Published in final edited form as:

Environ Res. 2016 May ; 147: 133–140. doi:10.1016/j.envres.2016.02.003.

The role of diet in children's exposure to organophosphate pesticides

Francesca Holme¹, Beti Thompson^{2,*}, Sarah Holte², Eric M. Vigoren³, Noah Espinoza², Angela Ulrich², William Griffith³, and Elaine M. Faustman³

¹Department of Global Health, University of Washington, Seattle, WA, USA

²Public Health Sciences Division, Fred Hutchinson Cancer Research Center, Seattle, WA, USA

³Department of Environmental and Occupational Health Sciences, University of Washington, Seattle, WA, USA

Abstract

Background—Studies suggest that some of the greatest exposure to OPs in children occurs in agricultural communities and various pathways of exposure including the take-home pathway, proximity to orchards, and diet have been explored. However, the importance of the dietary pathway of exposure for children in agricultural communities is not well understood.

Objectives—Our goal was to ascertain whether there were associations between measures of OP exposure and apple juice, fruit, and vegetable consumption across growing seasons by children of farmworkers and non-farmworkers in a rural agricultural setting.

Methods—Study participants were children of farmworker (N=100) or non-farmworker (N=100) households from a longitudinal cohort study. Dietary intake of fruits and vegetables was assessed using a “5-A-Day” abbreviated food frequency questionnaire, and exposure to OPs was characterized using three urinary di-methyl and three di-ethyl metabolite measurements per child for each of three growing seasons. We used generalized estimating equations to examine data.

Results—Consumption frequency of fruits and vegetables was similar between children of farmworkers and non-farmworkers and across seasons. There were a few significant trends between dimethyl metabolites (DMAP) and fruit, vegetable or apple juice consumption; however, no clear pattern held across seasons or occupation. One difference was found in vegetable consumption during the harvest season, where the farmworker families showed a significant relationship between vegetable consumption and dimethyl metabolite levels ($p=0.002$). We also found a significant difference in this relationship between farmworkers and non-farmworkers

*Corresponding Author: Fred Hutchinson Cancer Research Center, 1100 Fairview Ave. N, M3-B232, Seattle, WA 98109. bthompso@fhcrc.org, Telephone: 206-667-4673; Fax: 206-667-5779..

Publisher's Disclaimer: This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final citable form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

Conflict of Interest No actual or potential competing financial interests exist among the authors of this manuscript. The authors' freedom to design, conduct, interpret, and publish research is not compromised by any controlling sponsor as a condition of review and publication.

($p=0.001$). No significant trends between fruit and vegetable consumption and diethyl (DEAP) metabolites were found.

Conclusions—Our study shows the importance of considering season and parents' occupation in understanding OP exposure routes among children in an agricultural community. The impact of these factors on dietary OP exposure requires a more thorough analysis of the availability and consumption of produce from different sources including farms using pesticides where parents worked.

Keywords

children; diet; farmworker; organophosphate pesticides; pesticide; pesticide exposure; rural; agricultural community

Introduction

Organophosphate pesticides (OPs) are the most heavily used insecticides in United States (US) farming (Rosas and Eskenazi 2008), posing a widespread risk of occupational and environmental exposure. Children are particularly sensitive to environmental toxicants such as pesticides due to a variety of factors, including more sensitive organ systems (particularly the brain and nervous system) and lower capacity to absorb and eliminate chemicals compared to adults (Makri et al. 2004; National Research Council 1993; Perera et al. 2006). Characterizing various environmental contributors to children's exposure is an important step toward understanding health effects among children and ultimately protecting this vulnerable population from harm.

A possible source of OP exposure among children is diet. A 2004 study of National Health and Nutrition Examination Survey (NHANES) data by Barr et al. found that up to 70% of children aged 6–11 in the general population had detectable levels of at least one urinary metabolite of OPs (Barr et al. 2004), suggesting widespread exposure of the kind one might expect from dietary sources. A 2008 study by Boon et al. showed that 15% of produce consumed by Dutch children ages 1–6 contained residues of at least one OP pesticide (Boon et al. 2008). It has also been hypothesized that fruit and vegetable consumption is a particularly important source of OP exposure in children because OP residues are typically detected in greater amounts on fruits and vegetables compared to other foods (Mills and Zahm 2001; US Food and Drug Administration 2008), and children tend to eat more of these products than adults per unit of body weight. For example, the National Research Council reported that children between 1–6 years of age eat 2.8–4.8 times more food per pound of apples, apple juice, orange juice, and bananas than the average American adult (National Research Council 1993).

Dietary consumption of fruits and vegetables has been further studied as a source of pesticide exposure among children in urban and suburban communities. A 2003 study of urban preschool age children by Curl et al., for example, found that the 18 children in the study who consumed nearly all organic fruits, vegetables, and juices had lower concentrations of urinary metabolites of OPs (diethylthiophosphate (DETP) and dimethylthiophosphate (DMTP)) compared to the 21 children who consumed nearly all

conventionally grown produce. These findings held even after excluding families that reported some use of OPs in the household or garden (Curl et al. 2003). A longitudinal study by Lu et al. in 2008 of 19 suburban children aged 3–11 measured urinary metabolites of OPs for 12 to 15 day sampling periods at each of the four seasons of the year. The children primarily ate conventionally-grown fruits and vegetables, and were given all organic substitutes to eat during two five-day intervals: one during the spring sampling period and one in the fall. Metabolites of two OPs, malathion and chlorpyrifos, dropped during the periods in which the children ate organic produce. None of the families reported household use of OPs. Lu et al. concluded that diet was the primary contributor to OP exposure in these children (Lu et al. 2008). A 2005 analysis of data from five previous studies further demonstrated that among the 110 children analyzed who lived in metropolitan areas, median DMTP and DMAP levels were respectively indistinguishable from and greater than levels in 211 children of farmworkers during the winter months when pesticides were not applied to crops (Fenske et al. 2005). The researchers speculate that the higher metabolite levels in urban children may be due to greater intake of juices, fresh fruits, and vegetables (Fenske et al. 2005).

The dietary pathway of exposure has only recently been explored in agricultural communities. In their 2011 study, Bradman et al. found significant associations between fruit and vegetable intake and levels of urinary metabolites of dimethyl OPs among children living in the Salinas Valley in California, at 6 months and 24 months of age (Bradman et al. 2011).

In this study, we examined the relationship between dietary consumption of fruits, vegetables, and juices and OP exposure among children living in an agricultural community in eastern Washington State. Because we wished to understand the role of diet on pesticide exposure among children in the agricultural community whose parents worked or did not work in agricultural fields, we identified children in each category. We then analyzed data on dietary habits and urinary metabolites of OPs collected during a research project examining multiple exposure pathways among farmworker and non-farmworker adults and children as part of the Centers for Child Environmental Health Risks Research at the University of Washington and the Fred Hutchinson Cancer Research Center. Given the associations observed in other studies between dietary consumption of fruits and vegetables and urinary metabolites of OPs, we hypothesized that consumption of fruits, fruit juices, and vegetables contributes substantially to OP exposure in children of farmworkers compared to children of non-farmworkers in the Lower Yakima Valley.

Materials and Methods

Setting

The setting is a rich agricultural region in Washington State that is known for its fruit and vegetable production. Orchard crops, such as apples, pears, cherries, and peaches are predominant, as are hops and grapes (Greater Yakima Chamber of Commerce). The Hispanic population in the Valley has burgeoned in recent years; the U.S. census bureau estimates that people of Hispanic or Latino origin made up 47% of the population in Yakima county in 2007, compared to 23.9% in 1990 (US Census 2000). In the setting where this

study took place, the population is 67% Hispanic, making it a majority minority area in the state.

Study design

Data were collected during a longitudinal cohort study that took place in the region between June 2005 and February 2006. Two cohorts were recruited: A cohort of 100 farmworkers along with a referent child between 1–7 years of age in the household; and a cohort of 100 non-farmworkers, also with a referent child between 1–7 years of age. All farmworkers worked in pome fruit crops (apples and pears). The non-farmworkers did not work in agriculture or in produce-packing plants; occupations included positions in dairies, factories, schools, and daycares. Both cohorts lived in the agricultural communities and an analysis of residence showed no differences between farmworker and non-farmworker families in proximity to orchards (data not shown). The cohorts were contacted three times: during the thinning season for apples and pears, when OPs are in heavy use and farmworkers remove small buds, shoots, and fruit from the limbs of trees; during the harvest season for pome fruits, when OPs are used less frequently on orchard crops; and in the non-spray season, when crops are dormant and pesticides are not in use.

Cohort members were recruited through flyers distributed through multiple means throughout the region; project staff distributed them at grocery stores, community organizations, churches, worksites, health fairs, and other activities and events. The flyers specified the eligibility criteria and provided information on samples that would be taken. All families who became members of the cohort were given a household total of \$160 for participation in all the phases of data collection in the study. Informed consent was obtained for all participants. The inclusion criteria required that the participant be 18 or older, have a child between 1–7 years of age who could participate in the study, and plan to be in the region for an entire year. All study materials and sample collection protocols were approved by the Institutional Review Board at the FHCRC (File #5946).

Six bilingual (Spanish and English) project staff members were trained in survey interviewing. At the end of the training, staff were tested and certified in interview and consent procedures. Staff interviewed each participating adult twice each season, five days apart. Topics included socio-demographic characteristics, self-reported level of general pesticide exposure, family pesticide use, proximity to fields, child behavioral practices, and child eating behaviors.

The questionnaire included dietary items from the “5-A-Day” abbreviated food frequency questionnaire, which is widely used to assess fruit and vegetable consumption in many diverse communities (Field et al. 1998; Kristal et al. 2000; Serdula et al. 1993). Our questionnaire items were adapted slightly to reflect dietary practices common in Hispanic communities and include vegetables common in Mexican meals (e.g., salsa, beans). An item ascertaining apple juice consumption was added, because the presence of preformed OP metabolites in apple juice had been detected in Lu's study (Lu et al. 2005). Parents were asked to report how often their child drank or ate particular categories of fruit juices, fruit or vegetable items. The food items were asked in terms of number of servings per day. A serving was described as 10 ounces of juice, a half a cup serving of fruits or vegetables, or a

small size of apples, pears, or bananas. Parents could answer in number of servings per day, week, or month in the past month. The dietary information was collected on days 1 and 5 of the data collection period. We also asked where the fruit was obtained that was brought into the home: purchased from a store or brought from the fields.

Three urine samples were collected during each season from each child. Spot urine samples were collected separated by two days each (Days 1, 3, and 5). The first morning voids were collected. Urine was collected using commode specimen collection pans and was then transferred into 125 ml plastic urine cups. Samples were placed in a plastic bag and then put on frozen ice packs in a cooler immediately after collection. Samples were then transported to the field office where they were stirred and 10 ml pipetted into 15 ml bottles, frozen and stored in freezers at -10°C prior to being sent on dry ice for analysis to the Centers for Disease Control (CDC) in Atlanta, GA.

Urine samples were analyzed for six common metabolites of OPs using high performance liquid chromatography-linked tandem mass spectrometry (HPLC-MS/MS). Limits of detection for the three diethyl metabolites (diethylphosphate (DEP), diethylthiophosphate (DETP), and diethyldithiophosphate (DEDTP)), and three dimethyl metabolites (dimethylphosphate (DMP), dimethylthiophosphate (DMTP), and dimethyldithiophosphate (DMDTP)) were 0.2, 0.1, 0.1, 0.6, 0.2, and 0.1 ng/ ml of urine, respectively (see (Thompson et al. 2014) for more detail. For children, the percentage below the level of detection varied by metabolite and season. These are summarized in Table 2. For measures of urinary metabolite below LOD we used half the value of the level of detection, ie. the midpoint between zero and level of detection. We did not adjust for creatinine because earlier work showed for young children that adjusting for creatinine did not reduce variability, and that for first morning voids there was slightly less variability if no adjustment was made (Barr DB et al. 2005; Kissel et al. 2005).

The OPs used most frequently in the region during this time were azinphosmethyl, phosmet, malathion, and to a lesser extent, diazinon, and chlorpyrifos (National Agricultural Statistical Services 2005). Azinphosmethyl, phosmet, and malathion metabolize as dimethyl compounds, while diazinon and chlorpyrifos metabolize as diethyls. In 2005, when these data were collected, greater than 196,000 pounds of azinphosmethyl, 87,000 pounds of phosmet, 187,000 pounds of chlorpyrifos, and 13,000 pounds of diazinon were used in Washington state (National Agricultural Statistical Services 2005). During the time of this study, dimethyl compounds were used much more than diethyl compounds.

Statistical analysis

To characterize fruit and vegetable intake for use in our models, we converted all reported instances of fruit and vegetable consumption into occasions per day. We then combined frequencies of all fruit items (including orange juice, apple juice, other fruit juices, and pieces of fruit) into one measurement of daily fruit intake, and similarly combined all frequencies of vegetable consumption (including lettuce salad, vegetables, vegetables as part of a mixed dish, and potatoes that were not fried) into measure of daily vegetable intake. We also combined all items into a total produce frequency measurement.

We created a combined concentration measure for dimethyl compounds (DMAP) consisting of the three dimethyl metabolites (DMP, DMTP, and DMDTP) and for diethyl compounds (DEAP) consisting of the three diethyl metabolites (DEP, DETP, and DEDTP). Each measure was divided by the molecular weights of each compound, and then the three weighted dimethyl or diethyl compounds were added together, giving us a single measure in nmol/mL for both dimethyls (DMAPs) and diethyls (DEAPs). DMAP and DEAP measurements were log-transformed to correct for skewness common in metabolite data. We used linear regression models to test for linear trends in the number of occasions of apple juice, fruits, vegetables, and total produce consumption and DMAP and DEAP levels. Generalized estimating equations (GEE) with an exchangeable working correlation matrix were used to account for repeated urine samples for each child. We analyzed children of farmworkers and children of non-farmworkers separately as parental occupation was expected to be a potential confounding factor.

Using two-way comparisons, we considered the association between the consumption of particular fresh fruits and vegetables (yes/no) during the prior month and DMAP and DEAP levels and tested for statistical significance. Because using generalized estimating equations as described above with linear regression model; $\log_{10}(\text{DMAP})$ or $\log_{10}(\text{DEAP})$ as the outcome variable and consumption of produce yes/no as the covariate, significance of the estimated coefficient for the consumption yes/no covariate was used to determine statistical significance. Statistical analysis was performed using SAS 9.3.

Results

Study participants

Initially, there were 200 children in our study. One non-farmworker household withdrew from the study and 4 households changed their occupational status over the course of the study and were omitted from this analysis. Child gender, age, and number of children in the household were closely balanced between the farmworker and non-farmworker households. Children's ages ranged from 1–7 years (see Table 1), with an average age of just over 4 years in both groups. There were statistically significant differences in birthplace, marital status, household income, and type of home between the farmworker and non-farmworker households. About a third of the households analyzed earned \$15,000 per year or less. Most parents of the children in our sample were born in Mexico (81% overall), although the proportion was greater among children of farmworkers.

We included data on every child for each season, provided that complete information on dietary habits and at least one measurement of urinary DMAP and DEAP levels was available for that season. Few children were lost to follow-up, with 175 of 195 children participating in all 3 seasons of the study, a 90% retention rate. Of the 555 urine sample collections, 536 (96.7%) were comprised of 3 urine samples and the remainder contained 2 urine sample.

Dietary data

When we examined total produce consumption among the children in our study, consumption varied only slightly by season and by parent occupation (see Figure 1). Among children of farmworkers, median fruit consumption ranged between 2.2 and 2.6 consumption occasions per day, depending on the season; median vegetable consumption was around 1.0 occasion per day, and total produce consumption ranged between 3.2 and 3.7 occasions per day. Fruit and vegetable consumption of children of non-farmworkers was fairly similar: median fruit consumption among children of non-farmworkers ranged from 2.0 to 2.3 occasions per day depending on the season. Median vegetable consumption ranged between 0.8 and 1.2 occasions per day, and median total produce consumption ranged from 3.0 to 3.7 consumption occasions per day. A relatively wide range of fruit and vegetable consumption existed among our subjects; considering all seasons and occupations, a range of 0 to 16.3 occasions per day of total produce was observed.

Additionally, we examined apple juice consumption, as this was expected to be an important contributor to overall produce consumption among children. Median apple juice consumption was similar among children of farmworkers and children of non-farmworkers, and stayed around 0.42 consumption occasions per day across seasons. Seasonal variability in the consumption of particular fruits and vegetables in this region has been documented elsewhere (Locke et al. 2009). Consumption of fruits and vegetables that are more readily available across seasons was most frequently reported; these items included apples, grapes, carrots, tomatoes, and cucumbers. Plums, apricots, and peppers were the least frequently consumed. When controlling for where produce was attained, there were no significant differences between those purchased in a store or brought home from the fields (data not shown).

Urinary metabolite data

We observed fluctuations in both DMAP and DEAP across seasons, particularly among the children of farmworkers and in the harvest season. Among children of farmworkers, median DMAP levels ranged from 0.077 nmol/mL in the non-spray season to 0.205 nmol/mL in both the thinning and harvest seasons. Among children of non-farmworkers, median DMAP levels were lower in two seasons (0.095 nmol/mL in the thinning season and 0.107 in the non-spray season) and slightly higher (0.197 nmol/mL) in the harvest season. The between child variability (standard deviation) for urinary metabolites was 0.21 for both DMAP and DEAP metabolites and the standard deviation for within child was 0.59 for DMAP and 0.55 for DEAP.

We found a few significant trends between fruit and vegetable consumption and urinary DMAP levels (see Figure 2a). Among farmworker children, but not among non-farmworker children, we found a significant positive trend in the relationship between the number of times vegetables were consumed per day and urinary DMAP levels during the harvest season ($p=0.002$). We also found that this trend differed significantly from the trend between vegetable consumption and DMAP levels in non-farmworker children ($p=0.01$). No other differences in trends between farmworkers and non-farmworkers were found in any other season or in servings of fruit or vegetables per day for diethyl metabolites.

We conducted the same analysis using the combined diethyl measure, DEAP, and observed trends similar to those detected in the dimethyl metabolite concentrations in fruit and vegetable consumption frequency (see Figure 2b). No significant trends between servings of fruits or vegetables per day were found in any season for either farm workers or non-farmworkers. When we included each child's age as a covariate in the model of both DMAPs and DEAPs, there were no changes in either the point estimates of associations between servings per day and metabolite or statistical significance in the associations (data not shown). There was no convincing evidence of association between the consumption of any particular fresh fruit or vegetable during the past month and DMAP or DEAP levels. Consumption of fresh apples was found to be associated with higher DMAPs in the thinning season among children of non-farmworkers, but this association did not appear in other seasons, and a significant association in the opposite (unexpected) direction was found in the same season among children of farmworkers. Where other significant associations were found in the anticipated direction, the small sample size of people consuming that particular fruit or vegetable (i.e. peaches in the non-spray season) may account for this finding as well as confounding by other fruits or vegetable that had been consumed during the past month. There were no patterns or consistencies across seasons or among either children of farmworkers or children of non-farmworkers, and as significant associations were found almost equally in the expected and unexpected directions, we conclude that it is unlikely that a relationship between reported consumption of particular fruits and vegetables during the last month and DMAP or DEAP levels exists in our samples.

Discussion

This study sought to contribute to the literature on farmworker children and their exposure to pesticides through diet. Specifically, we hypothesized that consumption of fruits, fruit juices, and vegetables would contribute significantly to OP exposure in children of farmworkers compared to children of non-farmworkers in the agricultural Lower Yakima Valley. The data did not support that reasoning. It must be noted, however, that many other avenues of pesticide exposure, including spray drift, may have led to pesticide exposure among all children in the agricultural community. Farmworker children had a significant positive trend between fruit or vegetable consumption and DMAP and DEAP levels; however, a significant trend was observed only during the harvest season for vegetable consumption. This study provides new implications for the added impact of OP exposure via a dietary pathway. It may be that other factors, such as drift or ambient exposure contribute to pesticide exposure in agricultural communities, attenuating the impact of dietary exposure. We have identified significant trends in the children of farmworkers in the relationship between occasions of vegetables consumed during the harvest season. Median DMAP levels were higher among both the children of farmworkers and non-farmworkers during the harvest season. Our study shows the importance of considering season and household occupational status in analysis of dietary OP exposure. The statistically significant differences in household demographics between farmworker and non-farmworker households may also contribute to potential differences dietary OP exposure. This would suggest a more thorough analysis of the availability and consumption of produce from different sources.

Other studies have examined the relationship between diet and OP exposure in children. Fenske et al. using DMAPs as a measure of OP exposure have suggested that the higher levels of exposure to OPs that were observed among urban children compared to farmworker children were due to greater consumption of juices and fresh produce among urban children (Fenske et al. 2005). Our study cohort was drawn from a rural population and the consumption frequency patterns were very similar for both farmworker and non-farmworker children. Our study was able to examine multiple food items on which OPs are used. Both Curl et al. and Lu et al. found consumption of conventionally-grown fruits and vegetables to be important sources of pesticide exposure in children; consumption of organics was found to be associated with lower levels of urinary metabolites of OPs (Curl et al. 2003; Lu et al. 2008). Our cohort of children was much larger than in these studies, with 200 children compared to about 20 in each of Curl et al.'s two cohorts (Curl et al. 2003), and 23 children total in Lu et al.'s cohort (Lu et al. 2008). Their cohorts live in suburban and urban neighborhoods, whereas ours live in an agricultural community. Each of these authors also used different methods of assessing dietary consumption of fruits and vegetables: Curl et al.'s subjects kept food diaries; Lu et al.'s were actually provided with either conventional or organic food by the researchers. In contrast, in our study we used a common food frequency questionnaire to assess dietary intake of fruits and vegetables. These differences in study design may contribute to the difference in findings between our study and theirs.

A study by Bradman et al. involved a cohort and methods that were much closer to ours; their cohort was also large (460 families) and also lived in an agricultural community (Bradman et al. 2011). Bradman et al. also used a food frequency questionnaire to assess dietary intake of fruits and vegetables. Like Bradman et al., we also analyzed our data using 1 occasion per day as the unit of measure with produce consumption as a continuous variable. One important distinction between our study and theirs was the age of the children: those in their study were younger than those in ours (6, 12, and 24 months of age compared to our cohort of 2–7 year-olds; the small number of 2 year olds in our study makes a direct comparison with Bradman et. al.'s 24 month olds unsuccessful). This age difference may account significantly for the higher DMAP levels that we observed. In our sample median DMAP levels were higher than in the Bradman et. al. study: both children of farmworkers and children of non-farmworkers had higher median DMAPs, ranging from 0.077–0.208 nmol/mL; converting the Bradman et. al. median combined dimethyl and diethyl phosphate metabolite levels to nmol/mL, their levels ranged from 0.036–0.076 nmol/mL depending on age group (Bradman et al. 2011). We also collected three urine samples during each season from each child, separated by two days each, whereas Bradman et al. collected just one; our statistical model takes into account the DMAP and DEAP levels in each of the three samples. Another important difference is that in our cohort the occupational status of the parent was found to be an important association with DMAP levels, whereas among the Bradman et al. cohort this relationship was not found to be significant.

A more recent paper by Bradman and colleagues focused on children in the same age range as ours (ages 3 through 6). In that project, children living in suburban and agricultural settings were fed a conventional diet and an organic diet. Urinary metabolites were significantly lower when an organic diet was consumed. Children residing in the agricultural community showed a lower decrease in dimethyl metabolites than those in a suburban

community (Bradman et al. 2015). It may be that the background noise in an agricultural community (e.g., spray drift) has an effect on all children in an agricultural community (Richter ED et al. 2015). Indeed, previous analyses from our data indicated there were no differences in proximity by occupation; that is, the cross tabulation using a chi-square test of different proportions of farm worker status by home-to-farmland distance resulted in a high p-value ($p=0.7514$) indicating no evidence that home-to-farmland distance varied by farm worker status (Coronado et al. 2011). Further, an analysis of foods consumed as a result of food brought home from the workplace indicated virtually no food was obtained from the orchards (data not shown).

The “5-A-Day” food frequency questionnaire we used is widely accepted as a reasonably accurate measure of usual fruit and vegetable consumption, and has been demonstrated to correlate with other, longer food frequency questionnaires and food records (Kristal et al. 2000; Serdula et al. 1993). In assessing consumption of particular individual fruits and vegetables, our questionnaire items asked participants to estimate fruit and vegetable consumption over the past month (usual diet). OPs are generally eliminated from the body between 24–48 hours after exposure depending on individual metabolism (Wessels et al. 2003), and thus may more closely reflect exposure over the two days preceding the urine sample collection.

It appears that diet simply did not contribute substantially to OP exposure in our cohort. Sources of long-term, low-level exposure to OPs in various communities (agricultural, urban and suburban) are still being explored and are not yet fully understood. If we compare our farmworker and non-farmworker populations to NHANES data available from the same time period, we see that in our cohort children of farmworkers have higher DMAPs than the general population; children of non-farmworkers show levels that fall between those of the children of farmworkers in our study and those of the NHANES population. (It is important to note that children in our study are younger than those captured in NHANES data.) Our findings provide an important contribution to this developing body of knowledge of pesticide exposure through diet in an at-risk community.

Limitations

This study is not without limitations. We asked parents what their children ate and there may be some reporting bias; however, these were still relatively young children and it is assumed that parents had a good sense of what their children were eating. The survey questionnaires asked parents about their child's eating habits over the past month. Considering that many OPs have short half-lives (hours), this study lacks the specificity to look at recent or acute associations. The survey instrument also did not query parents about their child's consumption of organic food, albeit organic food items were not readily available in our rural study setting. Although statistically significant associations ($p < 0.05$) were found in just 3 out of 24 analyses, it should be noted that these occurred only in the children of farmworkers. Also, the consumption frequency data was aggregated in a nested, hierarchical manner, with apple juice contained within fruit, and fruit and vegetables contained within total produce, so the effects of individual food items could be diluted. The significant associations that we observed between DMAP levels and consumption (yes/no) of particular

fresh fruits and vegetables in the past month may be spurious, resulting from the volume of tests performed. Further, this was not a true food consumption survey, and we did not adjust for age. Thus the results here must be interpreted with care.

Finally, these data are dated and alterations in the use of specific pesticides have changed since this project was undertaken. Nevertheless, the project adds information to pesticide exposure in children living in an agricultural community.

Conclusions

Among our cohort of farmworker and non-farmworker children ages 2–6 we observed some significant trends between urinary metabolite levels and the quantity of vegetable consumption among farmworker children in the harvest season, and in fruit consumption during the thinning season, compared to non-farmworker children. Although we observed some seasonal differences, the contribution of diet to OP exposure in our cohort remains unclear. These findings and the rather low association with total produce were unexpected, given results of studies in other communities of the relationship between produce consumption and OP exposure. It must be noted that our study took place in an agricultural community where there are potentially multiple sources of pesticide exposure. Our results indicate the need for further study of the contribution of various sources of OP exposure in children, such as diet, the occupational take-home pathway, and proximity to fields.

The health benefits of fruit and vegetable consumption are widely acknowledged. Our study in both farmworkers and non-farmworkers in an agricultural community notes that greater consumption of fruits and vegetables were not totally related to urinary pesticide metabolite exposure; however, others have found a significant relationship between diet and pesticide exposure in children. It may be that other factors in agricultural communities contribute to pesticide exposure by both children of farmworkers and non-farmworkers.

Acknowledgements

The authors would like to thank the participants in the Lower Yakima Valley who gave their time and energy for this research. This research was supported by grants from The National Institute of Environmental Health Sciences (PO1 ES009601) and The Environmental Protection Agency (R831709 and RD834514). The opinions expressed here are those of the authors and do not necessarily reflect those of the funding agencies.

This work was reviewed and approved by the Institutional Review Board at the Fred Hutchinson Cancer Research Center (File #5946)

List of Abbreviations

OP	Organophosphate pesticide
DMAP	A combined concentration measure consisting of the three dimethyl urinary metabolites of organophosphate pesticides (DMP, DMTP, and DMDTP)
DMP	Dimethylphosphate
DMTP	Dimethylthiophosphate
DMDTP	Dimethyldithiophosphate

DEAP	A combined concentration measure consisting of the three dimethyl urinary metabolites of organophosphate pesticides (DEP, DETP, and DEDTP)
DEP	Diethylphosphate
DEPT	Diethylthiophosphate
DEDTP	Diethyldithiophosphate

References

- Barr DB, Wilder LC, Caudill SP, AJ G, NL, JL P. Urinary Creatinine Concentrations in the U.S. Population: Implications for Urinary Biologic Monitoring Measurements. *Environmental Health Perspectives*. 2005; 113(2):192–200. [PubMed: 15687057]
- Barr DB, Bravo R, Weerasekera G, Calabiano LM, Whitehead RD Jr. Olsson AO, et al. Concentrations of dialkyl phosphate metabolites of organophosphorus pesticides in the U.S. population. *Environmental health perspectives*. 2004; 112(2):186–200. [PubMed: 14754573]
- Boon PE, Van der Voet H, Van Raaij MT, Van Klaveren JD. Cumulative risk assessment of the exposure to organophosphorus and carbamate insecticides in the Dutch diet. *Food and chemical toxicology : an international journal published for the British Industrial Biological Research Association*. 2008; 46(9):3090–3098. [PubMed: 18652871]
- Bradman A, Castorina R, Barr DB, Chevrier J, Harnly ME, Eisen EA, et al. Determinants of organophosphorus pesticide urinary metabolite levels in young children living in an agricultural community. *International journal of environmental research and public health*. 2011; 8(4):1061–1083. [PubMed: 21695029]
- Bradman, A.; Quiros-Alcala, L.; Castorina, R.; Schall, R.; Camacho, J.; Holland, N., et al. *Environmental Health Perspectives Advance Publication*. 2015. Effect of organic diet intervention on pesticide exposures in young children living in low-income urban and agricultural communities.
- Coronado GD, Holte S, Vigoren E, Griffith WC, Faustman E, Thompson B. Organophosphate pesticide exposure and residential proximity to nearby fields: evidence for the drift pathway. *Journal of occupational and environmental medicine/American College of Occupational and Environmental Medicine*. 2011; 53(8):884. [PubMed: 21775902]
- Curl CL, Fenske RA, Elgethun K. Organophosphorus pesticide exposure of urban and suburban preschool children with organic and conventional diets. *Environmental health perspectives*. 2003; 111(3):377–382. [PubMed: 12611667]
- Fenske RA, Lu C, Curl CL, Shirai JH, Kissel JC. Biologic monitoring to characterize organophosphorus pesticide exposure among children and workers: an analysis of recent studies in Washington State. *Environmental health perspectives*. 2005; 113(11):1651–1657. [PubMed: 16263526]
- Field AE, Colditz GA, Fox MK, Byers T, Serdula M, Bosch RJ, et al. Comparison of 4 questionnaires for assessment of fruit and vegetable intake. *American journal of public health*. 1998; 88(8):1216–1218. [PubMed: 9702152]
- Greater Yakima Chamber of Commerce. [accessed October 4th, 2012] Demographics. Available: <http://www.yakima.org/yakima/demo.html>
- Kissel J, Curl C, Kedan G, Lu C, Griffith W, Barr D, et al. Comparison of organophosphorus pesticide metabolite levels in single and multiple daily urine samples collected from preschool children in Washington State. *Journal of Exposure Analysis and Environmental Epidemiology*. 2005; 15(2): 164–171. [PubMed: 15187987]
- Kristal AR, Vizenor NC, Patterson RE, Neuhaus ML, Shattuck AL, McLerran D. Precision and bias of food frequency-based measures of fruit and vegetable intakes. *Cancer epidemiology, biomarkers & prevention : a publication of the American Association for Cancer Research, cosponsored by the American Society of Preventive Oncology*. 2000; 9(9):939–944.

- Locke E, Coronado GD, Thompson B, Kuniyuki A. Seasonal variation in fruit and vegetable consumption in a rural agricultural community. *Journal of the American Dietetic Association*. 2009; 109(1):45–51. [PubMed: 19103322]
- Lu C, Barr DB, Pearson MA, Waller LA. Dietary intake and its contribution to longitudinal organophosphorus pesticide exposure in urban/suburban children. *Environmental health perspectives*. 2008; 116(4):537–542. [PubMed: 18414640]
- Lu C, Bravo R, Calabiano LM, Irish RM, Weerasekera G, Barr DB. The presence of dialkylphosphates in fresh fruit juices: implication for organophosphorus pesticide exposure and risk assessments. *Journal of toxicology and environmental health Part A*. 2005; 68(3):209–227. [PubMed: 15762180]
- Makri A, Goveia M, Balbus J, Parkin R. Children's susceptibility to chemicals: a review by developmental stage. *Journal of toxicology and environmental health Part B, Critical reviews*. 2004; 7(6):417–435.
- Mills PK, Zahm SH. Organophosphate pesticide residues in urine of farmworkers and their children in Fresno County, California. *Am J Ind Med*. 2001; 40(5):571–577. [PubMed: 11675626]
- National Agricultural Statistical Services. Washington's Agricultural Fruit Chemical Usage. 2005.
- National Research Council. Pesticides in the diets of infants and children. The National Academy Press; Washington D.C.: 1993.
- Perera F, Viswanathan S, Whyatt R, Tang D, Miller RL, Rauh V. Children's environmental health research—highlights from the Columbia Center for Children's Environmental Health. *Annals of the New York Academy of Sciences*. 2006; 1076:15–28. [PubMed: 17119191]
- Richter ED, Rosenvald Z, Kaspi L, N G. Sequential cholinesterase tests and symptoms for monitoring organophosphate absorption in field workers and in persons exposed to pesticide spray drift. *Toxicology Letters*. 2015; 33(1):25–35. [PubMed: 3775819]
- Rosas LG, Eskenazi B. Pesticides and child neurodevelopment. *Current Opinion in Pediatrics*. 2008; 20(2):191–197. [PubMed: 18332717]
- Serdula M, Coates R, Byers T, Mokdad A, Jewell S, Chavez N, et al. Evaluation of a brief telephone questionnaire to estimate fruit and vegetable consumption in diverse study populations. *Epidemiology*. 1993; 4(5):455–463. [PubMed: 8399695]
- Thompson B, Griffith WC, Barr DB, Coronado GD, Vigoren EM, Faustman EM. Variability in the take-home pathway: Farmworkers and non-farmworkers and their children. *Journal of Exposure Science and Environmental Epidemiology*. 2014; 24(5):522–531. [PubMed: 24594649]
- US Census. [accessed September 24th, 2012] United States Census 2000 for the State of Washington. 2000. Available: <http://www.census.gov/census2000/states/wa.html>
- US Food and Drug Administration. Pesticide residue monitoring program: Results and discussion FY 2006. 2008.
- Wessels D, Barr DB, Mendola P. Use of biomarkers to indicate exposure of children to organophosphate pesticides: implications for a longitudinal study of children's environmental health. *Environmental health perspectives*. 2003; 111(16):1939–1946. [PubMed: 14644670]

Highlights

- Diets have been implicated in children's pesticide exposure
- In an agricultural community, we looked for associations between diet and OP pesticide metabolites in children of farmworkers as well as children of non-farmworkers
- Consumption of fruits and vegetables was similar in children of farmworkers and non-farmworkers.
- A few significant trends (3 out of 24) were found between consumption and urinary metabolites; however no clear pattern emerged

Figure 1.

Cumulative percentage of children's total produce consumption frequency (juices, fruits, and vegetables) per day by season and household occupational status (farmworker or non-farmworker). The groups are similar with no statistically significant differences observed in the consumption frequency patterns.

Figure 2a.

Total fruit and total vegetable consumption versus mean DMAP levels (nmol/mL) during the thinning, harvest, and non-spray seasons by household occupational status (farmworker or non-farmworker). Significant positive trends with the farmworker child group between DMAP levels and vegetable consumption during the harvest season ($p=0.002$), significantly different than the trend in non-farmworkers vegetable consumption in the harvest season ($p=0.01$).

Figure 2b.

Total fruit and total vegetable consumption per day versus mean DEAP levels (nmol/mL) during the thinning, harvest, and non-spray seasons by household occupational status (farmworker or non-farmworker). No differences in trend by occupation in any season. .

Table 1

Demographics of study participants

Characteristic	Parental Occupation		p value
	Farmworker (n = 100)	Non-farmworker (n = 94)	
Child Age (mean)	4.42	4.35	
1	4	2	
2	14	16	
3	18	21	
4	27	17	0.293
5	16	24	
6	13	13	
7	2	0	
Gender			
Male	53	48	0.775
Female	47	46	
Parent marital status			
Married/living as married	92	70	
Widowed/divorced	6	14	0.005
Never married	2	8	
Household income			
< \$15,000	39	26	
\$15,001–\$25,000	40	29	0.025
> \$25,000	21	35	
Number of children in household			
1	11	13	
2	26	30	
3	30	23	0.609
4 or more	33	28	
Parent Birthplace			
Mexico	97	59	
US	2	35	<0.001
Type of home			
Single family home	52	74	<0.001
Apartment	26	15	
Trailer	2	5	

Note: where n = 100, data were missing for one or more subjects.

P-values calculated using Fisher's Exact Test

Table 2

Percentage of children below the levels of detection (LOD) by season

Metabolite Type	Time of Collection (Season)		
	Thinning	Harvest	Non-Spray
DMP	14	23	30
DMTP	01	02	03
DMDTP	09	20	18
DEP	23	47	37
DETP	13	33	15
DEDTP	39	61	51