.4)
Ex-smoker	3(4.4)
Never smoked	45(66.1)
Alcohol No. (%)	
Drinker	6(8.8)
Nondrinker	62(91.1)
Self-perceived health status No. (%)	
Excellent	8(11.7)
Good	13(19.1)
Average	33(48.5)
Fair	9(13.2)
Poor	4(5.8)
Disease history No.(%)	
Heart disease	3(4.4)
Diabetes	1(1.4)
Tendinitis	9(13.2)
Arthritis	5(7.3)
Spine, intervertebral disc disorders	5(7.3)
Skin disorder	7(10.2)
Rhinitis	4(5.8)
Pneumonia, bronchitis	5(7.3)
Emphysema	3(4.4)
Allergy	25(36.7)
Cough over 3 months	10(14.7)
Shortness of breath	16(23.5)
Wheezing	4(5.8)
Asthma	2(2.9)



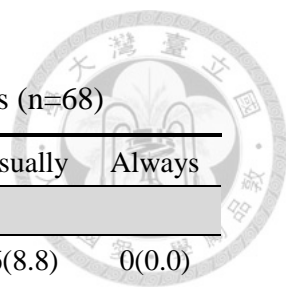


Table 19 Prevalence of workers reporting health symptoms (n=68)

No.(%)	Never	Seldom	Sometimes	Usually	Always
Eye symptoms					
Eyes dry , itchy , watery eyes	43(63.2)	12(17.6)	7(10.2)	6(8.8)	0(0.0)
Eye irritation	50(73.5)	12(17.6)	2(2.9)	4(5.8)	0(0.0)
Foreign body sensation in eyes	60(88.2)	6(8.8)	1(1.4)	1(1.4)	0(0.0)
Respiratory symptoms					
Itchy nose, throat	41(60.2)	13(19.1)	7(10.2)	6(8.8)	0(0.0)
Nose irritation	52(76.4)	9(13.2)	2(2.9)	4(5.8)	0(0.0)
Runny nose, stuffy nose	40(58.8)	15(22.0)	5(7.3)	7(10.2)	0(0.0)
Sneezing, coughing	34(50.0)	18(26.4)	8(11.7)	6(8.8)	1(1.4)

Table 20 Prevalence of workers reporting health symptoms (n=68)

No.(%)	Never	Seldom	Sometimes	Usually	Always
Skin symptoms					
Burn	43(63.2)	18(26.4)	3(4.4)	2(2.9)	1(1.4)
Peeling	56(82.3)	8(11.7)	1(1.4)	2(2.9)	0(0.0)
Itching , dryness, soreness	44(64.7)	12(17.6)	4(5.8)	6(8.8)	1(1.4)
Rash , eczema	53(77.9)	6(8.8)	5(7.3)	3(4.4)	0(0.0)
Skin breakdown	49(72.1)	11(16.1)	3(4.4)	2(2.9)	1(1.4)
Musculoskeletal symptoms					
Wrist, arm	30(44.1)	12(17.6)	12(17.6)	6(8.8)	7(10.2)
Neck, shoulder	32(47.0)	10(14.7)	10(14.7)	9(13.2)	6(8.8)
Back	35(51.4)	7(10.2)	10(14.7)	8(11.7)	7(10.2)
Leg	37(54.4)	12(17.6)	6(8.8)	4(5.8)	8(11.7)
Other symptoms					
Dizziness, headache, drowsiness	45(66.1)	12(17.6)	7(10.2)	1(1.4)	1(1.4)
Fatigue, weakness, incoordination	45(66.1)	11(16.1)	7(10.2)	3(4.4)	0(0.0)
Sweat a lot due to overheating	19(27.9)	10(14.7)	13(19.1)	12(17.6)	8(11.7)
Bad ventilation	23(33.8)	8(11.7)	19(27.9)	5(7.3)	8(11.7)



Table 21 Asthma-like symptoms among different level flour dust exposure groups

Groups	Allergy	Cough>3 months	Shortness of breath	Wheezing	Asthma
High exposure	18(45)	8(20)	12(30)	3(7.5)	1(2.5)
Low exposure	7(25)	2(7.1)	4(14.2)	1(3.5)	1(3.5)

Groups	Dry/itchy nose and throat	Nose and throat irritation	Runny nose, stuffy nose	Sneezing, coughing
High exposure	10(25)	4(10)	9(22.5)	10(25)
Low exposure	3(10.7)	2(7.1)	3(10.7)	5(17.8)

Table 22 Part of materials frequently used in baking industry

品名	成分
烘焙粉狀物	
健康全粒粉	
黑麥萃取粉	
日清法國小麥粉	
純裸麥粉	
綜合麵糰改良劑	小麥粉、黃豆粉、乳化劑、砂糖、碳酸鈣、抗氧化劑(維他命 C)、酵素
乳香粉	葡萄糖、 香料 、食用色素(黃色四號.黃色五號)
蛋白霜	糖、山梨醇、麥芽糊精、蛋白粉、乙醯化磷酸二澱粉、塔塔粉、環狀糊精、羧甲基纖維素、香草香料、 牛奶香料
五穀雜糧麵包專用酵素	酵素、澱粉
日式抹茶粉	高級茶葉、乳糖、丙二醇、食用色素、 食用香料
即發酵母	天然酵母、乳化劑、山梨醇酐單硬脂酸酯、抗氧化劑、維生素 C
鬆餅粉	麵粉、糖、玉米澱粉、酥油粉、奶精、泡打粉、在萊米粉、奶油粉、蛋黃粉、奶粉、黃豆粉、起司粉、熟化澱粉、小麥纖維素、 牛奶香粉 、鹽
銅鑼燒粉	麵粉、糖粉、無水奶油、無鉛泡打粉、修飾澱粉、小蘇打、 蜂蜜香料
塔塔粉	乳糖、馬鈴薯粉、磷酸二氫鈣、酸性焦磷酸鈉
芝士粉	葡萄糖、 香料 、食用色素(黃色四號.黃色五號)
布丁粉	奶粉、奶精、β胡蘿蔔素、 香草粉 、豆膠、玉米糖膠、 奶香粉 、磷酸鉀
吉利丁粉	砂糖、奶粉、奶精、鹿角菜膠、刺槐豆膠、氯化鉀、食鹽、 香料 、食用色素
卡士達粉	糖、乙醯化磷酸二澱粉、奶精粉、麥芽糊精、海藻膠、 牛奶香料 、 香草香料 、胡蘿蔔素
茉莉茶凍粉/雞蛋味布	漿、氯化棕櫚油、磷酸氫二甲、多磷酸鈉、偏磷酸鈉、乾酪素鈉、脂肪酸甘油酯、單及雙脂肪
丁粉	酸甘油二乙烯酒石酸酯、香料、二氧化矽、鹽、檸檬酸鈉)、鹿角菜膠、玉米糖漿、刺槐豆膠、香料、洋菜粉、檸檬酸鉀/鈉、食用色素黃色 4、5 號

烘焙用油品	
動物性鮮奶油(36%油脂)	乳脂、乳化劑(脂肪酸甘油酯、乳酸甘油酯、聚山梨醇脂八十)、 香料(奶油酯) 、粘稠劑(關華豆膠、玉米糖膠、鹿角菜膠)
植物鮮奶油	水、棕櫚仁油、葡萄糖、糖、大豆卵磷脂、粘稠劑(羥丙基甲基纖維素)、 鹽 、 香料 、著色劑(β胡蘿蔔素)
噴式鮮奶油	鮮奶油(乳製品)、水、糖、脫脂牛奶、麥芽糊精、微結晶狀&纖維素、脂肪酸甘油酯、 香料 、鹿角菜膠、羧甲基纖維素鈉、推進劑:一氧化二氮
活 xx 無水奶油	棕櫚油、乳脂、 香料 、著色劑(β胡蘿蔔素)
王牌起酥片	精製動植物性油脂、水、食鹽、乳化劑、 香料 、己二烯酸鉀(防腐劑)、維生素 E(防腐劑)、維生素 C 棕櫚酸脂(抗氧化劑)、β胡蘿蔔素、檸檬酸
維 x 無水奶油	植物油(棕櫚油、椰子油、大豆油)、味琳、水、乳化劑(脂肪酸甘油酯)、 複方香料 、抗氧化劑、著色劑(葵花油、β胡蘿蔔素)
其他原料	
法式栗子抹醬	新鮮栗子、糖、 香草
切達乳酪抹醬	水、乾酪、乳糖、乾酪粉、植物油(棕櫚油、大豆油)、脫脂奶粉、牛奶蛋白、品質改良劑(六偏磷酸鈉、磷酸鈉)、粘稠劑(羥丙基磷酸二澱粉、羧甲基纖維素鈉)、 香料 、食鹽、防腐劑(乳酸鏈球菌素、己二烯酸鉀)、天然色素(婀娜多、紅椒色素)、關華豆膠
花生抹醬	花生、砂糖、植物油、乳化劑、維生素 E、 香料
楓糖風味糖漿	蔗糖、水、 香料
蜜柑果汁	蜜柑汁、砂糖、檸檬酸、山梨醇、阿拉伯膠、醋酸異丁蔗糖酯、棕櫚油、 香料 、β-胡蘿蔔素
軟質純白巧克力	特級砂糖、芥花油、乳糖、全脂奶粉、棕櫚油、軟磷脂、脂肪酸甘油酯、 香料(中鏈脂肪酸甘油酯、香料) 、食鹽、脂肪酸蔗糖酯、 香莢蘭醛
蘋果藍莓餡	水、高果糖漿、黏稠劑、藍莓、脫水蘋果、調味劑、 天然和人工香料 、防腐劑、著色劑
芋頭餡	白鳳豆、芋頭、麥芽糖、D-山梨醇粉、特砂糖、大豆沙拉油、麥芽糊精、奶粉、椰奶粉、黃豆纖維、 鹽 、 芋頭香料 、著色劑(紅色 6 號、藍色 1 號)
紅豆粒餡	台灣紅豆、砂糖、麥芽糖、海藻糖、麥芽糖粉、山梨醇甜味劑、洋菜膠、檸檬酸、 紅豆香料

草莓餡	草莓、果糖、乙醯化磷酸二澱粉、玉米糖膠、結蘭膠、檸檬酸、偏磷酸鈉、己二烯酸鉀、 香料 、食用色素
酥油芋泥餡	白豆沙、芋泥、砂糖、麥芽糖、海藻糖、麥芽糖粉、黃豆油、無水奶油、鮮奶油、食用藍色一號、食用藍色 40 號、 芋頭香料
經典設計師裝飾醬-焦糖風味	玉米糖漿、高果糖玉米糖漿、糖、濃縮脫脂乳、水、鮮奶油、鹽、柑橘果膠、 香料 、防腐劑(己二烯酸鉀)、食用色素(普通焦糖)、磷酸氫二鈉
北海道奶油香料	香料 、玉米糖膠、防腐劑(苯鉀酸鈉)、水
沖繩黑砂糖香料	黑砂糖香料 、丙二醇、甜味劑
咖啡香料	香料 、食用色素(焦糖色素)、甜味劑、
芋頭香料	香料 、丙二醇、食用色素(紅色六、七、四十號)、藍色一號、甜味劑、水
香蕉油	香料 、丙二醇
杏桃果醬膠	果膠(柑橘)、糖、水、葡萄糖漿、調味劑(檸檬酸、檸檬酸鈉)、防腐劑(己二烯酸鉀)、 香料(杏桃) 、食用色素(紅色 6 號、黃色 4 號)
原味焦糖	砂糖、水、果糖、麥芽糖、丙二醇、 香料 、焦糖色素、鹽、檸檬酸、己二烯酸鉀
色漿、色膏	水、丙二醇、食用色素、甜味劑
蘋果濃縮汁	蘋果果粒、蘋果濃縮汁、高果糖糖漿、砂糖、水、檸檬酸、香料、蘋果酸、檸檬酸鈉、焦糖色素、乳酸鈣、氨基乙酸、苯甲酸鈉、三仙膠、醋、磺內酯鉀(甜味劑)、結蘭膠

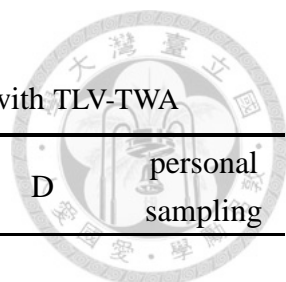


Table 23 Comparison of detected inhalable dust concentration with TLV-TWA

sampling sites	A-1	A-2	B	C	D	personal sampling
	mg/m ³					
Factory 1	0.55	0.41	0.01	*	*	-
Factory 2	0.82	0.76	*	0.05	0.13	0.83*
Retail store 3	0.1	0.02	0.49	0.38	0.09	-
Retail store 4	0.26	0.52	0.77	0.38	0.18	-
Retail store 5	0.15	0.11	*	*	0.26	-

≥ TLV-TWA
 < TLV-TWA, ≥ 1/2 TLV-TWA
 < 1/2 TLV-TWA, ≥ 1/10 TLV-TWA

Table 24 Results of air sampling in baking mix plants

Reference	Sampling target	Result
G. Day et al. 2011.	Air sampling and raw material survey at working areas in baking mix plants using diacetyl substitutes	diacetyl substitutes: 2,3-pentanedione, 2,3-hexanedione, 2,3-heptanedione, and acetoin 2,3-pentanedione TWA: 78ppb (0.31mg/m ³) personal sampling: 91ppb (0.37 mg/m ³)
	G. Day et al. 2009.	Air sampling and raw material survey at working areas in baking mix plants using diacetyl substitutes The inhaled risk of flavoring dust is unknown but may be important.

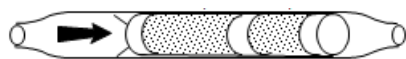


Figure 1 Silica gel tube



Figure 2 2-(hydroxymethyl)piperidine treated XAD-2 tube

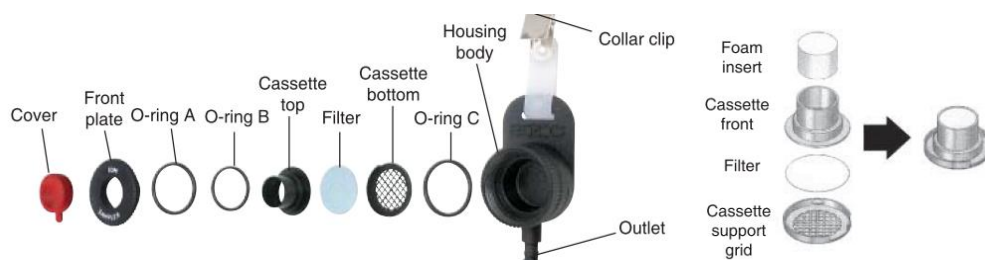


Figure 3 IOM sampler with MultiDust Foam Disc [51]



Figure 4 ppb RAE3000 VOC monitor



Figure 5 AEROCET 531 Handheld Particle Mass Profiler



Figure 6 Position of sampler during task-based personal sampling

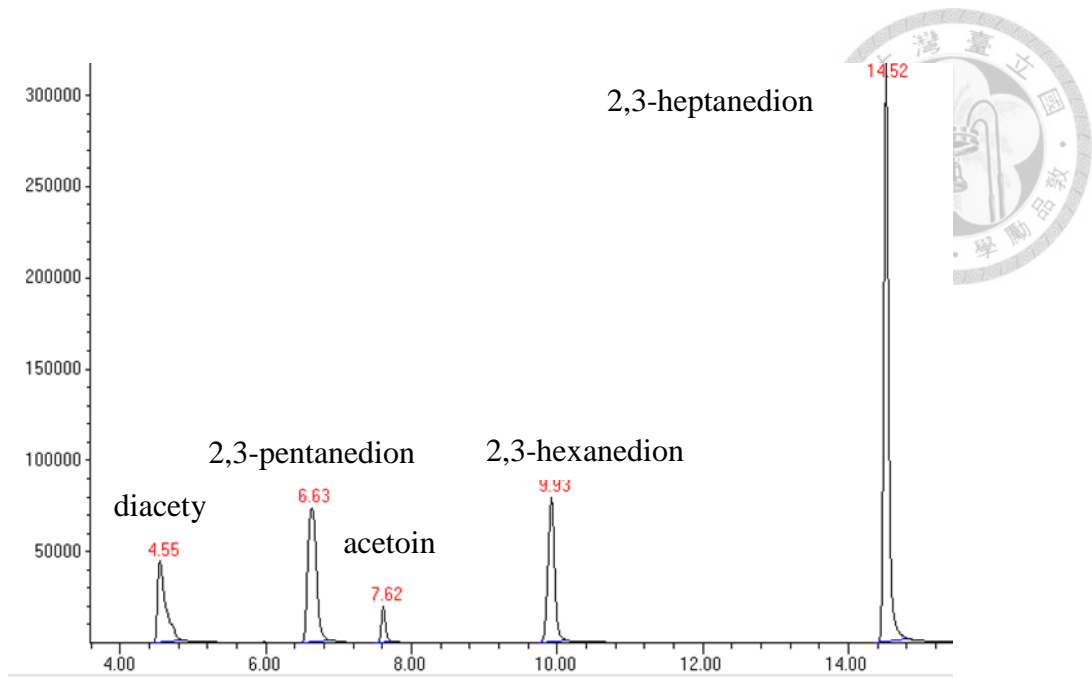


Figure 7 Chromatograms of diacetyl, 2,3-pentanedione, acetoin, 2,3-hexanedione, and 2,3-heptanedione

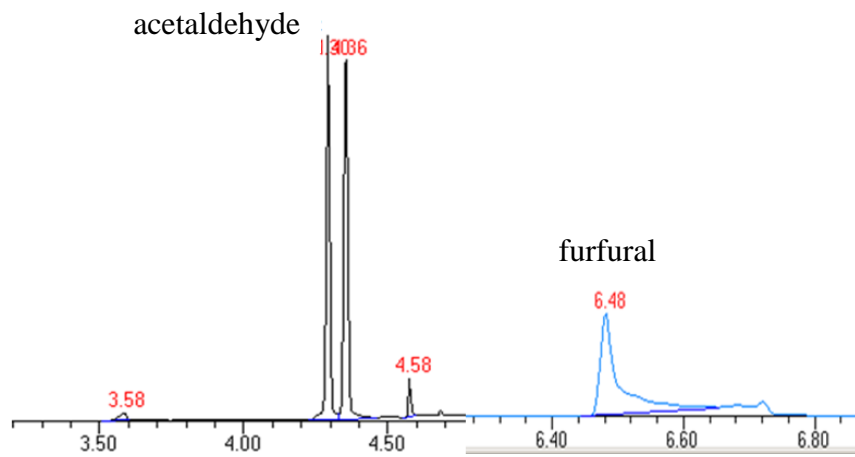


Figure 8 Chromatograms of acetaldehyde and furfural

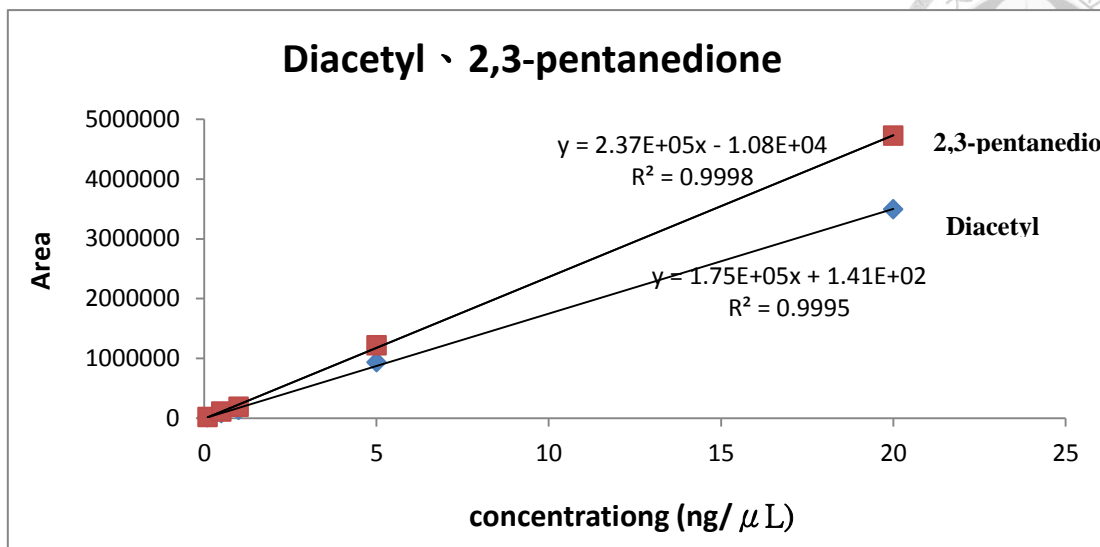


Figure 9 Calibration curve of diacetyl、2,3-pentanedione (0.05-20 ng/μL)

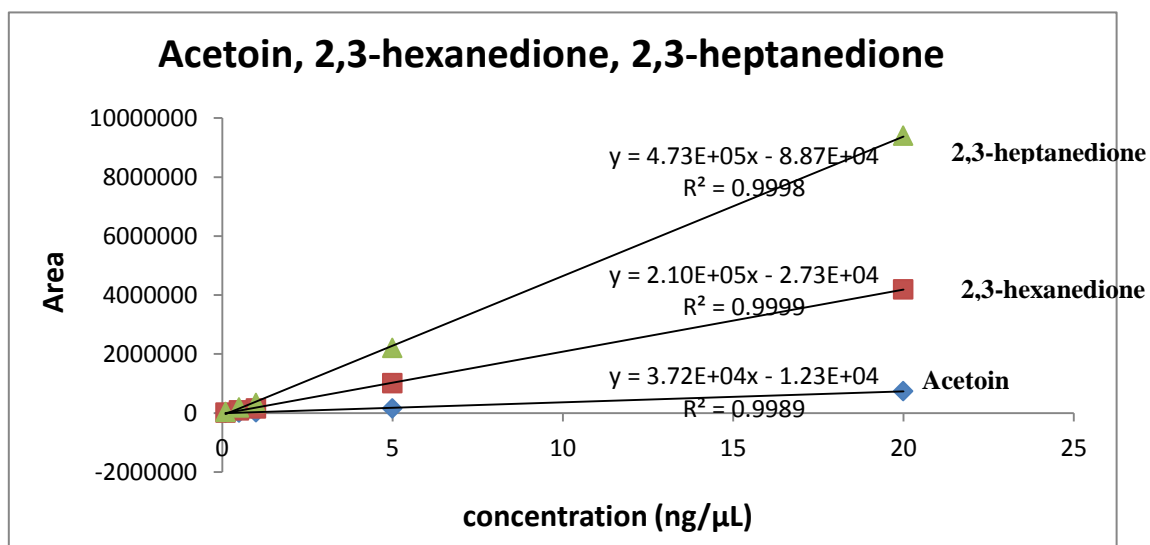


Figure 10 Calibration curve of acetoin, 2,3-hexanedione, 2,3-heptanedione (0.1-20 ng/μL)

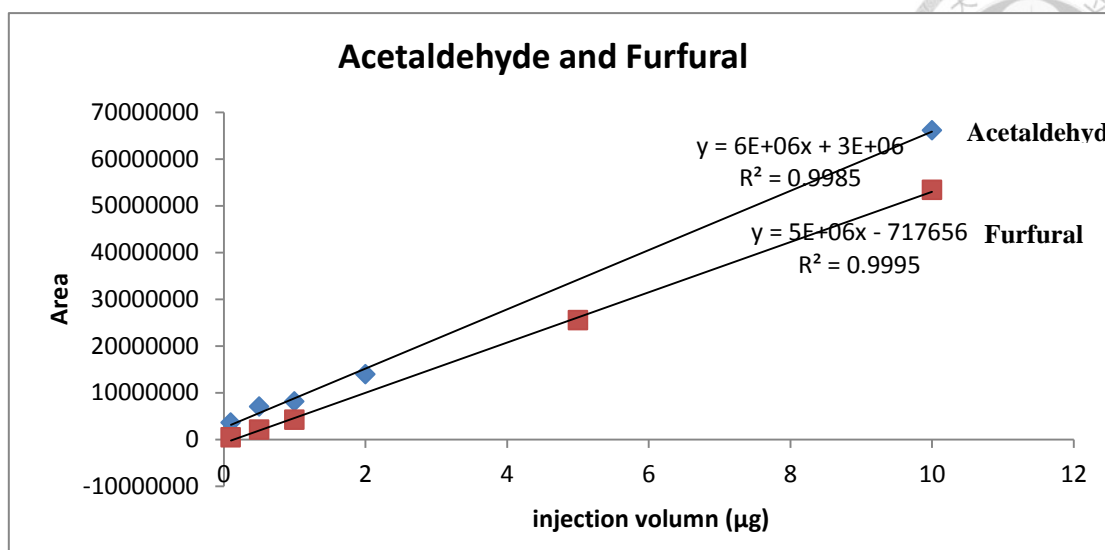


Figure 11 Calibration curve of acetaldehyd and furfural (0.1-10µg)

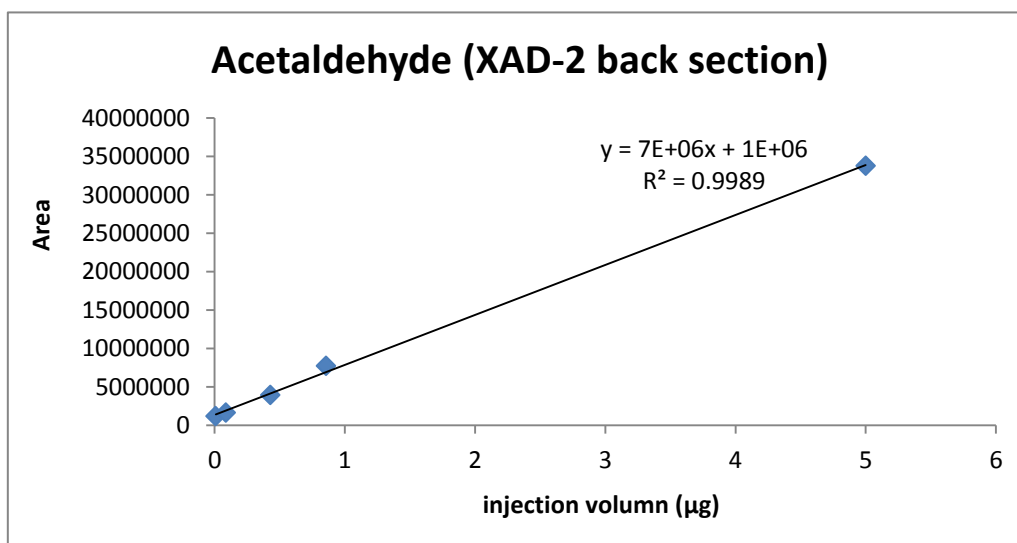


Figure 12 Calibration curve of acetaldehyde in back sorbent section (0.08-5µg)

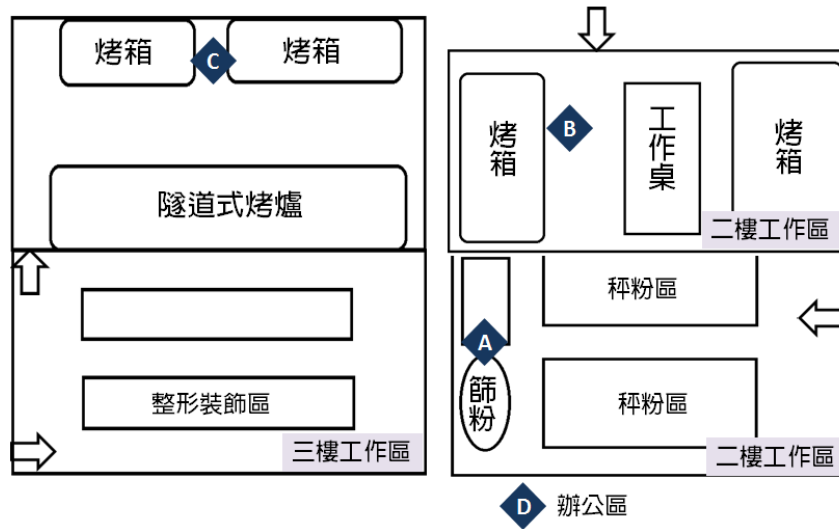


Figure 13 Factory 1 similar exposure group and sampling sites

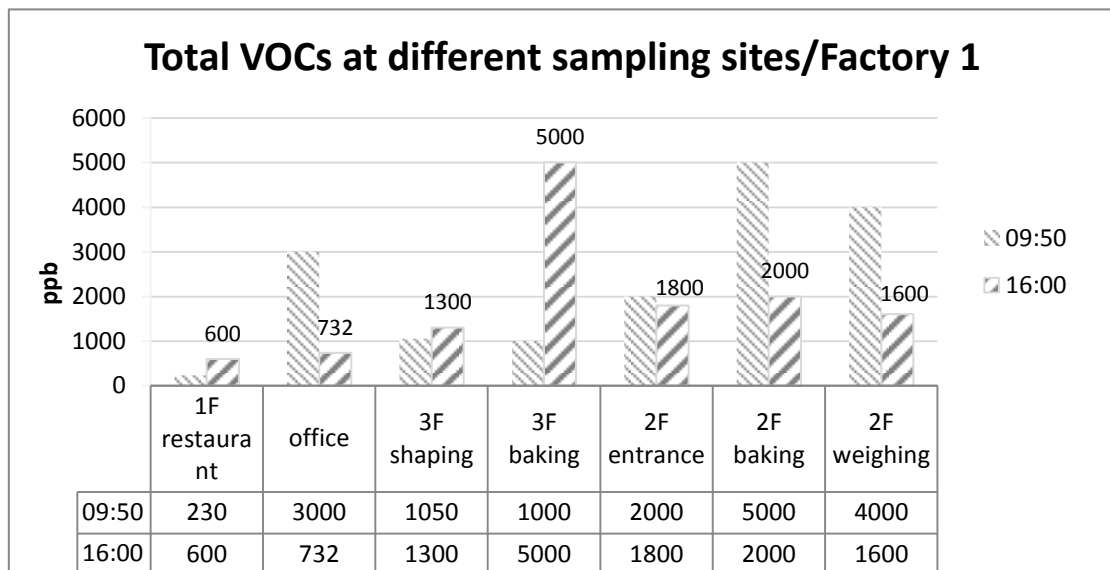


Figure 14 Concentrations of total volatile organic compounds in factory 1

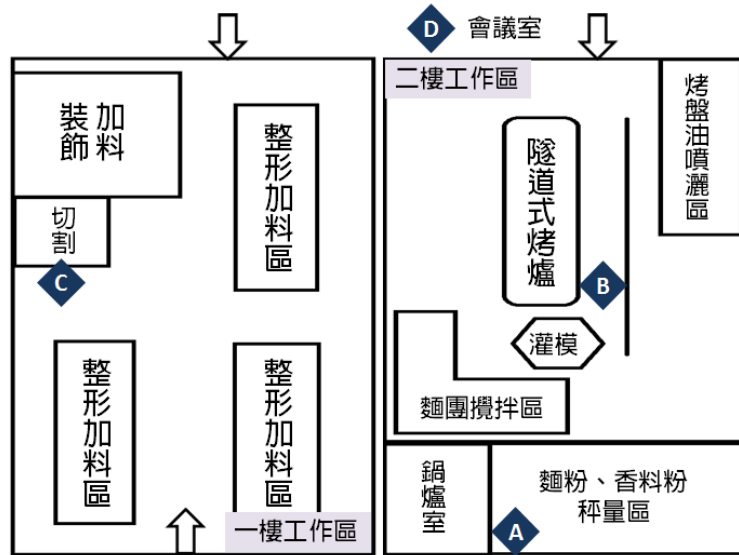


Figure 15 factory 2 similar exposure group and sampling sites

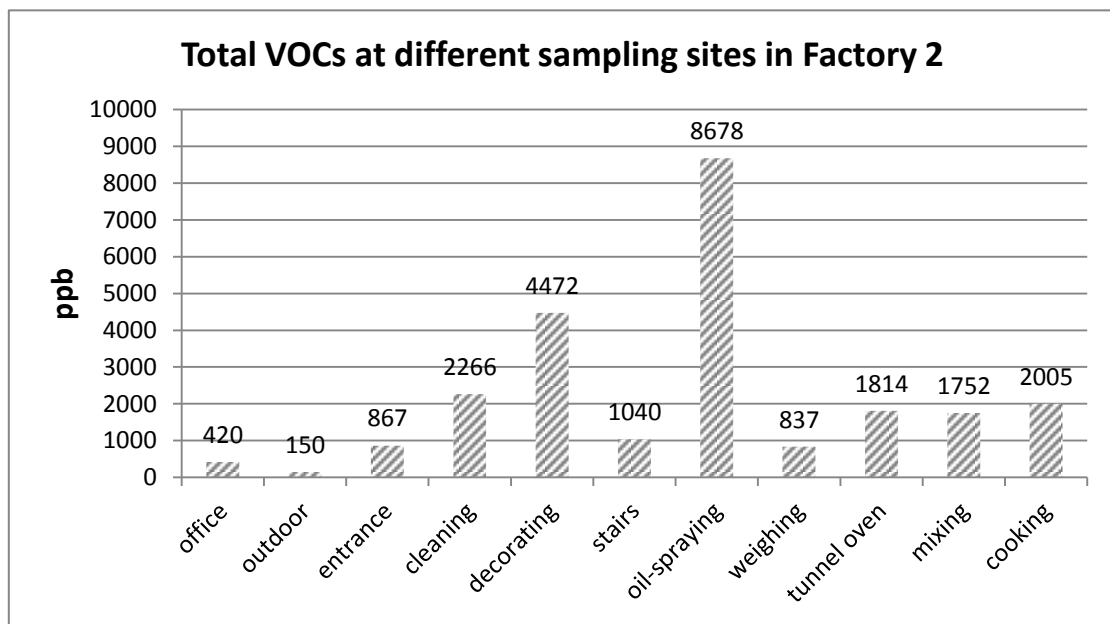


Figure 16 Concentrations of total volatile organic compounds in factory 2

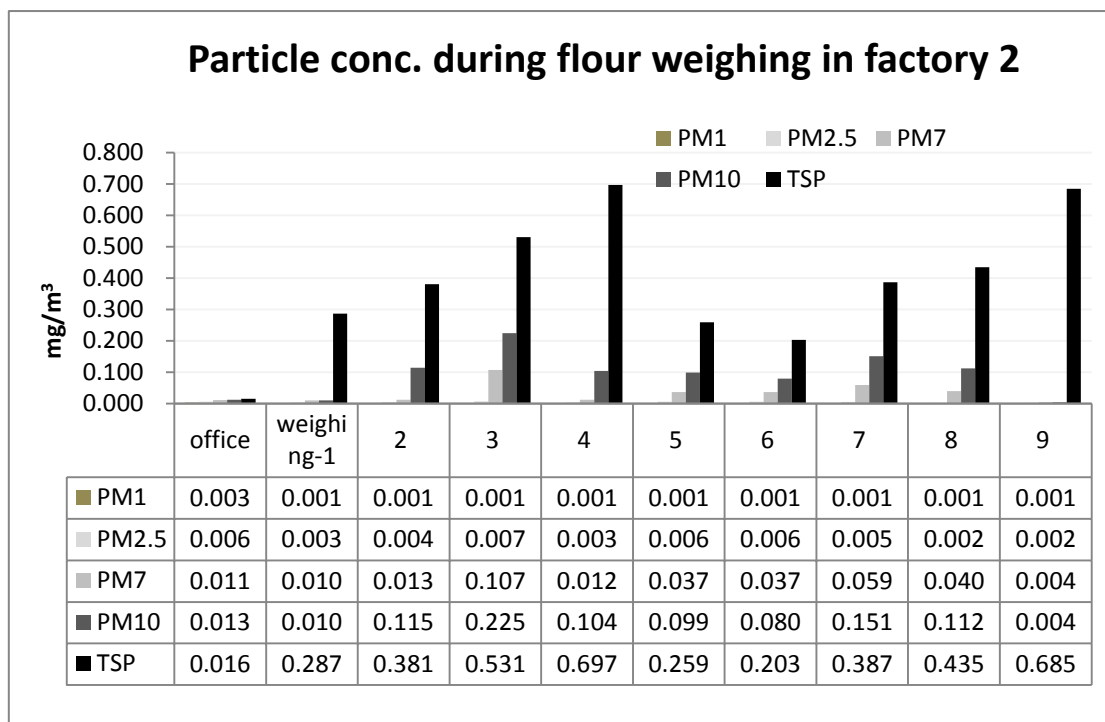


Figure 17 Particle mass concentrations during flour weighing in factory 2

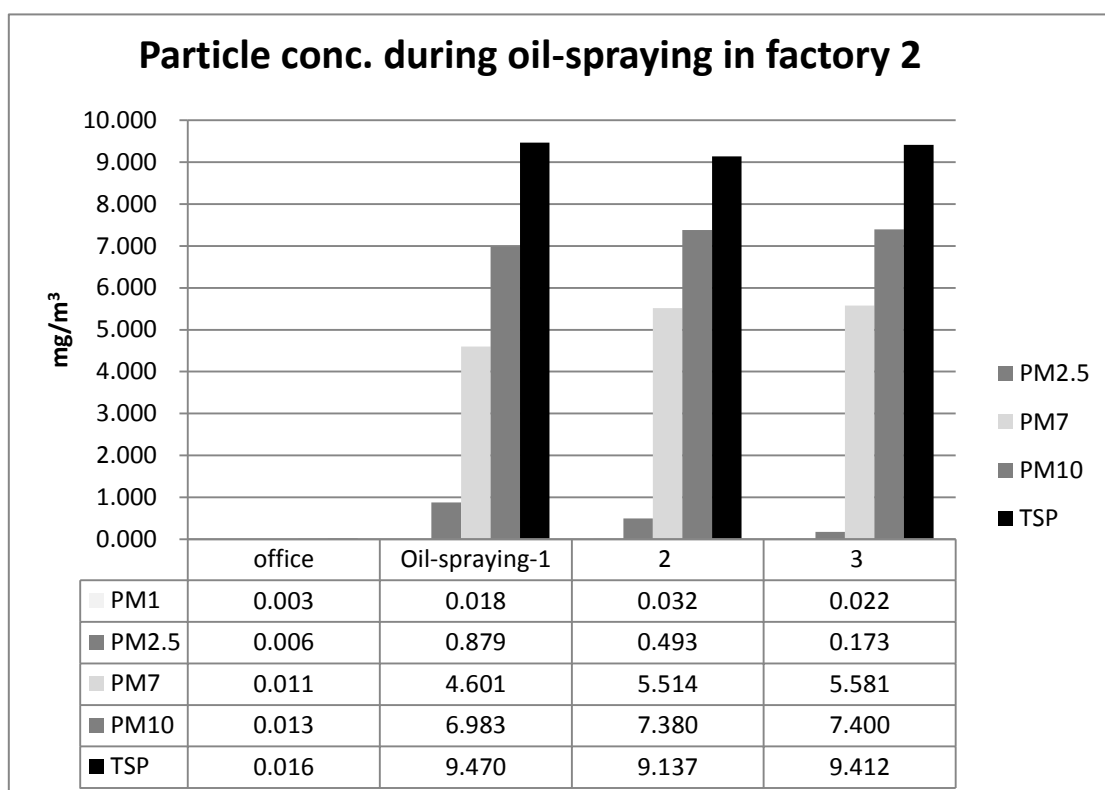


Figure 18 Particle mass concentrations during oil sprayed in factory 2

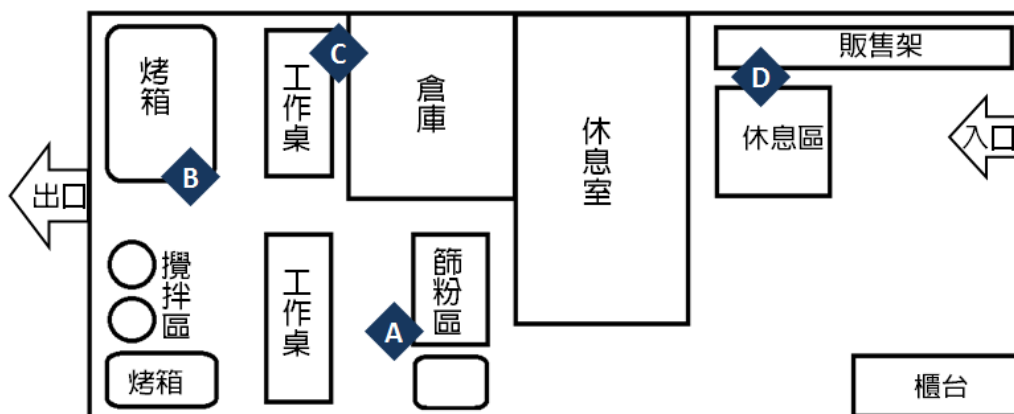


Figure 19 Similar exposure group and sampling sites in retail store 3

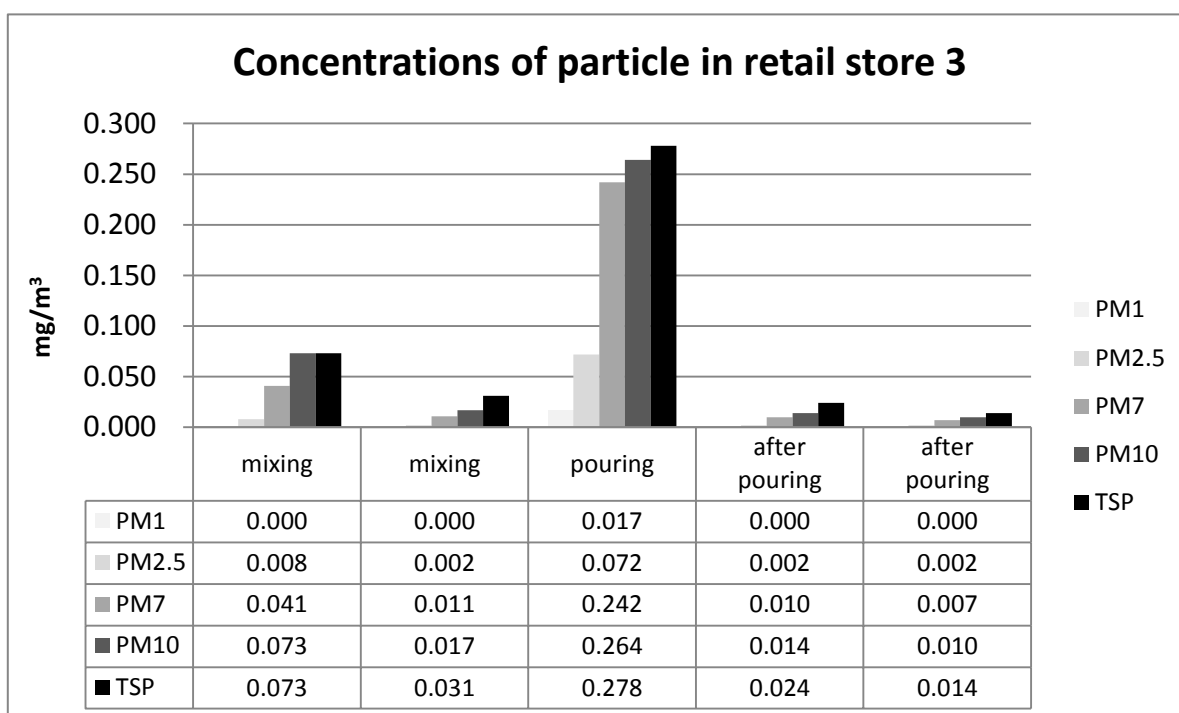


Figure 20 Particle mass concentrations in retail store 3

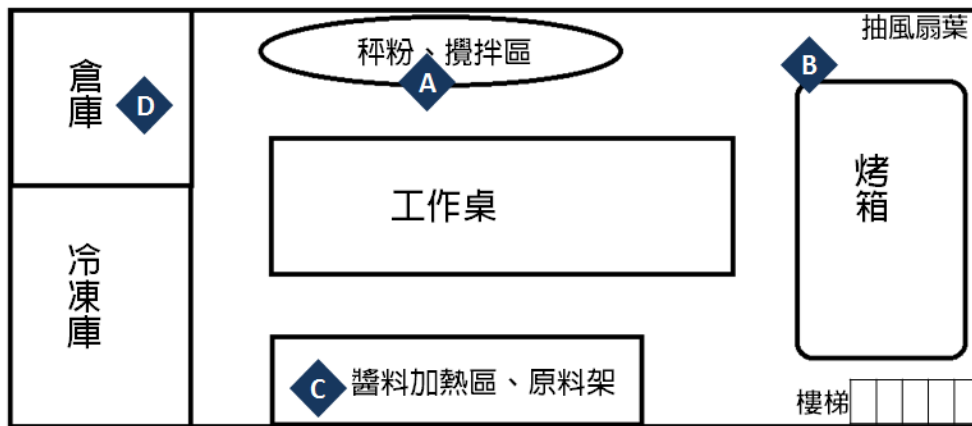


Figure 21 Retail store 4 similar exposure group and sampling sites

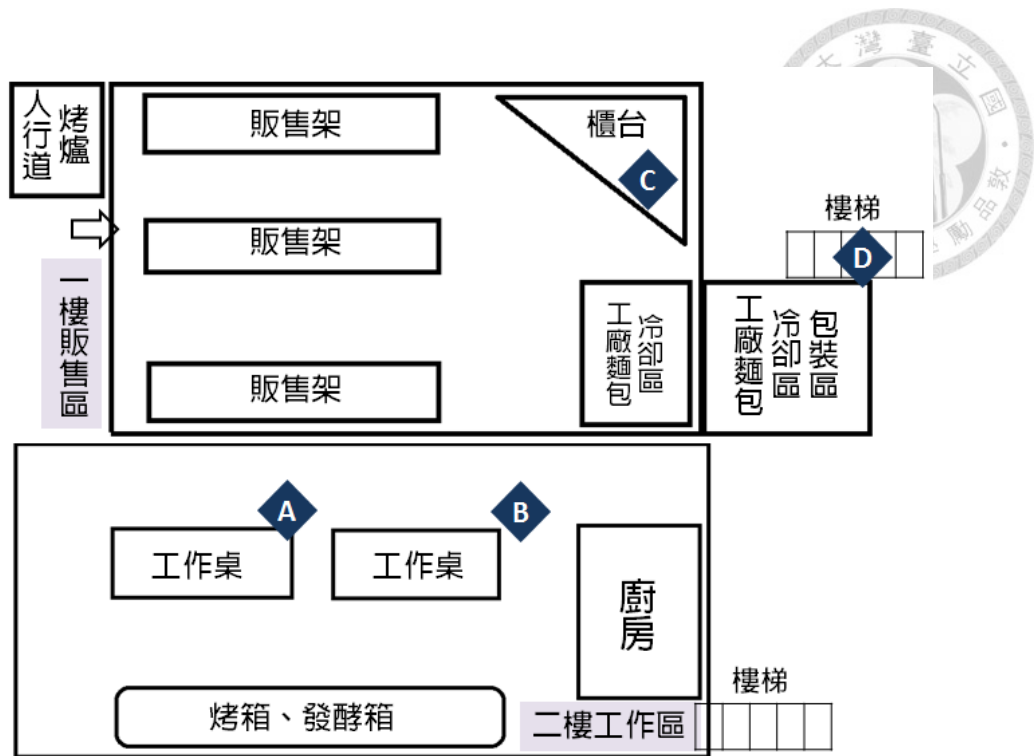


Figure 22 Retail store 5 similar exposure group and sampling sites

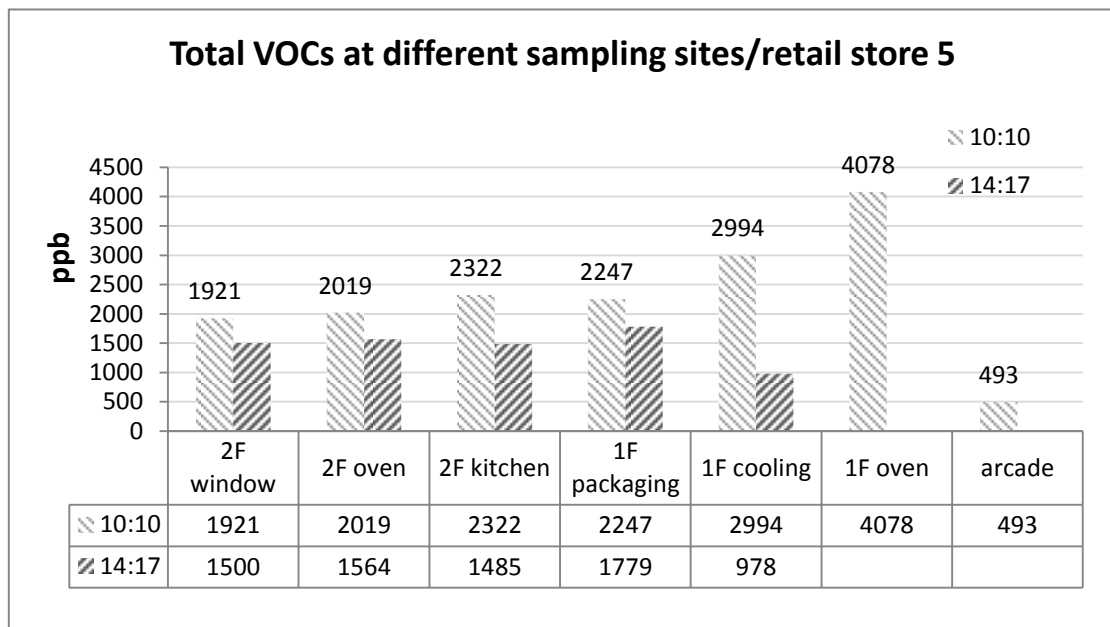


Figure 23 Concentrations of total volatile organic compounds retail store 5

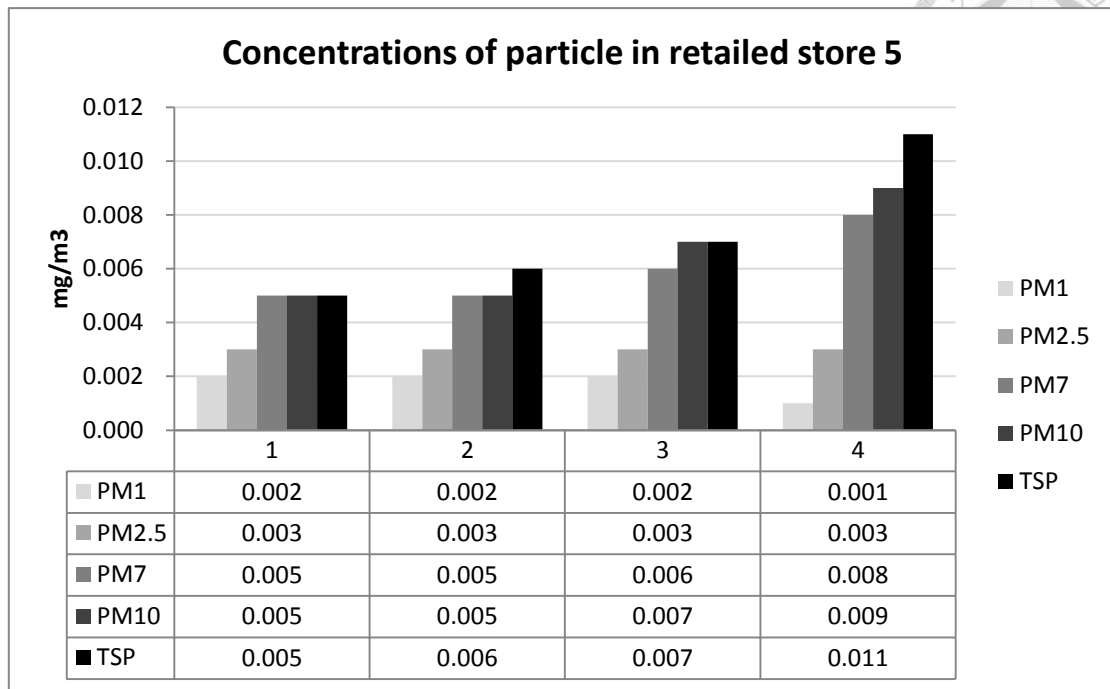


Figure 24 Particle mass concentrations in retail store 5

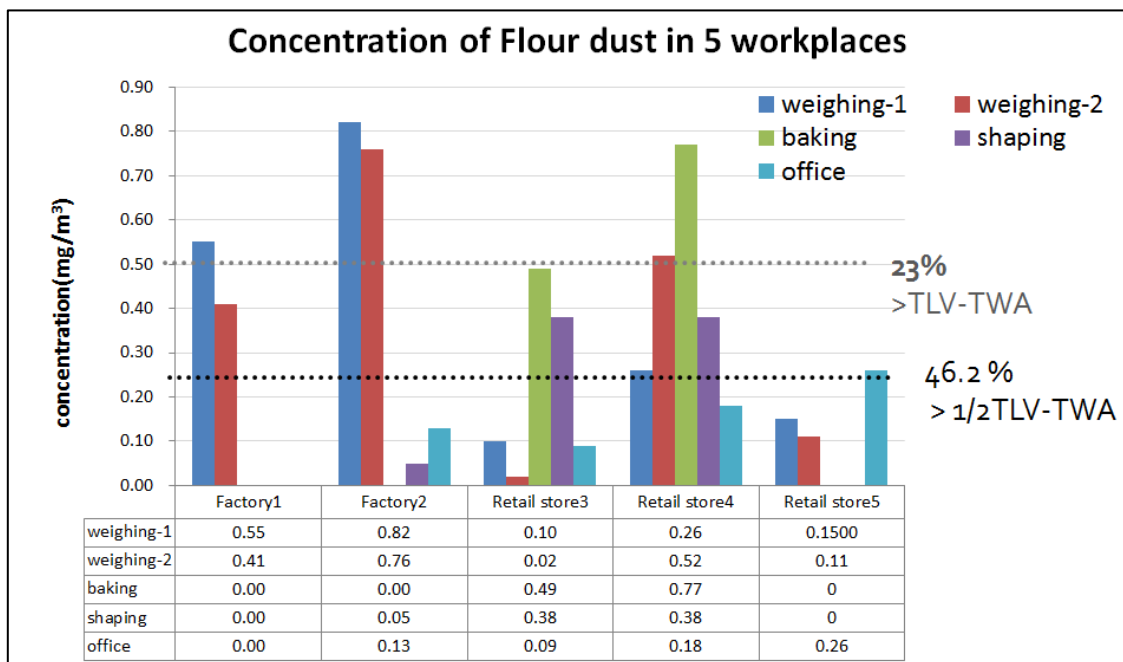


Figure 25 Comparison of detected inhalable dust concentration with TLV-TWA

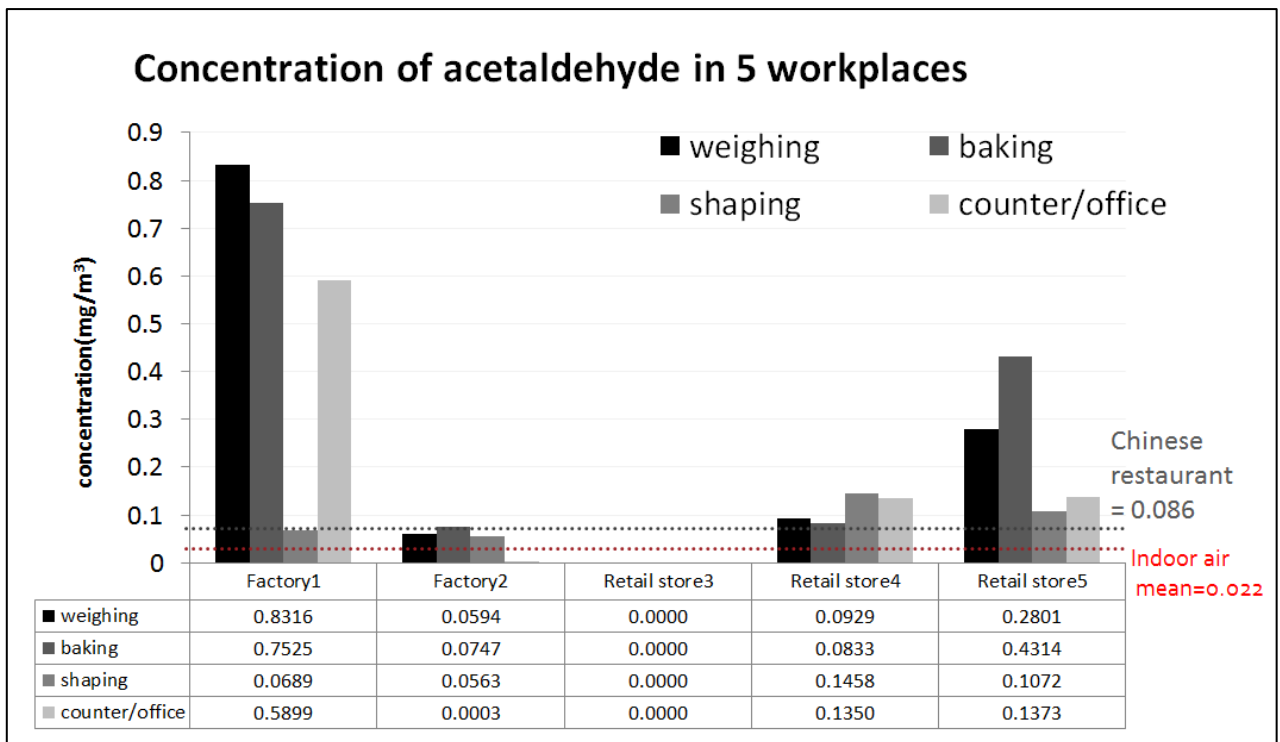


Figure 26 Concentration of acetyldehyde in different workplaces

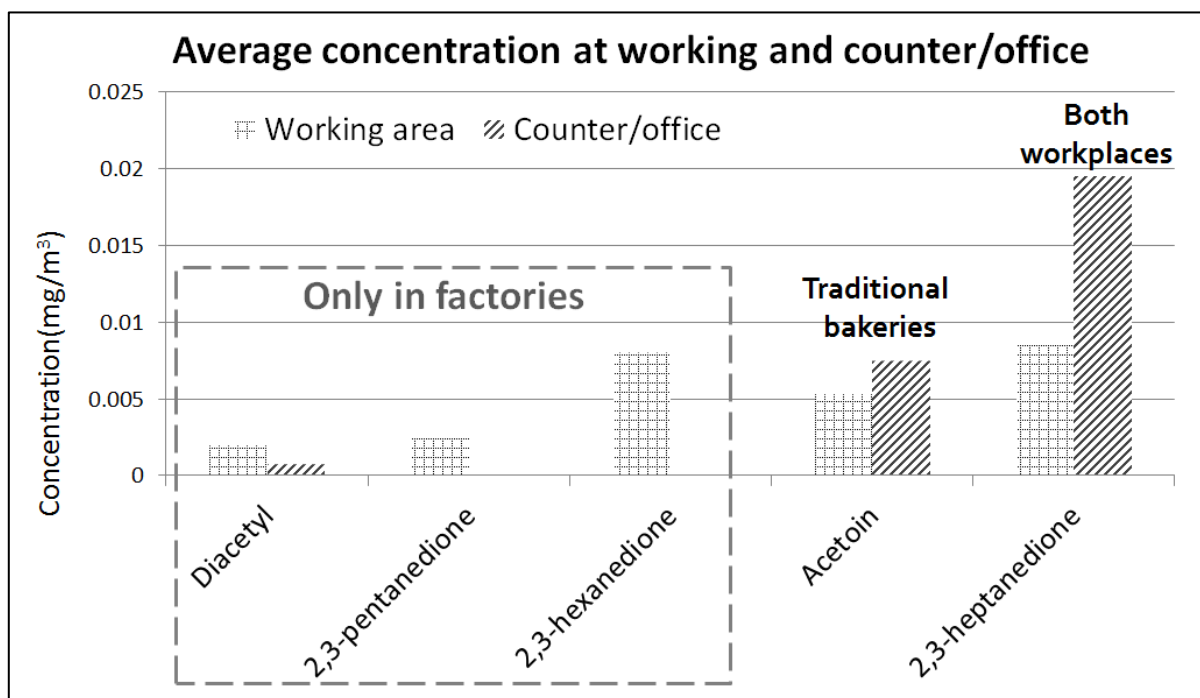


Figure 27 Average concentrations of ketones at working and counter/office