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Cooking activities in a domestic kitchen: chemical and toxicological profiling of emissions

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Abstract

To obtain emission factors and cooking-related chemical signatures, a monitoring campaign was carried out in a modern kitchen where different dishes of the Latin cuisine were prepared. Particulate matter (PM_{10}, $PM_{2.5}$ and PM_1) and total volatile organic compounds (TVOCs) were continuously. Passive ~~diffusion~~ tubes for carbonyls and a high volume PM_{10} sampler were simultaneously used. PM_{10} filters were analysed for organic and elemental carbon and for multiple organic compounds, including polyaromatic hydrocarbons (PAHs). The toxic potential of PM_{10} was evaluated using a bioluminescence inhibition bioassay. Acrolein was never detected, while formaldehyde and acetaldehyde levels were comparable to those in the background air. The protection limit for TVOCs was always exceeded. Fine particles comprised more than 86% of the PM_{10} mass concentrations. PM_{10} emission rates ranged from 124 to 369 µg min^{-1}. Relatively low PAH concentrations were obtained. PM_{10} encompassed alcohols, acids, plasticisers, alkyl esters, sterols, sugars, polyols, glyceridic compounds, phenolics, among others. Total concentrations of these compounds were 1.9-5.3 times higher during cooking than in the background air but, for some compounds, differences of tens or hundreds of times were registered. PM_{10} from grilled pork was found to contribute to non-negligible cancer risks and to be very toxic, while samples from other dishes were categorised as toxic.

Keywords: cooking, indoor air quality, PM_{10} emission rates, organic compounds, bioluminescence inhibition bioassay

1. Introduction

When the COVID-19 pandemic forced global lockdowns, one positive, although temporary, aspect was a decrease in outdoor air pollution (e.g. Baldasano, 2020; Wang et al., 2020). Nevertheless, this focus on outdoor air pollution overlooks the simple fact that most of our exposure takes place indoors, where levels can far exceed those measured outdoors (Alves et al., 2020a). Lockdowns most likely exacerbated this even further. It has long been recognised that cooking is one of the main indoor pollution sources (Abdullahi et al., 2013; Zhao et al., 2019a). It can release unhealthy air contaminants from heating oil, fat and other food ingredients, particularly at high temperatures. Studies have shown that cooking-related pollutants can increase the risk of many diseases (Lee and Gany, 2013; Wang et al., 2017; Zhao et al., 2019a). While there is ample research on the impact of gaseous and particulate matter ($PM_{2.5}$ and PM_{10}) pollution outdoors, much less is known on the health effects of these pollutants when they are generated inside the house. Archer-Nicholls et al. (2016) modelled surface $PM_{2.5}$ fields to assess the impact of residential emissions from cooking and heating activities on the burden of disease in China, estimating that 341,000 premature deaths (159,000 and 182,000 from heating and cooking emissions, respectively) are attributable to residential combustion, which represent about 1/3 of the total deaths due to ambient $PM_{2.5}$ pollution by all causes. These findings stress the need to mitigate emissions from these sources to reduce the health impacts of air pollution.

Most households in developing countries without access to clean energy use inefficient combustion appliances and fuels (wood, charcoal, peat, agricultural residues and dung), generally in very poorly ventilated conditions. Due to the extremely high global burden of disease that result from exposure to smoke from household air pollution, research on indoor air quality has been focused on kitchens of low-income countries, mainly considering polycyclic aromatic hydrocarbons (PAHs), because of their documented carcinogenicity (e.g. Chen et al., 2016; Ding et al., 2012; Katiyar and Rastogi, 2014; Munyeza et al., 2020; Taylor and Nakai, 2012). Although more than 2.6 billion people worldwide still do not have access to clean cooking, over 450 million people have changed to modern kitchen appliances since 2010 in India and China, as an outcome of liquefied petroleum gas (LPG) programmes and clean air policies (IEA, 2020). The global household cooking appliance market has been segmented by product into cooktops and cooking ranges, ovens, and specialised appliances. Cooktops and cooking ranges are sub-segmented into gas cooktops, electrical cooktops, induction cooktops, and others. As environmental groups and health authorities have increasingly sounded the alarm over natural gas use in homes, electricity has been promoted as a better option for cooking. The lack of a gas network in many regions, on the one hand, and the ease of cleaning electrical ranges and cooktops, on the other, represent other reasons why the market share of these latter devices has grown. In 2018, across the global market, electrical cooktops represented 33% of the global household cooking appliance market share, while gas cooktops, induction cooktops and others accounted for 40%, 22% and 5%, respectively (OMR, 2019).

In addition to the cooking appliance, extraction/ventilation equipment and fuel types, the food preparation techniques, such as frying, roasting and grilling, and the ingredients used can exert a significant impact on pollutant emissions, as demonstrated in bibliographic review articles on the subject (Abdullahi et al., 2013; Kim et al., 2011; Torkmahalleh et al., 2017; Zhao and Zhao, 2018; Zhao et al., 2019a). Cooking ingredients and methods vary widely, reflecting geographical, economic and cultural factors. Thus, it is not possible to generalise emission profiles, being necessary to obtain specific information for each region. A large body of literature has been focused on characterising emissions from Chinese cooking styles and their effects on indoor air quality (Chen et al., 2018; Gao et al., 2013; He et al., 2004a; Hou et al., 2008; Li et al., 2015; Lin et al., 2019; Pei et al., 2016; Peng et al., 2017; Wang et al., 2017; Yao et al., 2015; Zhao et al., 2014, 2018, 2019b; Zhu and Wang, 2003). The determination of new particulate matter emission factors for other types of dishes, more detailed chemical composition profiles, exposure health risk assessments and toxicity testing have been pointed out among the aspects that should be addressed in future researches (Zhao and Zhao, 2018). In order to respond to these challenges and to further develop new cooking-related chemical signatures, which would be beneficial for a quantitative source apportionment, the present study aimed at monitoring indoor air quality in a modern kitchen with clean cooking facilities, equipped with electrical cooktop and range hood, where typical dishes of Latin cuisine were prepared. The study included the determination of particle emission rates, a comprehensive screening of organic compounds and the employment of a toxicity bioassay usually applied to several other matrices but, as far as we know, never to this type of samples.

2. Methodologies

2.1. Sampling

The kitchen was equipped with a vitroceramic cooktop with four burners and a stainless steel under cabinet range hood with 3 speed settings and maximum suction of 162 m^3 h^{-1}. Following the routines of the owner of the house, all the experiments were conducted with the hood turned on, operating at the maximum suction level, and under minimum ventilation (doors and window closed). The 15.5 m^2 kitchen was located on the ground floor of a detached house on the outskirts of the city of Aveiro, Portugal. During the experiments, only the cook remained in the kitchen. Aveiro is characterised by a warm summer Mediterranean climate, due to its proximity to the Atlantic Ocean. As typical of Mediterranean climates, summers are dry, and winters are wet. A coastal feature is that frosts are very occasional and never severe. The maritime influence causes a narrow temperature range resulting in summers averaging around 24 °C in daytime, substantially lower than inland regions on the same parallel in the Iberian Peninsula. Measurements of cooking emissions took place in September and October 2017. Meteorological information for these two months can be found in Tables S1 and S2. October was exceptionally hot and dry.

Real time measurements of temperature, relative humidity, CO_2, and CO were carried out with indoor air quality probes (Gray Wolf®, WolfSense IQ-610). To monitor CO_2 concentrations outdoors, an IAQ instrument from TSI (model 7575 Q-Trak^{TM}) was used. Airborne particulate matter (PM_1, $PM_{2.5}$ and PM_{10}) mass concentrations were continuously recorded by laser photometric instruments (DustTrak, DRX 8533). These measurements were made in duplicate, simultaneously placing monitors next to the cooktop and at about 2.3 m, above the kitchen table (Figure 1). The real time monitors were calibrated by the manufacturers and intercompared with each other at the beginning of the experimental campaign. The DustTrak readings were corrected using the intercomparison line with the gravimetric concentrations obtained in different kitchens, including the measurements of the present study. The main specifications of these automatic instruments can be found in the supplementary material.

PM_{10} was collected with a high-volume air sampler (MCV, model CAV-A/mb) equipped with 150 mm quartz fibre filters (Pallflex®) and operating at a constant flow of 30 m^3 h^{-1}. The filters were preconditioned at 500ºC for 6 h. The instrument was positioned between the cooktop and the kitchen table. In order to guarantee enough mass for the subsequent analyses, in some filters it was necessary to accumulate the PM_{10} emitted during the preparation of two or three meals of the same dish. Table 1 contains information on what was cooked in the various experiments. The cooking temperature was continuously monitored by a thermocouple immersed in the frying pan or pot. Carbonyls were sampled in parallel with PM_{10} filters using Radiello diffusive passive tubes (Code 165). As for continuous measurements, two sets of passive samplers were used, one next to the electric cooktop, the other on the table. PM_{10} and carbonyl background samples were collected for periods equivalent to the sampling of cooking emissions, after ventilating the kitchen, in the absence of any other activity.

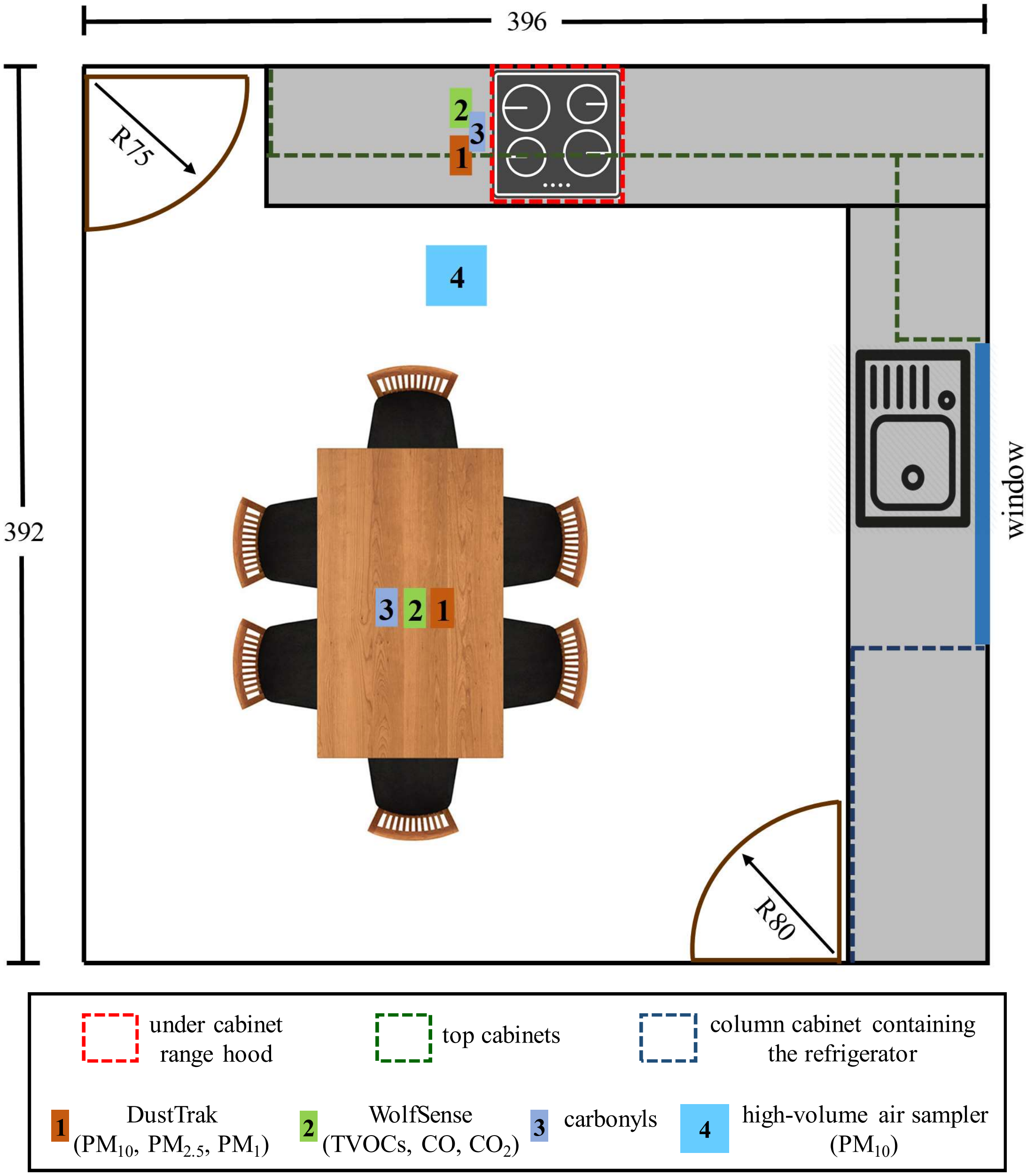
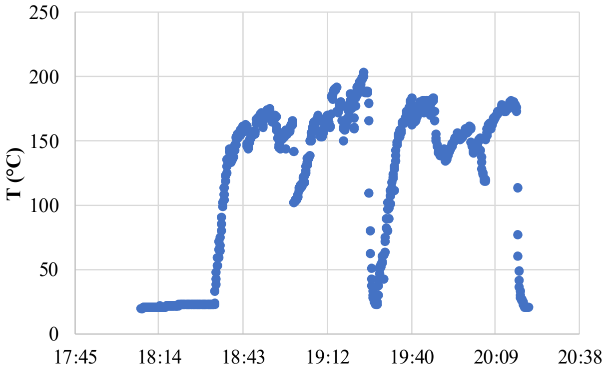
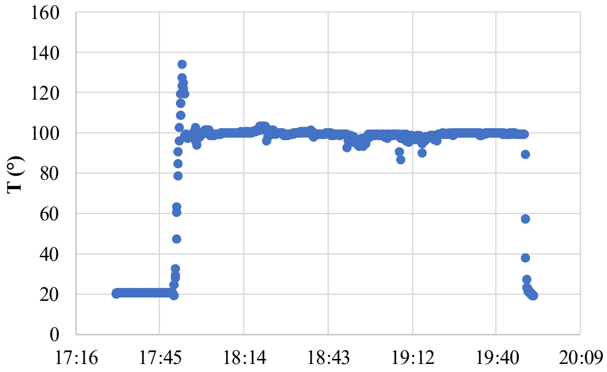
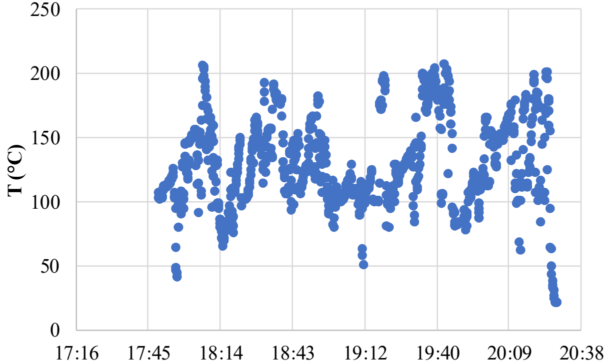
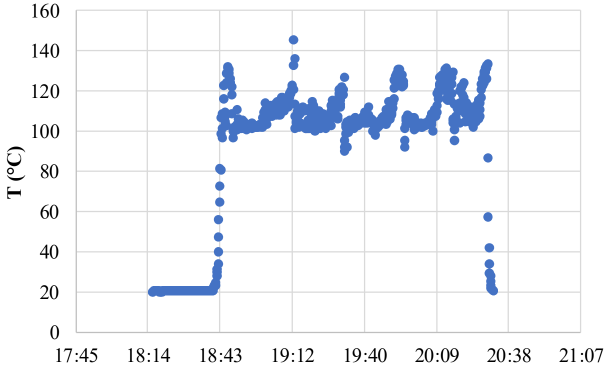


Figure 1. Layout of the kitchen (dimensions in cm)

Table 1. Details of the preparation of the various dishes

Experience nº	Preparation details	Typical temperature profile
	Fried horse mackerel	
# 1	i) 20 little horse mackerels coated with flour + 250 g sunflower oil ii) oil from the frying pan was changed iii) 20 little horse mackerels coated with flour + 250 g sunflower oil Total fish weight = 1630 g Approximate cooking time = 2 h 10 min	
# 2	i), ii) and ii) Idem Total fish weigh = 1273 g Approximate cooking time = 2 h 05 min	
# 3	i), ii) and ii) Idem Total fish weight = 1465 g Approximate cooking time = 2 h 00 min	
	Stuffed chicken	
# 1	olive oil 60 g chopped onion and garlic 93 g 1 bay leaf tomato 160 g ½ green bell pepper (*Capsicum*) 50 g salt + pepper white wine 50 g hot water chicken (with skin partially removed) 1781 g Approximate cooking time = 1 h 50 min	
# 2	olive oil 55 g chopped onion and garlic 104 g 1 bay leaf tomato 185 g ½ green bell pepper (*Capsicum*) 65 g salt + pepper white wine 115 g hot water chicken (with skin partially removed) 1293 g Approximate cooking time = 2 h 00 min	

# 3	olive oil 67 g chopped onion and garlic 130 g 1 bay leaf tomato 180 g ½ green bell pepper (*Capsicum*) 70 g salt + pepper white wine 110 g hot water chicken (with skin partially removed) 1955 g Approximate cooking time = 2 h 15 min	
	Grilled boneless pork strips	
# 1	3100 g of meat seasoned with lemon juice, salt, pepper and chopped garlic Approximate cooking time = 2 h 55 min	
# 2	1360 g of meat seasoned with lemon juice, salt, pepper and chopped garlic Approximate cooking time = 1 h 55 min	
	Fried boneless pork strips	
# 1	2030 g meat marinated for 1 h in wine (200 g), garlic, salt, pepper, bay leaf 300 mL olive oil Approximate cooking time = 2 h 00 min	
# 2	1595 g meat marinated for 1 h in wine (145 g), garlic, salt, pepper, bay leaf 300 mL olive oil Approximate cooking time = 2 h 20 min	

2.2. Analytical techniques

After gravimetric determination of the mass concentrations, two 9 mm filter punches from each quartz filter were used to analyse the carbonaceous content (organic and elemental carbon, OC and EC) by a thermal optical transmission technique following the EUSAAR2 protocol. A detailed description of the analytical methodology can be found in Vicente et al. (2020). Two filter punches of 47 mm from each sample were extracted, first with dichloromethane (125 mL), and then two times with methanol (25 mL + 25 mL). The total organic extracts were concentrated to a volume lower than 1 mL and dried under a gentle nitrogen stream. The dry extracts were then subjected to silica gel flash chromatography using eluents of increasing polarity to separate organic compounds into different classes. After elution, each organic fraction was vacuum concentrated and dried by nitrogen blow down. Polar compounds with hydroxylic and carboxylic groups were converted into the corresponding trimethylsilyl derivatives. The detailed organic speciation was performed by gas chromatography-mass spectrometry. About two hundred standards were used in the calibration. Standards and sample extracts were both co-injected with internal standards. A full description of the entire procedure for the speciation of organic compounds can be found elsewhere (Alves et al., 2011). Carbonyls were analysed by reverse phase high performance liquid chromatography with UV detection at the Istituti Clinici Scientifici Maugeri (Pavia, Italy) (ICS Maugeri, 2019).

The uncertainties associated with the quantification of several organic compounds were estimated following the methodology described by Jiménez et al. (2010). Five main contributions were taken into account: sampling, extraction, clean-up, derivatisation and chromatographic analysis. Depending on the individual compounds, the overall combined uncertainties ranged between 5-12% (PAHs and plasticisers), 10-13% (alcohols), 12-14% (steroids), 6-15% (acids), and 7-11% (sugars).

2.3. Particle emission rates

Particle emission rates were estimated by a simplified mass balance equation as follows:

$$\frac{dC_{in}}{dt} = P\alpha C_{out} + \frac{Q_s}{V} - (\alpha + \kappa)C_{in} \quad (1)$$

where C_{in} and C_{out} represent the indoor and outdoor particle concentrations, respectively, P is the penetration efficiency, k is the deposition rate, α is the air exchange rate, Q_s is the indoor particle generation rate, t is time and V is the kitchen volume. The air exchange rates (AER) were estimated based on the CO_2 decay curve (Alves et al., 2020b; see supplementary material), and were as follows: 0.35 ± 0.29 h^{-1}, 0.51 ± 0.10 h^{-1}, 0.24 ± 0.08 h^{-1} and 0.27 ± 0.22 h^{-1} during the preparation of fried horse mackerel, stuffed chicken, fried pork and grilled pork, respectively. The Excepting V, all the parameters in this equation are functions of some other factors and can vary with time. To estimate an average emission rate ($\overline{Q_S}$), equation (1) is simplified by using average values instead of functions. Some further assumptions have been discussed by He et al. (2004b). Thus, the average emission rate can be obtained by equation (2), which ignores the effects of particle dynamics such as condensation, evaporation and coagulation, because these are qualified as being of minor importance, in particular under the conditions usually encountered in residential environments (Buonanno et al., 2009):

$$\overline{Q_s} = V \times \left[\frac{C_{in} - C_{in0}}{\Delta t} + \overline{(\alpha + \kappa)}\,\bar{C}_{in} - \alpha C_{in0}\right] \tag{2}$$

where C_{in} and C_{in0} are the peak and initial indoor particle concentrations, respectively, Δt is the time difference between the initial and peak particle concentration, $\overline{(\alpha + \kappa)}$ is the average removal rate and α is the average AER. The particle removal rate is the slope of the line obtained by plotting $ln(C_{in}(t)/C_{in0})$ versus time, where $C_{in}(t)$ are the indoor particle concentrations during the decay period, from the moment the peak concentration is reached, and C_{in0} is the initial indoor concentration (Vicente et al., 2020).

2.4. Cancer risk assessment

Carcinogenic risks associated with inhalation exposure to PAHs were estimated using the methodology proposed by the United States Environmental Protection Agency and widely described in the literature (Alves et al., 2020b; and references therein). These estimates were made for 2 scenarios: a) a person who spends 4 hours a day cooking, b) a person who spends all day at home, assuming that the background air of the kitchen is representative of the concentrations in the various compartments of the dwelling (4 cooking hours, 20 non-cooking hours). In the latter case, a time-weighted average of the concentrations was calculated. The benzo[a]pyrene equivalent carcinogenicity (BaPeq) was evaluated by multiplying individual PAH concentrations by their toxicity equivalent factor (TEF). The exposure concentration (EC) is given by:

$$\text{EC} = (\text{CA} \times \text{ET} \times \text{EF} \times \text{ED}) / \text{AT} \tag{3}$$

where CA are BaPeq concentrations (ng m^{-3}), ET is exposure time (h day^{-1}), EF is exposure frequency (350 days $year^{-1}$, considering that people spend 15 days on vacation away from home), ED is exposure duration in residential environments (30 years) and AT is average lifetime (613,200 h). The lifetime lung cancer risk (CR) is estimated based on the World Health Organisation inhalation unit risk (IUR) (WHO, 2000) of 8.7 cases per 100,000 people (8.7×10^{-5} (ng $m^{-3})^{-1}$) and is calculated by multiplying EC by IUR.

2.5. Toxicity assessment

An ecotoxicity assessment of the bulk material was carried out by the *Vibrio fischeri* bioluminescence inhibition bioassay, as described in the ISO standard 21338 (2010). Being a direct contact test, it simulates a potentially realistic exposure route that occurs between the particles and the recipient biological systems. The repeatability of the kinetic test was assessed in a previous work with the control solution (2% NaCl solution), one sediment sample and a Chromium (VI) solution and was found to be excellent. The coefficient of variation was normally below 1% for 10 replicates of each set (Lappalainen et al., 2001).

Filter sample spots of 25 mm in diameter were cut and ground in an agate mortar and then transferred into pre-cleaned 4 mL vials. High-purity water (2 mL) was added to each vial and suspensions were prepared by continuous stirring. The lyophilised bacteria were rehydrated with the reconstitution solution and stabilised at 12°C for 35 min before the luminometer measurements. A duplicate series of eleven two-fold serial dilution was prepared for each sample in 96 well plates. The dilutions were done following the manufacturer protocol with the supplied reagent (2% NaCl solution in water) to ensure optimal osmotic conditions for the bacteria. After addition of the bacterial suspension to the samples, the bioluminescence intensity was continuously recorded for the first 30 s. After the pre-set exposure time (30 min), the luminescence intensity was read again. EC_{50} (concentration causing 50% of ecological effect, bioluminescence inhibition in this case) was calculated using the Ascent Software provided by Aboatox Co., Finland. The toxicity of each sample was expressed in Toxic Units (TU), which is a dimensionless value given as $100/EC_{50}$. Different toxicity classes have been suggested (Chang et al., 2013): $TU < 1$ non-toxic, $1 < TU < 10$ toxic, $10 < TU < 100$ very toxic and $TU > 100$ extremely toxic.

3. Results and discussion

3.1. Gaseous compounds

It has been documented that cooking, especially frying, generates substantial amounts of certain gaseous pollutants such as formaldehyde, acetaldehyde and acrolein (Abdullahi et al., 2013; Katragadda et al., 2010; Peng et al., 2017). In the present study, acrolein, together with butanal, could not be quantified because they were below the detection limit (Table 2). Except next to the cooktop, when horse mackerel was fried, benzaldehyde was also below the detection limit. The levels of formaldehyde and acetaldehyde were generally of the same order of magnitude as those measured in the background air of the kitchen. Formaldehyde never exceeded the protection limit of 100 $\mu g\ m^{-3}$ (8-h average) imposed by the Portuguese legislation for indoor air quality (Ordinance nº 353-A/2013). In the case of acetaldehyde, only when boneless pork strips were fried, concentrations were slightly higher (1.2-1.6 times) than those registered without cooking activities. Propanal concentrations were up to 15 times higher than in background air. The highest values were recorded for the chicken stew. For isopentanal and pentanal, increases in concentrations in relation to the background levels (1.3-1.8 and 1.3-4.3, respectively) were only observed for frying horse mackerel. In general, there were no marked differences between carbonyls in samples next to the cooktop and those obtained on the kitchen table. All compounds showed concentrations tens of times higher than those recorded outdoors.

As expected, since gas was not used for cooking, CO levels were always less than 2 mg m^{-3}, well below the threshold of 10 mg m^{-3} (8-h average) imposed by the Portuguese legislation. However, the protection limit stipulated for TVOCs was always exceeded (Figure 2). On average, concentrations during cooking were 1.5-2.0 times higher than those recorded without any activity and are within the wide range of values reported for commercial and residential kitchens. Singh et al. (2017) measured TVOC mean concentrations of 2244 μg m^{-3} and 932 μg m^{-3} in commercial kitchens equipped with LPG stoves with efficient range hoods in north India (Lucknow) and south India (Coimbatore), respectively, while a lower value of 746 μg m^{-3} was recorded in control locations (non-kitchen areas). From measurements in China, it was concluded that cooking with electric stoves in commercial kitchens would decrease the concentrations of TVOCs by approximately 44-48% compared to those fuelled by gas (Zhao and Zhao, 2018). Zhao et al. (2014) investigated the effect of exhaust hood while cooking typical dishes of 8 Chinese cuisines. The Chinese researchers concluded that the generation of TVOCs has little to do with the preparation times or the common cooking techniques, but rather with seasonings and ingredients used. When wine was added into a dish, the maximum TVOC concentrations were at least 527-543% higher than those registered during cooking of other dishes. Marinating was pointed out as another reason for high TVOC emissions, even without cooking wine, contributing to peak concentrations that were 80-556% higher than the others. Compared to hood idle mode, the decrease in peak concentrations of TVOCs was 137-4212% in hood working mode. The results of the present study corroborate the conclusions by Zhao et al. (2014), since the highest TVOC concentrations were recorded during the preparation of the dish with addition of wine (stuffed chicken) and for the meat that had previously been marinated (fried pork).

Table 2. Carbonyl concentrations during cooking, in the background air of the kitchen and in the outdoor air

Sampling point	Menu	Concentrations (μg m^{-3})								
		Formaldehyde	Acetaldehyde	Acrolein	Propanal	Butanal	Benzaldehyde	Isopentanal	Pentanal	Hexanal
Next to cooktop	Fried horse mackerel	33.8	36.6	< 0.02	11.8	< 0.10	2.95	17.4	34.0	156
On the kitchen table		33.7	30.5	< 0.02	19.7	< 0.10	< 0.02	12.2	7.59	48.4
Next to cooktop	Stuffed chicken	31.3	40.6	< 0.02	59.9	< 0.10	< 0.02	7.17	< 0.05	27.9
On the kitchen table		33.2	30.1	< 0.02	19.9	< 0.10	< 0.02	11.0	5.42	47.5
Next to cooktop	Grilled boneless pork strips	33.6	24.1	< 0.02	7.08	< 0.10	< 0.02	7.07	< 0.05	30.1
On the kitchen table		33.4	23.2	< 0.02	6.75	< 0.10	< 0.02	6.80	< 0.05	29.0
Next to cooktop	Fried boneless pork strips	36.9	60.5	< 0.02	5.41	< 0.10	< 0.02	6.66	< 0.05	26.4
On the kitchen table		33.2	46.9	< 0.02	4.37	< 0.10	< 0.02	5.29	< 0.05	25.1
Background air of the kitchen	-	43.2±0.12	38.0±0.68	< 0.02	4.04±0.12	< 0.10	< 0.02	9.77±0.98	4.88±1.45	36.4±0.40
Outdoor air	-	2.23±0.06	0.75±0.03	< 0.02	0.24	< 0.10	0.25±0.14	0.26±0.07	< 0.05	0.34±0.01

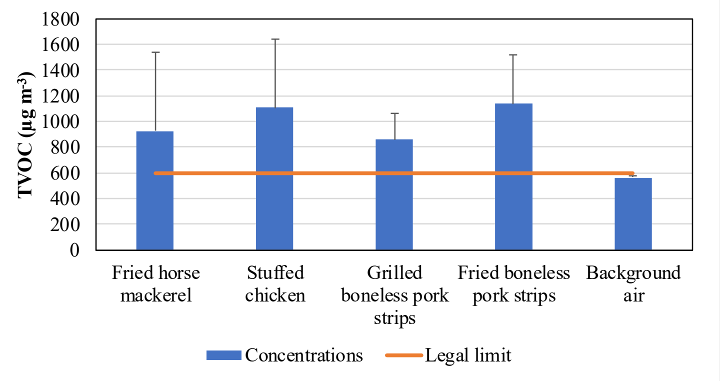


Figure 2. Concentrations of total volatile organic compounds during cooking and protection limit (8-h average) stipulated by the Portuguese legislation of indoor air quality

3.2. Particle emission rates

The PM_{10} emitted by cooking was mainly composed of "high risk" respirable sizes. In fact, fine particles represented a large fraction of the aerosol. On average, $PM_{2.5}/PM_{10}$ ratios of 0.88, 0.88, 0.95 and 0.89 were registered for fried horse mackerel, stuffed chicken, grilled pork and fried pork, respectively. The corresponding ratios of submicron particles (PM_1/PM_{10}) were 0.86, 0.87, 0.94 and 0.87. The temporal evolution of the PM_{10} values measured next to the cooktop and on the table followed the same profile, but the concentration spikes in the latter point were not as pronounced. The global averages recorded near the cooktop were 1.3-1.4 times higher than those obtained on the table. To estimate the PM_{10} emission rates, the time series obtained at the point closest to the emission source were used.

PM_{10} emission rates did not differ significantly between dishes and were of the same order as those reported for kitchens in Australia, but well below the values described for heating oils and Chinese cooking (Table 3). However, it is necessary to keep in mind that many of the published values were obtained in laboratory simulations with the hood turned off. Chen et al. (2018) reported $PM_{2.5}$ emission rates in the order of thousands of µg min^{-1} for the preparation of 25 oil-based Chinese recipes in a residential kitchen with range hood off. The repetition of two of the experiments with the exhaust range hood running (233 m^3 h^{-1}) showed a reduction of approximately 58% in the $PM_{2.5}$ emission rates. Even so, the emission rates obtained during cooking with the hood on, or those generated during the heating of the pan without ingredients (398 µg min^{-1}), are higher than those of our study. The differences are, at least in part, due to the use of a gas range in the Chinese kitchen. It was also documented that, when a hood was turned on, the peak concentrations of $PM_{2.5}$ suffered a decrease of about 30.8% and 59.6% for oil heating and stir-frying, respectively, with windows and doors closed (Zhao and Zhao, 2018; and references therein). Emission rates of particulate matter have been reported to differ enormously, depending on the type of appliance, cooking method, ingredients, meat/vegetable ratio, among other factors (Chen et al., 2018). Particulate emissions rates from the oil heating process can also be in a broad spectrum. Buonanno et al. (2009) found that when grilling, a gas stove produced more particles than an electric stove. In a compilation of values from the literature, Hu et al. (2012) reported arithmetic means of 633±1550 and 183±817 µg min^{-1} for electric and gas ranges, respectively.

Table 3. Particulate matter emission rates in different cooking experiments

Experimental conditions	Food	Emission rates (µg min^{-1})	Reference
PM_{10} Residential kitchen Electrical cooktop Hood turned on	Fried horse mackerel Stuffed chicken Grilled pork Fried pork	124-318 250-369 142-225 149-217	This study
Median values of $PM_{2.5}$ Residential kitchens, Brisbane Details not provided	Cooking Cooking pizza Frying Grilling Kettle Microwave Oven	110±990 1590 2680±2180 2780±17,800 670±30 420±30 530±30	He et al. (2004b)
$PM_{2.5}$ Heating oils Measurements in a 0.81 m^3 laboratory hood Oil heated in a glass beaker over a hot plate	Olive Peanut Safflower Soybean Rapeseed Corn Coconut	54×10^3 3600 3000 6000 5400 25.8×10^3 27×10^3	Torkmahalleh et al. (2012)
$PM_{2.5}/PM_{10}$ Heating oils Laboratory kitchen Exhaust hood turned off	Rapeseed Soybean Peanut Olive Sunflower Blend	$42.6\times10^3/67.2\times10^3$ $22.8\times10^3/34.8\times10^3$ $66\times10^3/100\times10^3$ $69.6\times10^3/140\times10^3$ $22.2\times10^3/30.6\times10^3$ $24.0\times10^3/40.2\times10^3$	Gao et al. (2013)
$PM_{2.5}$ Chinese residential cooking with range hood off	Chinese cooking Stir-frying, pan-frying, and deep-frying	2056±3034 3352±3358	Chen et al. (2018)
$PM_{2.5}$ Chinese residential cooking with exhaust hood was turned off	Stir-frying Pan-frying Deep-frying Steaming Boiling	2560-2650 1610-1690 320-560 40 80	Zhao et al. (2019b)
Portable kitchen in an 80 m^2 open-plan laboratory Gas stove at maximum power when grilling	Cheese Pork meat Bacon Eggplant	9.5×10^3 1.0×10^4 1.2×10^4 5.2×10^2	Buonnano et al. (2009)

Grilling over a gas stove at both minimum and maximum stove power	50 g of bacon	$1.3\pm0.5\times10^4$ (full power) $5.2\pm0.2\times10^2$ (min. power)	Buonnano et al. (2009)
Grilling over a gas stove and an electric stove	50 g of bacon	$5.2\pm0.2\times10^2$ (gas) $1.5\pm0.2\times10^3$ (electric)	Buonnano et al. (2009)
Gas stove at maximum power for the frying of 50 g of chips	Olive oil Peanut oil Sunflower	2.8×10^3 1.8×10^3 1.2×10^3	Buonnano et al. (2009)
Electric frying pan for frying 50 g of chips and 250 g of cheese	Chips (olive oil) Chips (peanut oil) Chips (sunflower oil) Cheese (sunflower oil)	2.0×10^2 6.3×10^1 3.1×10^1 3.3×10^1	Buonnano et al. (2009)

3.3. PM_{10} levels and carbonaceous constituents

The concentrations of PM_{10} in the filters sampled during cooking were 3 to 6 times higher than that obtained in the background air (Table 4). Bibliographic compilations of particle mass concentrations measured in indoor environments close to cooking activities can be found in Abdullahi et al. (2013), Zhao and Zhao (2018) and Zhao et al. (2019a). Most studies concluded that high-fat foods produce more PM, and frying emit more fine particles than water-based cooking. Concentrations of PM are much higher in gas-fuelled kitchens than those measured in spaces equipped with electrical appliances. In general, PM levels are higher in commercial kitchens than in domestic kitchens mainly due to differences in the amounts cooked. The average mass concentrations of $PM_{2.5}$ released during cooking are within the very wide ranges from 22 to 44,920 $\mu g\ m^{-3}$ and from 12 to 4493 $\mu g\ m^{-3}$ in commercial and domestic kitchens, respectively. PM_{10} and $PM_{2.5}$ peak concentrations from heating different types of oil could achieve 7400-30,000 $\mu g\ m^{-3}$ and 6500-18,800 $\mu g\ m^{-3}$, respectively, under distinct ventilation conditions.

Organic carbon accounted for PM_{10} mass fractions between 17% (fried pork) and 36% (fried horse mackerel), whereas a value of 15% was found in the background air. Regardless of the menu, EC contributed to mass fractions always around 3%, while the background percentage was slightly higher (4.4%). OC/EC ratios in aerosols from cooking were 1.7 to 3.5 times higher than in particulate matter sampled in the absence of activities. Zhao et al. (2019b) collected samples of emissions from a Chinese residential kitchen for the five most common cooking methods. In comparison with our study, higher particulate matter ($PM_{2.5}$) concentrations were obtained, especially for frying processes: stir-frying 0.68-0.99 mg m^{-3}, pan-frying 0.29-0.48 mg m^{-3}, deep-frying 0.14-0.24 mg m^{-3}, steaming 0.04 mg m^{-3}, and boiling 0.08 mg m^{-3}. In addition to the different cooking styles, the higher concentrations in the Chinese study most likely result from the fact that the fan of the exhaust hood was turned off during the measurement periods. Zhao et al. (2019b) concluded that, in general, the three oil-based cooking methods produced similar chemical profiles, where OC represented the major mass fraction (72-74%)

of $PM_{2.5}$, while the EC contribution was minor (1.0-1.3%). OC mass fractions were lower in samples from steaming (43.5%) and boiling (59.6%), but the EC proportions were larger compared to the frying methods (steaming 2.4%, boiling 8.4%). Lower Huboyo et al. (2011) determined the carbonaceous content of $PM_{2.5}$ collected in a small kitchen of 3 m^2 in an apartment in Kyoto equipped with exhaust fan and with a gas-fuelled appliance. OC concentrations ranged from 6.8 $\mu g\ m^{-3}$ (chicken boiling) to 43.3 $\mu g\ m^{-3}$ (chicken frying), whereas EC varied between 0.78 $\mu g\ m^{-3}$ (tofu boiling) and 4.1 $\mu g\ m^{-3}$ (chicken frying). Except in $PM_{2.5}$ from chicken boiling, for which an OC mass fraction of 22% was obtained, the mass fractions for the other 3 samples were around 40%. The EC mass fractions were in the 3-4% range, irrespective of the menu, in agreement with what was found in the present study. See and Balasubramanian (2008) reported that the proportions of EC to $PM_{2.5}$ were 9% in boiling and 8-12% in frying, whilst the respective OC mass fractions were 44% and 52-63%. Since Huboyo et al. (2011) and See and Balasubramanian (2008) made similar dishes in the same type of appliance, the variations observed are probably the result of differences in ventilation conditions, given that the latter authors did not use an exhaust hood. Li et al. (2015) collected $PM_{2.5}$ samples from five different cooking activities (meat roasting, cafeteria frying, fish roasting, snack-street boiling, and cafeteria boiling) in Ya'an, China. According to the authors, oils and high-fat raw materials contributed to the high OC contents (>53% of $PM_{2.5}$) and OC/EC ratios (>54) in meat roasting and cafeteria frying samples. Contrary to OC, no significant variation of EC was noticed in all the cooking samples (0.8–2.8% of $PM_{2.5}$). It was argued that, in conventional Chinese cooking, the major fuel is natural gas, which has relatively high kindling temperature and a low EC emission factor. Although clearly higher than those of traffic emissions, very variable OC/EC ratios have been documented for cooking aerosols in other studies (Li et al., 2015; and references therein). The wide range arises from differences in the sampling and cooking conditions.

Table 4. Concentrations of PM_{10} and carbonaceous constituents during cooking operations and in the background air of the kitchen

	PM_{10} ($\mu g\ m^{-3}$)	OC ($\mu g\ m^{-3}$)	EC ($\mu g\ m^{-3}$)	OC/EC
Fried horse mackerel	71.1	25.7	2.13	12.1
Stuffed chicken	24.3	4.74	0.729	6.5
Grilled boneless pork strips	73.1	25.1	2.39	10.5
Fried boneless pork strips	32.4	5.42	0.918	5.9
Background air	11.7	1.77	0.510	3.5

3.4. PM_{10}-bound polycyclic aromatic hydrocarbons

It has been argued that, at high temperature, by pyrosynthesis, organic compounds are partially cracked to smaller unstable fragments, which recombine and lead to relatively stable PAHs (Zhu and

Wang, 2003). Total PAH concentrations of 2.38, 0.920, 2.79, 1.43 and 1.21 ng m^{-3} (Table 5) were found in PM_{10} samples from fried horse mackerel, stuffed chicken, grilled boneless pork strips, fried boneless pork strips and background air, respectively. The corresponding PM_{10} mass fractions were 33.5, 37.9, 38.2, 44.2 and 104 µg g^{-1} (Table S3). Contrary to that observed for the other menus, aerosols sampled during the preparation of the chicken presented concentrations lower than those recorded in the background air. This can result from the extraction efficiency of the hood. Chen et al. (2019) conducted a study in a test chamber with an exhaust hood installed 0.7 m above the deep-frying pan operating at flows ratios in the range of those of the present study. The capture efficiencies of the exhaust hood for total PAHs (gaseous and particulate phases) were found to be up to 77%. It is necessary to bear in mind that concentrations of the present study may, in fact, be significantly higher, since an important part of the PAHs, especially the lighter ones, is in the gas phase. The highest PAH concentrations were observed in the aerosol emitted when grilling pork. PAHs are formed when fat and juices from meat drip onto the heated surface of the grill causing charring and smoke. The concentration obtained when frying horse mackerel was about twice that observed during the frying of pork. It should be noted that higher temperatures, up to 200ºC, were reached by the sunflower oil used in the first dish, while lower values, up to 140ºC, were measured in the olive oil where the second dish was made. It has been reported in previous studies that oil temperatures significantly affect PAH emissions in cooking fumes. Chen and Chen (2003) analysed the smoke emitted during the cooking of chicken legs and concluded that canola oil emitted the highest levels of PAHs, followed by soybean and sunflower oils. Yao et al. (2015) reported that cooking with rapeseed oil produced the highest oil fume PAH concentrations, followed by cooking with olive, peanut and soybean oils.

Zhao and Zhao (2018) summarised the PAH levels measured from Chinese cooking in domestic and commercial kitchens. In general, total particle-phase PAH concentrations ranged from 5.6 to 60 ng m^{-3} and from 6.7 to 63,050 ng m^{-3} for domestic and commercial kitchens, respectively, which greatly depended on the cooking methods. Jørgensen et al. (2013) measured the gas and particulate phase levels of 32 PAHs in a laboratory kitchen equipped with a canopy hood. Measurements were performed by pan frying fresh and smoked bacon on both electric and gas stoves. Total PAH concentrations ranged between 270 and 300 ng m^{-3}. Frying fresh bacon in a gas or in an electric stove was found to produce similar PAH contributions. The highest level of particulate PAHs was obtained when frying smoked bacon. The smoked bacon experiment showed a different PAH profile, in which retene represented 10% of total PAHs, while for the two fresh bacon experiments, it constituted less than 1%. In the present study, retene was also among the compounds with the highest values, accounting for 3.3-8.3% of total PAH concentrations. In the 80's, this alkylated compound was proposed as a marker for softwood combustion and PAH source apportionment but, more recently, it was also detected in coal (Shen et al., 2012) and traffic-related aerosols (Alves et al., 2020c). The presence of retene in cooking aerosols raises strong doubts about its use as a tracer and opens doors for future research on its formation mechanisms. It has been speculated that retene probably has a unique formation process during cooking (Jørgensen et al., 2013). Recently, retene in PM_{10} from the Amazon region has been proven to cause DNA damage and cell death (Alves et al., 2017).

See and Balasubramanian (2008) collected $PM_{2.5}$ samples in the kitchen of an apartment in Singapore while cooking in a gas stove. No exhaust extractor was employed. The mass concentration of the 16 priority PAHs was the highest during deep-frying (36.5 ng m^{-3}), followed by pan-frying (25.0 ng m^{-3}), stir-frying (21.5 ng m^{-3}), boiling (14.3 ng m^{-3}), and steaming (10.5 ng m^{-3}). These concentrations represented a significant enhancement (by a factor of 3-12) over the total PAH loading in the background air (3.10 ng m^{-3}). PAH concentrations of the same order of magnitude as those reported by See and Balasubramanian (2008) were found in $PM_{2.5}$ sampled in a Chinese residential kitchen during the preparation of different recipes with the fan of the exhaust hood turned off (Zhao et al., 2019b): stir-frying (58.9-92.1 ng m^{-3}), pan-frying (41.2-72.6 ng m^{-3}), deep-frying (34.6-50.9 ng m-3), steaming (29.5 ng m^{-3}) and boiling (8.00 ng m^{-3}). Concentrations tens or hundreds of times lower in the present work compared to those reported in other studies result not only from different types of cooking, but also from the fact that gas was not used as fuel and the hood was turned on. Much higher PAH levels have been documented for a commercial kitchen in India, equipped with a “low side wall” rangehood chimney, where at least 5-10 frying activities were conducted during indoor air monitoring. In this kitchen, mean individual concentrations up to 18 mg m^{-3} of particulate-phase PAHs were recorded (Singh et al., 2016). See et al. (2006) determined the levels of $PM_{2.5}$-bound 16 priority PAHs in a university canteen (Chinese, Malay and Indian food stalls). The mass concentrations of PAHs were the bhighest at the Malay stall (609 ng m^{-3}), followed by the Chinese stall (141 ng m^{-3}), and the Indian stall (37.9 ng m^{-3}). This difference in levels was mainly attributed to the distinctive cooking methods employed at the three food stalls and, to a lesser extent, to the amount of food cooked, and the cooking time. Frying processes, especially deep-frying, release more air pollutants, probably due to the high oil temperatures used in such operations. Moreover, it was observed that deep-frying at the Malay stall or stir-frying at the Chinese stall gave rise to greater abundances of higher molecular weight (HMW) PAHs, while low-temperature cooking, such as simmering at the Indian stall, presented higher concentrations of lower molecular weight (LMW) PAHs. The present study contradicts this finding, since the lowest HMW/LMW ratios were obtained in PM_{10} samples from fried horse mackerel and fried boneless pork strips. These ratios were 1.0 and 1.7, respectively, whereas higher values were found for stuffed chicken (2.6) and grilled boneless pork strips (4.3). The highest ratios were obtained for very fluctuating temperatures between 100 and 200ºC, in the case of grilled pork strips, and for very constant values around 100ºC, in the case of chicken. Temperatures in the ranges 150-200ºC and 100-140ºC were recorded when frying horse mackerel and pork strips, respectively. Thus, it was not possible to observe an unequivocal increase in the concentrations of HMW PAHs with the increase of the cooking temperature. This is in line with the results of Zhao et al. (2019b) who reported higher HMW and LMW abundances for steaming and oil-based methods, respectively, arguing that five- to seven-ring PAHs can be decomposed or destroyed at high cooking temperatures during frying, which facilitates LMW-PAH formation.

Table 5. Concentrations of PM_{10}-bound PAHs (pg m^{-3}). Empty cells mean not detected or of the same level of blanks.

	Fried horse mackerel	Stuffed chicken	Grilled boneless pork strips	Fried boneless pork strips	Background air
Naphthalene	218	2.04	14.0		156
Acenaphthylene	9.13			4.36	4.67
Acenaphthene	11.3	7.48	5.87	3.96	13.4
Fluorene	134	24.7	11.2	91.0	79.8
Phenanthrene	153	43.4	61.6	91.6	27.0
Anthracene	9.62	3.38	6.35	6.45	5.23
Fluoranthene	133	51.7	144	92.8	23.4
Pyrene	341	86.4	185	168	64.9
p-Terphenyl	2.83		3.28		
Retene	198	36.8	90.9	71.4	45.7
Benzo[a]anthracene	232	52.1	212	118	64.7
Chrysene	616	244	864	421	188
Benzo[b]fluoranthene	90.0	142	291	122	169
Benzo[k]fluoranthene	35.9	55.8	194	66.8	
Benzo[e]pyrene	111	132	298	126	202
Benzo[a]pyrene	45.0	1.89	152	21.6	44.6
Perylene					
Indeno[1,2,3-cd]pyrene	20.0	16.7	122	6.76	52.2
Dibenzo[a,h]anthracene			11.0		
Benzo[g,h,i]perylene	22.6	17.9	128	21.6	71.3
SUM	2382	920	2794	1433	1213

Diagnostic ratios of PAH isomers are not source-specific, since they markedly reflect the efficiency of combustion and fuel quality. However, these ratios can give some clues about the relative importance of possible sources (Jørgensen et al., 2013). Most of the ratios were similar between the different cooking operations. Except for the Phe/(Phe+Ant) ratio (Table S4), for which the values are clearly higher than those reported for petrogenic sources (0.5 gasoline engines, 0.37-0.70 diesel engines), all the others overlap with the typical values of traffic exhaust emissions (Saldarriaga-Noreña et al., 2015; and references therein).

The compounds that contributed most to the BaPeq concentrations were benzo[a]pyrene (5.8-58.9%), followed by benzo[a]anthracene (8.2-55.4%) and benzo[b]fluoranthene (9.8-43.4%). Cancer risks for a typical behaviour pattern (4 h day^{-1} cooking, 350 days year^{-1}) are shown in Figure 3). Grilling pork contributed to risks that exceeded the acceptable level (1×10^{-6}). Although during the preparation of some dishes the CR values were below the recommended limit, the integrated daily exposure presented non-negligible risks, indicating an increased concern with PAHs in the background air. Higher risks have been reported in the literature for commercial kitchens and deprived rural areas. See et al. (2006) estimated cancer risks of 4.08×10^{-3}, 1.21×10^{-3} and 1.07×10^{-3} at Chinese, Malay and Indian stalls, respectively. Sharma and Jain (2020) measured personal PAH concentrations among three types of kitchens while using traditional and improved cookstoves in rural settings in India. The overall cancer risks were higher in enclosed (2.5×10^{-3}, 6.4×10^{-4}) compared to semi-enclosed (8.4×10^{-4}, 1.3×10^{-4}) and open kitchens (2.2×10^{-4}, 4.6×10^{-5}) during use of traditional and improved cookstoves, respectively.

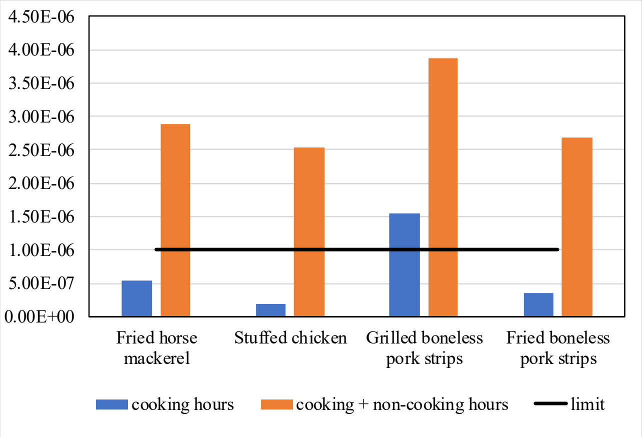


Figure 3. Cancer risks from inhalation of PM_{10}-bound PAHs for common kitchen usage patterns (4 hours a day, 350 days a year)

However, given that the inhaled concentrations, and consequently the cancer risks, depend on the frequency and duration of the exposure, a sensitivity analysis was made considering several cooking times per day and variable annual periodicities (Figure 4). It can be observed that, for chicken and fried pork, regardless of exposure times and frequencies, values are always lower than the carcinogenic target risk of 1×10^{-6}. Exposure to fumes from frying horse mackerel for more than 7 hours a day or more than 250 days a year leads to the possibility of developing 1 excess cancer case per million people. The PM_{10} emitted when grilling pork is the one that constitutes the highest risk, exceeding the value recommended by the WHO when this dish is made every day of the year for periods of exposure greater than 3 hours a day. If the frequency of cooking is reduced to 180 days a year, the associated risks are considered unacceptable for periods of exposure that exceed 5 h per day.

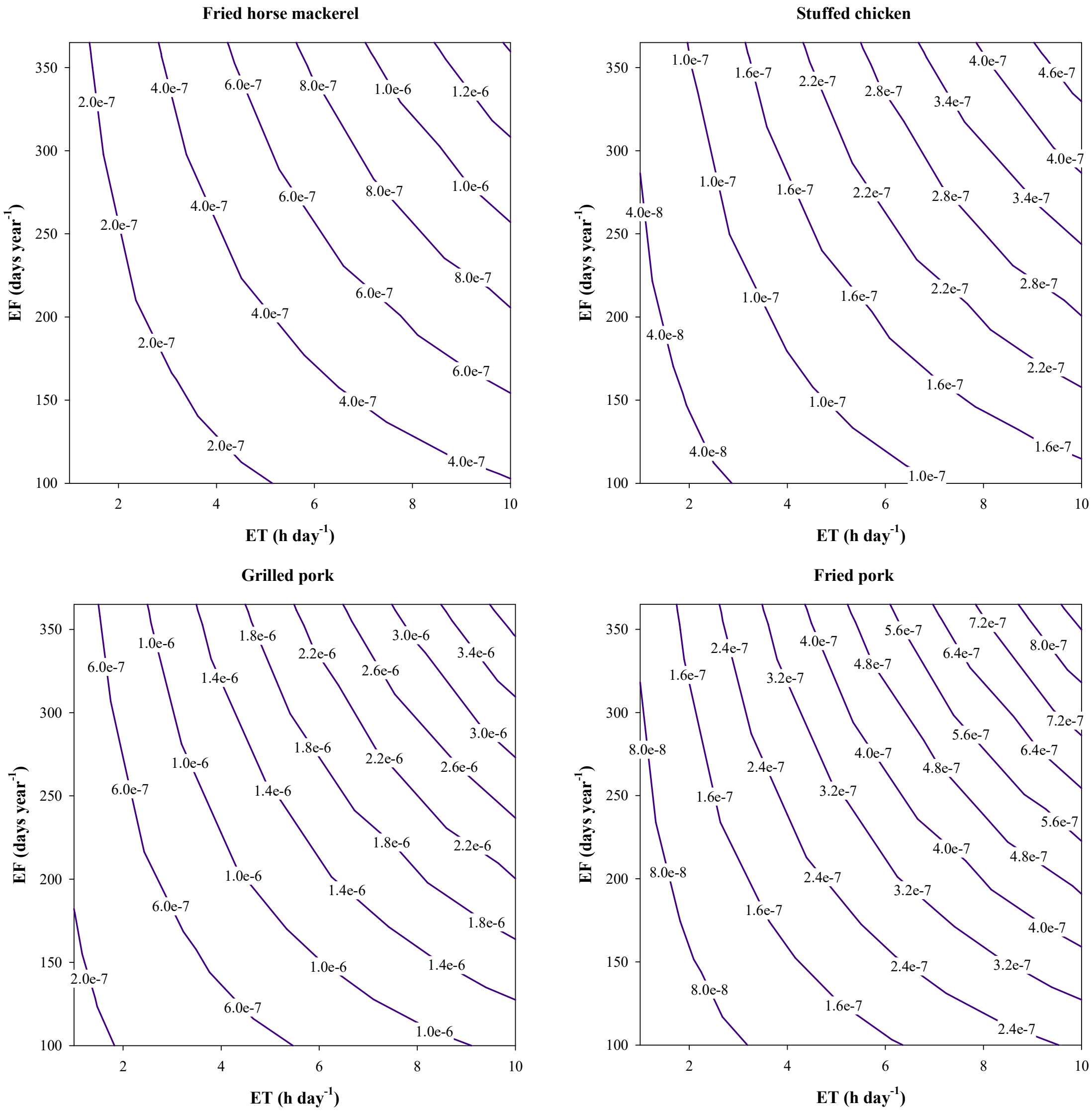


Figure 4. Variation of cancer risks with exposure time and exposure frequency

3.5. PM_{10}-bound oxygenated organic compounds

About 150 oxygenated constituents were quantified in the particulate matter sampled in the kitchen, comprising alcohols, several types of acids, plasticisers, alkyl esters, sterols, sugars, polyols, glyceridic compounds, phenolics and other substances (Figure 5). The full list can be found in the supplementary material (Tables S6 and S6). Total concentrations of these compounds were globally 1.9 (stuffed chicken) to 5.3 (grilled pork) times higher during cooking than in the background air. As summarised by Abdullahi et al. (2013), cooking involves a vast array of chemical reactions. When heated, disaccharides and polysaccharides or carbohydrates suffer hydrolysis reactions, which break down the complex molecules into single ring sugars. If sugars are further heated, degradation reactions will take place with opening of the rings, leading to the formation of new compounds, such as acids. With a sufficiently high temperature rise, recombination of degradation products may occur to form chain-like molecules. Fat in uncooked meat, which occurs as triglycerides (fatty acids esterified to a glycerol backbone), is thermally oxidised or hydrolysed. These reactions result in the formation of free glycerol, free fatty acids and mono and diglycerides. Chemical reactions between proteins and carbohydrates or sugars (Maillard reactions) comprise initial degradation to amino acids and smaller sugars and then production of acids and aldehydes. These latter two classes react with amino acids to form several other new chemicals.

Carboxylic acids were always a dominant organic class, constituting 46, 23, 24, 18 and 11% of the total quantified compounds in the PM_{10} from fried horse mackerel, stuffed chicken, grilled pork, fried pork and background air, respectively. This class encompassed the homologous series of *n*-alkanoic acids from C_6 to C_{26} and some alkenoic acids. As observed in Chinese cooking aerosols (Lin et al., 2019; Pei et al., 2016; Zhao et al., 2007, 2019a), palmitic, linoleic, stearic and myristic were the most abundant acids. The strong prevalence of even-numbered homologs is highlighted by carbon preference indices (CPI) between 6 and 12. Zhao et al. (2007) reported that concentrations of saturated and unsaturated fatty acids were 14 and 3.2 times higher, respectively, in aerosols from Western-style fast food compared to Chinese cooking, attributing the differences mainly to ingredients and temperatures. Ingredients with higher fat content can produce more fatty acids than low fat-content ingredients under the same cooking condition. Higher temperatures favour the degradation of triglycerides and phospholipids and the release of fatty acids. In our study, the highest concentrations of saturated and unsaturated fatty acids were observed in the PM_{10} from fried horse mackerel and grilled pork. The highest temperatures, around 200ºC, were indeed reached during the preparation of these dishes. The distribution and emission rates of fatty acids in cooking aerosols can also be markedly influenced by the fat content and composition of raw foods. The ratios of the polyunsaturated linoleic acid to the saturated stearic acid ($C_{18:2}/C_{18}$) was 4 in PM_{10} from horse mackerel, while values < 1 were found in the remaining samples, according to a much higher content of unsaturated fatty acids in fish.

The abundances of dicarboxylic acids were far less than those of saturated and unsaturated fatty acids. Regardless of the menu, nonanedioic acid was always the most abundant diacid, as described for Chinese and Italian cooking styles (Pei et al., 2016; Zhao et al., 2007). However, hexanedioic acid has been depicted as the dominant diacid in meat cooking fumes (Rogge et al., 1991; He et al., 2004a; Zhao et al., 2007). Thus, hexanedioic to nonanedioic ratios > 1 have been pointed out as typical of Western-style fast food, while values < 1 are distinctive of Chinese cooking (Zhao et al., 2007). In our study, this ratio was always below 0.16.

Aerosols from cooking also comprised the homologous series of *n*-alkanols from decanol to octacosanol, maximising at C_{16}. CPI values always above 14 reflect the even over odd carbon number predominance. The concentrations of these compounds were 2 to 3 times higher in samples collected during cooking periods compared to the background air. Phenolic compounds were another group of substances with hydroxyl groups present in PM_{10}. They can be classified as synthetic or natural. All parts of plants may contain phenolic compounds such as hydroxycinnamic acid derivatives (e.g. coumaric, caffeic, ferulic) and hydroxybenzoic acid derivatives (e.g. hydroxybenzoic, vanillic, syringic, gallic). All these constituents were detected in PM_{10} from cooking. Phenolic compounds are used as primary antioxidants to delay or inhibit the initiation step or interrupt the propagation step of lipid oxidation, thus decreasing the formation of volatile decomposition products that cause rancidity (Shahidi and Ambigaipalan, 2015). The most abundant compound was 2,6-di-tert-butylphenol, a synthetic product. Among other applications, 2,6-di-tert-butylphenol is added as antioxidant to plastics. Due to contact with plastic piping, drinking water may contain 2,4-di-tert-butylphenol. It can also be part of machine wash liquids/detergents. Thus, contamination of food by multiple routes can occur. The concentration of this compound was lower in PM_{10} from stuffed chicken than in the background air. However, in the aerosols of all other foods the levels were 3 times higher, suggesting that its emission may depend not only on the ingredients, but also on the cooking temperatures. Liu et al. (2020) investigated the effects of four cooking methods (boiling, pressure, microwave, slow) and three heating solutions (water, salt, sugar) on the phenolic acids and antioxidant properties of different legumes. It was shown that cooking increased free phenolic acids and lessened bound phenolic acids in some legumes, while decreased both free and bound phenolic acids in others. The effect of cooking methods on the phenolic composition showed significant differences among the four cooking methods. The possible physico-chemical mechanisms by which phenolic compounds are released to form particulate matter are still unclear.

Some plasticisers were detected in PM_{10}. These compounds are extensively used in the manufacturing of plastic materials and are now widespread in all environmental compartments. Among the commercially important plasticisers, phthalic acid esters, or phthalates, account for the major share of the market. The migration of phthalates from packaging materials to fatty food stuffs is a well-known source of food contamination (Petersen and Breindahl, 2000). In the last decades, phthalates have been the focus of much attention since several of these compounds are suspected of owning endocrine and disrupting properties either by mimicking or antagonising the effects of sex hormones or by more indirect mechanisms (Bui et al., 2016). Concentrations of plasticisers in aerosols from meat cooking were 1.2-1.6 times higher than the background level, but in PM_{10} from frying horse mackerel an identical value was obtained. Diethylhexyl phthalate was the most abundant compound. Fierens et al. (2012) analysed 8 phthalate compounds in food products before and after cooking (boiling, steaming, deep-frying and grilling). In general, phthalate concentrations in foods declined after cooking, except in vegetables, where almost no effect was seen. The authors raised the possibility that some phthalates with high vapour pressure can evaporate during processing. After evaporation and condensation, they can partition to the particle-phase. On the other hand, since phthalates are lipophilic, when food products lose fat during processing, they are removed together with the fat phase. Thus, oily fumes can be enriched in plasticiser compounds that were originally present in the lipid phase of foodstuffs. Phthalates can also originate in coatings of non-stick cookware products.

Levoglucosan was detected in similar concentrations in background air and in PM_{10} from stuffed chicken and fried boneless pork strips. However, the levels of these anhydrosugar were 4.6 and 2.2 times higher in aerosols from fried horse mackerel and grilled pork compared to the background value, respectively. Although levoglucosan has been widely used as a biomass burning tracer (Vicente and Alves, 2018), it was previously observed in emissions from Chinese cooking (He et al., 2004a; Hou et al., 2008; Zhao et al., 2007). It was hypothesised that the high temperatures reached in cooking processes could lead to thermal degradation of vegetable cellulose and, consequently, to the emission of levoglucosan. Spices such as *Cumimum cyminum* and *Capsicum* (powder of dry vegetables) used as condiments can also decompose to form levoglucosan (Hou et al., 2008). Although spices and/or green bell pepper were used to season the chicken and fried pork, the temperatures necessary to convert cellulose into levoglucosan were possibly not reached. The highest concentrations in horse mackerel PM_{10} may be associated with the flour used to bread the fish. Most of the fibre present in flour is cellulose.

PM_{10} from grilled boneless pork strips and fried horse mackerel displayed high amounts of sterols, exceeding by 337 and 91 times the concentration recorded in the absence of activities, respectively. Sterols of plant origin are generally referred to as phytosterols, and those of animal origin as zoosterols. Nevertheless, these groups are not mutual exclusive. Cholesterol, a chief zoosterol, can also be found in plant sources, sometimes in large quantities. In the present study, this zoosterol dominated, although the concentration of sitosterol in horse mackerel PM_{10} also deserves to be highlighted. Sitosterol was detected in Chinese cooking aerosols, but not in emissions from Western-style fast food (Zhao et al., 2007).

Several glyceridic compounds were present in the samples of particulate material. Among them, the most abundant were free glycerol and the monoglycerides monomyristin, monostearin and monopalmitin. Globally, the levels of these compounds exceeded by 3 to 40 times the background value. The maximum concentration was achieved in the fumes of grilled pork. The fat in uncooked meat occurs as triglycerides, which consist of three fatty acids esterified to a glycerol backbone. During the cooking process, triglycerides can be hydrolysed or thermally oxidised, yielding, in addition to fatty acids, free glycerol, mono- and diglycerides (Nolte et al., 1999). Triglycerides are also main constituents of vegetable oils. Thus, upon heating, triglycerides of edible oils can form the same reactional products as those observed in meat cooking.

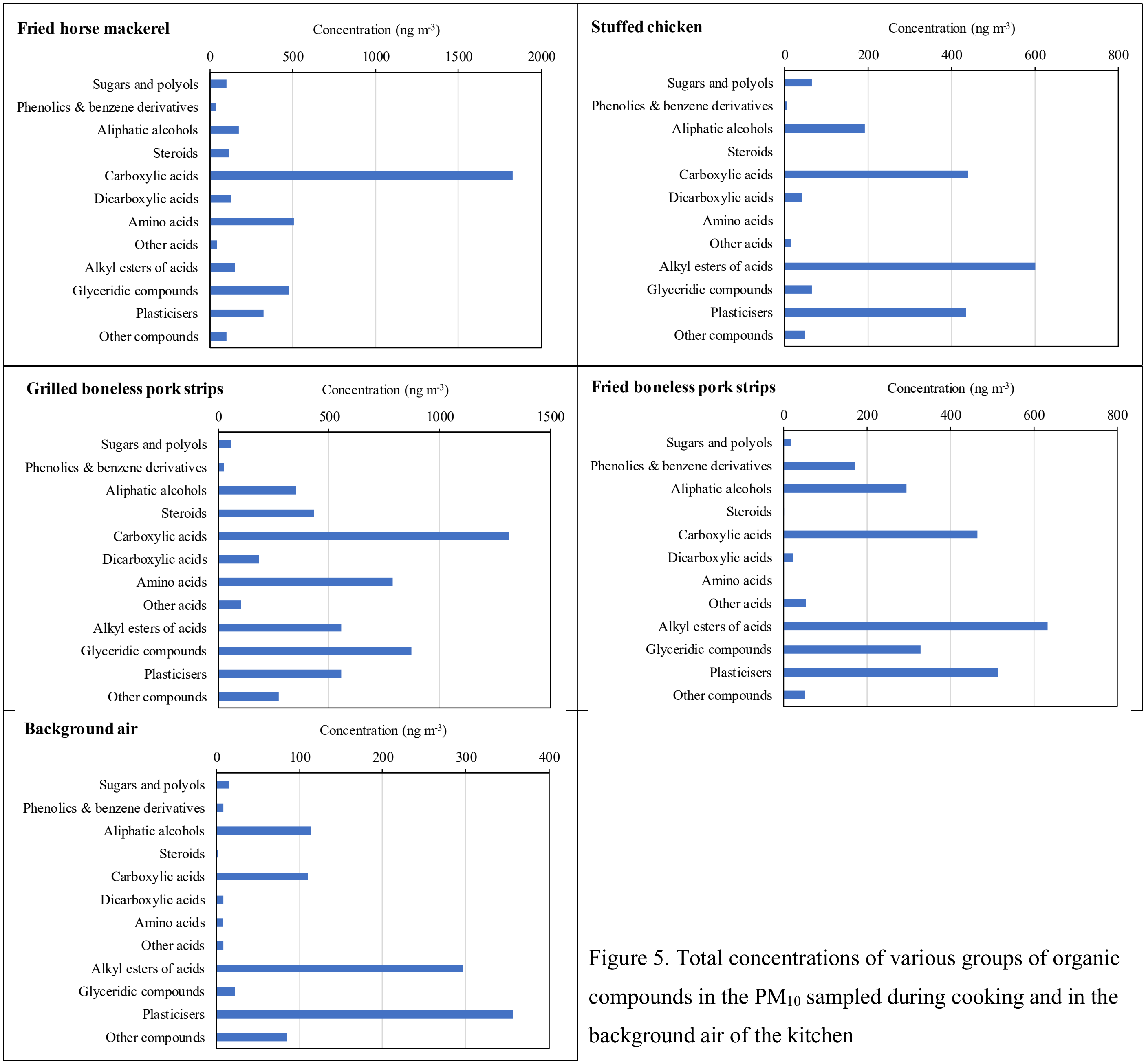


Figure 5. Total concentrations of various groups of organic compounds in the PM_{10} sampled during cooking and in the background air of the kitchen

Various fatty acid alkyl esters were detected both in the background air of the kitchen and in the samples collected while cooking. Isopropyl myristate and isopropyl palmitate were the most abundant compounds. These constituents are widespread because they are in the list of ingredients of several cosmetics and personal care products. Fatty acid alkyl esters are also a family of natural neutral lipids present in vegetable oils formed by esterification of free fatty acids with low molecular alcohols. Inappropriate practices during the olive oil extraction process and bad quality of the olive fruits promote their formation. Thus, alkyl esters of fatty acids are direct indicators of degradation or fraudulent adulteration of vegetable oils (Costa et al., 2017). It is also possible that these ester compounds are a secondary product of lipid oxidation, which include destruction of essential fatty acids, during meat cooking (Domínguez et al., 2019). It has been observed that there is a great variability in changes concerning oxidation of individual fatty acids in response to different cooking methods, but it seems that, in general, losses of total lipids increase directly with the cooking time and internal temperature reached by meat (Alfaia et al., 2010). For the three meat dishes of the present study, the total concentrations of fatty acid alkyl esters were approximately double that recorded in the background air.

In the PM_{10} emitted during the frying of horse mackerel and the grilling of pork, several amino acids were detected. Their concentrations exceeded by 70 and 108 times, respectively, those obtained in the absence of activities. Although the presence of these compounds, as far as we know, has not been previously described for cooking aerosols, they have been quantified as components of primary biological particles in urban (e.g. Abe et al., 2016; Di Filippo et al., 2014), marine (e.g. Mandalakis et al., 2011) and Artic (e.g. Rad et al., 2019) environments. Some works on food degradation during cooking have found that the degree of protein denaturation depends on the cooking method, temperature and type of food, demonstrating differences in protein and amino acid contents (e.g. Hodgkinson et al., 2018; Kim et al., 2017).

3.6. PM_{10} toxicity

The ecotoxicity assessment demonstrated that PM_{10} emissions from grilled pork are very toxic, while those obtained during cooking of all other dishes are classified as toxic (Figure 6). Although the TU value for the background air sample was 1.2 to 14 times lower than those of cooking emissions, it still reveals some toxicity of PM_{10} in the absence of activities. Globally, TU values correlated reasonably well with PM_{10} ($r^2 = 0.59$), OC ($r^2 = 0.58$) and EC ($r^2 = 0.68$) concentrations. Ecotoxic effects of cooking-generated aerosols depend directly on the quantity of carbonaceous particles produced, which act as carriers for toxic compounds bound to this particulate material. A moderate relationship was also obtained between TU and total PAH levels ($r^2 = 0.68$). However, when PAHs are split into molecular weight classes, LMW compounds do not show any correlation with TU, while HMW constituents present an excellent association with toxicity values ($r^2 = 0.94$). HMW PAHs are generally less water soluble, have lower vapour pressures and Henry's constants, and partition more readily into organic matter than LMW PAHs. High concentrations of carbonaceous aerosol strongly favour partitioning of semi-volatile toxic species (such as HMW PAHs) to the particulate phase, thus contributing to the enhanced ecotoxicity of aerosol particles. LMW PAHs exist predominantly in the gas phase due to their relatively high vapour pressure.

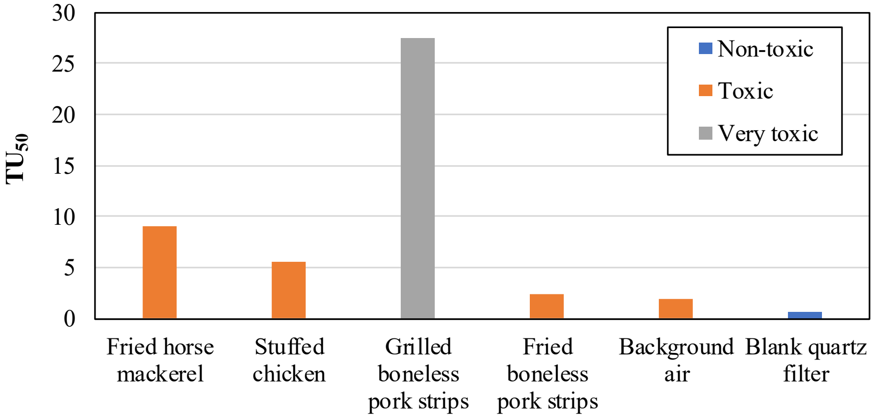


Figure 6. Toxicity of each sample, expressed in toxic units, based on the results of the *Vibrio fischeri* bioluminescence inhibition bioassay

Significant positive correlations between total concentrations of glyceridic compounds, dicarboxylic acids and amino acids and ecotoxicity were also found (Table S7). Likewise, excellent positive relationships ($r^2 > 0.90$) between TU and levels of some individual PM_{10}-bound constituents were derived. The oxygenated compounds most related to toxicity were mannosan (a stereoisomer of levoglucosan), 4-hydroxycinnamic acid, oleic acid, hexacosanoic acid, some diacids (succinic, malic, adipic and sebacic), glyceric acid, citric acid, several n-alkanols (C_{18}, C_{22}, C_{23}, C_{25}, C_{27} and C_{28}), cholesterol, monopalmitin and monostearin.

4. Conclusions

Given that cooking is recognised as a major air pollution source in indoor environments and bearing in mind that culinary methods, and consequently emissions, greatly depend on geography, a monitoring programme was carried out in a modern domestic kitchen, equipped with electrical cooktop and range hood, where typical dishes of the Latin cuisine were prepared: fried horse mackerel, stuffed chicken, and grilled and fried boneless pork strips. The study included measurements of gaseous compounds, the determination of particle emission rates, a detailed screening of PM_{10}-bound organic constituents, and a direct contact bioassay, which has never been applied to cooking samples, to assess toxicity.

Although acrolein has been described as an important carbonyl in cooking emissions, its presence was not observed in the present study. Formaldehyde and acetaldehyde levels were, in general, comparable to those found in the background air of the kitchen, when no activity was being performed. Propanal was enriched in all cooking emissions, whereas isopentanal and pentanal were more abundant in samples obtained while frying horse mackerel. TVOCs were within the wide range of values described for commercial and residential kitchens. The use of marinated meat and the addition of wine during the cooking process seem to contribute to higher concentrations of these compounds.

PM_{10} was mainly composed of high-risk respirable sizes. PM_{10} emission rates did not vary significantly between dishes and were well below the values documented in previous studies for heating oils and Chinese cooking. Likewise, when compared with many of the values described in the literature, much lower PAH levels were obtained. The differences are justified not only by distinctive ingredients and cooking methods, but also by the fact that, in our study, gas was not used as fuel and an exhaust hood was continuously operated. Retene, an alkylated polyaromatic employed so far as a marker of softwood combustion, was among the most abundant PAHs. The highest concentrations of PAHs were recorded for higher cooking temperatures. In addition to PAHs, about 150 oxygenated organic compounds were quantified, some of which were described for the first time, as far as we know, as constituents of cooking aerosols. The proportions of the various organic classes depended on the menu.

Grilling pork was found to emit “very toxic” particles with non-negligible cancer risks, while PM_{10} samples from other dishes have shown to be less hazardous, but still classified as “toxic”. Although the concentrations of most of the compounds were lower in the absence of activities, the background air sample still showed some toxicity. The organic constituents that contributed most to toxicity were HMW PAHs, glyceridic compounds (monopalmitin and monostearin), diacids, amino acids and some individual species, such as cholesterol, oleic acid, mannosan, heavier alkanols, among others.

The chemical signatures for cooking emissions in the present study should be seen as representative of some Latin cuisine dishes made in a biomass-free kitchen with modern appliances. Since cooking emissions are unregulated and potentially toxic, it is necessary to conduct additional studies, covering other cuisines and styles. New studies would be beneficial not only to obtain specific emission profiles, but also to investigate which chemical markers induce health effects. The toxicological significance must be further explored through multiple assays (cytotoxicity, mutagenicity, inflammatory processes, oxidative stress, etc.), especially with respect to the exposure to hazardous vapours and particulate constituents. It seems increasingly important to educate the public of the potential risks of cooking emissions so that they may take informed choices about their behaviours, including the adoption of appropriate kitchen exhaust ventilation technologies.

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CRediT authorship contribution statement

Célia Alves: Conceptualisation, Supervision, Funding acquisition, Project administration, Formal analysis, Writing - Original draft preparation. **Estela Vicente**: Methodology, Formal analysis, Writing – Review & Editing. **Margarita Evtyugina**: Methodology, Writing – Review & Editing. **Ana Vicente**: Methodology, Writing – Review & Editing. **Tsend-Ayush Sainnokhoi**: Methodology, Writing – Review & Editing. **Nora Kováts:** Supervision, Writing – Review & Editing.

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.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at https://doi.org/10.1016/XXXX.XXXX

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SUPPLEMENTARY MATERIAL

Cooking activities in a domestic kitchen: chemical and toxicological profiling of emissions

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Weather in Aveiro in the period of measurements

Table S1. Weather in September 2017

Day	Cloudiness	Temperatures (min/max), °C	Precipitation, mm
1	☀	21/26	0
2	☀	22/28	0
3	☀	20/24	0
4	☁	21/24	0
5	☀	21/24	0
6	☀	23/28	0
7	☀	23/28	0
8	☀	18/22	0
9	☀	18/21	0
10	☀	18/21	0
11	☀	19/23	0
12	☀	19/23	0
13	☀	20/24	0
14	⛅	19/22	0
15	☀	17/20	0
16	☀	16/20	0
17	☀	17/20	0
18	⛅	18/21	0
19	☀	18/22	0
20	⛅	18/22	0
21	☀	18/22	0
22	☀	19/23	0
23	☀	17/22	0
24	☀	19/23	0
25	☀	18/22	0
26	☀	18/23	0
27	☀	20/24	0
28	☀	20/25	0
29	☀	19/24	0
30	☀	18/21	0

Table S2. Weather in October 2017

Day	Cloudiness	Temperatures (min/max), °C	Precipitation, mm
1	☀	20/25	0
2	☀	22/29	0
3	☀	19/25	0
4	☀	18/24	0
5	☀	17/23	0
6	☀	17/20	0
7	☀	22/29	0
8	☀	20/28	0
9	☀	20/27	0
10	☀	20/26	0
11	☀	19/24	0
12	☀	20/28	0
13	☀	17/23	0
14	⛅	21/28	0
15	☀	25/31	0.1
16	☁	17/23	2.8
17	☀	16/20	14
18	⛅	15/18	4.7
19	☁	14/17	0.1
20	☁	18/20	2
21	⛅	15/19	0
22	☀	14/19	0
23	☀	15/22	0
24	☀	18/25	0
25	☀	18/25	0
26	☀	18/26	0
27	☀	20/28	0
28	☀	20/25	0
29	☀	18/24	0
30	☀	17/22	0
31	☀	15/23	0

Air exchange rates

In the present study, the air exchange rates per hour (α, h^{-1}) were estimated by the CO_2 concentration decay method. For a well-mixed space, the change in CO_2 concentration with time is given by:

$$C_{\tau} = C_{ext} + \frac{q_{CO_2} \times 10^6}{Q} - \left(C_{ext} - C_0 + \frac{q_{CO_2} \times 10^6}{Q} \right) e^{\left({}^{-Q_t}\!/\!{}_{v} \right)} \quad (1)$$

where C_t is the indoor concentration of CO_2 at time t (ppm), C_{ext} is the outdoor concentration of CO_2 (ppm), C_0 is the concentration of CO_2 in the indoor air at time 0 (ppm), Q is the volume flow rate of air entering the space (m^3 s^{-1}), q_{CO2} is the volumetric indoor emission rate of CO_2 (m^3 s^{-1}), V is the volume of the room (m^3) and t is the interval since $t = 0$ (s). When the room is unoccupied there is no CO_2 emission from the occupants, and $q_{CO_2} = 0$. Thus, Eq. (1) can be rearranged to give the following expression, which allows the ventilation rate (Q) to be estimated from measured concentration values time t apart:

$$Q = -\frac{V}{t} \times \ln\left(\frac{C_t - C_{ext}}{C_0 - C_{ext}} \right) \quad (2)$$

The air exchange rate is defined as:

$$\alpha = Q/V \quad (3)$$

Main specifications of real-time measurement equipment

- Graywolf (IQ-610 probe, WolfSense Solutions, USA)
  a) CO_2 (NDIR)
  Range: 0 to 10,000 ppm; Accuracy: ± 35 ppm over the IAQ range (350 ppm – 2000 ppm), ± 35 ppm ± 3% of reading > 2000 ppm, ± 50 ppm ± 3% of reading over the full range
  b) CO (electrochemical)
  Range: 0 to 500 ppm; Accuracy: ± 2 ppm < 50 ppm, ± 3 % of reading > 50 ppm
  c) Total volatile organic compounds (PID)
  Range: 5 to 20,000 ppb; Resolution: 1 ppb, L.O.D. < 5 ppb
  10.6 eV PIDs do not respond to VOCs with ionization potentials > 10.6, such as ethane, methane or formaldehyde. However, they do respond to the vast majority of VOCs. Standard calibration is to isobutylene.

- TSI (Q-Trak IAQ Monitor, Model 7575, USA)
  CO_2 (NDIR)
  Range: 0 to 5000 ppm; Accuracy: ± 3% of reading or ± 50 ppm, whichever is greater; Resolution: 1 ppm

- DustTrak monitor (8530 model, USA) - light-scattering laser photometer
  Measuring range of PM_{10}, $PM_{2.5}$, and PM_1: 0.001 mg m^{-3} to 400 mg m^{-3}; Resolution: ±0.1% of reading or 0.001 mg m^{-3}, whichever is greater; Zero stability: ± 0.002 mg m^{-3} per 24 hours at 10 s time constant; Flow rate: 3.0 L min^{-1}; Flow accuracy: ± 5% of factory set point, internal flow controlled

Table S3. PM_{10} mass concentrations of PAHs (μg g^{-1})

	Fried horse mackerel	Stuffed chicken	Grilled boneless pork strips	Fried boneless pork strips	Background air
Naphthalene	3.07	0.084	0.192	-	13.4
Acenaphthylene	0.128	-	-	0.135	0.399
Acenaphthene	0.158	0.308	0.080	0.122	1.15
Fluorene	1.88	1.02	0.154	2.81	6.82
Phenanthrene	2.15	1.79	0.843	2.83	2.30
Anthracene	0.135	0.139	0.087	0.199	0.447
Fluoranthene	1.87	2.13	1.97	2.86	2.00
Pyrene	4.79	3.56	2.53	5.19	5.55
p-Terphenyl	0.040	-	0.045	-	-
Retene	2.79	1.51	1.24	2.20	3.91
Benzo[a]anthracene	3.27	2.14	2.90	3.63	5.53
Chrysene	8.67	10.1	11.8	13.0	16.1
Benzo[b]fluoranthene	1.27	5.86	3.99	3.77	14.5
Benzo[k]fluoranthene	0.505	2.30	2.65	2.06	-
Benzo[e]pyrene	1.55	5.45	4.08	3.88	17.2
Benzo[a]pyrene	0.634	0.078	2.08	0.666	3.81
Perylene	-	-	-	-	-
Indeno[1,2,3-cd]pyrene	0.282	0.685	1.67	0.209	4.46
Dibenzo[a,h]anthracene	-	-	0.150	-	-
Benzo[g,h,i]perylene	0.317	0.737	1.76	0.668	6.09
SUM	33.5	37.9	38.2	44.2	104

Table S4. Comparison of diagnostic ratios of PAHs

Sample	Location	Type of cooking	Phe/(Phe+Ant)	Flt/(Flt+Pyr)	BaA/(BaA+Chr)	Ind/(Ind+BghiP)	Reference
PM_{10}	Kitchen (indoor air)	Fried horse mackerel, electric cooktop	0.94	0.28	0.27	0.47	This study
		Stuffed chicken, electric cooktop	0.93	0.37	0.18	0.48	
		Grilled boneless pork strips, electric cooktop	0.91	0.44	0.20	0.49	
		Fried boneless pork strips, electric cooktop	0.93	0.36	0.22	0.24	
TSP and gaseous phase	Kitchen (indoor air)	Fresh bacon, electric stove	0.99	0.53	0.31	0.47	Jørgensen et al. (2013)
		Fresh bacon, gas stove	0.94	0.33	0.33	0.47	
		Smoked bacon, gas stove	0.96	0.30	0.30	0.42	
$PM_{2.5}$	Kitchen (indoor air)	Stir-frying		0.45	0.31	0.51	Zhao et al. (2019b)
		Pan-frying		0.34	0.25	0.16	
		Seep-frying		0.27	0.16	0.22	
		Steaming		-	0.27	0.47	
		Boiling		-	0.24	0.36	
$PM_{2.5}$	Kitchen (indoor air)	Steaming	0.96	0.51	0.31	0.54	See and Balasubramanian (2008)
		Boiling	0.96	0.52	0.34	0.52	
		Stir-frying	0.94	0.56	0.28	0.45	
		Pan-frying	0.94	0.55	0.29	0.46	
		Deep-frying	0.95	0.53	0.28	0.44	
$PM_{2.5}$	Food stall in a	Chinese	0.21	0.32	0.40	0.43	See et al. (2006)
		Malay	0.28	0.38	0.32	0.38	

	university canteen	Indian	0.21	0.43	0.50	0.39	
TSP and gaseous phase	Stacks of restaurants	Chinese	0.86	0.50	0.62	0.63	Li et al. (2003)
		Western	0.86	0.46	0.38	0.63	
		Fast food	0.96	0.60	0.32	0.53	
		Japanese	0.97	0.66	0.13	0.83	
$PM_{2.5}$	Exit of the restaurants' purification systems	Shanghai-style	0.91	0.53	0.22	-	Pei et al. (2016)
		Sichuan-style	0.72	0.44	0.43		
		Italian-style	0.63	0.46	0.49		
$PM_{2.5}$ and gaseous phase	Under a laboratory fume hood equipped with an electric stove	Deep-frying	0.31	0.16	0.65	0.19	Yao et al. (2015)
		Frying	0.24	0.19	0.88	0	

Table S5. Concentrations of oxygenated compounds (ng m^{-3}). Empty cells mean not detected or of the same level of blanks.

	Fried horse mackerel	**Stuffed chicken**	**Grilled boneless pork strips**	**Fried boneless pork strips**	**Background air**
SUGARS and POLYOLS					
Mannosan	0.644	0.331	3.31	0.284	0.497
Levoglucosan	52.3	8.23	25.4	8.10	11.4
Ribitol	2.53	2.37	-	3.69	0.557
Meso-Erythritol	0.910	-	-	-	0.315
Other sugars and polyols	47.2	54.9	29.6	5.01	2.08
PHENOLIC COMPOUNDS & BENZENE DERIVATIVES					
2-Methylphenol (o-cresol)	-	-	-	1.69	0.0278
Benzyl alcohol	11.1	-	-	114	-
Pyrocatechol	-	-	-	0.0314	0.00331
5-Isopropyl-3-methylphenol	0.122	-	-	0.174	0.125

Resorcinol	0.00534	-	0.00407	0.00897	0.000930
4-Methylcatechol	-	-	-	-	-
2,6-Dimethoxyphenol	0.000843	0.000866	-	-	0.00222
Eugenol	0.00277	0.00102	0.00157	0.00494	0.00117
Isoeugenol	0.577	-	0.0117	1.28	-
4-Allyl-2,6-dimethoxyphenol (methoxy eugenol)	-	-	0.00168	0.0171	-
2,4-Di-tert-buthylphenol	17.9	1.65	19.7	19.1	6.86
Pyrogallol	0.00279	0.00206	0.00212	0.00798	0.00532
2-methoxy-4-propylphenol	0.00384	0.261	0.00242	20.5	0.00514
4-Phenylphenol	0.206	-	-	-	-
4-Octylphenol	-	-	-	0.374	-
Coniferyl alcohol	0.00597	0.00447	-	0.0102	0.00634
Sinapyl alcohol	-	-	-	-	-
2-Isopropyl-5-methylphenol (Thymol)	1.23	-	0.432	1.14	0.0630
4-tert-Butylphenol	3.72	-	1.74	7.95	0.826
Vanillic acid	0.144	0.0131	0.129	0.0280	0.00775
2,3,4-Trimethoxybenzoic (gallic) acid	-	-	-	-	-
Syringic acid	0.0352	0.00596	0.0453	0.00214	0.00206
4-Hydroxybenzoic acid	-	3.82	-	-	-
Benzoic acid	1.31	0.180	0.178	2.26	0.0734
4-hydroxybenzoic acid	0.684	0.278	0.370	0.0729	0.0201
α-Hexylcinnamaldehyde	-	0.640	1.023	4.01	0.0996
Trans-cinnamic acid	0.635	0.105	0.341	0.150	0.0412
4-hydroxycinnamic (p-coumaric) acid	-	0.0554	0.483	0.0151	0.00156
4-hydroxy-3-methoxycinnamic (ferulic) acid	0.333	0.0119	0.0483	-	0.00778
3,4-Dihydroxy-cinnamic (caffeic) acid	-	-	0.117	-	-
Bisphenol A	0.211	-	1.06	-	0.567
ALIPHATIC ALCOHOLS					
1-Decanol	0.193	-	-	0.316	0.0151
1-Dodecanol	0.657	1.44	-	4.49	0.704

1-Tetradecanol	4.84	5.54	7.92	18.0	3.51
1-Pentadecanol	5.70	5.34	10.1	18.1	4.96
1-Hexadecanol	105	131	226	193	66.9
Unidentified C_{16} alcohol	6.13	8.77	12.7	18.4	3.81
C_{17} alcohol isomers	1.97	3.41	3.90	1.32	0.624
1-Octadecanol	37.0	33.8	54.0	35.6	27.5
1-Nonadecanol	1.79	0.527	-	-	0.858
1-Eicosanol	5.68	-	10.0	2.13	1.75
1-Docosanol	2.51	1.05	4.73	1.39	0.788
1-Tricosanol	0.159	0.0337	0.801	0.0580	0.0570
iso-Tricosanol	-	-	-	1.08	-
1-Pentacosanol	0.266	0.0432	1.23	0.284	0.0798
1-Heptacosanol	0.0198	0.00376	0.378	-	0.0254
1-Octacosanol	-	0.0998	1.53	-	0.269
1-Tetracosanol	0.364	0.522	11.0	-	-
1-Pentacosanol	-	-	3.84	-	-
1-Hexacosanol	1.49	0.899	-	1.03	0.936
1-Heptacosanol	-	-	0.860	-	-
1-Octacosanol	0.620	0.394	1.80	-	0.233
1-Triacontanol	-	-	0.316	-	0.0830
STEROIDS					
Cholesterol	75.3	2.02	422	0.861	1.08
5-Cholesten-3-ol (dihydrocholesterol)	0.0891	0.0618	0.516	-	-
5-Cholesten-3-β,7-β-diol	-	-	4.33	-	-
Stigmasterol	6.56	-	2.83	-	-
β-Sitosterol	35.0	0.123	1.86	0.318	0.201
CARBOXYLIC ACIDS					
Hexanoic (caproic) acid	86.7	1.35	4.29	1.97	-
Heptanoic acid	8.99	3.27	6.66	5.90	0.455
Octanoic (caprilic) acid	1.78	0.666	1.41	1.16	0.703

Nonanoic (pelargonic) acid	75.6	33.5	30.1	48.0	0.653
Decanoic (caproic) acid	1.91	1.51	0.624	1.18	4.60
Undecanoic acid	1.43	0.812	1.23	0.288	0.0723
Dodecanoic (lauric) acid	7.17	5.74	7.52	7.50	1.35
Tridecanoic (tridecylic) acid	2.54	0.971	2.53	1.32	0.159
Tetradecanoic (myristic) acid	216	83.6	89.4	63.3	19.2
C_{14} acid isomers	3.00	2.06	-	3.36	0.750
Pentadecanoic acid	29.5	9.98	14.3	7.69	3.47
Hexadecanoic (palmitic) acid	710	205	515	225	60.4
Heptadecanoic acid	20.7	2.28	9.40	1.45	0.385
C_{17} acid isomers	24.7	4.69	8.18	5.26	2.69
cis-9,cis-12-Octadecadienoic (linoleic) acid	325	8.52	141	1.45	0.546
Octadecanoic (stearic) acid	78.7	46.1	145	78.9	9.44
Nonadecanoic acid	1.07	1.94	0.436	0.0801	0.0168
Eicosanoic (arachidic) acid	7.38	0.881	2.94	0.578	0.139
Docosanoic (behenic) acid	17.1	2.89	3.65	0.360	0.151
Tetracosanoic acid	8.00	5.74	13.0	-	-
Pentacosanoic acid	1.82	-	-	-	-
Hexacosanoic acid	0.695	0.797	17.8	0.0743	0.0165
Nonenoic acid	58.7	-	5.26	-	-
9-cis-Hexadecenoic (palmitoleic) acid	38.3	0.726	12.4	0.197	0.807
Heptadecenoic acid	8.36	-	6.80	-	-
cis-9-Octadecenoic (oleic) acid	89.9	17.7	265	11.3	3.24
Eicosenoic acid	-	-	9.12	-	0.914
DICARBOXYLIC ACIDS					
1,4-Butanedioic (succinic) acid	12.3	3.65	59.5	1.61	0.428
1,5-Pentanedioic (glutaric) acid	5.35	4.74	2.15	8.99	2.70
2-Hydroxy-butanedioic (malic) acid	6.29	3.07	25.6	2.81	0.677
Hexanedioic (adipic) acid	3.50	2.23	5.95	0.970	0.450
Heptanedioic (pimelic) acid	3.23	0.824	4.03	0.454	0.184

Octanedioic (suberic) acid	8.90	1.32	6.68	0.726	0.301
Nonanedioic (azelaic) acid	90.5	24.7	76.7	6.11	3.04
Decanedioic (sebacic) acid	1.67	0.837	3.54	0.474	0.192
Hexadecanedioic (Thapsic) acid	0.0297	0.0130	0.0513	-	0.00121
AMINO ACIDS					
Alanine	31.5	-	271	-	-
Valine	193	-	106	-	0.437
Leucine	57.4	-	80.0	-	-
iso-Leucine	133	-	56.3	-	-
Thymine	26.3	-	-	-	-
5-Oxo-L-proline	65.0	-	276	-	6.85
OTHER ACIDS					
Laevulic acid	-	-	-	-	2.38
Hydracrylic acid	10.5	5.05	12.4	29.1	2.24
Glyceric acid	20.6	2.40	75.5	9.53	0.684
Pyruvic acid	7.67	-	0.269	-	0.291
3,4-Dihydroxybutanoic acid	4.87	2.25	3.05	7.37	1.06
3-Hydroxybutanoic (hydroxybutyric) acid	0.260	0.156	0.179	0.416	0.139
4-Hydroxy-3-pentenoic acid	-	3.34	-	4.44	-
cis-Pinonic acid	1.11	1.02	2.22	1.28	0.580
Pinic acid	-	1.19	4.15	1.27	0.876
Citric acid	0.490	0.130	1.86	0.139	0.0295
Abietic acid	-	-	0.269	-	-
Dehydroabietic acid	0.835	0.139	0.608	0.107	0.112
Isopimaric	0.592	0.03004	0.785	0.0172	0.00496
ALKYL ESTERS OF ACIDS					
Palmitic acid methyl ester	1.34	8.34	15.6	42.5	14.7
Palmitic acid ethyl ester	0.894	9.10	14.6	26.9	15.7
Palmitic acid isopropyl ester (Isopropyl palmitate)	9.47	94.5	104	125	53.6
Palmitic acid butyl ester	0.283	0.876	1.20	0.288	0.853

Palmitic acid hexadecyl ester	7.94	14.9	3.77	-	0.785
Isopropyl laurate (dodecanoic acid, 1-methylethyl ester)	0.00582	0.0531	0.0258	0.243	0.0229
Dodecanoic acid isooctyl ester	20.5	45.3	34.5	5.58	26.5
Methylisostearate	1.10	9.40	15.9	15.1	12.7
Heptadecanoic acid, 15-methyl, ethyl ester	-	1.03	2.15	1.33	2.42
Octadecanoic acid methyl ester	0.297	10.3	11.7	9.04	11.5
Myristic acid isopropyl ester (Isopropyl myristate)	-	250	202	372	96.4
Myristic acid isobutyl ester (Isobutyl myristate)	5.65	5.93	2.89	-	4.38
Myristic acid tetradecyl ester	14.7	16.2	27.8	-	2.18
Myristic acid hexadecyl ester	5.74	11.9	3.07	-	0.932
Benzoic acid alkyl esters	81.9	102	112	35.6	51.2
Hexanoic acid 2-ethyl-, hexadecyl ester (Hexadecyl 2-ethylexanoate)	2.29	17.9	4.51	-	2.97
Hexadecanoic acid hexadecyl ester	2.62	4.54	1.34	0.0999	0.246
GLYCERIDIC COMPOUNDS					
Glycerol	92.0	26.9	200	293	15.4
1-Monolauroyl-rac-Glycerol	-	-	-	-	-
1-Monooleoylglycerol	69.4	Nd	126	1.13	-
1-Monomyristin	108	0.9	9.15	1.25	0.482
Glycerol monostearate (monostearin)	49.5	13.2	169	14.2	1.72
1-Monopalmitin	156	23.2	359	19.9	1.85
Tetraethylene glycol dimethacrylate	-	-	-	-	2.31
Glycerol tricaprylate	3.73	1.28	9.64	-	0.331
PLASTICISERS					
Phthalic acid	-	-	1.05	-	-
Dimethyl phthalate	0.0117	0.00276	-	0.00786	-
Diethyl phthalate	2.57	5.16	3.12	23.0	1.51
Di-n-butyl phthalate	2.64	0.547	0.674	1.40	-
Benzyl butyl phthalate	5.46	4.57	5.44	3.27	3.51
Bis(2-ethylhexyl) adipate	0.117	0.00622	0.0169	0.0312	0.0147
Bis(2-ethylhexyl)phthalate	14.5	2.63	0.379	0.547	0.182

Diethylhexyl phthalate (DEHP)	204	121	209	-	159
Unidentified phthalates	97.5	303	335	488	193
OTHER COMPOUNDS					
Diethylene glycol	3.254	1.88	3.75	-	2.32
Lupeol	0.651	Nd	0.192	-	0.0696
2,6-Di-tert-butyl-1,4-benzoquinone	0.853	0.366	0.416	4.23	0.437
α-Hexylcinnamaldehyde	-	0.178	0.373	0.971	0.0462
Diethyltoluamide (DEET)	-	2.28	-	6.44	0.575
2-Propanol-1-chloro-,phosphate	11.8	-	-	-	-
7,9-Di-tert-butyl-1-oxaspiro[4.5]deca-6,9-diene-2,8-dione	7.64	10.1	9.67	12.8	7.59
Parsol MCX	21.7	24.0	58.1	23.9	14.0
Galoxolide	-	0.245	1.01	1.33	0.150
Pyrimidine	43.0	-	61.4	-	-
Tributyl acetylcitrate	-	-	-	-	5.53
Piperine	-	-	111	-	-
15-Nonacosanonone	0.911	4.74	-	-	-
Irganox 1906	-	4.44	-	-	33.4
Oxidised irgafos 168	-	-	-	-	18.7
Isophorone	0.253	-	0.0193	-	0.177
Benzothiazole	-	-	-	0.0217	0.0243
Carbazole	0.0284	0.00385	0.00828	-	-
Cholesteryl acetate	12.8	-	12.1	-	-
Cholesteryl esters	0.481	-	5.84	-	-
α-Tocopherol (Vitamin E)	0.316	0.0113	0.0176	0.0177	0.00347
Vitamin E acetate	-	0.992	7.62	1.96	1.36
1,2,3-Hexanetriol	-	-	-	-	0.0116
Methylcyclohexanol	0.0557	-	-	-	-
Myrtenol	-	0.00505	0.0148	0.0194	0.0190
Citronellol	-	-	-	-	-
2,3-Pinanediol	0.0684	0.0218	0.107	0.180	0.0421

Table S6. Particulate mass fractions of oxygenated compounds (ng g^{-1} PM_{10}). Empty cells mean not detected or of the same level of blanks.

	Fried horse mackerel	**Stuffed chicken**	**Grilled boneless pork strips**	**Fried boneless pork strips**	**Background air**
SUGARS and POLYOLS					
Mannosan	9.05	13.6	45.3	8.76	42.5
Levoglucosan	736	339	347	250	977
Ribitol	35.5	97.7	-	114	47.6
Meso-Erythritol	12.8	-	-	-	26.9
Other sugars and polyols	665	2261	406	155	178
PHENOLIC COMPOUNDS & BENZENE DERIVATIVES					
2-Methylphenol (o-cresol)	-	-	-	52.0	2.38
Benzyl alcohol	156	-	-	3504	-
Pyrocatechol	-	-	-	0.969	0.283
5-Isopropyl-3-methylphenol	1.71	-	-	5.36	10.7
Resorcinol	0.0751	-	0.056	0.277	0.080
4-Methylcatechol	-	-	-	-	-
2,6-Dimethoxyphenol	0.0119	0.0356	-	-	0.190
Eugenol	0.0390	0.0418	0.0215	0.153	0.100
Isoeugenol	8.12	-	0.160	39.4	-
4-Allyl-2,6-dimethoxyphenol (methoxy eugenol)	-	-	0.0230	0.53	-
2,4-Di-tert-buthylphenol	251	67.7	270	591	586
Pyrogallol	0.0393	0.0850	0.0290	0.246	0.454
2-methoxy-4-propylphenol	0.0540	10.8	0.0332	632	0.439
4-Phenylphenol	2.90	-	-	-	-
4-Octylphenol	-	-	-	11.55	-
Coniferyl alcohol	0.084	0.184	-	0.316	0.542
Sinapyl alcohol	-	-	-	-	-

2-Isopropyl-5-methylphenol (Thymol)	17.3	-	5.91	35.1	5.38
4-tert-Butylphenol	52.3	-	23.8	245	70.6
Vanillic acid	2.02	0.539	1.76	0.863	0.662
2,3,4-Trimethoxybenzoic (gallic) acid	-	-	-	-	-
Syringic acid	0.495	0.246	0.620	0.0662	0.176
4-Hydroxybenzoic acid	-	157	-	-	-
Benzoic acid	18.4	7.41	2.43	69.8	6.27
4-hydroxybenzoic acid	9.63	11.4	5.07	2.25	1.72
α-Hexylcinnamaldehyde	-	26.4	14.0	124	8.51
Trans-cinnamic acid	8.94	4.31	4.66	4.61	3.52
4-hydroxycinnamic (p-coumaric) acid	-	2.28	6.61	0.466	0.133
4-hydroxy-3-methoxycinnamic (ferulic) acid	4.68	0.489	0.661	-	0.665
3,4-Dihydroxy-cinnamic (caffeic) acid	-	-	1.60	-	-
Bisphenol A	2.97	-	14.5	-	48.4
ALIPHATIC ALCOHOLS					
1-Decanol	2.71	-	-	9.73	1.29
1-Dodecanol	9.24	59.4	-	139	60.2
1-Tetradecanol	68.1	228	108	556	300
1-Pentadecanol	80.2	220	138	559	424
1-Hexadecanol	1484	5394	3092	5963	5720
Unidentified C_{16} alcohol	86.2	361	173	567	326
C_{17} alcohol isomers	27.6	140	53.4	40.9	53.3
1-Octadecanol	520	1390	740	1100	2351
1-Nonadecanol	25.1	21.7	-	-	73.3
1-Eicosanol	79.9	-	137	65.8	150
1-Docosanol	35.3	43.2	64.7	42.9	67.4
1-Tricosanol	2.23	1.39	11.0	1.79	4.87
iso-Tricosanol	-	-	-	33.2	-
1-Pentacosanol	3.75	1.78	16.8	8.75	6.82
1-Heptacosanol	0.279	0.155	5.17	-	2.17

1-Octacosanol	-	4.11	20.9	-	23.0
1-Tetracosanol	5.12	21.5	151	-	-
1-Pentacosanol	-	-	52.6	-	-
1-Hexacosanol	20.9	37.0	-	31.6	80.0
1-Heptacosanol	-	-	11.8	-	-
1-Octacosanol	8.72	16.2	24.6	-	19.9
1-Triacontanol	-	-	4.33	-	7.09
STEROIDS					
Cholesterol	1060	83.2	5778	26.6	92.0
5-Cholesten-3-ol (dihydrocholesterol)	1.25	2.55	7.07	-	-
5-Cholesten-3-β,7-β-diol	-	-	59.3	-	-
Stigmasterol	92.3	-	38.7	-	-
β-Sitosterol	492	5.04	25.4	9.81	17.2
CARBOXYLIC ACIDS					
Hexanoic (caproic) acid	1220	55.6	58.7	60.6	-
Heptanoic acid	126	134	91.2	182	38.9
Octanoic (caprilic) acid	25.0	27.4	19.3	35.9	60.1
Nonanoic (pelargonic) acid	1063	1379	413	1480	55.8
Decanoic (caproic) acid	26.8	62.2	8.54	36.3	393
Undecanoic acid	20.1	33.4	16.8	8.89	6.18
Dodecanoic (lauric) acid	101	236	103	231	116
Tridecanoic (tridecylic) acid	35.8	40.0	34.7	40.7	13.6
Tetradecanoic (myristic) acid	3044	3442	1223	1952	1641
C_{14} acid isomers	42.2	84.9	-	104	64.1
Pentadecanoic acid	415	411	195	237	296
Hexadecanoic (palmitic) acid	9982	8445	7054	6947	5164
Heptadecanoic acid	291	93.9	129	44.7	32.9
C_{17} acid isomers	347	193	112	162	230
cis-9,cis-12-Octadecadienoic (linoleic) acid	4569	351	1928	44.8	46.7
Octadecanoic (stearic) acid	1108	1897	2011	2433	806

Nonadecanoic acid	15.1	79.9	5.97	2.47	1.44
Eicosanoic (arachidic) acid	104	36.3	40.3	17.8	11.9
Docosanoic (behenic) acid	241	119	50.0	11.1	12.9
Tetracosanoic acid	113	236	178	-	-
Pentacosanoic acid	25.6	-	-	-	-
Hexacosanoic acid	9.77	32.8	243	2.29	1.41
Nonenoic acid	826	-	72.0	-	-
9-cis-Hexadecenoic (palmitoleic) acid	538	29.9	170	6.07	69.0
Heptadecenoic acid	118	-	93.1	-	-
cis-9-Octadecenoic (oleic) acid	1265	729	3622	347	276
Eicosenoic acid	-	-	125	-	78.1
DICARBOXYLIC ACIDS					
1,4-Butanedioic (succinic) acid	172	150	814	49.7	36.6
1,5-Pentanedioic (glutaric) acid	75.2	195	29.4	277	231
2-Hydroxy-butanedioic (malic) acid	88.5	127	350	86.5	57.9
Hexanedioic (adipic) acid	49.2	91.7	81.5	29.9	38.4
Heptanedioic (pimelic) acid	45.5	33.9	55.2	14.0	15.7
Octanedioic (suberic) acid	125	54.2	91.4	22.4	25.8
Nonanedioic (azelaic) acid	1272	1018	1050	188	260
Decanedioic (sebacic) acid	23.5	34.4	48.4	14.6	16.4
Hexadecanedioic (Thapsic) acid	0.418	0.536	0.702	-	0.104
AMINO ACIDS					
Alanine	443	-	3714	-	-
Valine	2718	-	1444	-	37.3
Leucine	807	-	1096	-	-
iso-Leucine	1874	-	771	-	-
Thymine	369	-	-	-	-
5-Oxo-L-proline	915	-	3780	-	585
OTHER ACIDS					
Laevulic acid	-	-	-	-	204

Hydracrylic acid	148	208	169	897	192
Glyceric acid	289	98.9	1033	294	58.4
Pyruvic acid	108	-	3.69	-	24.9
3,4-Dihydroxybutanoic acid	68.5	92.5	41.8	227	90.5
3-Hydroxybutanoic (hydroxybutyric) acid	3.65	6.42	2.45	12.8	11.9
4-Hydroxy-3-pentenoic acid	-	137	-	137	-
cis-Pinonic acid	15.6	42.1	30.3	39.5	49.5
Pinic acid	-	49.1	56.8	39.1	74.8
Citric acid	6.90	5.34	25.4	4.28	2.52
Abietic acid	-	-	3.68	-	-
Dehydroabietic acid	11.7	5.72	8.32	3.30	9.56
Isopimaric	8.33	1.25	10.7	0.532	0.423
ALKYL ESTERS OF ACIDS					
Palmitic acid methyl ester	18.8	343	213	1312	1259
Palmitic acid ethyl ester	12.6	375	200	829	1343
Palmitic acid isopropyl ester (Isopropyl palmitate)	133	3890	1421	3843	4584
Palmitic acid butyl ester	3.98	36.1	16.4	8.90	72.8
Palmitic acid hexadecyl ester	112	614	51.6	-	67.1
Isopropyl laurate (dodecanoic acid, 1-methylethyl ester)	0.0818	2.19	0.35	7.50	1.95
Dodecanoic acid isooctyl ester	289	1866	473	172	2260
Methylisostearate	15.4	387	218	466	1083
Heptadecanoic acid, 15-methyl, ethyl ester	-	42.2	29.4	41.1	207
Octadecanoic acid methyl ester	-	426	160	279	982
Myristic acid isopropyl ester (Isopropyl myristate)	-	10309	2760	11463	8236
Myristic acid isobutyl ester (Isobutyl myristate)	79.5	244	39.6	-	374
Myristic acid tetradecyl ester	207	667	381	-	186
Myristic acid hexadecyl ester	80.8	489	42.0	-	79.7
Benzoic acid alkyl esters	1153	4208	1528	1098	4371
Hexanoic acid 2-ethyl-, hexadecyl ester (Hexadecyl 2-ethylexanoate)	32.2	737	61.7	-	254
Hexadecanoic acid hexadecyl ester	36.9	187	18.3	3.08	21.0

GLYCEROL DERIVATIVES					
Glycerol	1295	1106	2731	9044	1316
1-Monolauroyl-rac-Glycerol	-	0.0281	0.102	0.221	0.152
1-Monooleoylglycerol	976	-	1720	34.9	-
1-Monomyristin	1515	36.7	125	38.6	41.2
Glycerol monostearate (monostearin)	696	545	2317	439	147
1-Monopalmitin	2198	957	4919	615	158
Tetraethylene glycol dimethacrylate	-	-	-	-	197
Glycerol tricaprylate	52.5	52.8	132	-	28.2
PLASTICISERS					
Phthalic acid	-	-	14.4	-	-
Dimethyl phthalate	164	114	-	242	-
Diethyl phthalate	3546	4065	1270	3935	1447
Di-n-butyl phthalate	37116	22533	9230	43347	-
Benzyl butyl phthalate	1610	1052	74.4	101	300
Bis(2-ethylhexyl) adipate	1639	256	232	961	1256
Bis(2-ethylhexyl)phthalate	204230	108215	5186	16866	15566
Diethylhexyl phthalate (DEHP)	2875	4993	2855	-	13591
Unidentified phthalates	1371	12462	4585	15048	16456
OTHER COMPOUNDS					
Diethylene glycol	45.8	77.3	51.4	-	198
Lupeol	9.15	-	2.63	-	5.95
2,6-Di-tert-butyl-1,4-benzoquinone	12.0	15.1	5.69	128	37.3
α-Hexylcinnamaldehyde	-	7.32	5.10	30.0	3.95
Diethyltoluamide (DEET)	-	94.0	-	199	49.1
2-Propanol-1-chloro-,phosphate	166	-	-	-	-
7,9-Di-tert-butyl-1-oxaspiro[4.5]deca-6,9-diene-2,8-dione	107	415	132	395	649
Parsol MCX	306	990	796	736	1196
Galoxolide	-	10.1	13.9	41.2	12.8
Pyrimidine	605	-	840	-	-

Tributyl acetylcitrate	-	-	-	-	473
Piperine	-	-	1525	-	-
15-Nonacosanonone	12.8	195	-	-	-
Irganox 1906	-	183	-	-	2857
Oxidised irgafos 168	-	-	-	-	1600
Isophorone	3560	-	265	-	15152
Benzothiazole	-	-	-	669	2078
Carbazole	400	158	113	-	-
Cholesteryl acetate	179	-	166	-	-
Cholesteryl esters	6.76	-	80.0	-	-
α-Tocopherol (Vitamin E)	4.45	0.466	0.240	0.548	0.296
Vitamin E acetate	-	40.9	104	60.4	116
1,2,3-Hexanetriol	-	-	-	-	0.993
Methylcyclohexanol	0.784	-	-	-	-
Myrtenol	-	0.208	0.202	0.598	1.62
Citronellol	-	-	-	-	-
2,3-Pinanediol	0.962	0.897	1.47	5.55	3.60

Table S7. Linear correlations with $r^2 > 0.50$ between total concentrations of groups of compounds, or individual compounds, and toxic units

($y = m\,x + b$, where y is TU and x represents concentrations in ng m^{-3})

Organic compounds	m	b	r^2
Steroids	0.0563	3.0582	0.982
PAHs	0.0109	-9.7951	0.683
HMW PAHs	0.0158	-9.0431	0.937
Glyceridic compounds	0.0274	-0.3897	0.800
Dicarboxylic acids	0.1255	-0.4395	0.827
Amino acids	0.0263	2.4428	0.831
Other acids	0.2469	-1.868	0.740
Other oxygenated organic compounds	0.1112	-3.1894	0.934
Mannosan	7.9984	1.1861	0.952
Vanillic acid	113.64	1.9754	0.509
Syringic acid	451.24	1.1082	0.768
4-Hydroxycinnamic acid	48.871	3.8981	0.921
Tridecanoic acid	7.4040	-1.8455	0.520
Stearic acid	0.1837	-3.8664	0.753
Oleic acid	0.0951	1.9239	0.985
Hexacosanoic acid	1.3227	4.1626	0.947
Succinic acid	0.4207	2.7709	0.989
Malic acid	1.0301	1.3694	0.987
Adipic acid	4.5885	-2.7318	0.913
Pimelic acid	5.2486	0.1344	0.760
Sebacic acid	7.7450	-1.1083	0.973
Glyceric acid	0.3349	2.0086	0.965
cis-Pinonic acid	15.939	-10.506	0.829
Citric acid	13.771	1.9955	0.987
Benzoic acid	0.2397	-9.0599	0.545
Isopimaric acid	24.789	2.2043	0.767
C_{17} alcohol isomers	5.7834	-3.6924	0.571
1-Octadecanol	1.0303	-29.427	0.923
1-Eicosanol	2.4178	-0.1682	0.826
1-Docosanol	6.365	-4.0357	0.941

1-Tricosanol	31.784	2.2422	0.966
1-Pentacosanol	20.739	1.3968	0.907
1-Heptacosanol	62.289	3.9777	0.930
1-Octacosanol	14.916	0.2004	0.981
Cholesterol	0.0574	3.5395	0.980
Parsol MCX	0.5941	-75469	0.924
Benzyl butyl phthalate	7.5321	-24.228	0.543
Monostearin	0.1521	1.7562	0.987
Monopalmitin	0.0685	1.6169	0.957