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Pesticide Residues in Imported, Organic, and "Suspect" Fruits and Vegetables

Carl K. Winter*

Department of Food Science and Technology, University of California, One Shields Avenue, Davis, California 95616, United States

ABSTRACT: Consumers are frequently urged to avoid imported foods as well as specific fruits and vegetables due to health concerns from pesticide residues and are often encouraged to choose organic fruits and vegetables rather than conventional forms. Studies have demonstrated that while organic fruits and vegetables have lower levels of pesticide residues than do conventional fruits and vegetables, pesticide residues are still frequently detected on organic fruits and vegetables; typical dietary consumer exposure to pesticide residues from conventional fruits and vegetables does not appear to be of health significance. Similarly, research does not demonstrate that imported fruits and vegetables pose greater risks from pesticide residues than do domestic fruits and vegetables or that specific fruits and vegetables singled out as being the most highly contaminated by pesticides should be avoided in their conventional forms.

KEYWORDS: *pesticide residues, imported foods, organic foods, risk assessment, pesticide monitoring*

INTRODUCTION

Pesticide residues in foods have been subject to intense legislative, regulatory, and public scrutiny in the United States for the past three decades. Significant legislative activity culminated in the unanimous passage of the landmark Food Quality Protection Act (FQPA) in 1996.[1] The FQPA required pesticide regulators to consider, among other things, the potential increased susceptibility of infants and children to pesticides, the cumulative impacts of pesticides having a common mechanism of toxicological action, and the aggregate exposure of consumers to pesticides from food, water, and all other nonoccupational sources (e.g., residential).[1] By 2006, the U.S. Environmental Protection Agency (EPA) achieved nearly full implementation of the FQPA and had completed more than 99% of its pesticide tolerance reassessments.[2]

In more recent times, pesticide residue issues have predominantly bypassed the legislative process and have frequently been communicated directly to consumers through food product marketing, media coverage, and public relations efforts of industry, environmental, and consumer organizations. Although consumers receive a variety of different messages from such campaigns, effective messages frequently encourage consumers to purchase particular food products and/or avoid other products due to concerns over pesticide residue risks. Consumers are often advised to (1) avoid imported foods, (2) purchase organic fruits and vegetables instead of conventional ones, and (3) avoid purchasing conventional forms of specific fruits and vegetables alleged to possess the highest levels of contamination from pesticide residues.

To assess the scientific validity of consumers adopting the aforementioned advice, this paper compares pesticide residues on imported and domestic fruits and vegetables, residues on organic and conventional fruits and vegetables, and exposure to pesticide residues on specific "suspect" fruits and vegetables.

COMPARISON OF PESTICIDE RESIDUES IN IMPORTED AND DOMESTIC FRUITS AND VEGETABLES

Results from federal monitoring programs have demonstrated that pesticide residue violations occur much more frequently in imported fruits and vegetables than in domestic fruits and vegetables (Table 1). Concern over the presence of violative residues from imported foods prompted the release of the landmark U.S. General Accounting Office report in 1992 titled *Adulterated Imported Foods are Reaching US Grocery Shelves*.[3] It has also been alleged that U.S. consumers experience upward spikes in pesticide exposure during the winter months when imported fresh fruits and vegetables have a greater market share.[4] In light of such findings and allegations, consumers are frequently warned to avoid consuming imported fruits and vegetables.[4]

Results from the U.S. Food and Drug Administration (FDA) regulatory monitoring program for pesticide residues in fruits and vegetables between 2003 and 2008 are shown in Table 1. Such results confirm the findings from the 1992 U.S. General Accounting Office report as pesticide residue violation rates for imported fruits and vegetables are much greater than those for domestic fruits and vegetables. Violation rates on imported fruits ranged from 3.7 to 5.6%, whereas those on domestic fruits ranged from 0 to 2.7%. A similar pattern is shown with vegetables; imported vegetables had pesticide residue violation rates ranging from 4.4 to 6.9% as compared with violation rates for domestic vegetables ranging from 1.4 to 2.8%.

Before we can conclude that imported fruits and vegetables pose greater risks from pesticide residues than domestic fruits

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Table 1. U.S. Food and Drug Administration Pesticide Program Residue Monitoring: Imported and Domestic Monitoring Results 2003−2008[a]

year	no. of samples	percentage of samples with no detections	percentage of samples with legal residues	percentage of samples with violations
		Imported Fruits		
2003	1537	63.6	31.1	5.3
2004	1613	61.1	33.3	5.6
2005	1256	64.6	30.9	4.5
2006	1151	70.3	26.0	3.7
2007	1282	64.2	31.8	4.0
2008	771	67.7	27.5	4.8
		Domestic Fruits		
2003	813	48.6	49.2	2.2
2004	868	42.9	55.9	1.2
2005	822	45.1	53.5	1.6
2006	372	43.8	54.9	1.3
2007	403	60.6	36.7	2.7
2008	333	42.3	57.7	0.0
		Imported Vegetables		
2003	2494	72.5	20.8	6.7
2004	2819	65.4	28.9	5.7
2005	3331	54.5	38.6	6.9
2006	2486	60.4	33.9	5.7
2007	3203	58.2	37.3	4.5
2008	1839	66.3	29.3	4.4
		Domestic Vegetables		
2003	1132	69.2	28.9	1.9
2004	1383	61.9	36.6	1.5
2005	1316	64.4	34.2	1.4
2006	711	74.4	23.1	2.5
2007	672	63.1	34.1	2.8
2008	713	64.8	33.5	1.7

[a]Source: U.S. Food and Drug Administration, http://www.fda.gov/Food/FoodSafety/FoodContaminantsAdulteration/Pesticides/ResidueMonitoringReports/default.htm.

and vegetables due to their higher rates of violations, it is critical to understand how the allowable levels of pesticide residues, known as tolerances, are established as well as the health implications of violative residues. Briefly, tolerances are not barometers of levels of health concern but are established to represent the maximum pesticide residue levels anticipated provided that a pesticide is used legally.[5] Before approving a tolerance, the EPA performs a risk assessment to ensure that consumer exposure to the pesticide on the specific commodity, as well as on other commodities, in drinking water, and in the residential environment, is low enough to represent a "reasonable certainty of no harm" according to the provisions of FQPA.[1] If the risk assessment concludes that the pesticide poses a "reasonable certainty of no harm," the tolerance is established at or slightly above the highest level anticipated from legal use of the pesticide on the specific commodity. In the event that residues are detected at levels above the tolerance, such residues constitute violations and indicate that the pesticide was likely applied improperly or that the commodity was harvested before the preharvest interval had elapsed. Such a finding does not, however, imply consumer risk.[5]

Most violative residues, however, occur when pesticides are detected on commodities for which no tolerance has been established. Such residues could occur from drift, uptake from contaminated soil, commingling with other agricultural products, or improper pesticide application. Again, however, such violations do not necessarily imply consumer risk.

From a human health perspective, a comparison of potential consumer exposure levels to pesticides from imported or domestic fruits and vegetables would provide a much better indicator than violation rates to assess the relative risks between imported and domestic fruits and vegetables. A closer look at Table 1 reveals that imported fruits and vegetables, although demonstrating a higher frequency of violative residues, also typically showed a higher percentage of samples for which no pesticide residues were detected. Imported fruits, for example, had no detectable residues on 61.1−70.3% of the samples between 2003 and 2008, whereas no detectable residue rates for domestic fruits were lower, ranging from 42.3 to 60.6%. Such findings suggest that consumer exposure to pesticides from imported fruits might even be lower than exposure from domestic fruits.

A study by Katz and Winter compared pesticide exposure from consumption of imported and domestic fruits and vegetables.[6] Rather than rely upon the typical residue monitoring data that lists rates of violations, legal residues, and no detectable residues, they collected results from all FDA fruit and vegetable samples analyzed for residues of 18 common pesticides in 2003 and incorporated the actual levels found on each of the samples into a probabilistic risk assessment. Of the 15 pesticides for which direct comparisons between imported and domestic exposure could be made, domestic exposures were higher for 11 pesticides, whereas imported exposures were higher for four, and the five highest exposure levels all resulted from domestic exposures. The pesticide most frequently found to be violative, methamidophos, showed 36 violations from imported foods and only 1 violation from a domestic food; all imported and domestic violations occurred when methamidophos residues were detected on commodities for which methamidophos had no established tolerance. Exposure to methamidophos from domestic fruits and vegetables was 70% higher than from imported fruits and vegetables, suggesting that violative residues contributed very little to the overall methamidophos exposure.

The findings from this study dispel the notion that imported fruits and vegetables pose greater potential health risks to consumers than do domestic fruits and vegetables, even when the large differences among violation rates between imported and domestic fruits and vegetables are considered. The greater incidence of violations among imports may result from the complexities of international standards for pesticide residues. A producer from an exporting country may face a variety of standards for the same commodity/pesticide combination in the various countries the produce is being exported to; in some countries the pesticide may not be allowed on the commodity, whereas, in others, the allowable residue levels may vary markedly. If a fruit and vegetable exporter is not careful enough to comply with the differing standards in different countries, such mistakes could lead to pesticides being detected on fruits and vegetables for which maximum allowable levels had not been established, resulting in violations. Ironically, concern to avoid violations due to complex and nonuniform standards among importing countries might also discourage fruit and vegetable exporters from using pesticides. This could help explain why the percentages of nondetectable pesticide residues are typically higher from imported fruits and vegetables than from domestic fruits and vegetables and might result in lower consumer exposure.

COMPARISON OF PESTICIDE RESIDUES IN ORGANIC AND CONVENTIONAL FRUITS AND VEGETABLES

Organic food sales in the United States have increased dramatically over the past two decades, with total organic food sales exceeding $26.6 billion in 2010.[7] Organic fruits and vegetables represented 11% of U.S. fruit and vegetable sales in 2010.[7]

Surveys have indicated that consumers purchase organic foods for a number of reasons, including perceived health and nutritional benefits, avoidance of genetically modified foods, environmental factors, and worker safety. For many consumers, avoidance of pesticide residues is a key factor influencing their purchase of organic fruits and vegetables. According to the Organic Trade Association, 40% of U.S. families are purchasing more organic foods than they did one year ago, and 78% bought organic food in 2010.[8]

Although many consumers equate organic production with "pesticide-free" production, it should be noted that organic production methods do allow the use of EPA registered pesticides provided that such pesticides are approved by the National Organic Standards Board.[9] Most of the pesticides allowed for use in organic production are naturally occurring, although a few synthetic pesticides are allowed in cases when the pesticides do not contribute to contamination of crops, water, or soil or when other organic pest management practices are not sufficient to prevent or to control pests.[9]

It is also recognized that organic fruits and vegetables may contain residues of synthetic pesticides even if such pesticides were not directly applied to the crops. Inadvertent contamination may occur through drift from adjacent pesticide applications, from contamination of irrigation water, and from uptake of persistent pesticides residing in the soil. Recognizing this, the U.S. National Organic Program permits organic producers to make organic claims in cases when residues of pesticides not allowed for organic production are detected at no more than 5% of the EPA tolerance level.[4]

A few studies have been published that compare pesticide residue findings between organic and conventional fruits and vegetables. The most comprehensive study analyzed three different sets of pesticide monitoring data.[10] Data from the U.S. Department of Agriculture's Pesticide Data Program (PDP) showed that 23% of 127 samples labeled as organic between 1994 and 1999 had detectable pesticide residues. About 40% of the detected residues on the organic fruits and vegetables resulted from the presence of persistent chlorinated hydrocarbon pesticides that have been banned for many years but still are available for plant uptake from contaminated soil. For fruits and vegetables analyzed by PDP from 1994 to 1999 that did not make any market claims, 73% of the 26571 samples were shown to be positive for pesticide residues.[10]

The same study also analyzed results from the California Department of Pesticide Regulation (CDPR) from 1989 to 1998 and from a Consumers Union study of four foods conducted in 1998. Pesticide residues in organic fruits and vegetables were detected in 6.5% of CDPR samples, whereas samples making no market claim showed a pesticide detection rate of 30.9%.[10] In the Consumers Union study of apples, peaches, peppers, and tomatoes, organic samples had a pesticide detection rate of 27% compared with a detection rate of 79% for samples not making a market claim.[10]

Monitoring results from Belgium from 1995 to 2001 yielded comparable results; pesticide residues were detected in 12% of organic fruit and vegetable samples and in 49% of samples for which no market claim was made.[11]

Different sampling practices and the use of different analytical methods for each of the four data sets discussed previously make direct comparisons of the results difficult. To simplify the findings, pesticide residues were 3.2, 4.8, 2.9, and 4.1 times more likely to be detected in conventional samples than in organic samples in the PDP, CDPR, Consumers Union, and Belgium studies, respectively.[9]

The PDP added organic lettuce to its pesticide monitoring program in 2009. A total of 387 samples were analyzed for 57 pesticides, isomers, metabolites, and breakdown products with a focus on pesticides approved for use in organic agriculture and on environmental contaminants.[12] The most commonly detected pesticides were the organically approved biological pesticides spinosad and neem oil, which were found on 78 samples. Synthetic insecticides were detected on four samples.[12]

In 2010, CDPR analyzed 137 organic fruit and vegetable samples for pesticide residues.[13] A total of 20 samples (14.6%) contained detectable pesticide residues, including 6 samples with detectable residues of spinosad and 4 samples containing DDE, a breakdown product of the persistent chlorinated hydrocarbon insecticide DDT. Two samples showed detectable residues of two different pesticides, whereas two other samples showed detectable residues of three different pesticides. Seven samples (5.1%) contained residue levels greater 5% of the established tolerance levels and would not be allowed to be marketed as organic according to the rules of the U.S. National Organic Program.[13]

It can be concluded pesticide residues are commonly detected on organic fruits and vegetables, although the incidence of detectable residues in organic produce is significantly lower than that in conventional produce. A diet emphasizing more organic fruits and vegetables should therefore lead to lower pesticide exposures, as has been demonstrated when children's diets are altered to substitute organic foods for conventional ones and cause a significant drop in urinary pesticide metabolites.[14] From a public health standpoint, it remains questionable as to the significance of such differences. The EPA allows pesticides to be used provided that they meet the "reasonable certainty of no harm" criteria established by FQPA. Such criteria include consideration of the specific sensitivities of infants and children to pesticides, consideration of cumulative exposure to all members of a family of pesticides possessing a common toxicological end point, and consideration of aggregate exposure from pesticides in food, water, and nonoccupational settings. Chronic exposure to pesticides must not pose a cancer risk of greater than one in a million, calculated using very conservative (risk-enhancing) mathematical models, whereas acute exposures must not exceed the acute reference dose (RfD) at the 99.9th percentile of daily exposure for the "reasonable certainty of no harm" criterion to apply.[1] Most acute and chronic RfDs are derived by applying large uncertainty factors (usually 100 but often 1000 in cases involving infants/children) to doses that do not cause harm in laboratory animals to determine acceptable human daily levels of exposure.[15] On rare occasions, acute RfDs are derived from human studies. Thus, typical consumer exposure to pesticide residues is currently at very low levels relative to those required for health concern, and reducing consumer exposure further through consumption of more organic fruits and vegetables may not provide much of an additional incremental health benefit with respect to pesticide residues. Similar conclusions were drawn in a review paper by Magkos et al.[16]

■ PESTICIDE RESIDUES ON "SUSPECT" FRUITS AND VEGETABLES

There is a consensus in the scientific community that the health benefits from consuming fruits and vegetables outweigh any potential risks from pesticide residues in fruits and vegetables. Many consumers, through their purchase of organic fruits and vegetables, make the choice to further reduce their dietary exposure to pesticides, although it is possible that adopting a diet that avoids conventionally produced fruits and vegetables might limit availability, affordability, variety, and ultimately consumption of fruits and vegetables.

Efforts have been made to identify specific fruits and vegetables that may pose the greatest potential consumer risk from exposure to pesticides. The Consumers Union published a report that analyzed 27 foods for "toxicity scores" based upon results of federal pesticide residue monitoring results and the toxicity of each of the pesticides detected.[17] Another similar approach has been taken to develop "pesticide dietary risk index scores" that can be used to identify imported and domestic fruits and vegetables of greatest concern.[4] Neither approach has been subject to external, expert scientific peer review or involves development of a risk assessment that attempts to actually quantify consumer exposure and risks from pesticide residues on fruits and vegetables, however, so the findings and recommendations should be viewed with caution.

A similar but more influential approach comes from the Environmental Working Group (EWG), a U.S. based environmental advocacy organization. The EWG has been releasing its annual *Shoppers Guide to Pesticides* that provides a list of the 12 most highly contaminated fruits and vegetables, dubbed the "Dirty Dozen," since 1995.[18] Consumers are urged to avoid conventionally grown fruits and vegetables on the Dirty Dozen list and to substitute organic forms of those foods when possible. If organic options are not available, consumers are instructed to seek out other conventionally grown fruits and vegetables with lower contamination loads. The annual release of the Dirty Dozen typically generates significant newspaper, magazine, radio, and television coverage and likely influences the produce-purchasing decisions of millions of U.S. residents.

According to the EWG, apples topped the 2011 Dirty Dozen list as the most contaminated food, followed by celery, strawberries, peaches, spinach, nectarines (imported), grapes (imported), sweet bell peppers, potatoes, blueberries (domestic), lettuce, and kale/collard greens.[18] The 2010 list was similar with the exception of slightly different rankings and the substitution of cherries for lettuce. According to the news release announcing the 2010 Dirty Dozen list, EWG stated "consumers can lower their pesticide consumption by nearly four-fifths by avoiding conventionally grown varieties of the 12 most contaminated fruits and vegetables".[19]

Such a statement implies that the EWG must have conducted an exposure assessment to enable the conclusion that consumers avoiding conventional forms of the Dirty Dozen could significantly decrease their exposure to pesticide residues. Rather than considering the three key factors necessary to perform an appropriate risk assessment (toxicity of the pesticides, residue levels found, consumption of the food items), the EWG's methodology to derive the Dirty Dozen rankings focuses specifically on the *presence* (but not the magnitude) of pesticide residues detected on foods based upon PDP data and ignores critical risk assessment elements. The EWG methodology has not been subject to appropriate scrutiny through the scientific peer review process, although its conclusions have been broadly communicated to consumers through the relatively uncritical mass media, and its recommendations have been cited in other peer-reviewed scientific papers.[20]

Using probabilistic risk assessment techniques and PDP residue findings, Winter and Katz developed exposure assessments for the 10 most frequently detected pesticides on each of the 2010 Dirty Dozen commodities.[21] All estimated consumer exposures to the 120 commodity/pesticide combinations were well below EPA established chronic RfD levels; only one exposure exceeded 1% of the RfD (methamidophos on bell peppers at 2% of the RfD), and only seven exposure estimates exceeded 0.1% of the RfD. Exposure estimates below 0.01% of the RfD (corresponding to exposures 1 million times lower than doses that do not cause noticeable effects in laboratory animals) were observed in 75% of the commodity/pesticide combinations, whereas exposure estimates below 0.001% of the RfD were noted in 41% of the commodity/pesticide combinations. For three commodities (blueberries, cherries, and kale), the highest exposure for any of the 10 most frequently detected pesticides on the specific commodities was at least 30000 times lower than the RfD. It was concluded that exposures to the most commonly detected pesticides on the Dirty Dozen list pose negligible risks to consumers and that the methodology used by the EWG to rank commodities with respect to pesticide risks was not scientifically credible.

The above discussion illustrates the need to carefully evaluate methodologies from which public health recommendations are derived to ensure that the recommendations are scientifically valid. Distinctions between peer-reviewed and non-peer-reviewed science should also be made.

■ AUTHOR INFORMATION

Corresponding Author

*E-mail: ckwinter@ucdavis.edu. Phone: (530) 752-5448. Fax: (530) 752-4759.

Notes

The authors declare no competing financial interest.

■ ABBREVIATIONS USED

FQPA, Food Quality Protection Act; EPA, U.S. Environmental Protection Agency; FDA, U.S. Food and Drug Administration; PDP, Pesticide Data Program; CDPR, California Department of Pesticide Regulation; RfD, reference dose; EWG, Environmental Working Group.

■ REFERENCES

(1) Winter, C. K. Pesticide residues in fruits and vegetables. In *Improving the Safety of Fresh Fruits and Vegetables*; Jongen, W., Ed.; Woodhead Publishing and CRC Press: London, U.K., 2005; pp 135–155.

(2) U.S. Environmental Protection Agency. Implementation of Requirements under the Food Quality Protection Act (FQPA); http://www.epa.gov/pesticides/regulating/laws/fqpa/backgrnd.htm (accessed Feb 16, 2011).

(3) General Accounting Office. *Report to the Chairman, Subcommittee on Oversight and Investigations, Committee on Energy and Commerce, House of Representatives. Adulterated Imported Foods are Reaching US Grocery Shelves*, GAO/RCED-92-206; Washington, DC, 1992.
(4) Benbrook, C. *Simplifying the Pesticide Risk Equation: the Organic Option*; The Organic Center: Boulder, CO, 2008.
(5) Winter, C. K. Pesticide tolerances and their relevance as safety standards. *Regul. Toxicol. Pharmacol.* **1992**, *15*, 137−150.
(6) Katz, J. M.; Winter, C. K. Comparison of pesticide exposures from consumption of domestic and imported fruits and vegetables. *Food Chem. Toxicol.* **2009**, *47*, 335−338.
(7) Organic Trade Association. Industry Statistics and Projected Growth; http://www.ota.com/organic/mt/business.html (accessed June 2011).
(8) Organic Trade Association. Press Release: Seventy-eight percent of U.S. Families say they purchase organic food; http://www.organicnewsroom.com/2011/11/seventyeight_percent_of_us_fam.html (accessed Nov 2, 2011).
(9) Winter, C. K.; Davis, S. F. Organic foods. *J. Food Sci.* **2006**, *71*, R117−R124.
(10) Baker, B. P.; Benbrook, C. M.; Groth, E.; Benbrook, K. L. Pesticide residues in conventional, integrated pest management (IPM)-grown and organic foods: insights from three US data sets. *Food Addit. Contam.* **2002**, *19*, 427−446.
(11) Pussemier, L.; Larondelle, Y.; Van Peteghem, C.; Huyghebaert, A. Chemical safety of conventionally and organically produced foodstuffs: a tentative comparison under Belgian conditions. *Food Control* **2004**, *17*, 14−21.
(12) U.S. Department of Agriculture. P*esticide Data Program, Annual Summary, Calendar Year 2009*; Agricultural Marketing Service, Science and Technology Programs: Washington, DC, 2011.
(13) California Department of Pesticide Regulation. Pesticide Residue Monitoring Program, Annual Residue Data 2010; http://www.cdpr.ca.gov/docs/enforce/residue/rsmonmnu.htm (accessed Dec 12, 2011).
(14) Lu, C.; Toepel, K.; Irish, R.; Fenske, R. A.; Barr, D. B.; Bravo, R. Organic diets significantly lower children's dietary exposure to organophosphorus pesticides. *Environ. Health Perspect.* **2006**, *114*, 260−263.
(15) Winter, C. K.; Francis, F. J. Scientific status summary: assessing, managing, and communicating chemical food risks. *Food Technol.* **1997**, *51*, 85−92.
(16) Magkos, F.; Arvaniti, F.; Zampelas, A. Organic food: buying more safety or just peace of mind? A critical review of the literature. *Crit. Rev. Food Sci. Nutr.* **2006**, *46*, 23−56.
(17) Groth, E.; Benbrook, C. M.; Lutz, K. *Do You Know What You're Eating? An Analysis of U.S. Government Data on Pesticide Residues on Foods*; Consumers Union of United States, Inc., Public Service Projects Department, Technical Division: Yonkers, NY, Feb 1999.
(18) Environmental Working Group. EWG's 2011 Shoppers Guide to Pesticides in Produce^{TM}; http://www.ewg.org/foodnews/ (accessed Dec 13, 2011).
(19) Environmental Working Group. EWG's Shoppers Guide Helps Cut Consumer Pesticide Exposure; http://www.food-news.org/press.php (accessed June 2010).
(20) Lu, C.; Schenck, F. J.; Pearson, M. A.; Wong, J. W. Assessing children's dietary pesticide exposure: direct measurement of pesticide residues in 24-hr duplicate food samples. *Environ. Health Perspect.* **2010**, *118*, 1625−1630.
(21) Winter, C. K.; Katz, J. M. Dietary exposure to pesticide residues from commodities alleged to contain the highest contamination levels. *J. Toxicol.* **2011**, DOI: 10.1155/2011/589674.