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# Patterns of polychlorodibenzo-p-dioxins and furans and study the dietary intake in commercialized orange in Egypt

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ABSTRACT

A total of 18 orange samples were collected from 9 different governorates in Egypt and analyzed for dioxins, consisting of polychlorodibenzo-p-dioxins (PCDDs) and polychlorodibenzofurans (PCDFs), using High Resolution Gas Chromatography - High Resolution Mass Spectrometer (HRGC-HRMS). The mean concentration of ΣPCDD/Fs in orange samples was 1.8596 pg/g whole weight (w.w.). 1,2,3,4,6,7,8,9-Octachlorodibenzo-p-dioxin (OCDD) was the dominant congener of PCDD/Fs in orange samples. The Toxic Equivalency (TEQ) concentrations of PCDD/Fs were calculated using the Toxicity Equivalent Factors (TEF) established by the World Health Organization (WHO) in 2005. The mean TEQ concentration of ΣPCDD/Fs in orange samples was 0.1616 pgWHO-$TEQ_{2005}$/g w.w. This study showed that the average TEQ concentration of ΣPCDDs (0.1061 pgWHO-$TEQ_{2005}$/g w.w.) is higher than the average TEQ concentration of ΣPCDFs (0.0555pgWHO-$TEQ_{2005}$/g w.w.) which contributed about 65.66% from the total TEQ concentration of ∑PCDD/Fs in commercialized orange in Egypt. This study showed that the PCDD/Fs levels in orange were lower than the maximum permissible limits of Egyptian Standardization and European Community (0.30 pgWHO-$TEQ_{2005}$/g w.w.). The consumption of Egyptian people for orange attained according to GEMS/Food World Health Organization (WHO) consumption rate of orange for the Middle Eastern people is 38g/person/day, which showed that the Estimated Daily Intake (EDI) of ΣPCDD/Fs of the Egyptian consumer is 0.1023 pg WHO-TEQ/kg body weight/day lower than the WHO acceptable daily intake which is 4 pg WHO-TEQ/ kg b.w/day.

## Introduction

Polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDDs and PCDFs) are two groups of chemicals within the persistent organic pollutants (POPs) found in the environment because of their persistent, toxic, and bioaccumulative properties. Furthermore, they are the most toxic POPs [1]. The two families of POPs consist of 75 PCDDs and 135 PCDFs theoretical individual congeners, based on the number and position of chlorine atoms in the chemical structure [2]. Although they are 210 PCDD/Fs congeners, only 17 (those with a 2,3,7,8 substitution) have so far been found to be toxic. Among them, the most toxic compound is 2,3,7,8-tetrachlorodibenzo-p-dioxin or TCDD. The toxicity of other PCDD/Fs is measured in relation to TCDD.

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PCDD/Fs have well described toxicities at extremely low concentration, a highly competent system, which allows inter-comparison of toxicities between different isomers on the basis of toxic equivalents (TEQ), has been developed for humans and wildlife [3].

In general, PCDD/Fs compounds are of unintentional anthropogenic nature linked to several industrial processes that include thermal and combustion processes, waste incineration, industrial reservoir source, metal smelting and refining and production of pesticides [4, 5].

PCDDs and PCDFs may be transported over long distances from their source and travel via water, air and ground. Because of their high stability, low volatility and high resistance to degradation, they can remain long periods with half-lives between 7 and 10 years [6]. These characteristics render dioxins to be highly persistent

pollutants that experience bioaccumulation and bio magnification phenomena, so they can access into the feed and food chain [7-10].

Oranges represent around 30 percent of the total Egyptian fruit production and 65 percent of citrus production. Egypt is one of the world's leading orange producers and exporters. Egyptian orange production is high yielding and competitive due to the availability of irrigation water (the Nile), suitable climatic conditions, good soil, low labor costs, an early harvest compared to other major producers in the region, and Egypt's proximity to major importing countries. Egypt is the sixth orange producer in the world after Brazil, China, US, EU, and Mexico. Several orange varieties are produced in Egypt but the dominant varieties are six (*Baladi Orange, Valencia Orange, Blood Orange, Navel Orange, Khalily Orange and Sweet Orange*). Valencia and navel are the main exported varieties while the others are used more for domestic consumption [11].

A wide variety of extreme health effects have been related to high exposure to dioxin derivatives, such as growth retardation of the fetus and infants, developmental defects, reproductive effects, chloracne, hormonal dysfunctions, mood alterations, reduced mental performance, endometriosis, changes in white blood cells, dental defects and diabetes [12-17].

Since 1990s food has been identified as a pathway of human exposure to dioxin compounds. Dietary intake contributes about 90-98% of the total daily dioxin intake of the general population [18, 19]. The World Health Organization (WHO) has established a tolerable daily intake (TDI) range of 1–4 pg TEQ (Toxic Equivalency)/kg b.w. (body weight) for dioxins [20]. Likewise, a tolerable weekly intake (TWI) of 14 pg WHO-TEQ/kg b.w. (body weight) has been set up by the European Union through the Scientific Committee on Food [21].

Therefore, the aim of this study is the assessment of the risk on the human as dietary exposure to dioxins in consumed orange in Egypt through estimating their dietary intake relative to the acceptable daily intakes stated by the World Health Organization (WHO).

## Materials and methods

### Sampling

The procedures of sampling were performed following the Codex Alimentarius Commission regulation [22]. A total of 18 orange samples were purchased from 9 different governorates (Qaliubiya, Giza, Alexandria, Ismailia, Sharkia, Fayoum, Menoufiya, Beni Suef and Gharbiya) in Egypt to determine levels of Polychlorinated dibenzo-p-dioxins (PCDDs) and dibenzofurans (PCDFs). Samples were collected during the years 2015–2016 and were homogenized using a blender and stored at -20°C until analysis.

### Chemicals and reagents

All solvents used were analytical grade and purity not less than 99%. Silica gel and basic alumina were purchased from Aldrich (Brockmann I, Standard grade, Milwaukee, USA). Calibration standard solutions, labeled standard and injection solutions specified in Environmental Protection Agency (EPA) Method 1613B were obtained from Cambridge Isotopes Laboratories (Andover, USA).

### Apparatus and instrument

Soxhlet (50mm ID, 200 ml capacity with 500 ml flask), Top bench balance" Mettler Toledo" ranged from 0.1 mg to 210, Electrical apparatus for sample homogenization (e.g Bamix), Thimble (43mm ID*123mm H) to fit Soxhlet, Rotary evaporator (Heidolph VV2000), Calibrated Micro-liter pipettes and Heating Electro-mantle (Cat. No EM0500/C to fit 500 ml round-bottom flask).

High Resolution Gas Chromatography/High Resolution Mass Spectrometry (HRGC/HRMS).The High Resolution Mass Spectrometry (Micromass Auto-Spec Ultima) attached to GC chromatography (Agilent 6890 N).The GC equipped with Auto injector (Agilent 7683 series), Split/Splitless injection port for capillary column and a DB-5ms fused silica column (60 m × 0.25 mm × 0.25 µm).

### Method of analysis

### Extraction

Orange samples were grinded well. A known weight of samples (25 g) was spiked with known amounts of mixture of labeled PCDD/Fs. Next, samples were extracted by soxhlet for at least 18-24 h with Dichloromethane /Hexane 1/1 v/v. The extract was rotary evaporated and concentrated to near dryness. Complete removal of the solvent was performed using a stream of nitrogen. The extract residue was dissolved in 5 ml of n-hexane for cleanup.

### Cleanup and purification process

These steps were conducted according to U.S EPA 1613(B) Method [23], using Anthropogenic, Multilayer silica gel, Alumina and active Carbon column.

### HRGC/HRMS analysis

The qualitative and quantitative analyses of PCDD/Fs congeners and dl-PCBs congeners were performed using GC/HRMS in the selected ion monitoring mode at a resolution ≥10,000. Separation of congeners was carried out using a capillary column (60m length, 0.25 mm ID, and 0.25 µm thickness) coated with a DB-5 stationary phase. Helium was used as a carrier gas at a flow rate of 1ml/min. The temperature of the injector and the interface were 280 °C, respectively. The column temperature program was as follows: initial temperature was 90-220 ºC, at 15 ºC/min, then kept at 220 ºC for 15min then raised again from 220-290 ºC at a rate of 8 ºC/min and kept at 290 ºC for17.6 min [23].

### Quantitative determination

PCDD/Fs were performed by an isotope dilution method using relative response factors previously obtained from five standard solutions. The toxic equivalency TEQ concentrations were calculated guided to World Health Organization-toxic equivalent factor WHO-TEF established in 2005 [3]. The resulting values are presented in pg $WHO_{2005}$-TEQ/g whole weight (w.w.), by multiplying the concentration (ng/g) of each congener by its toxic equivalent factor WHO-TEF then summation values of 17 congeners to get the toxic equivalency

concentration of PCDD/Fs in the sample. It was assumed that non-detected isomer concentrations were equal to the limits of determination, as recommended by the European Regulation [24]. Detection and quantification limits, as well as, recoveries for all PCDD/Fs congeners were in good agreement with requirements laying down the sampling methods and the methods of the analysis for the official control of PCDD/Fs. For each run the samples were prepared including a method blank and quality control samples were performed.

## Results and discussion

### PCDDs/Fs levels in orange samples on a fresh basis

The mean levels measured by HRGC/MS of 17 PCDD/F congeners (pg/g) whole weight (w.w.), in the 18 orange samples collected from different markets in Egypt, are shown in **Table (1)**. The results showed that the ΣPCDD/Fs concentrations ranged from (0.4576 to 6.1600) pg/g w.w. and the mean concentration is1.8596 pg/g w.w. The ΣPCDDs concentrations ranged from (0.1848 to 4.4920) pg/g w.w. of the mean concentration 0.8827 pg/g w.w, while the ΣPCDFs concentrations ranged from (0.4576 to 3.0971) pg/g w.w. of the mean concentration 0.9769 pg/g w.w.

The contribution of PCDD/F congeners is also studied and the results are presented in **Figures 1 and 2**. The results showed that the mean concentration of ΣPCDFs (0.9769 pg/g w.w.) is slightly higher than of ΣPCDDs (0.8827 pg/g w.w.) which contribute about 52.54% from the total PCDD/F contents in all analyzed samples. The congeners were descending contributed in orange samples as follows OCDD (1,2,3,4,6,7,8,9-Octachlorodibenzo-p-dioxin), HpCDF (1,2,3,4,6,7,8 Heptachloro-dibenzofuran and 1,2,3,4,7,8,9-Heptachlorodibenzofuran), OCDF (1,2,3,4,6,7,8,9-Octachlorodibenzofuran), HxCDF (1,2,3,4,7,8 Hexachlorodibenzofuran, 1,2,3,6,7,8-Hexachlorodibenzofuran, 2,3,4,6,7,8-Hexachlorodibenzofuran and 1,2,3,7,8,9-Hexachlorodibenzofuran), PeCDF (1,2,3,7,8 Pentachlorodibenzofuran and 2,3,4,7,8-Pentachlorodibenzofuran), HpCDD (1,2,3,4,6,7,8-Heptachlorodibenzo-p-dioxin), TCDF (2,3,7,8 Tetrachlorodibenzofuran), HxCDD (1,2,3,4,7,8-Hexachlorodibenzo-p-dioxin, 1,2,3,6,7,8-Hexachlorodibenzo-p-dioxin and 1,2,3,7,8,9-Hexachlorodibenzo-p-dioxin), PeCDD (1,2,3,7,8-Pentachlorodibenzo-p-dioxin) and TCDD (2,3,7,8-Tetrachlorodibenzo-p-dioxin) of the mean contributions to the total PCDD/F contents in all analyzed samples are about 30.06, 15.33, 13.62, 9.71, 7.13, 6.97, 6.72, 5.33, 3.57 and 1.53%, respectively, with mean concentrations about 0.559, 0.285,0.253, 0.181, 0.133, 0.130, 0.125, 0.099, 0.066 and 0.028 ng/g w.w., respectively.

The results are in agreement with other reports in Europe in which the mean concentration of ΣPCDFs is higher than ΣPCDDs [25] and the most dominant congener is 1,2,3,4,6,7,8,9-Octachlorodibenzo-p-dioxin (OCDD) [26]. The most dominant congener OCDD has been reported to be dominant in emission from domestic combustion [27].

**Table (1):** Mean, Minimum, Maximum and 90thpercentile concentrations (pg/g whole weight) of the PCDD/Fs congeners corresponding to their toxic equivalency concentrations (pgWHO-$TEQ_{2005}$/g w.w.) in orange, (n=18)*.

| Congener | Concentration (pg/g) whole weight | | | | Dioxin WHO-$TEf_{2005}$ | Concentration pgWHO-$TEQ_{2005}$/g whole weight | | |
|---|---|---|---|---|---|---|---|---|
| | Mean | Min | Max | 90th percentile | | Mean | Min | Max |
| 2,3,7,8-Tetrachlorodibenzo-p-dioxin; (2,3,7,8-TCDD) | 0.0284 | 0.0048 | 0.0720 | 0.0573 | 1 | 0.0284 | 0.0048 | 0.0720 |
| 1,2,3,7,8-Pentachlorodibenzo-p-dioxin; (1,2,3,7,8-PeCDD) | 0.0664 | 0.0104 | 0.1408 | 0.1158 | 1 | 0.0664 | 0.0104 | 0.1408 |
| 1,2,3,4,7,8-Hexachlorodibenzo-p-dioxin; (1,2,3,4,7,8-HxCDD) | 0.0370 | 0.0088 | 0.1264 | 0.0730 | 0.1 | 0.0037 | 0.0009 | 0.0126 |
| 1,2,3,6,7,8-Hexachlorodibenzo-p-dioxin; (1,2,3,6,7,8-HxCDD) | 0.0330 | 0.0088 | 0.1040 | 0.0584 | 0.1 | 0.0033 | 0.0009 | 0.0104 |
| 1,2,3,7,8,9-Hexachlorodibenzo-p-dioxin; (1,2,3,7,8,9-HxCDD) | 0.0290 | 0.0072 | 0.0792 | 0.0541 | 0.1 | 0.0029 | 0.0007 | 0.0079 |
| 1,2,3,4,6,7,8-Heptachlorodibenzo-p-dioxin; (1,2,3,4,6,7,8-HpCDD) | 0.1297 | 0.0208 | 0.5968 | 0.2504 | 0.01 | 0.0013 | 0.0002 | 0.0060 |
| 1,2,3,4,6,7,8,9-Octachlorodibenzo-p-dioxin; (1,2,3,4,6,7,8,9-OCDD) | 0.5592 | 0.0336 | 3.6880 | 1.0724 | 0.0003 | 0.0002 | 0.0000 | 0.0011 |
| 2,3,7,8-Tetrachlorodibenzofuran; (2,3,7,8-TCDF) | 0.1249 | 0.0432 | 0.3533 | 0.2191 | 0.1 | 0.0125 | 0.0043 | 0.0353 |
| 1,2,3,7,8-Pentachlorodibenzofuran; (1,2,3,7,8-PeCDF) | 0.0660 | 0.0248 | 0.1050 | 0.0928 | 0.03 | 0.0020 | 0.0007 | 0.0032 |
| 2,3,4,7,8-Pentachlorodibenzofuran; (2,3,4,7,8-PeCDF) | 0.0667 | 0.0280 | 0.1264 | 0.1014 | 0.3 | 0.0200 | 0.0084 | 0.0379 |
| 1,2,3,4,7,8-Hexachlorodibenzofuran; (1,2,3,4,7,8-HxCDF) | 0.0684 | 0.0184 | 0.1136 | 0.1038 | 0.1 | 0.0068 | 0.0018 | 0.0114 |
| 1,2,3,6,7,8-Hexachlorodibenzofuran; (1,2,3,6,7,8-HxCDF) | 0.0428 | 0.0128 | 0.0672 | 0.0648 | 0.1 | 0.0043 | 0.0013 | 0.0067 |
| 2,3,4,6,7,8-Hexachlorodibenzofuran; (2,3,4,6,7,8-HxCDF) | 0.0399 | 0.0136 | 0.0744 | 0.0624 | 0.1 | 0.0040 | 0.0014 | 0.0074 |
| 1,2,3,7,8,9-Hexachlorodibenzofuran; (1,2,3,7,8,9-HxCDF) | 0.0296 | 0.0072 | 0.0648 | 0.0534 | 0.1 | 0.0030 | 0.0007 | 0.0065 |
| 1,2,3,4,6,7,8-Heptachlorodibenzofuran; (1,2,3,4,6,7,8-HpCDF) | 0.2361 | 0.0224 | 0.8445 | 0.5814 | 0.01 | 0.0024 | 0.0002 | 0.0084 |
| 1,2,3,4,7,8,9-Heptachlorodibenzofuran; (1,2,3,4,7,8,9-HpCDF) | 0.0491 | 0.0134 | 0.1296 | 0.0846 | 0.01 | 0.0005 | 0.0001 | 0.0013 |
| 1,2,3,4,6,7,8,9-Octachlorodibenzofuran; (1,2,3,4,6,7,8,9-OCDF) | 0.2534 | 0.0156 | 0.8376 | 0.5366 | 0.0003 | 0.0001 | 0.0000 | 0.0003 |
| Sum Polychlorodibenzo-p-dioxins (PCDDs) | 0.8827 | 0.1848 | 4.4920 | 1.5205 | | 0.1061 | 0.0187 | 0.2215 |
| Sum Polychlorodibenzofurans (PCDFs) | 0.9769 | 0.2728 | 1.8968 | 1.6939 | | 0.0555 | 0.0222 | 0.0886 |
| Sum Polychlorodibenzo-p-dioxins and furans (PCDD/Fs) | 1.8596 | 0.4576 | 6.1600 | 3.0971 | | 0.1616 | 0.0624 | 0.2884 |

*Number of orange samples (n) =18.

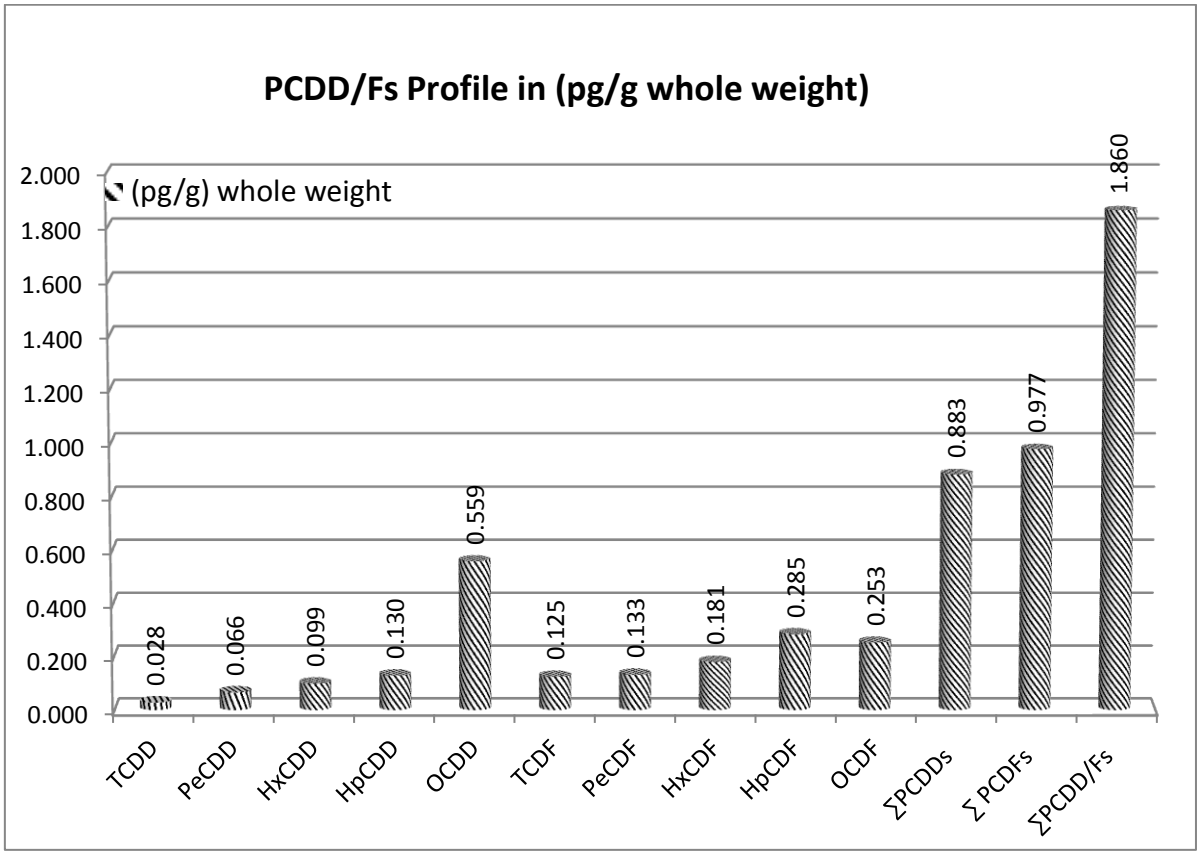


**Fig (1):** Mean concentrations of PCDDs/Fs profile in orange (pg/g w.w.).

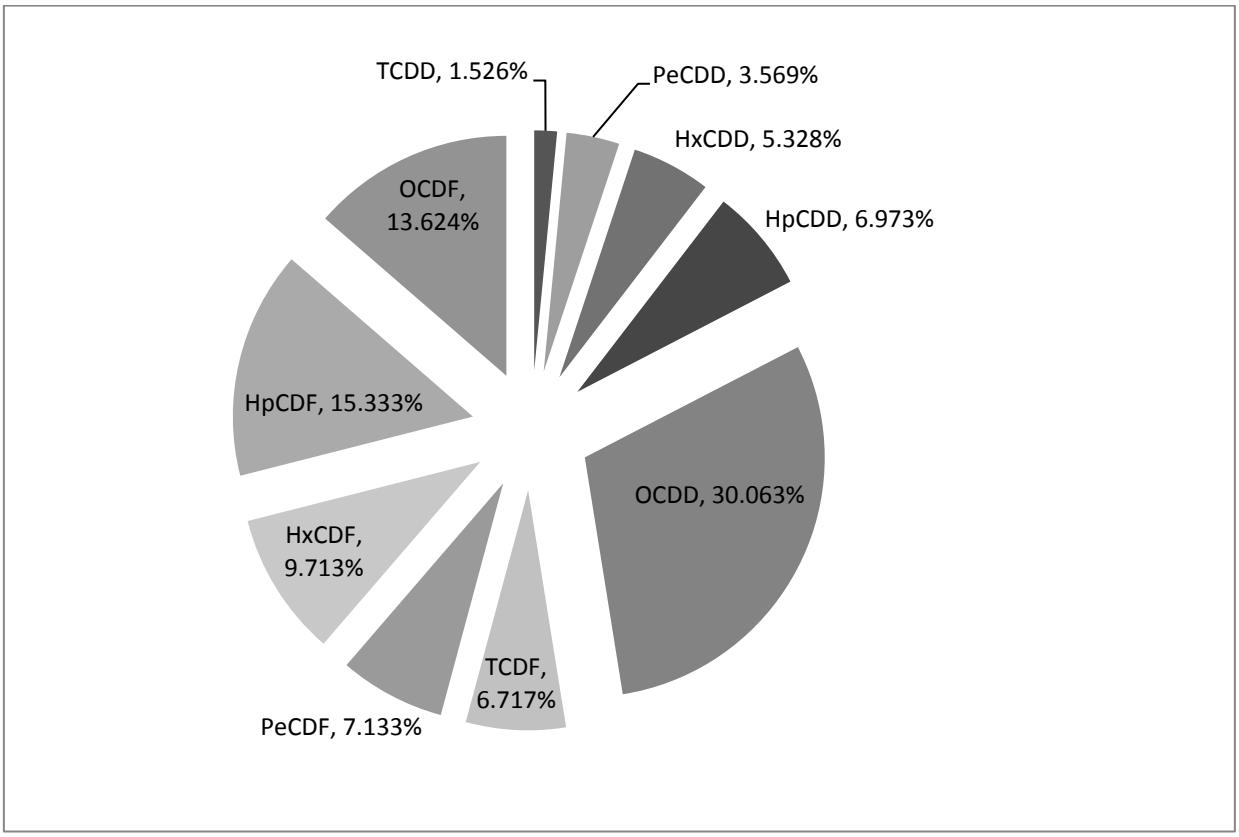


**Fig (2):** Contribution (%) of PCDD/F congeners to the mean concentration of ΣPCDD/Fs (pg/g w.w.) in orange.

**PCDD/Fs (pg WHO-TEQ/g) levels in orange samples**

The results obtained from the analysis of seventeen 2,3,7,8-substituted congeners of PCCD/Fs in the orange samples multiplied by a toxic equivalency factor (TEF) [6] are shown in **Table (1)**. The results showed that the toxic equivalency concentration of ∑PCDD/Fs ranged from (0.0624 to 0.2884) pgWHO-$TEQ_{2005}$/g w.w. and the mean is 0.1616 pgWHO-$TEQ_{2005}$/g w.w. which is lower than the maximum permissible limits of Egyptian Standardization and European Community (0.30 pgWHO-$TEQ_{2005}$/g w.w.) [24]. This study showed that the average toxic equivalency concentration of ΣPCDDs (0.1061 pgWHO-$TEQ_{2005}$/g w.w.) is higher than the average toxic equivalency concentration of ΣPCDFs (0.0555pgWHO-$TEQ_{2005}$/g w.w.) which contributes about 65.66% of the total toxic equivalency concentration of ∑PCDD/Fs in commercialized orange in Egypt.

The contribution of PCDD/F congeners according to their toxic equivalency factor (TEF) is also studied and the results are presented in **Figures 3 and 4**. The congeners were descending contributed in orange samples as following PeCDD, TCDD, PeCDF, HxCDF, TCDF, HxCDD, HpCDF, HpCDD, OCDD and OCDF which contribute from the total toxic equivalency concentration of ∑PCDD/Fs in analyzed samples about 41.08, 17.56, 13.60, 11.18, 7.73, 6.13, 1.76, 0.80, 0.10 and 0.05%, respectively, with mean concentrations about 0.066, 0.028, 0.022, 0.018, 0.013, 0.010, 0.003, 0.001, 0.0002 and 0.0001 pgWHO-$TEQ_{2005}$/g w.w., respectively.

Although OCDD showed the highest concentrations of total PCDD/Fs. in orange samples, it showed much lower TEQ concentration of total PCDD/Fs. The high chlorinated congeners, which exhibited the highest PCDD/F concentrations, did not account to a significant percentage of the WHO-TEQ content due to their relatively low WHO-TEF values as described in **Figures 2 and 4**.

**Dietary Intake of PCDD/Fs pg/g (TEQ) in orange samples**

Dietary exposure assessment combines food consumption data with data on the concentration of chemicals in food. The results of estimated dietary exposure then compared with the relevant health based guidance value for the food chemical of concern, if available, as part of the risk characterization.

Assessments may be undertaken for acute or chronic exposures, where acute exposure covers a period of up to 24 hours and chronic or long-term exposure covers average daily exposure over the entire lifetime [28].

The general equation for both acute and chronic dietary exposure was:

$$\text{Dietary exposure} = \frac{\sum(\text{Concentration of chemical in food} \times \text{Food consumption})}{\text{Body weight}}$$

In the chronic (long-term) risk assessment, the estimated dietary intake (EDI) for ΣPCDD/Fs of the Egyptian consumer was compared to the relevant toxicological reference values, i.e. acceptable Daily Intake of Dioxin (ADI) set by (International Programme on Chemical Safety (IPCS)) which was derived after a full hazard characterization of the compound. The consumer is considered to be adequately protected if the estimated dietary intake of detected dioxin does not exceed the acceptable provisional tolerable daily intake.

The limit values as given in **Table (2)** were based on a TDI (total daily intake) value of body weight. The maximum dioxin concentration in orange should not exceed 0.30 pg TEQ/g whole weight [24]. The consumption of Egyptian people for orange attained according to GEMS/Food is (38 g/person/day) [29] which showed that the Estimated Daily Intake (EDI) of ΣPCDD/Fs of the Egyptian consumer is 0.1023 (pg WHO-TEQ/kg body weight/day) lower than the WHO acceptable daily intake which is 4 pg WHO-TEQ/ kg b.w/day [20]. Thus, orange should not be out on the market if the dioxin contamination exceeds this value. These figures are still below the safe limits as the TDI of sum PCDD/Fs is (4 pg WHO-TEQ/person/day) according to the International Programme on Chemical Safety (IPCS).

**Conclusion**

The levels of PCDD/Fs were studied in commercialized orange in Egypt using High Resolution Gas Chromatography - High Resolution Mass Spectrometer (HRGC-HRMS).The results showed that the mean levels of PCDD/Fs measured by HRGC/MS multiplied by toxic equivalent factor (TEF) in orange was lower than the maximum permissible limits of Egyptian Standardization and European Community. The study showed that the dietary intake of the Egyptian consumer of orange was lower than the WHO acceptable daily intake.

**Table (2):** Estimated daily intake (EDI) of sum means concentration PCDD/Fs in orange.

| Mean of ΣPCDD/Fs (pgWHO-TEQ/g w.w) | Food consumption g/day* | Estimated Daily Intake (EDI) of ΣPCDD/Fs (pg WHO-TEQ/ Person/day) | Estimated Daily Intake (EDI) of ΣPCDD/Fs (pg WHO-TEQ/kg b.w/day)** | Acceptable Daily Intake of Dioxin (ADI) | Intake, % |
|---|---|---|---|---|---|
| **0.1616** | **38** | **6.1408** | **0.1023** | **4** | **2.5587** |

* Food consumption reference is GEMS/Food 2006[29].

** The Average body weight =60 kg

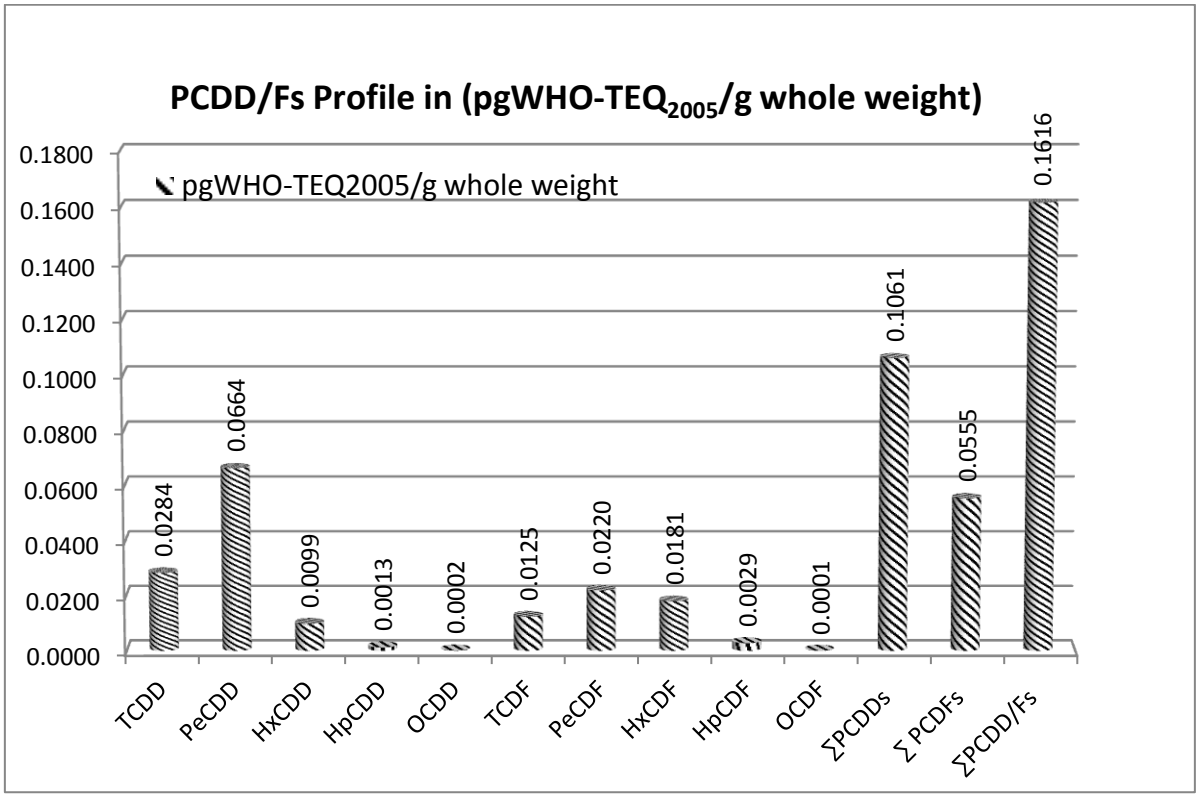


**Fig (3):** Mean concentrations of PCDDs/Fs profile in orange (pgWHO-$TEQ_{2005}$/g w.w.).

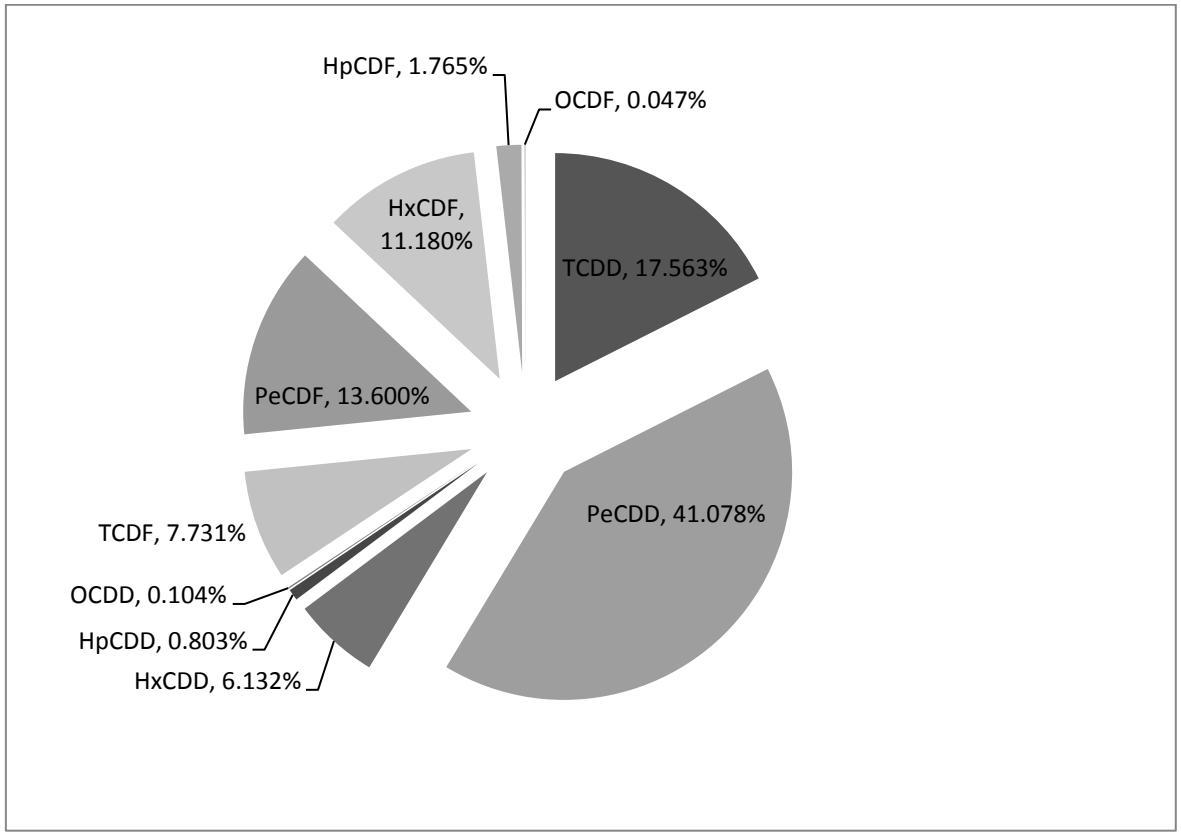


**Fig (4):** Contribution (%) of PCDD/F congeners to the mean of ΣPCDD/Fs (pgWHO-$TEQ_{2005}$/g w.w.) in orange.

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