BIOACCUMULATION FACTORS AND INTAKE OF 2,3,7,8 -POLYCHLORINATED DIBENZO-p-DIOXINS IN THE DOMESTIC CHICKEN (Gallus domesticus)

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Introduction

An important parameter used in environmental toxicology and risk assessment is the bioaccumulation factor (BAF). This parameter is used in the determination of the degree of intake and component storage of toxic compounds in animals[1]. One of the most commercially valuable farm animals in the United States is the domestic chicken (Gallus domesticus). Rapidly reared in controlled, intensive environments, the US Department of Agriculture (USDA) estimated the production of these animals exceeded eight billion in the United States during 2002[2]. This group comprises approximately 95% of the total poultry production in the U.S. A previous study of chickens exposed to contaminated soils mixed in the feed material[3] calculated bioconcentration factors for 2,3,7,8-polychlorinated dibenzo-p-dioxins (PCDDs) and -furans (PCDFs) in adipose tissue, which ranged from 0.5 to 11, congener and tissue specific[3]. It concluded that chickens foraging on soil contaminated with parts-per-trillion (ppt) concentrations of PCDDs/PCDFs may accumulate these compounds to unacceptable levels. During a national survey of dioxin-like compounds in poultry in association with the USEPA/Office of Research and Development's Dioxin Reassessment Program, it was discovered that several chickens samples contained elevated concentrations of PCDDs[4, 5]. It was determined that the source of this contamination in the soybean feed was the ball clay, an anti-caking component of the feed [6, 7, 8]. The profile of the PCDDs and PCDFs revealed that only the PCDDs were present at significant levels and the PCDFs were present at very low concentrations or below the detection limits. From the survey calculations were made to determine the BAFs and intake rates of the PCDDs in the chickens and how they compared to previously reported values.

Methods and Materials

The domestic chicken (Gallus domesticus) is reared in controlled poultry facilities using a series of different feed materials - starter, growth, finisher, and withdrawal, formulated for specific poultry

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groups - fryers, broilers, and roasters (hens and roosters)[9]. Fryers are reared for 3-4 weeks (21-28 days), broilers for 6-8 weeks (42-56 days), and roasters 12-14 weeks (84-96 days). As the chickens age, their percentage of total fat increases with fryers containing 5.6%, broilers 12.6%, and roasters 18.8%[10]. Additional information from a local poultry producer revealed that for a typical poultry rearing facility an average broiler raised over a 44 day period consumes 5.3 kg of feed (120 g/fowl/day) with an average final weight of 2.61 kg for a 2.03 feed conversion (total feed consumed kg /body weight gain kg)[11].

In the Survey of Dioxin-Like Compounds in Poultry Program, a joint program between the USDA/Food Safety and Inspection Service (FSIS) and the USEPA/ Office of Research and Development (ORD), the primary objective was to assess the national prevalence and concentration of PCDDs and PCDFs in the abdominal fat of poultry slaughtered in federally inspected establishments within the US. Abdominal fat was selected as the tissue compartment of interest because it is a matrix with high lipid content (~60-90% by weight) and, hence, maximizes the ability to detect lipophilic substances (e.g., PCDDs, PCDFs). The samples collected in the survey were from broiler grade chickens, which had been reared approximately 44 days.

There were four samples used from the survey: two elevated chicken samples collected by the USDA during the statistical survey of poultry throughout the United States[4] and two additional whole chicken broilers purchased from a local supermarket during the survey period. Inspections of the USDA records indicated that the samples were from the same production region. The ball clay used as the anti-caking component of the soybean feed was determined to be the source of the 2,3,7,8-PCDDs contamination and was traced to a mining facility in Northern Mississippi[6]. This clay was ultimately removed from animal feed use. All of these samples underwent extraction, clean-up and analysis by High Resolution Gas Chromatography coupled with High Resolution Mass Spectrometry (HRGC/HRMS) in accordance with a modification of EPA Method 1613[4, 8, 12].

A review of the average congener concentrations of the 2,3,7,8-PCDDs for the two samples of the two populations demonstrated relative percent differences (RPD) for TCDD through HpCDD of 12%, with a high for OCDD of 125%. The dioxin congener profiles in the four chicken samples were quite distinctive and consistent with the ball clay, indicating identical material source.

Bioaccumulation factors (BAFs) were calculated for each congener in the adipose tissue compartment as a ratio of the concentration (pg/g, wet weight) of a congener in the tissue to the concentration of the same congener in the feed (pg/g, wet weight):

$$BAF_{(adipose)} = \frac{[\text{Adipose Concentration (pg/g; wet weight)}]}{[\text{Soybean Feed (pg/g; wet weight)}]}$$

Intake was calculated as the average daily uptake in total toxic equivalence (TEQ) for the chicken which is the product of the TEQ concentration of the PCDDs in the feed (pg/g, TEQ), total feed consumed during rearing (kg) divide by the product of the final weight of the chicken (kg), days of rearing.

$$\text{Daily Intake}_{(chicken)} = \frac{[\text{Concentration of PCDDs in Feed (pg/g TEQ) x Total Feed (kg)}]}{[\text{Period of Rearing (days) x Final Weight of Chicken (kg)}]}$$

Results and Discussion

The bioaccumulation factors (BAFs) for the broiler chickens of the survey are presented and compared to the bioconcentration factors (BCFs) of the California Environmental Protection Agency (CEPA) study on chickens (Table 1). The BCFs of the CEPA study were equivalent to the BAFs of this survey. The CEPA study[3] had foraging chickens exposed to 2,3,7,8-PCDDs/PCDFs contaminated soils with a low exposure concentration of 42 ppt, I-TEQ and a high exposure concentration of 460 ppt, I-TEQ. The chicken of the survey were fed soybean feed containing the contaminated ball clay and had an exposure concentration of 15 ppt, WHO-TEQ. The CEPA study determined that equilibrium concentrations were reached in the adipose tissue only after 80 days. As chickens get older and larger, they become less efficient and eat more feed for each pound of weight gained. The chickens of the CEPA study were sampled at 80 and 164 days while broilers used in the survey were sampled at approximately 44-45 days, half of the foraging chickens.

It has been established that congener specific BAFs are highest in adipose tissues and that, within a tissue type, low chlorinated congeners have higher BAFs than the higher chlorinated compounds. This is confirmed in both studies. Selective absorption of the 2,3,7,8-PCDDs in chicken has previously been noted [13, 14]. In the survey and low exposure concentration portion of the CEPA study the 1,2,3,6,7,8-HxCDD had higher BAFs than the two other 2,3,7,8-hexa congeners.

A recent University of Vienna study[15] of chicken fed both contaminated (PCDDs/PCDFs) and uncontaminated feed for 42 days revealed residues of these compounds in the edible tissues of the breast and leg (meat plus skin). Rough estimates of the BAFs at the 4 pg/g, TEQ level for the adipose component of these tissues compare favorably with the CEPA study. A significant correlation was determined between the PCDD/PCDF accumulation in tissues and amount of their intake. These values are being examined as a means to predict the TEQ content in edible chicken.

The average daily intake of 2,3,7,8-PCDD/PCDFs expressed as ng/kg-day, TEQ for the broiler chickens of the survey was approximately 0.7 while average daily intakes for the roasters of the CEPA (low exposure) and (high exposure) were 0.3 and 2.5, respectively, and for the broiler chicken of the University Vienna study fed at 4 pg/g TEQ was 0.16.

A difference between the studies was the manner in which the PCDDs/PCDFs were bound to the feed. In both the CEPA and the University of Vienna studies, they were directly applied to the feed, most likely resulting in weak binding to the organic surface of the feed. However, in the case of the EPA survey, the PCDDs had absorbed into the ball clay, which possesses strong binding capacity. It is hypothesized that the chickens of the two studies more readily adsorbed the loosely bound PCDDs/PCDFs of the feed, while less readily the highly bound PCDDs on the ball clay[16].

Conclusion

Additional studies should be designed to determine how relative binding strengths of PCDDs/PCDFs in feed affect their bioavailability/bioaccumulation/uptake, as these parameters can be vital in the formulation of risk assessment and human health policy evaluation.

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Table 1. Bioaccumulation Factors (BAFs)

Congener	USEPA Adipose **(n=4)**	CEPA (Low) Adipose **(n=22)**	CEPA (High) Adipose **(n=22)**
2,3,7,8-TCDD	1.8	NA	17.4
1,2,3,7,8-PeCDD	1.5	7.1	14.4
1,2,3,4,7,8-HxCDD	1.3	4.5	11.1
1,2,3,6,7,8-HxCDD	1.4	6.8	7.5
1,2,3,7,8,9-HxCDD	0.9	3.1	4.5
1,2,3,4,6,7,8-HxCDD	0.5	1.6	2.5
OCDD	0.1	0.4	0.4
TEQ of Feed (pg/g)	15.0	3.2	35.8

NA (Not applicable)