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# Variability and uncertainty assessment of patulin exposure for preschool children in Flanders

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**Abstract**

The objective of the present study was to evaluate the patulin exposure of children consuming organic, handcrafted or conventional apple juice through a probabilistic approach and to evaluate the effectiveness of several risk management options aiming to reduce the risk for children due to patulin exposure. However, a large part of the data on patulin contamination of apple juice fell under the limit of detection (LOD). Different methods were tested to deal with these so-called left censored data and a uniform distribution with uncertain bounds was selected to handle this censorship. Variability and uncertainty assessment of patulin exposure showed that 0.9% [90% confidence interval (CI): 0.3–1.8%] of the children consuming only organic apple juice exceed the tolerable daily intake (TDI). For consumers of conventional and handcrafted apple juice this was respectively 0.1% [90% CI: 0–0.3%] and 0% [90% CI: 0–0.2%]. Reduction of the patulin contamination in apple juice to concentrations below 25 μg/kg reduced the percentage of the children exceeding the TDI to 0% [90%CI: 0–0.2%] for organic apple juice. Reduction of the apple juice consumption was less effective than a reduction of the patulin concentration in apple juice and is only useful when the patulin concentration of apple juice is below 25 μg/kg.


*Keywords:* Risk assessment; Patulin; Probabilistic approach; Second-order Monte Carlo simulation; Organic; Apple juice

## 1. Introduction

The mycotoxin patulin (4-hydroxy-4*H*-furo[3,2-c]pyran-2(6*H*)-one) is produced by a large number of fungi including *Penicillium expansum*. This mould is commonly identified as 'blue mould rot', a serious post-harvest disease of apples. As a consequence, patulin is frequently found as a contaminant in apples and apple products, and occasionally in other fruits such as pears, oranges and grapes (Moake et al., 2005). In animal studies, patulin has been found to act acutely toxic (Dailey et al., 1977), teratogenic (Sugiyanto et al., 1993) and immunosuppressive (Escoula et al., 1988) and a provisional maximum tolerable daily intake (TDI) of 0.4 μg/kg body weight has been set (JECFA, 1995). Based on this TDI, patulin is regulated in the European Union (EU) at levels of 50 μg/kg in fruit juices and fruit nectar, 25 μg/kg in solid apple products and 10 μg/kg in apple-based products for infants and young children (European Commission, 2003b).

In order to evaluate the exposure to patulin, five different studies have been conducted. A Scientific Cooperation (SCOOP) study conducted by the Directorate – General Health and Consumer Protection of the EU on the assessment of the dietary intake of patulin by the population of

*Abbreviations*: CI, confidence interval; EDR, estimated diet record; EU, European Union; FFQ, Food-frequency questionnaire; HPLC-UV, high performance liquid chromatography-ultra violet; LOD, limit of detection; LOQ, limit of quantification; ML, maximum limit; SCOOP, Scientific Cooperation; TDI, tolerable daily intake.

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EU member states showed that apple juice and apple nectar are the main sources of patulin intake in most countries, particularly for young children (Directorate – General Health and Consumer Protection, 2002). However, an important limitation of the last mentioned study and four other exposure studies (Leblanc et al., 2005; Piemontese et al., 2005; Tangni et al., 2003; Thuvander et al., 2001) is the use of point estimates or simple distributions (Kroes et al., 2002) to assess the exposure.

The aim of the present study was to estimate the consumers' exposure to patulin due to the consumption of organic, handcrafted and conventional apple juice, based on a probabilistic method. The findings were then compared with the TDI aiming to help risk managers in the regulatory decision making process. Since the SCOOP task has shown that small children have a higher patulin intake compared to other population groups and apple juice and apple nectar are the main sources of patulin intake in most countries (Directorate – General Health and Consumer Protection, 2002), the focus of this probabilistic exposure assessment was on this particular population group and these specific matrices. Secondly, the study aimed to evaluate the effectiveness of alternative risk management options to reduce the patulin exposure in children. A first risk management option tested in the model was the proposal of the EU commission to lower the regulatory limit for patulin contamination in apple juice (European Commission, 2003b). A second scenario evaluated in the model was a decrease in apple juice consumption by young children as advised by pediatrics (American Academy of Pediatrics, 2001).

## 2. Materials and methods

### 2.1. Consumption data

Data on apple juice consumption were obtained from a large-scale epidemiological study investigating nutrition habits of preschool children in Flanders (2.5–6.5 years old) (Huybrechts et al., 2006). Briefly, a total of 2095 children were asked to complete a Food-frequency questionnaire (FFQ), a 3-day estimated diet record (EDR) and a general questionnaire. A total of 1579 FFQ's and 1052 EDR's were collected by the end of the fieldwork.

### 2.2. Contamination data of organic, handcrafted and conventional apple juice

The contamination data used in the present study were derived from a previous study (Baert et al., 2006) in which 177 apple juice samples were analysed (65 organic, 90 conventional and 22 handcrafted). Organic apple juice stands for apple juice that is produced in accordance to the European regulation (EEC) Nr. 2092/91 on organic production of agricultural products (European Council, 1991). The limit of detection (LOD) and the limit of quantification (LOQ) of the used analytical method were 5.2 μg/kg and 8.6 μg/kg, respectively for clear apple juice. For cloudy apple juice, the LOD and LOQ were 8.1 μg/kg and 16.0 μg/kg, respectively.

### 2.3. Alternatives for values below LOD

All contamination data consisted for a large part of left censored data (between 87% and 91% as described by Baert et al., 2006). The censored data were treated in several ways (Fig. 1):

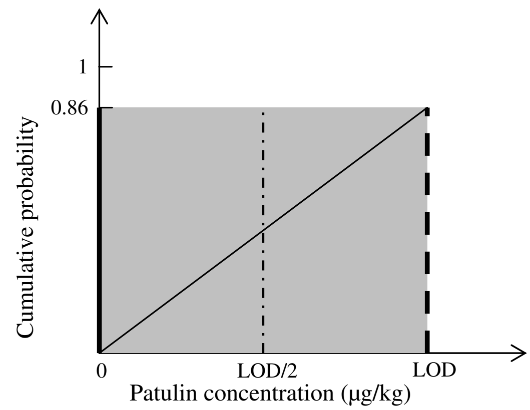


Fig. 1. Graphical representation of the different treatments for censored data (H1: ▬ ▬ ▬, H2: _._._, H3: ▬▬▬, H4: ______, H5: ■).

- H1: The censored data are replaced by the corresponding LOD (e.g. Govaerts et al., 2005; Tressou et al., 2004).
- H2: The censored data are replaced by the corresponding LOD divided by 2 (e.g. Govaerts et al., 2005; Tressou et al., 2004).
- H3: The censored data are replaced by zero (e.g. Govaerts et al., 2005; Tressou et al., 2004).
- H4: The censored data are replaced by random samples from a uniform distribution with zero as minimum and LOD as maximum (RiskUniform (0; LOD)) (Govaerts et al., 2005).
- H5: The censored data are replaced by random samples from a uniform distribution with α as a minimum (α = uniform distribution between zero and the LOD) and β as a maximum (β = a uniform distribution between zero and the LOD), with the restriction that α is smaller than β (RiskUniform (RiskUniform (0; LOD); RiskUniform (0; LOD))).

### 2.4. Exposure assessment

The patulin exposure was modeled by multiplying consumption data with contamination data of organic, conventional and handcrafted apple juice.

$$\text{patulin intake}\left[\frac{\mu g}{\text{kg bw}\cdot\text{day}}\right] = \text{concentration of patulin in apple juice}\left[\frac{\mu g}{\text{kg}}\right] \times \text{apple juice consumption}\left[\frac{g}{\text{kg bw}\cdot\text{day}}\right] \times 0.001\left[\frac{\text{kg}}{g}\right]$$

In this exposure assessment it was assumed that a consumer uses only one of the three commodities (e.g. a consumer of organic apple juice, will only consume organic apple juice). It was also assumed that the consumption pattern of the three groups of consumers (organic, handcrafted and conventional) is the same.

In order to characterize the variability, both the parametric and non-parametric approach were evaluated. Fitting of the probability distributions (parametric approach) to the data was performed using BestFit (Palisade, UK). In the non-parametric approach, a discrete uniform distribution (RiskDuniform) was used for both the observed consumption and contamination values (subsequent sampling was done by replacement). A discrete uniform distribution is a special case of the discrete distribution where all possible values have the same probability of occurrence (Vose, 2000). The censored data were replaced by some specific values or random samples from distributions according to the treatments mentioned in Section 2.3. For the final exposure assessment, the variability of the consumption and the contamination parameters was characterized by a non-parametric, discrete, uniform distribution.

Uncertainty characterization was only performed for the non-parametric approach using non-parametric bootstrap. The bootstrap theory assumes that the distribution $F$ (of e.g. patulin concentration in apple juice) can be reasonably approximated by the distribution $F'$ of $n$ observed values. This is of course a more reasonable assumption when more data are collected. For a sufficiently large number of times, $n$ random samples are taken with replacement from the distribution $F'$ and each time, a statistic of interest is calculated from that sample (Vose, 2000).

Propagation of variability and uncertainty was performed using second order Monte Carlo simulation. A second order or two-dimensional Monte Carlo simulation consists simply of two Monte Carlo loops nested one inside the other. The inner one deals with the variability of the input variables, while the outer one deals with uncertainty. It was executed with @RISK, a risk analysis software (@RISK 4.5 for excel professional edition, Palisade, UK). Latin Hypercube sampling was used to randomly sample the probability distribution functions of input parameters (consumption and contamination data) and the samples were used to calculate the intake by the described model. One thousand simulations were carried out to describe the variability in the consumption of the population and the contamination, and one thousand bootstrap iterations were carried out to estimate the confidence interval. This results in a total of $1000 \times 1000$ simulations.

### 2.5. Evaluating different risk management scenarios to reduce the exposure

Six scenarios to reduce the exposure to values below the TDI were evaluated.

- A1: Patulin contamination below 50 μg/kg (the samples above the legal limit (50 μg/kg) were removed from the dataset).
- A2: Patulin contamination below 25 μg/kg (the samples above 25 μg/kg were removed from the dataset).
- A3: Fruit juice consumption below 200 mL (For this, the fraction of apple juice on the total fruit juice consumption was calculated. When the total fruit juice consumption was above 200 mL, the value was replaced by 200 mL. The allowed fruit juice consumption (200 mL) was then multiplied with the fraction of apple juice in the fruit juice consumption to calculate the allowed apple juice consumption. When the total fruit juice consumption was below 200 mL, the reported apple juice consumption was used.).
- A4: Fruit juice consumption below 170 mL (as described for A3).
- A5: Apple juice consumption below 200 mL (the values of apple juice consumptions above 200 mL were replaced by 200 mL).
- A6: Apple juice consumption below 170 mL (as described for A5).

Since concentrations above 25 μg/kg were only found for organic apple juice, A1 and A2 were solely tested for organic apple juice.

## 3. Results and discussion

### 3.1. Evaluation of the proposed methods

In order to select a good representation of the variability in the consumption as well as in the contamination, the parametric and non-parametric approaches were both evaluated. In the parametric approach, several parametric distributions (for example, a log-normal distribution, a gamma distribution, etc.) were fitted to the consumption data. However, no distribution could be found that fitted the consumption and contamination data well (graphical representation showed systematic deviations, especially in the tails of the distribution, results not shown) and that accurately represented their variability. This was due to the large number of non-consumptions (0 g/kg body weight/day) and the large number of contamination data below the limit of detection (LOD). Since, the sample size was large, the data were considered to be more reliable than assuming a certain distribution, and the non-parametric approach was selected.

As described above, the contamination distributions contain a large part of left censored data. Indeed, between 87% and 91% of the data are under the limit of detection (LOD) (Baert et al., 2006). This induces a bias that can be dealt with, by considering several treatments of the censorship. In literature (e.g. Govaerts et al., 2005; Tressou et al., 2004), the censored data are often replaced by the corresponding LOD (H1), LOD divided by 2 (H2) or by 0 (H3) (Fig. 1). These three methodologies were compared for one apple juice commodity, namely organic apple juice, in order to determine the influence of the choice of one of the methodologies on the simulated exposure (Table 1). Although, the fact that high patulin concentrations (up to 122 μg/kg of apple juice) were found compared to the LOD (5.2 μg/kg for clear apple juice and 8.1 μg/kg for cloudy apple juice), the choice of a substitute for the censored data had an influence on the high percentiles of the exposure. The mean exposure was the highest for H1 (0.026 [90% confidence interval (CI): 0.019–0.039] μg/kg bw/day), which is likely to be an overestimation due to the assumption that all censored data are equal to the

Table 1
Comparison of the statistics on exposure (best estimation [90% confidence interval]; μg/kg bw/day) for organic apple juice calculated by different methodologies to replace values below the limit of detection

| | H1 | H2 | H3 | H4 | H5 |
|---|---|---|---|---|---|
| P50[a] | 0 [0–0] | 0 [0–0] | 0 [0–0] | 0 [0–0] | 0 [0–0] |
| P95 | 0.132 [0.116–0.166] | 0.068 [0.058–0.090] | 0 [0–0] | 0.081 [0.065–0.102] | 0.072 [0.027–0.117] |
| P97.5 | 0.216 [0.181–0.312] | 0.125 [0.096–0.197] | 0 [0–0.183] | 0.148 [0.103–0.237] | 0.135 [0.053–0.229] |
| P99 | 0.408 [0.261–0.815] | 0.341 [0.155–0.782] | 0.316 [0–0.775] | 0.373 [0.184–0.774] | 0.350 [0.143–0.822] |
| P99.9 | 1.449 [0.533–3.068] | 1.443 [0.506–3.246] | 1.445 [0.522–3.245] | 1.442 [0.499–3.268] | 1.471 [0.526–3.066] |
| Mean | 0.026 [0.019–0.039] | 0.019 [0.012–0.031] | 0.011 [0.003–0.024] | 0.019 [0.012–0.032] | 0.019 [0.010–0.032] |

H1: left censored data replaced by LOD; H2: left censored data replaced by LOD/2; H3: left censored data replaced by zero; H4: left censored data replaced by Riskuniform(0; LOD); H5: left censored data replaced by Riskuniform(α; β) with α and β = Riskuniform(0; LOD).

[a] 50th percentile.

LOD. For H3, the mean exposure (0.011 [90% CI: 0.003–0.024] μg/kg bw/day) was the lowest, which will most probably be an underestimation due to the assumption that all censored data are equal to zero. The mean exposure calculated by H2 was equal to 0.019 [CI: 0.012–0.031] μg/kg bw/day. Using H2 (LOD/2) is probably a good compromise which is commonly used but not without criticism (El-Shaarawi and Esterby, 1992). It was apparent that even the 99th percentile, with an exposure close to the tolerable daily intake (0.4 μg/kg bw/day), was influenced by the treatment of the censored data. It was rather unexpected that the left censorship of the contamination data strongly influenced the right tail of the exposures to patulin. A further in-depth analysis of the data explained that high apple juice consumption (up to 67.3 g/kg bw/day) with a concentration below the LOD (e.g. 8 μg/kg) gave rise to a patulin intake of 0.5 μg/kg bw/day, which is higher than the TDI. A proper treatment of censored concentration data is consequently not to be underestimated. Therefore, two other censored data treatments were tested. Those do not use a fixed value for the censored data but instead consider the variability (and uncertainty) by considering random samples. This was done since it can be expected that a natural variability is present in the concentration below the LOD. Firstly, the values below the LOD were replaced by random samples from a uniform distribution with zero as a minimum and the LOD as a maximum (H4). Secondly, a uniform distribution with uncertain boundaries was used. Therefore, the censored data were replaced by random samples from a uniform distribution with $\alpha$ as a minimum ($\alpha$ = uniform distribution between zero and the LOD) and $\beta$ as a maximum ($\beta$ = a uniform distribution between zero and the LOD) (H5). Comparison of the simulated exposures for method H4 and H5 with method H2 (Table 1), shows that the simulated exposures for the three treatments are not significantly different. The mean exposure is similar for the three treatments with a larger 90% CI for H5. Since H5 is the most realistic representation of the censored data (Fig. 1), this methodology was used further to assess the patulin exposure of Flemish preschool children via conventional, organic and handcrafted apple juice consumption.

### 3.2. Assessment of patulin exposure

In a previous study, higher patulin concentrations were found in organic apple juice (8.8 μg/L) compared to conventional (4.1 μg/L) and handcrafted apple juice (4.4 μg/L) (Baert et al., 2006). It was one of the aims of the present study to evaluate the implications of these higher concentrations with regard to public health. The estimated exposures to patulin together with the 90% CI are summarised in Table 2. For the three types of apple juice tested, 83% of the children showed no intake of patulin via apple juice (results not shown). Based on the best estimate, it can be observed that the exposure can be more than 3 times higher than the TDI for children consuming organic apple juice in 0.1% of the cases. The best estimate of the exposure through handcrafted and conventional apple juice was below the TDI. Although higher exposures are observed for organic apple juice compared to the other two practices, their CI overlap, which indicates that the average exposure to patulin of children will be roughly the same for the three kinds of apple juice tested. The simulated exposures were similar to the results found in other studies reporting mean exposures for children between 0.003 and 0.18 μg/kg bw/day (Directorate – General Health and Consumer Protection, 2002; Leblanc et al., 2005; Piemontese et al., 2005; Tangni et al., 2003; Thuvander et al., 2001). However, a tendency exists to overestimate mean exposures when a deterministic approach is used.

A comparison of the percentage of children exceeding the TDI for the three types of apple juice (Table 2) shows that the probability of exceeding the TDI is higher for organic apple juice than for conventional and handcrafted apple juice. With 90% certainty, it can be stated that between 0.3% and 1.8% of the children consuming organic apple juice exceed the TDI while for conventional and handcrafted apple juice this is between 0% and 0.3% and between 0% and 0.2% respectively.

### 3.3. Evaluation of risk management measures to reduce the patulin exposure

Since the simulation of the exposure showed that the TDI for patulin is sometimes exceeded for Belgian children,

Table 2
Statistics on exposure (best estimation [90% confidence interval]; μg/kg bw/day) and probability to exceed the tolerable daily intake (TDI) for different apple juices (AJ)

| | Organic AJ | Conventional AJ | Handcrafted AJ |
|---|---|---|---|
| P50[a] | 0 [0–0] | 0 [0–0] | 0 [0–0] |
| P90 | 0.039 [0.014–0.069] | 0.030 [0.011–0.049] | 0.037[0.013–0.066] |
| P95 | 0.072 [0.027–0.117] | 0.059 [0.031–0.085] | 0.065 [0.027–0.102] |
| P99 | 0.350 [0.143–0.822] | 0.156 [0.106–0.206] | 0.150 [0.084–0.229] |
| P99.5 | 0.615 [0.249–1.472] | 0.202 [0.141–0.287] | 0.195 [0.109–0.290] |
| P99.9 | 1.471 [0.526–3.066] | 0.328 [0.210–0.548] | 0.298 [0.156–0.460] |
| Mean | 0.019 [0.010–0.032] | 0.009 [0.006–0.013] | 0.010 [0.005–0.015] |
| Probability to exceed the TDI | 0.009 [0.003–0.018] | 0.001 [0–0.003] | 0 [0–0.002] |

[a] 50th percentile.

different scenarios to reduce the patulin intake were evaluated by simulation.

In 2003, the European Commission has extended the regulation on contaminants in foodstuffs (466/2001) by setting maximum limits for patulin in different products by implementation of regulation 1425/2003 (European Commission, 2003b). For apple juice the maximum limit (ML) was set at 50 μg/kg. However, during the study on the occurrence of patulin in apple juice in Flanders, two organic apple juices were found with a patulin content above 50 μg/kg (Baert et al., 2006). Therefore, the influence of a strict implementation of the current legislation on the patulin exposure in young children was tested by removing these two samples from the dataset (A1). In the regulation 1425/2003 it was also foreseen that the commission would review the maximum levels for patulin by 30th June 2005 at the latest in order to reduce these levels by taking into account the progress in scientific and technological knowledge and the implementation of the "Code of practice for the prevention and reduction of patulin contamination in apple juice and apple juice ingredients in other beverages" (European Commission, 2003a, 2003b). However, until now no new legislation has been published. In order to test the effect of lowering the ML, the limit was reduced by 50%, resulting in a new limit of 25 μg/kg, which is also the current ML for solid apple products. For this test, all samples above 25 μg/kg, were removed from the dataset (A2). Since concentrations above 25 μg/kg were only found for organic apple juice, both techniques (A1 and A2) were only tested for organic apple juice. Table 3 shows the simulated exposures for both scenarios compared to the current situation (as assessed in Section 3.2). It can be observed that the exposure is reduced when the contamination is below 50 μg/kg and will further reduce when the contamination decreases to 25 μg/kg. However, the obtained reduction is not significantly different. For the 99.9th percentile (best estimate), a reduction of 54% was achieved when the limit of 50 μg/kg is used and a reduction of 79% when a limit of 25 μg/kg is implemented. For the 95th percentile on the other hand, only a reduction of 4% was achieved when the limit of 50 μg/kg is followed, and a reduction of 11% when using a limit of 25 μg/kg. Also for the mean exposure the reduction was limited (26% and 47%, respectively). Based on these results, it can be stated that a reduction of the ML mainly affects the high intakes, which are the children at risk and to a lesser extent the mean and lower intakes. Comparing the percentage of the population exceeding the TDI (Table 3), it is shown that a decrease of the contamination below 50 μg/kg reduces the percentage of children exceeding the TDI, (between 0.1% and 1.2%). A restriction to 25 μg/kg reduces the exposure higher than the TDI further, towards 0–0.3% of the population under study. Therefore, it can be concluded that in order to reduce the exposure to patulin, a reduction of the legal limit to 25 μg/kg is necessary and causes a sixfold reduction of the probability to exceed the TDI (based on the upper limit of the 90% CI). However, it needs to be stressed that the implementation of a ML is only effective when this limit is followed and as a consequence control on the implementation is necessary. It was not useful to test a further reduction of the ML, since conventional and handcrafted apple juice had a maximum concentration of 15.6 and 10.9 μg/kg, respectively (Table 2) and still there was a small probability to exceed the TDI. This means that even with a reduction of the limit to about 11 μg/kg there is still a small probability to exceed the TDI. This is caused by the high apple juice consumption by some children (up to 67.3 g/kg bw/day), which leads to a patulin intake higher than the TDI for concentrations below the LOD (e.g. 8 μg/kg).

A second scenario that was tested, consisted of the reduction of apple juice consumption. From a nutritional point of view, it is advised to limit the consumption of fruit juices. Fruit juices contain fewer fibres than fresh fruit and more sugar in comparison to mineral water. In Belgium, young children are advised to limit their fruit juice intake to approximately 200 mL a day (Vlaams Instituut voor Gezonheidspromotie, 2004). The American Academy of Pediatrics recommends giving not more than 6 oz (about 170 mL) a day, to children between one and six years old and preferably as part of a meal or a snack (American Academy of Pediatrics, 2001). However, from the consumption data it can be determined that these recommendations are exceeded (99th percentile is 31 g/kg bw/day). Therefore,

Table 3
Statistics on exposure (best estimation [90% confidence interval]; μg/kg bw/day) and probability to exceed the tolerable daily intake (TDI) through the consumption of organic apple juice for the current situation and two alternatives to reduce the exposure

| | Current situation | A1 | A2 |
|---|---|---|---|
| P50[a] | 0 [0–0] | 0 [0–0] | 0 [0–0] |
| P90 | 0.039 [0.014–0.069] | 0.040 [0.013–0.072] | 0.038 [0.011–0.068] |
| P95 | 0.072 [0.027–0.117] | 0.069 [0.025–0.112] | 0.064 [0.022–0.102] |
| P99 | 0.350 [0.143–0.822] | 0.226 [0.107–0.443] | 0.154 [0.066–0.222] |
| P99.9 | 1.471 [0.526–3.066] | 0.682 [0.320–1.402] | 0.309 [0.171–0.491] |
| Mean | 0.019 [0.010–0.032] | 0.014 [0.007–0.021] | 0.010 [0.004–0.015] |
| Probability to exceed the TDI | 0.009 [0.003–0.018] | 0.005 [0.001–0.012] | 0 [0–0.003] |

A1: patulin contamination below 50μg/kg; A2: patulin contamination below 25 μg/kg.
[a] 50th percentile.

Table 4
Statistics on exposure (best estimation [90% confidence interval]; μg/kg bw/day) and probability to exceed the tolerable daily intake (TDI) for different apple juices (AJ) when fruit juice consumption is below or equal to 200 mL/day (A3)

| | Organic AJ | Conventional AJ | Handcrafted AJ |
|---|---|---|---|
| P50[a] | 0 [0–0] | 0 [0–0] | 0 [0–0] |
| P95 | 0.048 [0.018–0.077] | 0.038 [0.020–0.056] | 0.044 [0.018–0.073] |
| P99 | 0.183 [0.067–0.519] | 0.085 [0.058–0.118] | 0.085 [0.039–0.120] |
| P99.9 | 0.844 [0.371–1.634] | 0.167 [0.116–0.217] | 0.136 [0.066–0.167] |
| Mean | 0.006 [0.011–0.018] | 0.005 [0.004–0.007] | 0.006 [0.003–0.009] |
| Probability to exceed the TDI | 0.006 [0.001–0.014] | 0 [0–0] | 0 [0–0] |

[a] 50th percentile.

the exposure was simulated assuming that the consumption of fruit juice did not exceed 200 mL (A3). Table 4 shows the obtained results for the three types of apple juice. Comparing the exposures for the reduced consumption with the ones for normal consumption (Table 2) it is observed that for the 99.9th percentile, the exposure was reduced by 43% for organic apple juice, while for conventional and handcrafted apple juice this was 49% and 54%, respectively. These higher reductions for handcrafted and conventional apple juice can be linked to the lower patulin concentration observed in both commodities, showing that a reduction of the consumption has more effect when the patulin contamination is lower. The reduction of the apple juice consumption shows that for conventional and handcrafted apple juice it is 90% certain that none of the children will exceed the TDI. For organic apple juice there was a small reduction of the probability to exceed the TDI, but it was less effective than reducing the apple juice contamination. When the fruit juice consumption was restricted to 170 mL (A4), similar results were obtained (results not shown). However, when only patulin intake is considered and the apple juice consumption is restricted to 200 mL (A5) or 170 mL (A6), similar results are obtained with a probability to exceed the TDI of 0.008 [90% CI 0.002–0.017]; 0 [90% CI 0–0] and 0 [90% CI 0–0] for respectively organic, conventional and handcrafted apple juice (A5).

From both tested scenarios it can be concluded that in order to reduce the percentage of the population exceeding the TDI it is in the first place necessary to lower the ML for patulin in apple juice to 25 μg/kg. However, the implementation of a new ML will only be effective, when control on the implementation is executed. A further reduction of the exposure can be achieved by reducing the apple juice consumption. However, it is note-worthy that the ML-values are supposed to be implemented since it concerns a law, while the Food Based Dietary Guidelines are only recommendations, which often are ignored or unknown by our population.

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## References

American Academy of Pediatrics (Committee on Nutrition), 2001. The use and misuse of fruit juice in pediatrics. Pediatrics 107, 1210–1213.

Baert, K., De Meulenaer, B., Kamala, A., Kasase, C., Devlieghere, F., 2006. Occurrence of patulin in organic, conventional, and handcrafted apple juices marketed in Belgium. Journal of Food Protection 69, 1371–1378.

Dailey, R.E., Brouwer, E., Blaschka, A.M., Reynaldo, E.F., Green, S., Monlux, M.S., Ruggles, D.I., 1977. Intermediate-duration toxicity study of patulin in rats. Journal of Toxicology and Environmental Health 2, 713–725.

Directorate – General Health and Consumer Protection, 2002. Assessment of dietary intake of patulin by the population of the EU member states. Reports on tasks for scientific cooperation task 3.2.8, 135p.

El-Shaarawi, A.H., Esterby, S.R., 1992. Replacement of censored data observations by a constant: an evaluation. Water Research 26, 835–844.

Escoula, L., Thomsen, M., Bourdiol, D., Pipy, B., Peuriere, S., Roubinet, F., 1988. Patulin immunotoxicology: effect of phagocyte activation and the cellular and humoral immune system of mice and rabbits. International Journal of Immunopharmacology 10, 983–989.

European Commission, 2003a. Commission recommendation of 11 August 2003 on the prevention and reduction of patulin contamination in apple juice and apple juice ingredients in other beverages. Official Journal of the European Union L203, 54–59.

European Commission, 2003b. Commission regulation (EC) No 1425/2003 of 11 August 2003 amending regulation (EC) No 466/2001 as regards patulin. Official Journal of the European Union L203, 1–3.

European Council, 1991. Council regulation (EEC) No 2092/91, of 24 June 1991 on organic production of agricultural products and indications referring thereto on agricultural products and foodstuffs. Official Journal of the European Union L198, 1–15.

Govaerts, B., Beck, B., Lecoutre, E., le Bailly, C., Vanden Eeckaut, P., 2005. From monitoring data to regional distributions: a practical methodology applied to water risk assessment. Environmetrics 16, 109–127.

Huybrechts, I., De Bacquer, D., Matthys, C., De Backer, G., De Henauw, S., 2006. Validity and reproducibility of a semi-quantitative food-frequency questionnaire for estimating calcium intake in Belgian preschool children. British Journal of Nutrition 95, 1–14.

JECFA, 1995. Evaluations of certain food additives and contaminants. WHO Technical Report Series, No. 859.

Kroes, R., Müller, D., Lambe, J., Löwik, M.R.H., van Klaveren, J., Kleiner, J., Massey, R., Mayer, S., Urieta, I., Verger, P., Visconti, A., 2002. Assessment of intake from the diet. Food and Chemical Toxicology 40, 237–385.

Leblanc, J.-C., Tard, A., Volatier, J.-L., Verger, P., 2005. Estimated dietary exposure to principal food mycotoxins from the first French total diet study. Food Additives and Contaminants 22, 652–672.

Moake, M.M., Padilla-Zakour, O.I., Worobo, R.W., 2005. Comprehensive review of patulin control methods in foods. Comprehensive Reviews in Food Science and Food Safety 1, 8–21.

Piemontese, L., Solfrizzo, M., Visconti, A., 2005. Occurrence of patulin in conventional and organic fruit products in Italy and subsequent exposure assessment. Food Additives and Contaminants 22, 437–442.

Sugiyanto, J., Inouye, M., Oda, S.-I., Takagishi, Y., Yamamura, H., 1993. Teratogenicity of patulin, a mycotoxin, in mice. Environmental Medicine 37, 43–46.

Tangni, E.K., Theys, R., Mignolet, E., Maudoux, M., Michelet, J.Y., Larondelle, Y., 2003. Patulin in domestic and imported apple-based drinks in Belgium: occurrence and exposure assessment. Food Additives and Contaminants 20, 482–489.

Thuvander, A., Möller, T., Enghardt Barbieri, H., Jansson, A., Salomonsson, A.-C., Olsen, M., 2001. Dietary intake of some important mycotoxins by the Swedish population. Food Additives and Contaminants 18, 696–706.

Tressou, J., Leblanc, J.Ch., Feinberg, M., Bertail, P., 2004. Statistical methodology to evaluate food exposure to a contaminant and influence of sanitary limits: application to ochratoxin A. Regulatory Toxicology and Pharmacology 40, 252–263.

Vlaams Instituut voor Gezondheidspromotie, 2004. De voedingsdriehoek: een praktische voedingsgids.

Vose, D., 2000. Risk Analysis; A Quantitative Guide. Wiley, New York, 418 p.