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Human health risk assessment on the consumption of fruits and vegetables containing residual pesticides: A cancer and non-cancer risk/benefit perspective

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ABSTRACT

Pesticide residues in food is a public health concern. This study aimed to evaluate health risk and benefit associated with chronic consumption of fruits and vegetables (F & V) containing residual pesticides in the province of Quebec, Canada. Based on a representative sample of Quebecers (n = 4727, aged 1–79) enrolled in the Canadian nutrition survey, population's mean chronic dietary exposure through consumption of F & V was evaluated for 169 different pesticide active ingredients (PAI), including 135 for which toxicological reference values (TRV) were available in the literature. Total lifetime cancer risk was estimated to be 3.3×10^{-4} considering the 28 substances for which an oral slope factor was also available. Non-cancer risk quotients greater than 1 were obtained at the 95th percentile of children's exposure for 10 of the 135 PAIs, and considering the most severe pesticide-specific TRV. Dithiocarbamates and imazalil are the authorized PAI that contribute the most to cancer and non cancer risk; they are therefore identified as "priority" PAI. For each estimated case of cancer triggered by PAI exposure, at least 88 cases were deemed prevented by the consumed F & V, based on the population's etiological fraction of the cancer risk that F & V prevent. Concluding, chronic health risks investigated are low and health benefits of F & V consumption by far outweigh the PAI-related risk. However, risk estimates are not negligeable and uncertainties remain. Thus, reducing PAI exposure through F & V consumption with a particular focus on "priority" PAI mentionned above, while maintaining an abundant and varied F & V diet, is desirable.

1. Introduction

Historically, food safety and security has required the use of pesticide on crops in order to ensure quality and abundant supply of fruits and vegetables (F & V) to populations. This assertion has recently been challenged in a report presented to the United Nations (UN, 2017), and in recent years, synthetic pesticide-free food items have taken an increasing part of the food market (Barański et al., 2014; McCormack et al., 2010). Still, organic foods represent a small fraction of the offer to the consumers (USDA, 2017). As a result, the well-documented presence of pesticide residues in F & V available on the market (EFSA, 2013; Szpyrka et al., 2016; Wanwimolruk et al., 2016) has, for many years now, raised health concerns among the general population as well as public health authorities. In response to these pesticide-related concerns, numerous exposure and health risk assessments on pesticide residues in food initiatives have been realized around the world in recent years (e.g. ANSES, 2016, 2011; De Gavelle et al., 2016; Fang et al., 2015; Liu et al., 2016; Li et al., 2016; Nasreddine et al., 2016; Park et al., 2016; Quijano et al., 2016; Zentai et al., 2016; Zhang et al., 2016). These concerns on pesticide residues in F & V may also be viewed as conflictual with the official public health recommendations of having abundant and varied consumption of F & V to achieve good

Abbreviations: CCHS, Canadian Community Health Survey; CFIA, Canadian Food Inspection; Agency DTC, dithiocarbamates; ETU, ethylenethiourea; F & V, fruits and vegetables; LOD, limit of detection; NCRMP, National Chemical Residue Monitoring Program; PAI, pesticide active ingredient; RQ, risk quotient; TRV, toxicological reference value; WR, weighted risk

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health. Such recommendations are emitted because only a small fraction of the population consumes the daily amount of F & V that is recommended by dietary guidelines (Guenther et al., 2006), and low-income populations are less likely to be among this fraction (Blanchet et al., 2009; Kamphuis et al., 2006). Indeed, it is undoubtedly recognized that F & V provide protection against various chronic adverse health outcomes including cardiovascular diseases (Dauchet et al., 2006; He et al., 2007, 2006; Lock et al., 2005), type-II diabetes (Ford and Mokdad, 2001), and various types of cancer (Glade, 1999; IOM, 2006; Key, 2011; Liu and Russell, 2008; Prynne et al., 2006; WCRF/AICR, 2007; WHO, 2012a), most of which notworthingly disproportionnaly affect low-income populations (Nordahl, 2014; WHO, 2005).

In this context, the analysis of the risk-benefits balance is indicated in order to orientate public health messages and policies. Such analyses have seldom, if ever, been published in the scientific literature. Actually, Reiss et al. (2012) published a theoretical analysis in that sense that focussed on the putative cancer cases that would be prevented in the United States if half of its population would increase its daily consumption of F & V by one serving, in comparison to the cases attributable to the residues of carcinogenic pesticides present in those food items. However, to the best of our knowledge, such an exercice has not, to date, been realized on true F & V consumption data, nor on other health outcomes than cancer. Therefore, the objective of this study was to evaluate cancer and non cancer health risk associated with the exposure to pesticide active ingredients (PAI) residues in F & V consumed by the general population of the province of Quebec, Canada, while keeping a risk/benefit perspective in relation with the preventive effect of this consumption against many chronic adverse health effects, including certain types of cancer.

2. Methods

The methodological approach used in this study followed the hypothesis that the exposures to PAI residues in F & V assessed for a specific day in a high number of individuals of different age groups reflect the distribution of average chronic exposure of the entire population throughout lifetime. Thus, two databases depicting respectively the 24-h individual consumption of F & V by thousands of individual of various ages, and the PAI concentrations detected in samples of those food consumed, were combined. As a result, distributions of the calculated exposure doses were obtained. Then, cancer risk could be estimated quantitatively as the number of additional incidental cancer cases that could be attributed to the presence of PAI residues in F & V, whereas non cancer risks were assessed qualitatively by estimating how do the various percentile of exposure dose compares to available toxicological reference values (TRV).

2.1. Chronic exposure assessment

2.1.1. PAI residues in fruits and vegetables

Data on concentration of residual PAIs in F & V were obtained from the Canadian Food Inspection Agency (CFIA) datafiles. Under its National Chemical Residue Monitoring Program (NCRMP), this agency performs annual analyses, over a one-year period, of PAI residues in a random sample of food items deemed “as available” on the Canadian market, for both domestic and imported products (CFIA, 2013). CFIA datafiles covering years 2005 to 2008 (CFIA, 2008, 2007, 2006) were searched to bring out every PAI residue ($n = 169$) that had been detected in at least one sample of the food item analyzed through the NCRMP during that period. Mean PAI concentration in each food item selected (see Section 2.1.2) was calculated, with half the limit of detection being attributed to samples exhibiting undetected PAI concentration. Indeed, mean PAI concentration appears as a better proxy, than for instance upper percentile values, of the assumed chronic, continuous exposure that is believed to be measured here, in coherence with the hypothesis mentioned in the foreword of the Methods section.

2.1.2. Individual consumption of selected fruits and vegetables

Data on individual consumption of F & V in which at least one of the 169 identified PAI (see previous section) was detected, collected by means of a 24-h dietary recall questionnaire for 4727 Quebecers aged 1–79 enrolled in the Canadian Community Health Survey (CCHS)- cycle 2.2 held in 2004 were extracted from CCHS database (Health Canada, 2006; Statistics Canada, 2007). Given the initial huge amount of data, a selection process was applied to the food items that would be retained for the upcoming risk assessment. First, the 30 most consumed fruits and 30 most consumed vegetables, in the entire population of 4727 individuals, including people who had not consumed any fruit or vegetable the day prior to the survey, were selected. Additionally, the 30 fruits and 30 vegetables most consumed by participants who had effectively consumed them the day prior to the survey were selected. The resulting two lists were merged together and the doublets eliminated, yielding a list of 34 fruits and 42 vegetables, raw or processed. To this list, 13 F & V were added to ensure that the final list includes each one of the F & V most consumed by Quebec's adults as reported in a previous internal study (Blanchet et al., 2009). Overall, 89 raw and processed food items (41 fruits) were selected for inclusion in this study (see Supplemental Table S1). They were categorized in groups of food items according to their characteristical protective effect against cancer (see Section 2.2.2).

2.1.3. Chronic exposure doses

The possible individual exposure doses to each one of the 169 PAI reported in the CFIA reports were computed for each one of the 4727 Quebecers based on their consumption of the 89 F & V selected. Precisely, the amount of a given food item consumed, as reported for each individual, was multiplied by the mean concentration of each PAI measured in this food item, and divided by the individual's body weight, yielding an individual exposure dose expressed in μg/kg-d. Exposure to a given PAI calculated for each food item were summed to yield an individual total exposure dose:

$$TDD_p = \sum_{1}^{89} \frac{QF_i \times CP_{pi}}{BW} \quad (1)$$

where TDD_p is the individual total daily individual exposure dose to PAI “p”, in μg/kg/day; CP_{pi} is the mean concentration of PAI residue “p” in food item i, μg/g; QF_i is the daily amount of food item i consumed, in g/day; and BW is the body weight of the individual, in kg.

This total exposure dose therefore represents an individual's exposure to a given PAI due to its personal consumption of F & V. Taking all together the 4727 possible individual PAI exposure doses allows generating a distribution of exposure doses that is assumed to reflect the entire population's average, continuous and steady-state-like, chronic exposure to every PAI under study. This approach was performed for the whole population as well as six specific age groups specified by CCHS (Health Canada, 2006), namely 1–3 ($n = 320$), 4–8 ($n = 498$), 9–13 ($n = 578$), 14–18 ($n = 684$), 19–50 ($n = 1359$), and 51 years and over ($n = 1288$).

2.2. Cancer risk

2.2.1. Estimated cancer risk resulting from PAI residues in fruits and vegetables

Among the 169 PAIs that have been considered in this study, an oral cancer slope factor (“q*”) could be found in the literature for 28 of them in either CalEPA or US EPA databases (see Supplemental Table S2). Chlordane was the only substance for which two different q* are available in the literature, that is 1.3×10^{-3} (μg/kg-d)$^{-1}$ (CalEPA, 2006) and 0.35×10^{-3} (μg/kg-d)$^{-1}$ (US EPA, 1997); CalEPA's most conservative value was used. Besides, a single q* value was used for the whole dithiocarbamate (DTC) PAI chemical family (6×10^{-3} (μg/kg-