Assessment of Dietary Exposure and Risk of DDT Concerning Freshwater Fish Aquaculture

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Abstract: Pesticides may accumulate in freshwater fish due to contamination from the environment. This paper reports on a risk assessment of DDT and DDT metabolites in carp. A survey was conducted about dietary habits among fish consumers. Cluster analysis was accomplished based on the frequency and amount of carp consumption. Classical and carcinogenic risk assessments were performed for the clusters. While DDT contamination was present, it was not found to be risky concerning the complete diet of the clusters (carcinogenic risk was also negligible), moreover, carp consumption did not contribute significantly to the risk level even in the case of the extreme consumers.

Keywords: risk assessment; carcinogenic risk assessment; freshwater fish; DDT

1. Introduction

Fish is one of the essential protein sources for mankind with several advantageous nutritional effects. Due to its high content of omega-3 fatty acids, it has a beneficial effect on the cardiovascular system of the body. It also contains significant amounts of vitamins B12 and D [1,2]. Among others, because of its mentioned nutrient composition, the consumption of fish is part of a balanced, varied human diet.

According to the latest available European data, the annual fish consumption in Hungary is 5.6 kg/capita [3]. This value lags significantly behind most of the countries in the European Union, which puts Hungary at the bottom of the list in terms of fish consumption. Based on EUMOFA (European Market Observatory for Fisheries and Aquaculture Products) data for 2018, Hungarians spend 14 euros per year on fish and seafood, which is about one-eighth of the EU average [3]. Although Hungary is below the average considering total fish consumption, it leads the EU list in terms of carp consumption, with 1.2 kg annually [4].

In our preliminary research, the fish consumption habits of the Hungarian population were investigated in general, with a representative, questionnaire-based consumer survey, between 21 August 2018 and 12 September 2018, involving 1002 people. The sample was representative of the adult Hungarian population by gender, age and region of residence, based on the data of the 2016 micro-census [5]. As a result of the survey, five consumer groups were identified by hierarchical cluster analysis based on the frequency and the amount of carp consumption. Three clusters out of
five are worth further investigating if they are exposed to any risk of freshwater fish consumption because of their consumption patterns. The group of “The fishermen” is mostly men over the age of 40, consuming carp more times than the average in larger quantities (27.2 times a year, 225.01 g/occasion—6.12 kg/year). The cluster of “the hearty eaters” is the second potentially exposed group. Although they eat fish less frequently, the amount of fish consumed on one occasion is remarkably high (5.89 times a year, 309.80 g/occasion—1.82 kg/year). The last group is the “The carp fanatics”, mostly over 60 years old men. In their case, the frequency of carp consumption is remarkably high, almost ten times the average (109.34 times a year, 245.64 g/occasion—26.86 kg/year) [6].

The topic of heavy metal accumulation in marine fish is a widely studied research area [7–9]. In contrast, it is less known that the extreme consumption of freshwater fish may also have risky effects, regarding different groups of chemical compounds. Significant amounts of pesticides may accumulate in freshwater fish meat due to the pesticide contamination of the fishponds [10,11]. Fish—especially fatty fish species—can pose a health risk due to the accumulation of heavy metal contamination (such as arsenic, mercury, or cadmium) [12,13] and the presence of persistent organic pollutants (POPs) [14] as well. The fat content of pond-cultured carp may vary between 4–5% or even 10–23% depending on whether they are fed and if so, with what type of feed [15], therefore, carp could be considered as medium/high-fat fish [16].

Within the framework of a comprehensive survey carried out in the HappyFish project (NVKP_16-1-2016-0023 project funded by the National Competitiveness and Excellence Programme), the pesticide content of the water and the fish in Hungarian fishponds were analyzed. Based on the results, 21 of the 420 tested pesticides were present in detectable quantities in the fish samples, in 0.01–0.05 mg/kg amounts. One of the most common contaminants in Hungarian fishponds is the organochlorine insecticide DDT (dichloro-diphenyl-trichloroethane). DDT is a highly persistent, high-efficiency insecticide that was widely-used globally in the 20th century. Due to its neurotoxic and possibly carcinogenic effect (compound belonging to IARC group 2A), it has been banned in Hungary since 1968 [17–19]. DDT or the decomposition products of DDT could be detected in the fish samples of all the examined fishponds [6], therefore, presumably within certain dietary patterns, DDT could still pose a risk despite it being banned on the crop protection chemicals market for decades. The relevance of this hypothesis is emphasized by several research studies carried out in other countries, where fatty-fish consumption was associated positively with DDT levels in human adipose tissue [20].

As the aforementioned data shows, fish consumption in Hungary is well below the European Union average. However, there are consumer segments with extreme carp consumption habits. Due to the higher level of consumption, we assume that these consumer groups are more exposed to food safety risks than the whole population. Therefore, it is essential to have sufficient information about the type, the frequency, and the seriousness of the occurring risks in connection with fish consumption. Understanding the habits and behavior of exposed consumers is crucial to carry out a risk assessment and identify efficient risk communication activities [21].

Considering the above-mentioned principles, this study aims to investigate carp consumption patterns among extreme consumers via a questionnaire survey. Based on the results, an evaluation of the dietary intake and the related risks was performed regarding the most relevant chemical contamination in Hungarian freshwater fish, DDT, and its metabolites.

2. Materials and Methods

2.1. Quantitative Survey

Based on the results of the preliminary representative consumer survey of the HappyFish project, another survey involving 1000 people was conducted between 21 March 2019 and 4 June 2019, targeting extreme fish consumers. As a result of 479 personal interviews and 525 online respondents, 1004 extreme fish consumers participated in the survey in total (Table 1).
Table 1. Demographic data of the survey on extreme fish consumers.

| Gender | Female | Male |
|--------|--------|------|
|        | 33.37% | 66.63% |

| Age                  | 18-29 years old | 30-39 years old | 40-59 years old | 60+ years old |
|----------------------|-----------------|-----------------|----------------|---------------|
| Percentage           | 13.85%          | 13.94%          | 39.34%         | 32.87%        |

| Regions              | Central Transdanubia | Central Transdanubia | Western Transdanubia | Southern Transdanubia | Northern Hungary | Northern Great Plain | Southern Great Plain |
|----------------------|----------------------|----------------------|----------------------|----------------------|-------------------|----------------------|----------------------|
| Percentage           | 28.98%               | 14.05%               | 9.26%                | 5.38%                | 3.89%             | 16.83%               | 21.61%               |

In addition to carp consumption habits (frequency, serving size based on EU MENU project [22]) the questionnaire also included questions on the frequency of consumption of other food categories. Statistical analysis of the data was performed with the IBM SPSS Statistics 22.0 software package (IBM Corp., Armonk, NY, USA). Descriptive analysis (mean, standard deviation, minimum, maximum) and cluster analysis was carried out, using the Ward method.

2.2. Evaluation Procedures of Non-Genotoxic Carcinogenic Chemical Substances

Based on the cluster analysis, two evaluation methods distinguishing between non-carcinogenic and long-term carcinogenic effects were performed for the consumer groups of extreme consumers, regarding the frequency and the amount of carp consumption.

The comparison of the dietary exposure and the definite safety goal—the acceptable daily intake (ADI)—was carried out based on the following approach [23,24].

In the case of DDT, there is a risk of longer-term, chronic health effects. Therefore, the value of ADI should be considered instead of the acute reference dose (ARID) in the evaluation [25]. According to literature data, the ADI is 0.01 mg/kg bw/day for DDT and DDT metabolites [26].

Regarding the exposure assessment, the estimation of the total dietary intake for DDT contamination was conducted, considering the dietary intake data within each food category. The assessed exposure, the so-called estimated daily intake (EDI) is formulated as [24]:

\[
EDI = \frac{H \times C}{BW}
\]  

where \(H\) is the concentration of the certain chemical [mg/kg], \(C\) is the amount of the consumed food (kg/day), \(BW\) is the body weight (the average body weight in each cluster) (kg).

The frequency of consumption of each food category was asked in the questionnaire survey, considering the consumption habits of the previous year. The consumed amount of the different food types was calculated based on the serving size recommendations by “safefood” and Bupa organizations [27,28].

The evaluation of the ratio of tolerable (the ADI) and the estimated dietary intake (the EDI) for DDT was based on the HQ (hazard quotient)—a metric, which is used for chemicals with a threshold [24,29]. The ratio between 1 and 10 refers to moderate risk, while a value above 10 could be linked to increased risk [29]. The HQ is calculated as:

\[
HQ = \frac{EDI}{ADI}
\]  

A chemical risk assessment for DDT was also performed for carcinogenic effects according to the following outline:

1. Calculation of chronic daily intake (CDI—mg/kg of body weight per day)—also known as intake rate (I)—according to the following formula [30]:

\[
CDI = \frac{ADI \times BW}{PTWS}
\]
\[ CDI = C \cdot \left( \frac{CR \cdot EF \cdot ED}{BW \cdot AT} \right) \]

where \( C \): average concentration of the studied contaminant (average DDT concentration in carp based on laboratory tests. The detailed description of the laboratory analysis can be found in Supplementary Material S1.), average value in other food categories based on previous international research results) (mg/mg).

- CR: contact rate (the amount of the studied compound ingested daily) (mg/day).
- EF: exposure frequency (the number of days when the contaminated food was consumed in a year) (day/year).
- ED: exposure duration (over the lifetime - estimated at 70 years) (years).
- BW: body weight (the average body weight in each cluster) (kg).
- AT: the studied exposure period (over the lifetime - estimated at 70 years) (days).

2. Risk characterization

The product of chronic daily intake and the slope factor of the studied chemical contaminant characterize the identified risk for certain consumer groups. The slope factor is a value applied for the estimation of carcinogenicity. The slope factor of ingestion DDT is 0.34 [31]. Above the risk threshold—which is \( 10^{-6} \) according to the literature data—the existence of carcinogenic risk is identified [30].

3. Results and Discussion

3.1. Descriptive Analysis

The results of the questionnaire survey involving 1004 extreme fish consumers indicate that more than half of the respondents (53.44%) consume carp at least once a month, while a further 33.80% at least 6–8 times a year. This above-average amount of fish consumption confirms that the survey managed to reach the extreme fish-consuming stratum of the population. This is also indicated by the fact that 13.57% of the respondents also consumed carp within 24 h before the survey. In general, the participants consumed carp on average 15.5 times in the past year. The extreme carp consumption is mainly linked to Christmas—as the traditional meals of Christmas contain mainly carp in Hungary—but includes carp consumption on weekdays without any special occasion (Figure 1).

![Figure 1. The occasions of carp consumption.](image)

As a consequence of the undiminished popularity of fishing in Hungary, most of the extreme consumers obtain fish by fishing (3.87 on 1–5 Likert scale). Fish shops, butchers (2.77), and markets
(2.49) are also popular sources of fish acquisition, unlike supermarkets (1.93). Completely different trends are prevailing internationally, regarding the place of fish purchasing. Instead of fishing, fish is acquired from retailers, such as grocery stores and fish markets [32]. Based on the present study, more than two-thirds (70.30%) of extreme fish consumers regularly go fishing and 65.72% also consume self-caught fish. In accordance with that, Burger (2013) also investigated that the more often someone eats fish, the more likely they are to consume self-caught fish [33]. The survey also aimed to identify the consumption habits of different parts of the fish. 37.99% of the respondents do not reject even the fatty parts of the carp and skin is also consumed by almost half of the participants (46.36%).

3.2. Cluster Analysis

As a result of the cluster analysis, four groups of Hungarian extreme fish consumers could be separated based on the frequency of consumption and the service sizes (Table 2).

| Cluster 1 (The Hearty Eaters) | Cluster 2 (The Average Carp Lovers) | Cluster 3 (The Young Carp Lovers) | Cluster 4 (The Carp Fanatics) |
|-------------------------------|-------------------------------------|----------------------------------|-----------------------------|
| Size of the cluster (N)       | 401                                 | 311                              | 254                         | 38                          |
| Ratio in the sample (%)       | 39.9%                               | 31.0%                            | 25.3%                       | 3.8%                        |
| Frequency of consumption (occasion/year) | 16.67                              | 18.38                            | 6.94                        | 104.54                      |
| Serving size (g/occasion)     | 319.40                              | 215.95                           | 149.22                      | 249.21                      |
| Estimated annual fish consumption (kg/year) | 5.32                               | 3.97                             | 1.04                        | 26.05                        |

Cluster 1 is the group of hearty eaters, including men (77.6%) above 40 years (81.8%) mainly. They usually get carp through fishing, many of them also fish regularly. They usually eat the skin and fatty parts of the carp as well. As for their general diet, “the hearty eaters” consume offal more often than other clusters.

Cluster 2 consists of 31.0% of respondents, “the average carp lovers,” who consume carp in slightly smaller serving sizes than the average but often (1–2 times a month). The majority of this cluster is made up of men and women over the age of 40 (72.3%). In general, they consume mushrooms, eggs, and honey more often than other groups.

A quarter of the sample (25.3%) consists of “young carp lovers” who consume an average amount of carp regularly but not too often. This cluster includes the highest proportion of respondents under the age of 29 and the lowest BMI index. They do not consume the skin or the fatty parts of the carp, and they are also less likely to go fishing.

The smallest proportion of respondents (3.8%) form the cluster of “the carp fanatics”. The members of this group are the most extreme fish consumers, consuming carp almost every three days. They are mostly over 60 years of age (63.2%), who go fishing (81.1%), and eat carp skin and fatty parts as well.

3.3. Classical and Carcinogenic Risk Assessment

The bioaccumulation and biomagnification of POPs along the food chain is a considerable food safety risk. DDT and its metabolites can be detected in even more than 10^5 times larger amounts in the carp samples than in the fish pond water [34]. The high persistence level of DDT and its metabolites is supported by the fact that it is still present in water and fish worldwide. According to da Silva Rabitto et al. (2011) DDT or/and DDE contamination were detected in 95–100% of the laboratory tested fish samples from Amazon, ranging from 0.54 to 15.34 ng DDTs g^{-1} quantities [35]. As several research studies indicate that the presence of DDT is still problematic, risk assessment is essential, concentrating on the exposed consumer groups with extreme and/or unvaried diets.
The accomplished cluster analysis highlighted three clusters that include significantly extreme fish consumers, considering the amount and/or frequency of carp consumption. The chemical risk assessment was performed for the following three clusters: “the hearty eaters,” “the average carp lovers,” and “the carp fanatics.”

The results of the survey and the cluster analysis such as the characteristics of carp consumption and the average body weight of each cluster served as input information for the risk assessment (Table 3).

Table 3. Characteristics of the concerned clusters.

| Cluster | Frequency of Carp Consumption (Occasion/Year) | Estimated Annual Carp Consumption (kg/Year) | Average Body Weight (kg) |
|---------|---------------------------------------------|---------------------------------------------|--------------------------|
| Cluster 1— The hearty eaters               | 16.67                                      | 5.32                                       | 91.01                    |
| Cluster 2— The average carp lovers         | 18.38                                      | 3.97                                       | 80.99                    |
| Cluster 4— The carp fanatics               | 104.54                                     | 26.05                                      | 82.97                    |

In the present study, the DDT risk assessment was built on the DDT concentration in carp measured during the laboratory tests (detailed in Supplementary Material S1). To assess the whole dietary intake of DDT and its metabolites, several international studies were reviewed for collecting total DDT concentrations in the case of other food categories [36–57]. The average DDT levels of the food categories according to the relevant literature and the related Maximum Residue Levels (MRL) in force [58] are presented in Table 4. For exposure assessment, the average consumption quantity of each cluster was used for the studied food categories. Table 5 summarizes the average consumption per cluster based on the quantitative survey results.

Table 4. Average DDT levels and maximum residue levels of the food categories.

| Food Category                          | MRL for DDT (mg/kg) * | Average Concentration of DDT (mg/kg) | Research Article/Report for Calculation of Average Concentration |
|----------------------------------------|-----------------------|-------------------------------------|-----------------------------------------------------------------|
| Fruits (fresh, frozen, canned)        | 0.05                  | 0.00414                             | Galassi et al. (2008), Johnson et al. (2011), Goralczyk et al. (1999), |
| Vegetables (fresh, frozen, canned)    | 0.05                  | 0.00387                             | Lozowicka et al. (2016), Hura et al. (1999), Galassi et al. (2008), |
| Mushrooms                              | 0.05                  | 0.67464                             | Gałgowska et al. (2012), Gałgowska & Pietrzak-Fiecko (2017) |
| Cereals and bakery products           | 0.05                  | 0.09440                             | Darnerud et al. (2016), Galassi et al. (2008), Hura et al. (1999), Lozowicka et al. (2016) |
| Nuts and oilseeds                     | 0.05                  | 0.00876                             | Wieczorek & Garbowska (2020) |
| Tea, coffee                           | 0.2                   | 0.00580                             | Hura et al. (1999), Witczak et al. (2017) |
| Food Category                        | MRL | *P* Value | Sources                                      |
|-------------------------------------|-----|-----------|----------------------------------------------|
| Poultry and poultry products        | 1   | 0.00085   | Darnerud et al. (2016), Galassi et al. (2008), Polder et al. (2010) |
| Pork and pork products              | 1   | 0.00547   | Darnerud et al. (2016), EFSA (2013), Galassi et al. (2008), Polder et al. (2010) |
| Beef and beef products              | 1   | 0.00061   | Darnerud et al. (2016), Galassi et al. (2008), Polder et al. (2010) |
| Venison                             | 1   | 0.01747   | Galassi et al. (2008), Polder et al. (2010), Tomza-Marciniak et al. (2014) |
| Offal (e.g., liver, kidney, tripe)  | 1   | 0.00379   | Darnerud et al. (2016), Galassi et al. (2008), Naseri et al. (2019) |
| Sea fish and products               | -   | 0.00365   | Darnerud et al. (2016), Galassi et al. (2008) |
| Freshwater fish and fish products   | -   | 0.02844   | HappyFish project (Supplementary Material S1) |
| Milk                                | 0.04| 0.00150   | Darnerud et al. (2016), EFSA (2013), Galassi et al. (2008) |
| Dairy products (e.g., cheese, yoghurt, sour cream) | 0.04| 0.01112   | Darnerud et al. (2016), Galassi et al. (2008), Rusu et al. (2016) |
| Butter, margarine                   | 0.04| 0.00483   | Darnerud et al. (2016), Weiss et al. (2013), Witczak & Abdel-Gawad (2014) |
| Oils and fats                       | -   | 0.00743   | Darnerud et al. (2016), Galassi et al. (2008), Özbek & Ergönül (2020), Škrbić & Predojević (2008) |
| Egg                                 | 0.05| 0.00447   | Darnerud et al. (2016), EFSA (2013), Galassi et al. (2008), Okofo et al. (2016) |
| Honey                               | 0.05| 0.07171   | Blasco et al. (2004), Matusevicius et al. (2010) |
| Chocolate and cocoa products        | 0.5 | 0.02783   | Darnerud et al. (2016), Okofo et al. (2016) |

* MRL according to the REGULATION (EC) NO 396/2005 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL [58].
Table 5. The consumption patterns and DDT contamination of the food categories.

| Food Category                          | Serving Size (g) * | Frequency (Occasion/Year) | Quantity (kg/Year) | Frequency (Occasion/Year) | Quantity (kg/Year) | Frequency (Occasion/Year) | Quantity (kg/Year) |
|----------------------------------------|--------------------|---------------------------|--------------------|---------------------------|--------------------|---------------------------|--------------------|
| Fruits (fresh, frozen, canned)         | 80                 | 296.95                    | 23.756             | 342.74                    | 27.4192            | 398                       | 31.84              |
| Vegetables (fresh, frozen, canned)     | 80                 | 295.37                    | 23.63              | 314.29                    | 25.14              | 316.92                    | 25.35              |
| Mushrooms                              | 80                 | 62.73                     | 5.02               | 56.14                     | 4.49               | 61.16                     | 4.89               |
| Cereals and bakery products            | 50                 | 438.94                    | 21.95              | 422.26                    | 21.11              | 439.69                    | 21.98              |
| Nuts and oilseeds                      | 40                 | 137.39                    | 5.49               | 147.52                    | 5.90               | 183.63                    | 7.35               |
| Tea, coffee                            | 100                | 486.47                    | 48.65              | 517.88                    | 51.79              | 465.68                    | 46.57              |
| Poultry and poultry products           | 100                | 150.24                    | 15.02              | 173.57                    | 17.36              | 161.22                    | 16.12              |
| Pork and pork products                 | 100                | 134.27                    | 13.43              | 138.09                    | 13.81              | 85.83                     | 8.58               |
| Beef and beef products                 | 100                | 51.03                     | 5.10               | 54.22                     | 5.42               | 52.97                     | 5.29               |
| Venison                                | 100                | 26.09                     | 2.61               | 17.25                     | 1.73               | 19.26                     | 1.93               |
| Offal (e.g., liver, kidney, tripe)     | 100                | 36.24                     | 3.62               | 33.15                     | 3.32               | 16.92                     | 1.69               |
| Sea fish and products                  | 150                | 44.87                     | 6.73               | 34.35                     | 5.15               | 44.47                     | 6.67               |
| Freshwater fish and fish products      | 150                | 55.28                     | 8.29               | 51.23                     | 7.68               | 130.96                    | 19.64              |
| Milk                                   | 200                | 242.73                    | 48.55              | 251.33                    | 50.27              | 321.04                    | 64.21              |
| Dairy products (e.g., cheese, yoghurt, sour cream) | 75                 | 268.39                    | 20.13              | 295.07                    | 22.13              | 343.24                    | 25.74              |
| Butter, margarine                      | 10                 | 246.29                    | 2.46               | 264.74                    | 2.65               | 298.28                    | 2.98               |
| Oils and fats                          | 10                 | 19.86                     | 1.92               | 203.42                    | 2.03               | 234.31                    | 2.34               |
| Egg                                    | 130                | 170.85                    | 22.21              | 171.06                    | 22.24              | 198.09                    | 25.75              |
| Honey                                  | 20                 | 140.95                    | 2.82               | 152.31                    | 3.05               | 159.07                    | 3.18               |
| Chocolate and cocoa products           | 25                 | 165.26                    | 4.13               | 146.18                    | 3.65               | 184.61                    | 4.62               |

* Serving size [27,28].
The risk assessment carried out for the dietary intake of DDT indicates that no risk can be observed for all three clusters, as the ratio of the estimated and the tolerable dietary intake (HQ) for DDT is below 1 (Table 6).

Table 6. EDI and HQ values for the concerned clusters regarding DDT.

| Estimated Dietary Intake of DDT (mg/day) | Cluster 1 | Cluster 2 | Cluster 4 |
|-----------------------------------------|-----------|-----------|-----------|
| Hazard Quotient of DDT                  | 0.189     | 0.02244   | 0.02544   |

To gain a comprehensive view regarding DDT contamination in freshwater fish, risk evaluation was also performed considering the carcinogenic effect of chronic DDT dietary intake. Based on the respondents’ total dietary intake, the chronic daily DDT intake (CDI) is $1.93 \times 10^{-11}$mg/kg bw/day for Cluster 1, $1.85 \times 10^{-11}$ mg/kg bw/day for Cluster 2 and $2.08 \times 10^{-11}$mg/kg bw/day for Cluster 4. Considering the relevant slope factor for ingestion DDT intake (0.34), the risk of the carcinogenic effect caused by DDT is $6.55 \times 10^{-12}$ for Cluster 1, $6.28 \times 10^{-12}$ for Cluster 2, and $7.08 \times 10^{-12}$ for Cluster 4. As the carcinogenic risk value for all three clusters is below $10^{-6}$ mg/kg bw/day, the risk of the carcinogenic effect of DDT does not reach the threshold level for either clusters.

Based on the results of the dietary exposure evaluation, it can be concluded that the amount of DDT that can be ingested with food does not pose a carcinogenic risk to either extreme consumer clusters and other health risks linked to DDT and its metabolites are also not likely to be increased by the dietary intake. It should be noted that the used formulas for the evaluation of risks do not take the cluster members’ age into consideration. However, the risk is probably higher for older clusters, as studies find that age is in positive correlation with the concentration of DDT metabolites in human tissues [20].

The potential risk can be reduced by avoiding the consumption of fatty fish parts and skin, given that, according to literature data, these contaminants and their degradation products can be enriched to a greater extent in adipose tissue [59]. Certain studies claim that the increased consumption of cruciferous vegetables (e.g., soy, radish, cauliflower) and low-fat food products can considerably reduce the risk of chronic DDT toxicity owing to its chemopreventive agents [60]. As DDT is constantly present in the natural environment, therefore in the food chain, its transmission to food is inevitable. Although it has been observed that by reducing the intake of certain foods (for example dairy and red meat products, eggs) the amount of the accumulating compound in the body might be affected to some extent [61], the avoidance of some specific food categories, such as freshwater fish is not enough to eliminate the potential risk. By contrast, fish consumption has beneficial health effects owing to its rich nutritional composition, which also needs to be taken into consideration during following a balanced diet [62]. In addition, self-caught fish consumption plays an important role in ensuring food and nutritional security in low-income households in developing countries [63]. In conclusion, the risk management of DDT contamination in freshwater fish does not necessarily mean the absolute avoidance of these food products but the awareness of the risk and the endeavor for a varied diet as much as possible.

To be able to interpret the results of the present research correctly, the limitations of the research should also be kept in mind. During the preliminary laboratory analysis—which served as a basis of the risk assessment—fish meat samples were collected from only six different fishponds. As the amount and variety of chemical residues detected in the fish depend on the surroundings of the fish ponds as well (e.g., industrial facilities, unspoiled natural environment, agricultural area), the studied fishpond water and fish samples may not represent perfectly the DDT contamination in Hungarian freshwater fish. A remark should be made also in connection with the DDT concentration of other surveyed food categories, as data on contamination levels in Hungary is not available in most of the cases. The exposure and risk evaluation was based on the reported dietary habits by recalling the consumption frequencies of each food category from the previous year. The limitations of human memory could have been eliminated by keeping a food diary, resulting in more precise information on the dietary intake of the respondents.
Further research might include risk assessment for an especially vulnerable consumer group, children, investigating their specific—sometimes possibly unvaried—dietary habits. Research studies show that giving fish as a gift to others has an important role in fish consumption [33]. This topic could also be further investigated, as giving away the self-caught fish also influences the fish consumption patterns of the stratum of the society which is not engaged in fishing. Besides risk assessment, clinical trials could also be accomplished in the future, involving extreme consumers and anglers, as published in the fieldwork of Kiviranta et al. (2002) [64]. It could facilitate a better understanding of the long-term consequences of chronic DDT dietary intake, caused by the long biological half-life of persistent chemical contaminants, still present in the natural environment.

4. Conclusions

Although the amount of fish consumption in Hungary is below the European Union average, there are consumer groups with extreme freshwater fish consumption habits. To sum up the findings of the quantitative consumer survey and the cluster analysis, specific consumer groups were identified which bear extreme carp consumption patterns, thus, they are more exposed to the emerging risks because of chronic intake of chemical residues. Based on the results of the assessment of dietary exposure and risk to DDT, it can be concluded that there is probably no risk for non-carcinogenic effects of DDT contamination among extreme consumers for all of the studied clusters. At the same time, the level of carcinogenic risk is insignificant for these groups, as the results were well below the threshold. Identifying and understanding carp consumption habits can serve as a basis for risk assessors and risk managers for further research and can pave the way for an even more effective risk communication activity toward extreme freshwater fish consumers, especially toward anglers.

Supplementary Materials: The detailed description of the laboratory experiments is available in Supplementary Material 1. The following is available online at www.mdpi.com/2076-3417/10/24/9083/s1, Document S1: The laboratory analysis of DDT in carp.

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