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# Simulation of the Exposure to Deoxynivalenol of French Consumers of Organic and Conventional Foodstuffs

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**The aim of this study was to estimate the exposure to deoxynivalenol in wheat of consumers of organic and conventional products using a probabilistic method, and to compare these levels with a toxicological reference so as to provide risk managers with scientific data to be used in the regulatory decision-making process. First, a product consumption frequency questionnaire was completed by consumers of organic products, thus providing data on the consumption of organic products. Data on the consumption of conventional products were obtained from the French "INCA" survey. Data on deoxynivalenol levels in wheat came from a previous study. The results of exposure simulations using the Monte-Carlo sampling method showed that 10% of those consuming organic wheat containing deoxynivalenol may be exposed to this natural toxin at levels above the provisional maximum tolerable daily intake.** 

***Key Words*: deoxynivalenol; organic products; exposure assessment; probabilistic approach.**

## INTRODUCTION

The term *organic products* is employed to describe all raw commodities produced without the use of chemical pesticides. This type of farming currently arouses considerable enthusiasm among French consumers striving to eat a healthy diet (Fischer, 1999; PNUD, 2000). Although much study has been devoted to the behavior of organic product consumers (Sylvander and Melet, 1992; Jolly *et al.*, 1989; Hammitt, 1990), few data are available on the levels of organic food consumption in France. Demand for organic products is growing (Sylvander, 1999), but national production can no longer meet this demand. Although efforts in this direction would improve productivity, it must be ensured that new products comply with food safety requirements, particularly with respect to the consumption of cereals known to be contaminated by mycotoxins. First, deoxynivalenol (DON) is a widespread mycotoxin of wheat and wheat products known to be implicated in animal and human toxicity (JECFA, 2001). Second, in a previous study we showed that high levels of DON contamination could be found in both conventional and organic wheat (Malmauret *et al.*, 2001). These data are important not only from an economic point of view, but also toxicologically, as account must be taken of risk management options for public health issues; for example, the proposed international regulations under discussion at present concerning maximum levels in foodstuffs for mycotoxins (CCFAC, 2002). It is therefore very important to evaluate the exposure of these consumers to DON, by crossing contamination data with consumption data. In addition, probabilistic models are very useful as they provide a more realistic description of high percentiles of exposure, because different input values can be used to achieve a complete distribution of all possible outcomes (FAO/WHO, 1997).

Thus the aim of this study was, first, to provide data on the consumption of organic wheat products. Because, in France, organic products are still a niche market representing only 0.5% of total retail food sales (Piason, 1999), interviews were conducted at the point of sale of organic foods. At present, the organic market can be broken down into three distribution networks: open-air markets, health food stores, and supermarkets (Lévêque, 1996). Interviews thus took place in all three types of outlets, in Paris and in the Brittany region. Because of this design, a nonquantified food frequency questionnaire was employed, as this could be completed rapidly and thus enabled interviews of a larger number of subjects.

Second, the study aimed to simulate the exposure to DON of consumers of both organic and conventional wheat in cereal-based products, based on a probabilistic method. The findings were then compared with an international toxicology reference with the objective of helping risk managers in the regulatory decision-making process.

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## SUBJECTS AND METHODS

### *Consumption Data on Organic Products*

*Sample.* The study took place between August and October 2000. To ensure satisfactory representation of the population of French organic product consumers, we included subjects not only from Paris but also from two cities in the Brittany region (Rennes and Brest), where both organic production and the organic market are well developed. An ad hoc sample of 200 organic consumers, aged from 15 and older (149 women, 51 men) was surveyed at the point of sale of organic products (open-air markets, health food stores, supermarkets). Each time an individual bought an organic product, he or she was asked to participate in the study and complete the questionnaire. The sampling procedure is shown in Table 1.

*Dietary questionnaire.* A standard explanation of why the survey was being carried out was given to each subject before the interview. The interview, in two parts, consisted of a brief personal history, followed by the nonquantified frequency questionnaire. The brief personal history included gender, age, professional activity, composition of the family, and family income. Dietary information was then elicited using a consumption questionnaire which included 55 items of organic products, divided into 12 categories (drinks, cereals and cereal-based foodstuffs, soy-based foodstuffs, fat matter, animal-based foodstuffs, vegetables, fruits, sweets, dairy products, sauces and seasonings, aperitif biscuits, baby foods). For each item on the food list, the respondent was asked to estimate his or her frequency of consumption based on specified categories that indicated the number of times the food was usually consumed, per day, or per week, or never consumed.

*Data processing.* An individual frequency of consumption was determined for each item on the food list. When a subject could not estimate precisely his frequency of consumption and declared that he consumed a product many times a day or many times a week, we made the assumption that the frequency of consumption was 3 times a day or 3 times a week, respectively. Similarly, when a subject declared that she consumed a product from time to time, we made the assumption that the frequency of consumption was 0.5 time per week. All individual frequencies were then converted on the basis of the number of times per week.

**TABLE 1**
**Numbers of Subjects Surveyed by Point of Sale of Organic Products**

| | Supermarkets | Open-air markets | Health food stores | Total |
|---|---|---|---|---|
| Paris | 26 | 48 | 12 | 86 |
| Brittany region (Rennes and Brest) | 26 | 22 | 66 | 114 |

In the framework of the SU.VI.MAX study a handbook had been compiled by dieticians and statisticians and gave the equivalence in weight of the average food portions consumed by the French population (CNAM, 1994). By combining these data with the frequencies of consumption, it was possible to derive the weight of product X consumed by a person in the population studied, expressed in grams per day, as follows:

$$\begin{aligned}\text{Weight of product X consumed by a person in the population studied (g/day)} \\ = \text{individual frequency consumption for product X} \\ \times \text{weight of the average food portion consumed.}\end{aligned} \quad (1)$$

Because deoxynivalenol is a mycotoxin that is found mainly in wheat flour, and as we collected contamination data only for raw wheat during our study, we introduced a weighted factor to take account of this uncertainty when refining our exposure model. The consumption data for organic and conventional cereal-based products were then recalculated from the original consumption levels reported in each food survey by integrating the percentage of wheat flour contained in cereal-based products. This assumed that 40% of biscuits and breakfast cereals, 80% of bread, 95% of pasta, and 100% of cereals (semolina, couscous, etc.) were made up of wheat flour (Crédoc, 1999). This calculation had the advantage of grouping together cereal food items and thus producing a more simple exposure model with only one variable for the consumption of cereal-based products, corresponding to the consumption data for organic and conventional wheat from cereal-based products.

### *Consumption Data on Conventional Products*

Data on conventional cereal-based products were obtained from our INCA national and individual survey on food consumption, carried out in 1999 and based on 3003 individuals aged 3 years and older, representative of the French population (Crédoc-AFSSA-DGAL, 2000). This was the second survey to have addressed the dietary habits of French adults and children in France, the first having been carried out in 1994 (ASPCC, 1994). So that the age groups were coherent with those in the organic survey, we took account in our exposure model of individual consumption data only for those aged 15 years and older ($n = 1951$).

### *Data on Contamination of Organic and Conventional Products*

Contamination data were obtained from a previous study (Malmauret *et al.*, 2001). The levels of DON

contamination in 11 samples of organic produce and 11 samples of conventional raw wheat were available for study.

*Modeling of Exposure Assessment*

At this stage, the modeling of exposure consisted of a stochastic approach using @RISK, a risk analysis software (Palissade Corp., 1997). Exposure to DON from organic and conventional wheat-based products was simulated by combining organic and conventional consumption data per capita and by consumer only with data concerning the contamination of organic and conventional raw wheat.

In the first step of the simulation, the input of contamination and consumption data was described using frequency functions. They were then considered as histograms. Second, the probability density functions that fit on these histograms were searched for using the BestFit software. When no probability density function fit the histograms (the Kolmogorov–Smirnov test being used as a goodness-of-fit test), we retained the sampling in the histograms, considering each as a set of uniform and continuous distributions. This technique ensured that none of the individual variables used in simulations would fall outside the ranges actually observed in the input data.

Based on these density functions, exposure to DON from organic and conventional wheat products was simulated using the @RISK software. The mathematical principle applied to our data was that described by the Food and Agriculture Organization (FAO/WHO, 1997) and used by JECFA at it Fifty-sixth Session (JECFA, 2001). The simulations used algorithms to randomly sample the probability distribution functions of input parameters (consumption and contamination data). The sampling technique used in this study (the so-called Monte-Carlo method) takes values at random from the entire range of input probability distributions. The dietary exposure value was calculated per capita and per consumer only respectively for conventional and organic cereal-based products, using the sampled input values. By repeating this operation many times (10,000 iterations with convergence autostop simulation when the stability of all output percentage changes was less than 1%), the probability distribution for exposure to natural food toxins was obtained. All simulated exposure values were compared with the provisional maximum tolerable daily intake (PMTDI) of 1 $\mu$g/kg body wt for DON or 60 $\mu$g/day/person for adults weighing 60 kg, as established by the joint FAO/WHO Expert Committee on Food Additives (JECFA, 2001).

## RESULTS

*Consumption of Organic and Conventional Products*

The mean (and SD) levels of consumption (per capita and per consumer only) of organic cereal-based and conventional cereal-based products are listed in Table 2. It was found that 84 and 99% of consumers ate cereal-based products arising from organic and conventional production, respectively.

Bread and crisp breads were consumed six to seven times a week and were therefore the most frequently consumed organic foodstuffs. The estimated mean quantity of organic bread consumed was $115 \pm 148$ g/person/day. As for conventionally produced bread, consumption reached $105 \pm 148$ g/person/day. After bread, the estimated mean quantities of organically produced cereal-based foodstuffs such as biscuits, breakfast cereals, and pasta were $3 \pm 6$, $15 \pm 25$, and $26 \pm 34$ g/person/day, respectively. For the same conventional products, consumption reached $12 \pm 20$, $4 \pm 14$, and $33 \pm 37$ g/person/day, respectively.

If all cereals such as semolina and couscous were assumed to be wheat-based, and also that respectively 95% of pasta, 80% of bread, and 40% of biscuits and breakfast cereals were made from wheat flour (Crédoc, 1999), the estimated mean quantity of organically

**TABLE 2**
**Levels of Consumption of Organic ($n = 200$) and Conventional Cereal-Based Products ($n = 1951$) in g/person/day (per capita)**

| | Organic products | | | | Conventional products | | | |
|---|---|---|---|---|---|---|---|---|
| Product | % Consumers | Mean ± SD | Median | 95th percentile | % Consumers | Mean ± SD | Median | 95th percentile |
| Cereals (couscous, semolina, etc.) | 63 | 22 ± 37 | 11 | 75 | 10 | 3 ± 9 | 0 | 21 |
| Breakfast cereals | 39 | 15 ± 25 | 0 | 60 | 14 | 4 ± 14 | 0 | 29 |
| Biscuits | 54 | 3 ± 6 | 1 | 10 | 52 | 12 ± 20 | 1 | 49 |
| Bread | 65 | 115 ± 148 | 18 | 375 | 94 | 105 ± 92 | 83 | 264 |
| Pasta | 55 | 26 ± 34 | 14 | 86 | 74 | 33 ± 37 | 29 | 93 |
| Total cereal-based products | 84 | 180 ± 195 | 113 | 529 | 99 | 155 ± 103 | 135 | 330 |
| Total wheat flour from cereal-based products | 84 | 146 ± 158 | 90 | 415 | 99 | 124 ± 84 | 108 | 265 |

**TABLE 3**
**Distribution Functions Used for Food Consumption and Food Contamination Data as Input Variables for a Stochastic Model**

| Wheat from cereals and cereal products | Distribution of consumption (g/person/day) | | Distribution of contamination ($\mu$g/kg fresh wt) | |
|---|---|---|---|---|
| | Organic products | Conventional products | Organic products | Conventional products |
| Per capita | Histogram (0;631;{83;21;18;12; 12;14;13;5;1;2}) | Histogram (0;821;{681;774;366;82; 31;6;7;3;0;1}) | Lognorm (184;609) | Lognorm (78.4;68.3) |
| Per consumers only | Histogram (0.3;631;{55;20;18;12; 12;14;14;4;1;2}) | Histogram (2;821;{684;762;357;79; 31;6;7;3;0;1}) | Lognorm (184;609) | Lognorm (78.4;68.3) |

produced wheat-based products was $146 \pm 158$ g/person/day. For wheat-based products of a conventional type, the estimated consumption was $124 \pm 84$ g/person/day.

*Construction of Probability Density for Input Data*

Distribution functions and estimated parameters (e.g., lognormal (mean, SD), probability distribution, or histogram functions (minimum, maximum, {$p1$, $p2$, . . . , $p$n}) used to describe both consumption after refinement and contamination data are listed in Table 3. Frequency histograms were used because no appropriate functions fit the consumption data on organic or conventional cereals and cereal-based products. Lognormal (mean, SD) functions fit the contamination data for organic and conventional raw wheat.

*Exposure Simulations*

The results of simulation models concerning dietary exposure to DON from organic and conventional wheat and cereal-based products are represented by histograms both per capita and per consumer only (Fig. 1). This figure shows that all simulated exposure values (mean, median, and 95th percentile) concerning organic wheat and cereal-based products were higher than those obtained for conventional wheat and cereal-based products: 28 versus 10; 4 versus 6, and 120 versus 31 $\mu$g/day/person, respectively, with the exception of the median exposure to DON from organic wheat, which was very similar to that of conventional wheat. The mean, median, and 95th percentile simulated exposure values for DON in organic and conventional cereal-based products were all below the PMTDI, except

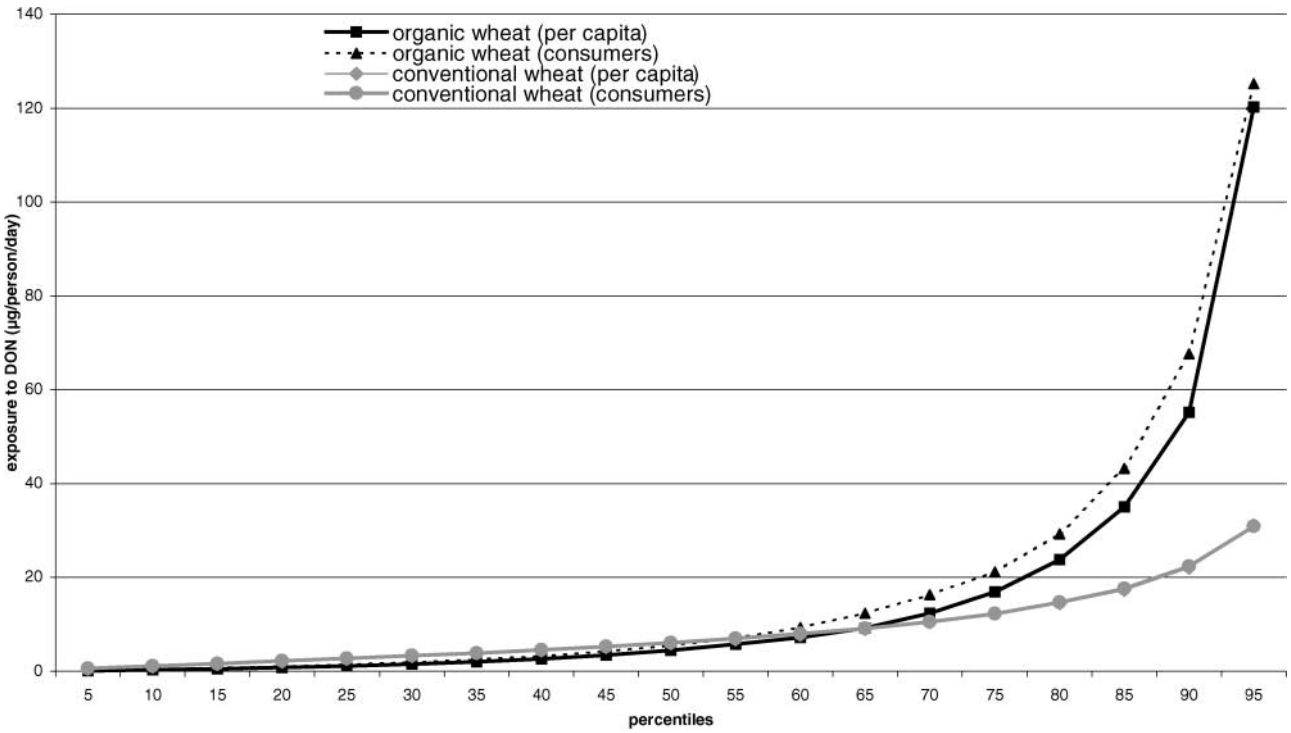


**FIG. 1.** Simulation of dietary exposure to DON from wheat and organic and conventional cereal-based products.

for the 90th percentile of exposure for organic consumers of wheat-based products and the 95th percentile of organic consumption per capita which exceeded the PMTDI established by JECFA for DON, being 70 and 120 $\mu$g/day/person, respectively, versus 60 $\mu$g/day/person (JECFA, 2001).

## DISCUSSION

It is very interesting to evaluate the general level of exposure to mycotoxins related to the consumption of cereal-based products, not only because these toxins are found mainly in these products, but also because in the total diet, cereals represent one of the most important food categories in terms of weight and frequency of consumption (CX/FAC 02/21, 2002; Gems/Food Regional Diet, 1998). Furthermore, from the toxicological and economic points of view, such an evaluation provides data on the consumption of organic products, thus enabling an assessment of the impact of different agricultural practices on exposure to mycotoxins. It is also useful to develop a methodological approach to exposure to mycotoxins in general and DON in particular, based on the comsumption of cereal-based products, because this food category often represents the most important contribution of these toxins to total dietary intake (JECFA, 2001).

Bread and crisp breads have the largest market share of the French organic food market. They are easily accessible as they are available in all three types of outlets: open-air markets, supermarkets, and health food stores. The mean quantity of organic bread consumed was close to that of conventional bread, 115 versus 105 g/person/day (Crédoc-AFSSA-DGAL, 2000). The mean consumption and 97.5th percentile for whole wheat flour from cereal-based products among consumers of organic foods were higher than for consumers of conventional products, being 146 versus 124 g/day and 415 versus 265 g/day, respectively. This difference may reflect the true situation but may also be due to the different methodologies employed.

The aim of the probabilistic approach is to provide the most realistic description of exposure (WHO/FAO, 1997). This method shows that there is a 10% chance that a high consumer of organically produced wheat will consume highly contaminated cereal-based products over his or her lifetime, the result being that the PMTDI for DON will be exceeded, at values of 120 $\mu$g/day/person versus 60 $\mu$g/day/person, respectively.

On the other hand, we observed that expressing dietary exposure to DON per capita or per consumer only did not demonstrate any differences within each mode of production, this being due to the fact that a large percentage of consumers (84 and 99% respectively for organic and conventional products) ate cereal-based products at least once a week (Fig. 1).

It should, however, be emphasized that these results were simulations and not experimental data, so that the distribution functions for DON contamination in both conventional and organic products were extrapolated from a small amount of data. The estimated exposure to DON in this study was based on a relatively limited number of analyses, which is why the levels of exposure thus calculated should be treated as approximate at present, because the exposure model needs to be refined, particularly by improving the contamination levels for DON in organic and conventional cereal-based products.

Nevertheless, even though the number of samples taken into account in the exposure model obtained from our previous study was relatively small ($n = 11$ data for DON of each of the 11 samples of organic and 11 samples of conventional raw wheat), it could be seen that the rate of contamination of organic wheat samples was lower than that of conventional wheat, 6/11 versus 10/11 > limit of quantification (LOQ = 10 $\mu$g/kg), but reached higher mean levels: 250 $\mu$g/kg versus 80 $\mu$g/kg (Malmauret *et al.*, 2001). In fact, it was impossible to demonstrate that this small number of samples reflected the true level of contamination in either kind of cereal, more data being required with respect to the variability of DON contamination in crops, which is known to depend on numerous factors such as climatic conditions and agronomic and production practices, etc. (JECFA, 2001). So as to gain a clearer understanding of the impact of agricultural practices on mycotoxin levels in experimental fields and crops, several studies are currently being conducted by the National Institute of Agronomical Research and the French Ministry of Agriculture. Furthermore, it is important to remember that the consumption and contamination data presented here were calculated from raw products and not as consumed. Some studies have shown that DON levels fall during bread making and particularly during fermentation (as a function of the bread processing technology employed) (Samar *et al.*, 2001). We need to confirm these results with additional analytical results on DON in organic and conventional cereals and cereal products as they are consumed, and then compare exposure to these natural toxins with the results obtained using other exposure methodologies. The results of the total diet survey conducted in 2000/2001 and of a specific study on levels of contamination in finished products from both organic and conventional agriculture will enable us to carry out this work in the near future.

## CONCLUSION

The mycotoxin under consideration in this study, DON, is a natural toxin. It cannot be excluded that organic products may be more prone to contamination by toxins from molds than conventional products because

they receive less treatment with antifungal agents. At present, a particular group at risk for exposure to DON may be the consumers of organic products as they may regularly eat foods containing higher levels of DON than the general population. One way to reduce the exposure of organic consumers, rather than proposing regulations to fix a maximum limit, would be to reduce the contamination of organic production by molds using appropriate techniques, such as planting more resistant varietis and or ensuring adequate nitrogen nutrition. This implies the need for further agronomic research and, for example, the conduct of cultivation studies.

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