

# Monitoring of Dioxins/Furans (PCDD/Fs) in Smoke of Charcoal Grilled Meat-Restaurants in Amman-Jordan

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## Research Article

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# Abstract

PCDDs /Fs were investigated in outdoor air of charcoal grilled meat-restaurants in Jordan. Restaurants were given the codes (S, Z, G, B, and J). Levels of PCDDs/Fs depend on the quantity of used charcoal, amount of grilled meat, and sampling season. Results in (ng TEQ/m<sup>3</sup>) found in the order: S restaurant (12.4) > J (3.4) > B (1.8) > G (1.6) > Z (0.2). Total emissions in (g TEQ / year) were in the order: S restaurant (1.295) > J (0.132) > B (0.092) > G (0.025) > Z (0.003). This study is the first of its kind in MENA region. Polychlorinated dibenzo-*p*-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) concentrations were studied in outdoor air of charcoal grilled meat-restaurants in Amman/Jordan. The studied restaurants were given the codes (S, Z, G, B, and J). The PCDD/Fs compounds were extracted from the filter using the green extraction method called QuEChERS and detected in extracts using GC/MS. The concentrations of PCDD/Fs in the chimneys were found to depend on many factors that were measured such as type and quantity of grilling fuels, amount quantities of grilled food after marinating and sampling season. The results showed that PCDD/Fs concentrations in toxic equivalents (TEQs) in (ng TEQ/m<sup>3</sup>) were found in the following order: S restaurant (12.4) > J (3.4) > B (1.8) > G (1.6) > Z (0.2) where some samples contained 2, 3, 7, 8-TCDD in considerable amounts. The total emissions of PCDD/Fs in (g TEQ / year) for all restaurants samples were in the following order: S restaurant (1.295) > J (0.132) > B (0.092) > G (0.025) > Z (0.003). This study is featured as the first of its kind in the Middle East and North Africa that reveals the dangers of using charcoal for grilling because it causes contamination of food and air. It also calls for advising people to minimize the consumption of grilled food since food will contain a portion of the carcinogenic B (a) P and 2,3,7,8-TCDD and also advising for using filters for restaurant chimneys.

## Introduction

Air pollution causes nowadays the atmosphere to be not clean as in the old time before the industrial revolution due to the increase of the concentrations of harmful chemicals in the atmosphere. Air pollution is caused from the entrance of one or more of contaminants that deteriorate the imbalance of air quality. These contaminants may be found as solid particles, liquid droplets, or mixtures of gases which affects negatively on human, animals, plants and all living organisms by man-made and natural sources (Arthur 1977; Hewitt and Jackson 2007). There are many sources of human activities such as power plants, refineries, factories and vehicles emissions (Aschner and Costa 2015; Manisalidis et al. 2019). In addition, the chemical and fertilizer industries, agricultural emissions, residential heating and cooking ,domestic cleaning activities, wars, nuclear tests are also other human-made sources (Hewitt and Jackson 2007 ; Pénard-Morand and Annesi-Maesano 2004; Manisalidis et al. 2019). On the other hand, natural sources such as volcanic erosions, forests fire, dust storms and oceans (Vallero 2007; Vesilind et al. 2013).Cooking activities produces many harmful pollutants that affect negatively the atmosphere and human health (Buonanno et al. 2009). Commercial restaurants kitchens are a main contribution source of outdoor air pollution (To et al. 2007; Chen et al. 2007). In addition, food emissions have negative effects on the workers' health in restaurants (Svendsen et al. 2003) and on people who live near them (To

et al. 2007). Cooking operations of food at high temperature cause emission of pollutants including volatile organic compounds (VOCs) and fine particulate organic matters, aliphatic hydrocarbons, Polycyclic aromatic hydrocarbons, dioxins/furans, heterocyclic aromatic amines (HCAs), BTEX (benzene, toluene, ethylbenzene, and xylenes), carbonyl compounds like (aldehydes, ketones, carboxylic acids), and others (Kabir and Kim 2011; Lin et al. 2010; Schauer et al. 1999). When charcoal is used in cooking processes at high temperatures, these harmful chemicals are also emitted from the charcoal itself and the food cooked, so it can be a major contributor to the deterioration of the outdoor air quality of the surrounding environment (Pandey et al. 2009; Kabir et al. 2010). PCDD/Fs are abundant persistent organic pollutants that have been classified in the Stockholm Convention (UNEP 2001). PCDD/Fs are planar tricyclic aromatic compounds with 1 to 8 chlorine atoms. They are stable nonpolar compounds, have low solubility in water, low vapour pressure, have lipophilic character and they are bio-accumulative in the environment through the food chain (Fiedler et al. 1990). The 2, 3, 7, 8-substituted congeners of PCDDs are considered as the most toxic (carcinogenic) anthropogenic compounds to the environment and humans (Fiedler 1996; Fiedler et al. 1990). Dioxins can be emitted from many anthropogenic sources into the atmosphere. They can be spread in other components of the environment such as soil, sediments, seawater, air, vegetation, and animals (Mosca et al. 2010). They are produced as unwanted by-products during the incomplete combustion of organic compounds from the anthropogenic sources (industrial and thermal processes) (Alcock and Jones 1996; Fries 1995). The most common source for PCDD/Fs exposure is food sources especially seafood and animal products during food processes (cooking) (Fries 1995; Hutzinger and Fiedler 1993).

This study will examine the emissions effects of charcoal grill restaurants on the outdoor air quality and to determine the levels of PCDD/Fs in stacks that depend on many factors and conditions that will be monitored, measured and investigated. Therefore, the main objective of this work is to monitor PCDD/Fs in the smoke of Amman's charcoal grilled meat restaurants in the chimneys. This study has the distinction of being the first of its kind to be conducted in Jordan, the Middle East and North Africa (MENA). It is also one of the very few studies in the world that has examined concentrations of PCDD/Fs emissions in the outdoor environment from restaurant stacks that use coal as grill fuel.

## Materials And Methods

### *Reagents and standards*

The EPA method 1613 native stock solution of PCDDs/PCDFs which contained 17 PCDD/Fs and the internal standard for PCDDs/PCDFs (1,2,3,4-tetrachloro[<sup>13</sup>C<sub>12</sub>] dibenzo-p-dioxin) of the concentration of 200 ng/mL and the purity of 99% were purchased from Willington Laboratory (Guelph/ Canada). Solvents used were as follows: dichloromethane and acetonitrile of 99.5% purity were of the HPLC/GC grade purchased from Tedia (USA); n-hexane of purity 95% was purchased from GCC (UK), and n-nonane of 98.7% purity was purchased from Reidel-deHaën (Hannover/Germany). QuEChERS extraction kit (AOAC ExtraBond Scharlau) with Catalogue No.: QUEXTAOAK1) and QuEChERS clean up kit (EN ExtraBond Scharlau) with Catalogue No.: QUDISENNK2) were purchased from Scharlau (Barcelona, Spain).

## ***Apparatus***

GC/MS-Saturn 2200, with Auto sampler CP-8400 was used where the injected volume was 1 µL in split less mode. Low polarity column (DB-5) with dimensions (30m x 0.25 mm i.d. (0.25µm film thickness) was used. Carrier gas flow rate was 1.0 mL/min. The carrier gas used was helium (99.999%), (8 – 10 psi) with constant flow mode at pressure of 99.8 kPa. Purge gas flow was set at 0.8 mL/min. The mass-spectrometer parameters settings included the following: Ion source Temperature was set at 250 °C and interface temperature at 310 °C. Solvent cut time was at 15.00 min. Detector Gain: 2.0 KV. The column temperature program was as follows: 150 °C (1 min); 150-200 °C (12 °C/min); 200-235 °C (3 °C/min); 235-310 °C (20 °C/min); 310°C (8 min). Detector: Ion Trap - detector. Acquisition mode: SIM – mode.

Other instruments used were analytical balance, drying oven, vortex mixer, centrifuge, anemometer, pump and Reacti-Therm with air compressor.

## ***Sampling and sample preparation***

Smoke samples from five charcoal grilled meat-restaurants in Amman city were collected for PCDD/Fs analysis. The restaurants were given the symbols [S, Z, G, B and J]. The glass fibre filters (37mm diameter, A/E type, PALL, Mexico) were used for collecting smoke samples. They were placed in Gelman cassette (37 mm 2 pieces, Supelco). Eighteen samples (chimneys sample and field blank for each) were collected by using pump system for smoke suction from the restaurants' chimney which contains the emitted PCDD/Fs. It was faced the chimney at a distance of 1 meter and the sampling period takes six to eight hours. Sampling was reiterated for each restaurant and location according to many conditions and factors that were measured, monitored and documented. These conditions were : weather temperature, stack emissions flow rate, temperature of emissions, wind speed, humidity, cross sectional area of the chimney, height of the chimney (height of the building), sampling seasons (summer and winter) , type of charcoal used and type of the meat. Beside main samples many simultaneous blank samples (reference) were collected from each restaurant by using the same pump and filter type but at a distance of 50 m from the chimney at the same parameters.

## ***Sample extraction and clean up***

The extraction and clean-up steps for PCDDs/Fs are summarized as follows:

The filter containing the collected sample was added to 50 ml empty polypropylene centrifuge tube. After that, 10 ml acetonitrile, 5 ml deionized water, and 70 µL of the internal standard (1, 2, 3, 4-tetrachloro [<sup>13</sup>C<sub>12</sub>] dibenzo-p-dioxin, 200 ppb) were added to the centrifuge tube followed by strong shaking. Then QuEChERS extraction pack with salts mixture was added followed by vigorous shaking using vortex for about 5 minutes, and then was centrifuged for 10 minutes at 3500 rpm. 6 mL of the supernatant of the extraction step were transferred to a QuEChERS dispersive SPE clean up tube followed by vigorous shaking for about 5 minutes and centrifugation for 10 minutes at 8000rpm.

Thereafter, 5 ml were evaporated to dryness at 40 °C and the residues were reconstituted in 350 µL solvent-mix of (1:1 of dichloromethane/ hexane) and transferred to a 350 µL insert-GC vials.

### ***PCDD/Fs quantitative identification***

The GC/MS quantitative analysis of the dioxins/furans was done in two ways namely: scan mode and Selective ion monitoring mode (SIM). First, the mass spectrometer was applied in the full scan mode by scanning the mass over a wide range of masses (mass to charged ratio m/z). Each PCDD/Fs was distinguished by its retention time and mass fragments after scanning of masses established. SIM mode is then used and allows the mass spectrometer to detect specific compounds of PCDD/Fs to get higher sensitivity with higher accuracy and precision instead of stepping a wide range of masses. Each compound was represented by a peak of a definite retention time (Stashenko and Martinez 2014). Standards of 17 dioxins/furans congeners with their mix standards were injected in triplicate onto the GC-MS column in the scan mode to identify the retention time of each PCDD/F. After that PCDD/Fs were sorted into groups in the SIM mode where each compound was designated by its retention time and two major m/z fragments as shown in Table 1.

**Table1:** PCDD/Fs quantitation masses m/z (U.S. EPA 1994)

PCDD/Fs	t <sub>R</sub> (min) ± 0.05	m/z	PCDD/Fs	t <sub>R</sub> (min) ± 0.05	m/z
2,3,7,8-TCDF	17.5	304, 306	1,2,3,6,7,8-H <sub>x</sub> CDD	28.14	390, 392
2,3,7,8-TCDD	18.01	320, 322	1,2,3,7,8,9-H <sub>x</sub> CDD	28.37	390, 392
1,2,3,7,8-P <sub>n</sub> CDF	21.39	338, 340	2,3,4,6,7,8-H <sub>x</sub> CDF	28.59	374, 376
2,3,4,7,8-P <sub>n</sub> CDF	22.69	338, 340	1,2,3,4,6,7,8-H <sub>p</sub> CDF	29.52	408, 410
1,2,3,7,8-P <sub>n</sub> CDD	23.18	354, 356	1,2,3,4,6,7,8-H <sub>p</sub> CDD	30.13	424, 426
1,2,3,4,7,8-H <sub>x</sub> CDF	27.29	374, 376	1,2,3,4,7,8,9-H <sub>p</sub> CDF	30.43	408, 410
1,2,3,6,7,8-H <sub>x</sub> CDF	27.43	374, 376	OCDD	31.94	458, 460
1,2,3,7,8,9-H <sub>x</sub> CDF	27.98	374, 376	OCDF	32.05	442, 444
1,2,3,4,7,8-H <sub>x</sub> CDD	28.10	390, 392			

### ***Instrument calibration***

### ***Preparation of mix PCDDs/Fs and internal standards solutions***

Dioxins/furans-mix of EPA method 1613 stock solution of PCDDs/PCDFs which contained 17 PCDD/Fs congeners was used. Dilution series of the standard-mix solution for the calibration curve were prepared in addition to check standard (stock solution diluted 1:5). 1, 2, 3, 4-tetrachloro [<sup>13</sup>C12] dibenzo-*p*-dioxin (200 ng/mL) was used as internal standard in the standard and the sample solutions.

### ***Linear range***

Dilution series of different concentrations were prepared and injected onto the GC-MS column to construct the calibration curves. Six concentration levels in (µg/L) of PCDD/Fs were used for the calibration curve to study the linearity of the 17 PCDD/Fs congeners. From the calibration curves, the linear equations and the coefficients of determination ( $R^2$ ) were calculated. The coefficients of determination were found between 0.9902 and 0.9983 indicating a good linearity in the studied concentration range.

### ***Detection limit and limit of quantitation***

Limit of detection (LOD) of the instrument was obtained for PCDDs/Fs by diluting the mix standard solution of PCDD/Fs until the ratio of signal to noise (S/N) is equal to 3, while the limit of quantitation (LOQ) was obtained when the (S/N) ratio is equal to 10. The results show that for all studied PCDD/Fs, the LODs were between 0.0043 and 0.0550 µg/L while the LOQs were between 0.0143 and 0.1832 µg/L.

### ***Extraction recoveries for PCDD/Fs samples***

PCDD/Fs recovery experiments were done by using three blank samples. The blank filter for each sample was split in half. The first half was extracted and cleaned-up by QuEChERS procedure. However, the second half was spiked with the three concentrations levels of PCDD/Fs standard solutions (low, medium, and high) in ppb and with the internal standard [1, 2, 3, 4 –Tetrachloro [<sup>13</sup>C12] dibenzo-*p*-dioxin] ; to give a final concentration in each sample of 1 ppm in 350 µL). Once the second half was prepared for each blank sample, it was extracted and cleaned up by the above mentioned procedure. The recovery results were ranged between 82 and 99% for the low concentration; 83–100% for the medium concentration and 82–101% for the high concentration. All recoveries were found to be within the acceptable range for trace analysis (84-102%) (Gonzalez and Herrador 2007).

### ***Instrument precision for PCDD/Fs***

The instrument precision was determined by the injection of three standard solutions in triplicate. The results show that the instrument precision was very good due to the results of the coefficients of variation (CV). The results of all CV were less than the accepted limit value for trace analysis (15%) (Gonzalez and Herrador, 2007).

### ***Analysis of PCDD/Fs samples***

Eighteen smoke samples from the chimneys of five charcoal grilled meat-restaurants and also eighteen. Eighteen samples field blank samples for each were collected. The samples were undergone all previous steps of preparation, extraction, and clean up. The extracts were injected in triplicate onto the GC/MS column. Every sample was given a symbol that indicates the location of restaurant. For every studied sample the surrounding conditions were gathered. The most prominent of these were: weather conditions such as (wind speed, humidity, and the average temperature), information about the stack itself as (stack outlet velocity, stack outlet temperature), and also sampling hours, sampling seasons, and the volume of air in m<sup>3</sup>. All PCDD/FS concentrations were calculated after subtracting the corresponding field blanks in µg/m<sup>3</sup>. Table 2 summarizes the profiles of the studied five restaurants. Table S1 indicates PCDD/Fs results of the samples of the five restaurants in µg/m<sup>3</sup> and the converted concentrations to the ng TEQ/m<sup>3</sup> smoke sample.

**Table 2:** The profiles of the five studied restaurants (Arar et al. 2021)

Items	Restaurants				
	J	S	Z	G	B
No. of samples	7	3	3	4	1
Amount of charcoal used	High	Low	Low	Moderate	Moderate
Type of meat	Romanian	Local	Romanian	Romanian	Local
Stack Height <sup>a</sup>	24 m	10 m	7 m	7.5 m	8m
Cross sectional area of the stack's vent	3721 cm <sup>2</sup>	1131 cm <sup>2</sup>	725 cm <sup>2</sup>	1962.5 cm <sup>2</sup>	1519.76 cm <sup>2</sup>

<sup>a</sup> Including the heights of restaurants' building.

## Results And Discussion

The smoke of five charcoal grilled meat-restaurants in Amman city were chosen to do this study. The restaurants were given the symbols [S, Z, G, B and J]. This study focused basically on S restaurant that many experiments (7 experiments) were done there under different conditions. A comparison was made between the restaurant S with the other restaurants [Z, G, B and J]. The results of the all restaurants samples for the 17 PCDD/Fs compounds are shown in Table S1 and in Figure 1. 2,3,7,8-TCDD was found in the concentration range from 0.0008 µg/m<sup>3</sup> (G) to 0.0179 µg/m<sup>3</sup> (S). 2,3,7,8-TCDF was found in the concentration range from 0.0129 µg/m<sup>3</sup> (S) to 0.0167µg/m<sup>3</sup> (B).1,2,3,7,8-PnCDD was found in the concentration range from 0.0066 µg/m<sup>3</sup> (J) to 0.0722 µg/m<sup>3</sup> (S).1,2,3,7,8-PnCDF was found in the

concentration range from 0.0041  $\mu\text{g}/\text{m}^3$  (B) to 0.0054  $\mu\text{g}/\text{m}^3$  (S). 2,3,4,7,8-PnCDF was found in the concentration range from 0.0012  $\mu\text{g}/\text{m}^3$  (B) to 0.0293  $\mu\text{g}/\text{m}^3$  (S). 1,2,3,7,8,9-HxCDD was found in the concentration range from 0.0086  $\mu\text{g}/\text{m}^3$  (B) to 0.0424  $\mu\text{g}/\text{m}^3$  (S). 1,2,3,4,7,8-HxCDF was found in the concentration range from 0.0004  $\mu\text{g}/\text{m}^3$  (Z) to 0.0007  $\mu\text{g}/\text{m}^3$  (S). 1,2,3,6,7,8-HxCDF was found in the concentration range from 0.0008  $\mu\text{g}/\text{m}^3$  (Z) to 0.013  $\mu\text{g}/\text{m}^3$  (S). 1,2,3,7,8,9-HxCDF was found in the concentration range from 0.0003  $\mu\text{g}/\text{m}^3$  (B) to 0.0847  $\mu\text{g}/\text{m}^3$  (S). 2,3,4,6,7,8-HxCDF was found in the concentration range from 0.0004  $\mu\text{g}/\text{m}^3$  (G) to 0.0101  $\mu\text{g}/\text{m}^3$  (S). 1,2,3,4,6,7,8-HpCDD was found in the concentration range from 0.0007  $\mu\text{g}/\text{m}^3$  (Z) to 0.0272  $\mu\text{g}/\text{m}^3$  (S). 1,2,3,4,6,7,8-HpCDF was found in the concentration range from 0.0009  $\mu\text{g}/\text{m}^3$  (G) to 0.0129  $\mu\text{g}/\text{m}^3$  (S). 1,2,3,4,7,8,9-HpCDF was found in the concentration range from 0.0002  $\mu\text{g}/\text{m}^3$  (G) to 0.0824  $\mu\text{g}/\text{m}^3$  (S). OCDD was found in the concentration range from 0.0042  $\mu\text{g}/\text{m}^3$  (J) to 0.0817  $\mu\text{g}/\text{m}^3$  (S). OCDF was found in the concentration range from 0.0038  $\mu\text{g}/\text{m}^3$  (G) to 0.0143  $\mu\text{g}/\text{m}^3$  (S). 1,2,3,6,7,8-HxCDD was found only in (S restaurant) with the concentration 0.0041  $\mu\text{g}/\text{m}^3$ . 1,2,3,4,7,8-HxCDD was not detected in any samples of the studied restaurants.

The results of the studied seven samples of **S** restaurant were compared with those of the other restaurants for the 17 PCDD/Fs compounds. The most detected compounds were 1,2,3,4,7,8,9-H<sub>p</sub>CDF (TEF= 0.01), OCDD (TEF= 0.0001), 1,2,3,7,8-P<sub>n</sub>CDD (TEF= 0.5), and 1,2,3,7,8,9-H<sub>x</sub>CDF (TEF= 0.1) and they also were the highest concentrations of PCDD/Fs compounds in  $\mu\text{g}/\text{m}^3$ . While the lowest concentrations of PCDD/Fs compounds were 1,2,3,6,7,8-H<sub>x</sub>CDD (TEF= 0.1), 1,2,3,4,7,8-H<sub>x</sub>CDF (TEF= 0.1), and 1,2,3,7,8-P<sub>n</sub>CDF (TEF= 0.05) as shown in Figure 2.

The average total PCDD/Fs concentrations were in the range 0.0220  $\mu\text{g}/\text{m}^3$  (J restaurant) to 0.5112  $\mu\text{g}/\text{m}^3$  (S restaurant) and the toxicity equivalency quantity values were found in the range from 0.5439 ng TEQ/ $\text{m}^3$  (Z restaurant) to 87.031 ng TEQ/ $\text{m}^3$  (S restaurant) as shown in Table S1 and Figure 1. The order of the restaurants according to the average total concentrations of PCDD/Fs in ng TEQ/ $\text{m}^3$  was: **S > J > B > G > Z**, as shown in Figure 3.

The total emissions of PCDD/Fs in g TEQ/year for the five restaurants were determined depending on the stack emissions for each restaurant and the average total concentrations in  $\mu\text{g TEQ}/\text{m}^3 \cdot \text{year}$  as shown in Table S2 and Figure 4.

Charcoal grilled meat-restaurants generate PCDD/Fs compounds. The concentrations of these pollutants and compounds strongly dependent on many factors and conditions mentioned previously. From these factors that were determined and studied, the results were discussed. The variations in results between samples of the five studied restaurants are caused by many possible factors. One of these studied factors is sampling time, (morning or evening). As we mentioned before we focused on S restaurant. For this restaurant the samples S2, S4, S6, and S7 those taken in the evening were the highest concentrations except for S4. The reason is simple, because the food consumption is more in the evening than in the

morning, and thus the increase in the amount of charcoal used. Eventually the increase of chimneys emissions means more production of PCDD/Fs pollutants, and this considered as a major source of urban outdoor air pollution. In addition, S restaurant was the highest restaurants in food consumption, therefore amount of charcoal used was higher than the other studied restaurants, which means that restaurant's food and charcoal consumption is another factor that explains the difference between restaurant emissions. Also, one of the important factors that play the main role in the difference between the studied restaurants was the type and quantity of oil used. Finally, the meat type such as local or Romanian is also an important factor due to the amount of fat that the meat contained.

Comparison was made between the results of this study and previous study (Lin *et al.* 2011). Lin studied the levels of seventeen (PCDD/Fs) in the stacks of three fast food restaurants in Taiwan. Table S3 shows a comparison between the results of restaurant S in this study and the results of (Lin *et al.*, 2011) study for PCDD/Fs. Table S5 shows a comparison between the average concentrations in ( $\text{ng}/\text{m}^3$ ) and in ( $\text{ng TEQ}/\text{m}^3$ ) in S restaurant with the values of 73.0229 and 12.4240 respectively, which are much higher than those of (Lin *et al.*,) study (0.0908 and 0.0085 respectively). This may have resulted from the highest concentrations of 2,3,7,8-TCDD , 1,2,3,7,8-PnCDD , and 2,3,4,7,8-PnCDF in our study, which are the most toxic congeners among the 17 PCDD/Fs . This could be due to different cooking styles used. The most detected and measured PCDD/Fs compounds in S restaurant were 1,2,3,4,7,8,9-H<sub>p</sub>CDF (TEF = 0.01), OCDD (TEF= 0.001), 1,2,3,7,8-P<sub>n</sub>CDD (TEF = 0.5) , and 1,2,3,7,8,9-H<sub>x</sub>CDF(TEF= 0.1). While in Lin *et al.* (2011) study ,the most detected and measured PCDD/Fs compounds were 1,2,3,4,6,7,8-H<sub>p</sub>CDF (TEF=0.01), OCDF(TEF= 0.001), OCDD(TEF= 0.001), and 2,3,7,8-TCDF(TEF= 0.1).The average concentration of the high TEF values PCDD/Fs compounds 2,3,7,8-TCDD , 1,2,3,7,8-PnCDD , and 2,3,4,7,8-PnCDF ( $\text{ng}/\text{m}^3$ ) in S restaurant were 8.95, 14.44, 9.65, respectively. But, in Lin *et al.* (2011) study were 0.00054, 0.00125, and 0.00709, respectively. In addition, the cooking oils and fuels were different between the two studies. In this study charcoal was used as a fuel, while in Lin *et al.* (2011) study vegetable oil , butter, or corn oil were used. Also the cooking style and method was different. In this study, S restaurant used grilling style while in the Lin *et al.* (2011) study deep frying and stewing methods were used. The mean stack outlet velocity in the Lin *et al.* (2011) study was 4.12 m/s, while in S restaurant was 19.5 m/s. Also the mean of stack diameters in S restaurant was more than that in the Lin *et al.* (2011) study.

## Conclusions

The results indicate that there are obvious variations of the PCDD/Fs concentrations from emitted emissions when compared with the previous studies. These variations in PCDD/Fs concentrations related to many conditions as quantities of food, food oil consumption rates, grilling fuels, marinating style, cooking times, Stack outlet velocity, Sampling season, and stack diameters. This study provides essential information that using charcoal as fuel for grilling is a major source for emissions of PCDD/Fs. The risk also revolves that the food containing considerable amounts of a "possibly carcinogenic" 2,3,7,8-TCDD compound.

# Declarations

## *Recommendations*

It is recommended to:

- Reduce the use of barbecue charcoal in restaurants and replacing it with electric and gas grills.
- Advise people to reduce consumption of grilled food because of the contaminants of meat and chicken with charcoal emissions which contains harmful PCDD/Fs like the carcinogenic 2,3,7,8-TCDD.
- Advise the charcoal grill restaurants to use special air filters due to the harmful effects of the dioxin/furans compounds on health and the surrounding environment.

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## *Author contributions*

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by [Sarya Ikbarieh ], [Sharif Arar] and [Mahmoud Alawi]. The first draft of the manuscript was written by [Sarya Ikbarieh] and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

## *Conflicts of Interest / Competing Interests*

The authors did not receive support from any organization for the submitted work.

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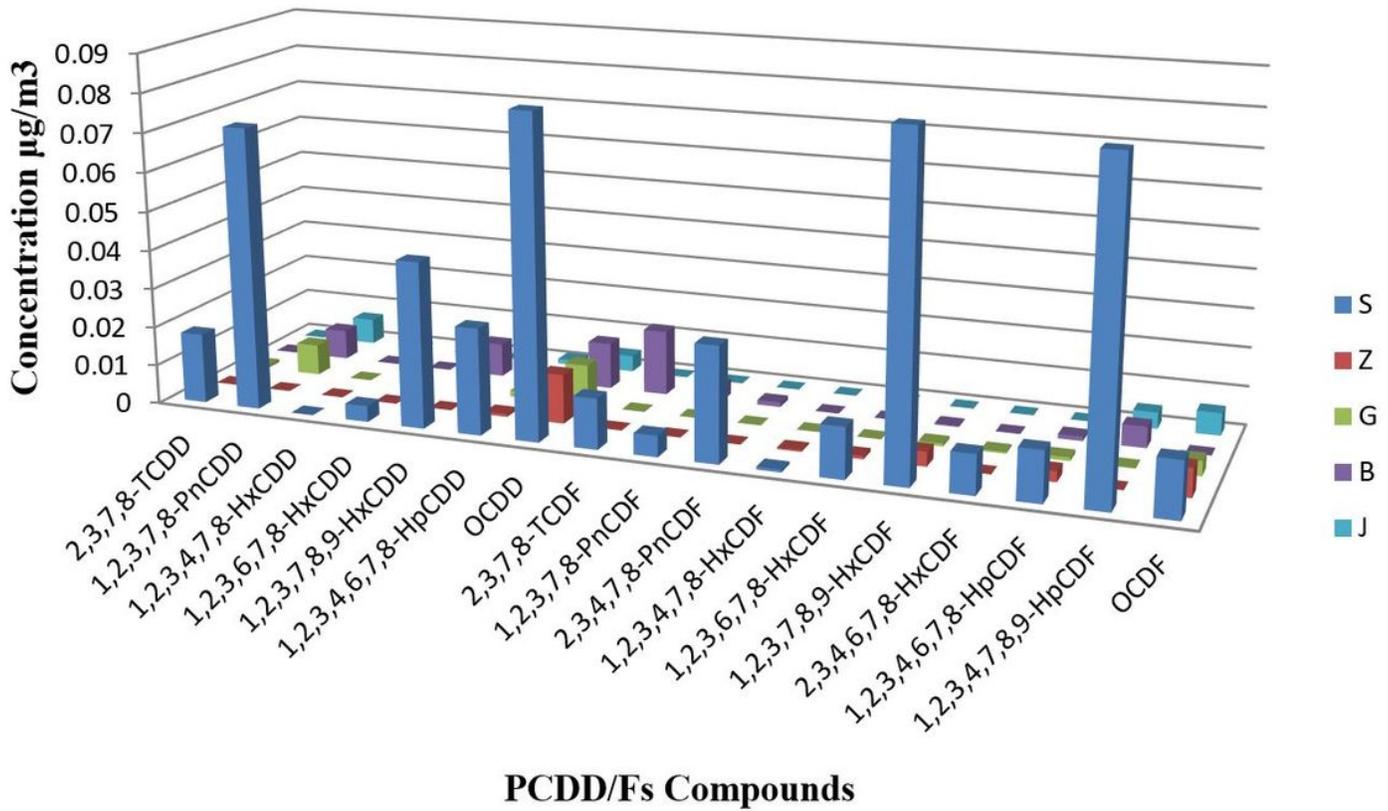
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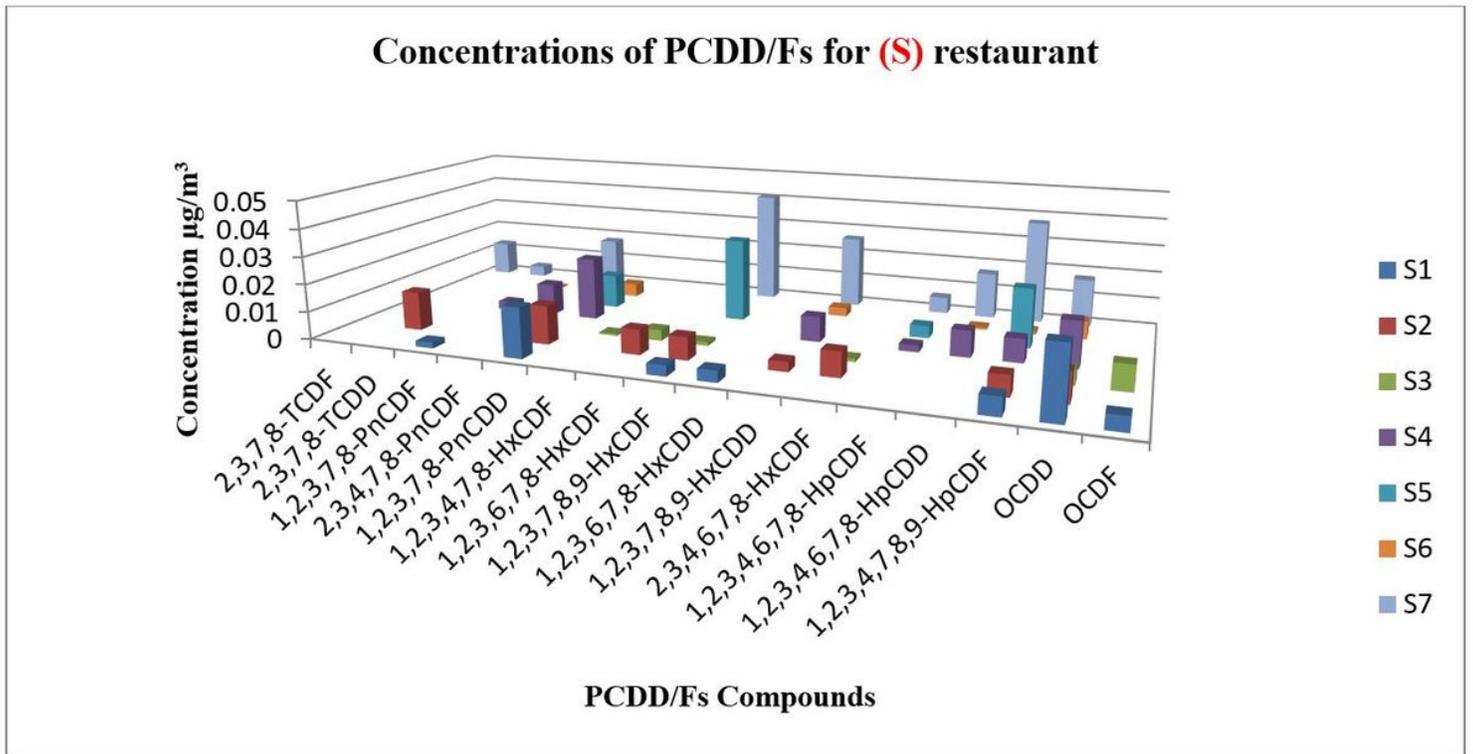
## Figures

## Concentrations of PCDD/Fs samples for five restaurants



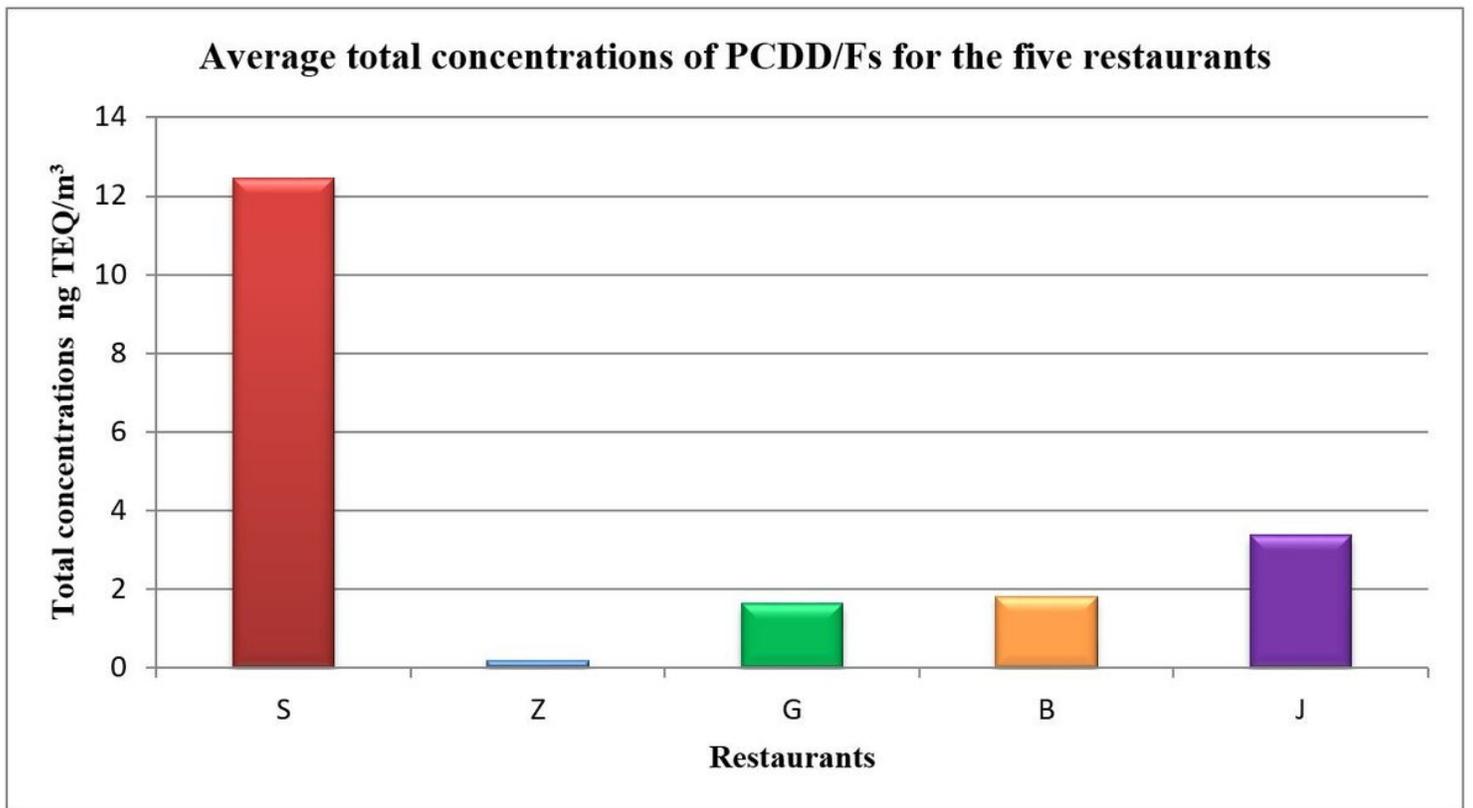
**Figure 1**

Concentrations of PCDD/Fs compounds ( $\mu\text{g}/\text{m}^3$ ) for five restaurants chimneys smoke.



**Figure 2**

Concentrations of PCDD/Fs compounds ( $\mu\text{g}/\text{m}^3$ ) for S restaurant chimney smoke at different sampling days.



**Figure 3**

Average total concentrations of PCDD/Fs (ng TEQ/m<sup>3</sup>) for the five restaurants Chimneys' smoke.

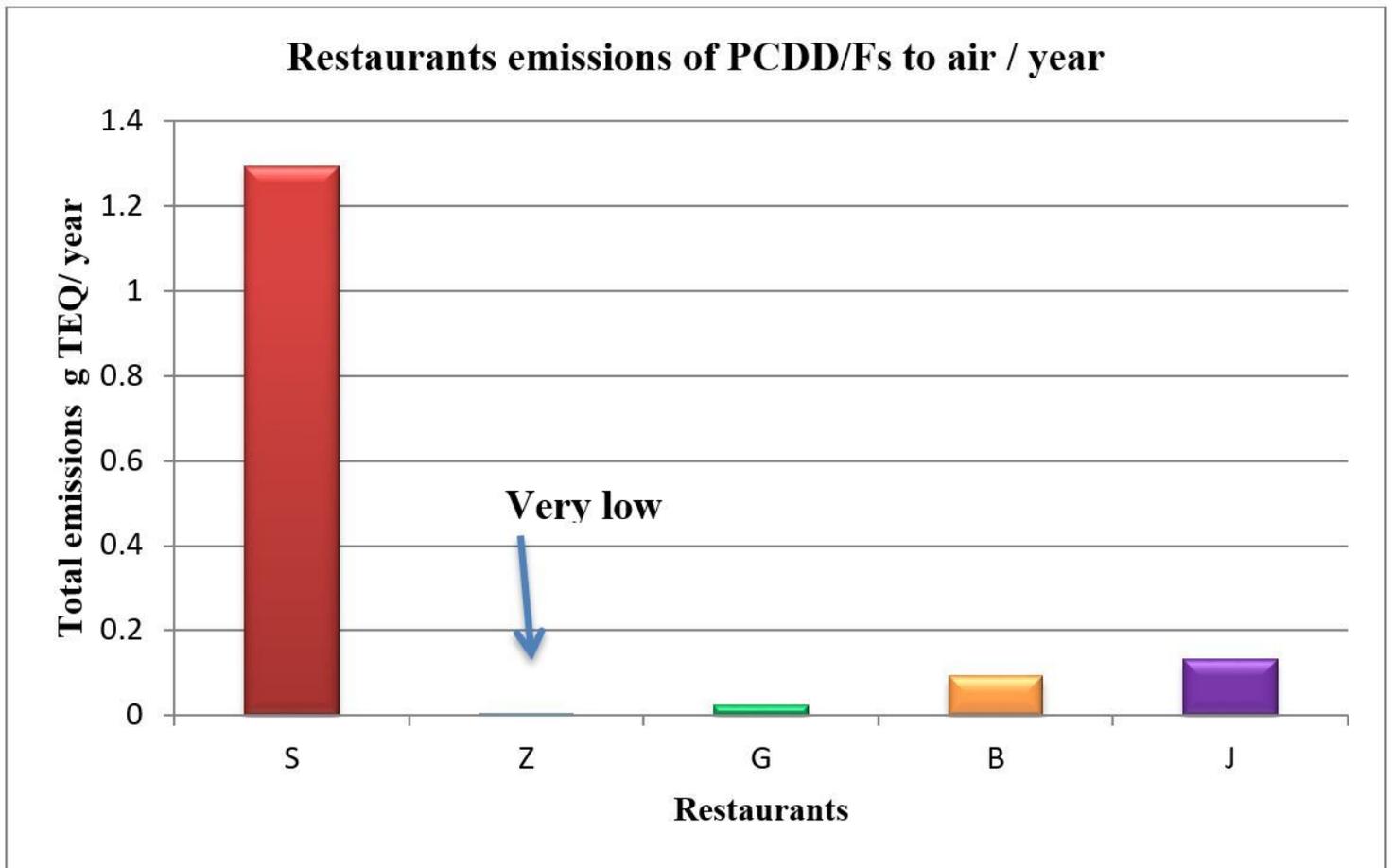


Figure 4

Total emissions of PCDD/Fs to air for the five restaurants chimneys' smoke in g TEQ/year.