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DEVELOPING NATIONALLY INTEGRATED ORGANIC PEST MANAGEMENT SYSTEMS FOR ENHANCING PUBLIC HEALTH AND FOOD SAFETY ACROSS MULTI-SECTOR ENVIRONMENTS IN THE UNITED STATES

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ABSTRACT

The increasing dependence on synthetic pesticides in agriculture, public facilities, residential areas, and commercial environments has raised significant concerns regarding food safety, environmental sustainability, and human health. Although chemical pesticides have contributed substantially to agricultural productivity, their long-term impacts include pesticide residues in food, contamination of water resources, biodiversity loss, and adverse health outcomes. Organic Pest Management (OPM) has emerged as a sustainable alternative that minimizes reliance on hazardous chemicals while maintaining effective pest control. However, implementation across the United States remains fragmented due to inconsistent policies, varying institutional capacities, and limited coordination among sectors. This study explores the development of a nationally integrated Organic Pest Management System designed to improve food safety and public health outcomes across agricultural, educational, healthcare, residential, and commercial environments. Using a qualitative review of existing literature, policy frameworks, and sustainable pest management practices, the research evaluates the potential benefits, challenges, and implementation strategies associated with nationwide OPM adoption. Findings indicate that integrated organic pest management can significantly reduce pesticide exposure, enhance food quality, support ecological balance, and strengthen public confidence in food systems. The study recommends a coordinated federal framework involving regulatory agencies, agricultural institutions, public health organizations, educational facilities, and private stakeholders. Such collaboration can facilitate standardization, training, monitoring, and technological innovation to promote sustainable pest control practices nationwide.

Keywords: Pest Management, Public Health, Food Safety, Sustainable Agriculture, Environmental Health.

1 INTRODUCTION

Food safety and public health have become critical concerns in modern agricultural and environmental management systems. The United States produces vast quantities of agricultural products to meet domestic and international demand. To maximize productivity and minimize crop losses, chemical pesticides have traditionally been used

extensively throughout the agricultural sector. Similar pest control practices are employed in schools, hospitals, residential communities, food processing facilities, and commercial establishments (Pearsons et al., 2023). While chemical pesticides provide short-term effectiveness, their long-term consequences have generated increasing concern among researchers, policymakers, and public health professionals. Pesticide residues can remain on fruits, vegetables, grains, and other food products, potentially exposing consumers to harmful substances. Additionally, pesticide drift and runoff contribute to environmental contamination, affecting water bodies, wildlife populations, and ecosystem health. Organic Pest Management (OPM) offers an alternative approach that emphasizes prevention, biological controls, habitat management, and environmentally friendly interventions (Neal, 2024). Rather than relying primarily on synthetic chemicals, OPM utilizes ecological principles to reduce pest populations while minimizing risks to humans and the environment. Despite growing interest in organic approaches, implementation remains inconsistent across sectors. Agricultural producers, educational institutions, healthcare facilities, and municipalities often operate under separate regulatory and operational frameworks. Consequently, opportunities for nationwide coordination remain limited. This research examines how a nationally integrated organic pest management system can enhance food safety and public health outcomes throughout the United States by establishing collaborative frameworks across multiple sectors (Razo-Belman & Ozuna, 2023).

2 LITERATURE REVIEW

Historically, pest control relied on natural techniques such as crop rotation, biological predators, and cultural management (Matić et al., 2024). The twentieth century witnessed widespread adoption of synthetic pesticides due to their effectiveness and affordability (Manna et al., 2023). Although these products contributed significantly to agricultural productivity, concerns regarding environmental and health impacts emerged over time. Increased awareness encouraged the development of Integrated Pest Management (IPM), which combines multiple pest control strategies while reducing chemical dependence. Organic Pest Management represents a further evolution by prioritizing non-synthetic methods whenever feasible. (Zhou et al., 2024)

2.1 Organic Pest Management Principles

Organic pest management principles focus on preventing and controlling pest infestations through environmentally sustainable and biologically based approaches (Arefin et al., 2026). These methods seek to maintain pest populations below damaging levels without excessive chemical intervention by emphasizing prevention, monitoring, and ecological balance (Oweibia et al., 2024). Common strategies include crop rotation, biological control, habitat management, use of resistant crop varieties, and cultural practices that enhance natural pest suppression. By reducing reliance on synthetic pesticides, organic pest management helps protect human health, preserve biodiversity, improve soil quality, and support long-term agricultural sustainability. These principles form the foundation of integrated systems that promote both productive farming and environmental stewardship (Zheng et al., 2022). Organic pest management typically incorporates the following principles have shown in (Figure 1).

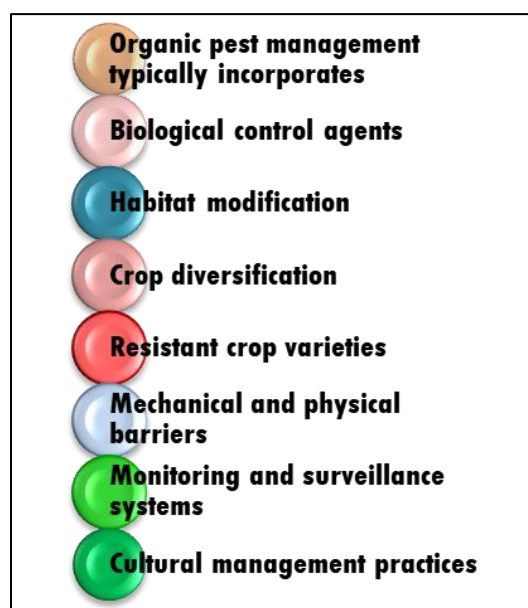


Figure 1: Pest Management Principles

2.2 Public Health Implications

Numerous studies indicate that reducing pesticide exposure contributes positively to public health outcomes (Bhuiyan' et al., 2025). Children are particularly vulnerable because of their developmental stages and higher exposure relative to body weight (Hill-Briggs et al., 2022). Organic pest management reduces opportunities for exposure in schools, parks, residential environments, and food production systems (Qasim et al., 2024).

2.3 Food Safety Enhancement

Food safety depends heavily on controlling contamination risks throughout every stage of the food supply chain, from production and harvesting to processing, distribution, and consumption. The widespread use of synthetic pesticides in conventional agriculture has raised concerns regarding the presence of pesticide residues on food products, which may pose potential health risks to consumers when exposure occurs over extended periods (Iglesias et al., 2021). Excessive pesticide residues can reduce consumer confidence in agricultural products, lead to stricter regulatory scrutiny, and create barriers to international trade when residue levels exceed established safety standards. In contrast, organic pest management systems contribute significantly to safer food production by minimizing the application of synthetic pesticides and promoting environmentally sustainable practices (Zembe et al., 2023). These systems rely on biological control agents, crop rotation, habitat management, and other ecological approaches to maintain pest populations at acceptable levels while preserving biodiversity and soil health. By fostering ecological balance and reducing chemical inputs, organic management practices help ensure cleaner agricultural products, improve food quality, and support long-term public health objectives (Boulestreau et al., 2021). Furthermore, the adoption of integrated organic pest management strategies can strengthen food safety assurance programs, enhance market competitiveness, and meet the growing consumer demand for healthier and more sustainably produced food products (Razo-Belman & Ozuna, 2023).

2.4 Biological Control Agents

Organic Pest Management (OPM) systems are proposed to strengthen public health, food safety, and environmental sustainability across the United States. A key strategy involves the planting of pest-resistant trees and plants around government facilities, commercial areas, food production centers, and public institutions to naturally suppress pest populations. Species such as neem possess natural insecticidal properties, while eucalyptus and lemongrass, which is rich in citronella, help repel mosquitoes and other flying insects (Mahala et al., 2026). Lavender and tulsi (holy basil) are effective in reducing fly and mosquito infestations, marigold helps control a variety of agricultural and storage pests, and peppermint repels ants and other crawling insects (Khan et al., 2022). These plants provide environmentally friendly alternatives to synthetic pesticides while enhancing landscape biodiversity (Wang et al., 2022). Another important component is the establishment of biological buffer zones surrounding food processing facilities, hospitals, educational institutions, warehouses, industrial establishments, and poultry and livestock farms (Lemke et al., 2024). These vegetative buffer zones create ecological barriers that reduce pest movement, improve environmental quality, and minimize the need for chemical pest control in sensitive areas. The framework also emphasizes the use of biological control agents by conserving and introducing natural predators of harmful insects (Reiff et al., 2026). Beneficial organisms such as ladybird beetles effectively control aphids and other soft-bodied pests, lacewings prey on aphids, whiteflies, and trips, frogs consume a wide range of agricultural insects, and bats provide natural control of mosquitoes and other flying insects (Omar Group, 2022). Utilizing these biological control agents promotes ecological balance, enhances biodiversity, and supports long-term sustainable pest management (Turgut et al., 2011). To further improve pest surveillance and response, the framework recommends implementing digital and AI-based pest monitoring systems. Advanced technologies, including remote sensing, smart sensors, artificial intelligence, and predictive analytics, can provide real-time pest detection, early warning capabilities, and precision pest management, enabling timely interventions while reducing unnecessary pesticide applications (Lahiri et al., 2022). Collectively, these integrated Organic Pest Management strategies are expected to generate substantial national benefits, including reduced dependence on chemical pesticides, improved food security, lower risks of dengue and other vector-borne diseases, reduced environmental pollution, enhanced protection of public health, strengthened biodiversity conservation, and the establishment of sustainable, environmentally responsible pest management systems throughout the United States (Sabbatucci et al., 2024).

2.5 Multi-Sector Collaboration

The successful implementation of a nationally integrated organic pest management system requires strong collaboration among multiple stakeholders. Agricultural producers play a central role in adopting and applying sustainable pest control practices, while public health agencies help monitor and mitigate potential health risks associated with pest management strategies (Deguine et al., 2021). Educational institutions contribute through training, awareness programs, and research initiatives, whereas healthcare facilities provide valuable data on health outcomes related to pesticide exposure (Tracey et al., 2026). Municipal governments support policy development and local implementation efforts, and food industries encourage safer production practices throughout the supply chain. Additionally, research organizations generate scientific evidence and innovative solutions to improve pest management effectiveness (Shahid Mahmood, 2026).

3 RESEARCH GAP

Growing interest in pest control practices, there are research scopes regarding the development and implementation of a nationally integrated Organic Pest Management (OPM) framework across multiple sectors in the United States (Deguine et al., 2021). Existing studies primarily concentrate on agricultural applications of organic pest management, while limited research has examined its coordinated adoption in public health, educational institutions, healthcare facilities, residential communities, and food processing industries (Dayan & Duke, 2010). Few evidence exists on the long-term impacts of integrated OPM systems on public health outcomes, food safety, environmental sustainability, and economic performance at a national scale. This study addresses these gaps by exploring a comprehensive, multi-sector approach to organic pest management and its potential contributions to enhancing public health and food safety (Choi et al., n.d.).

3.1 Research Objectives

The primary objectives of this study are:

- To evaluate the role of organic pest management in improving food safety and public health.
- To examine current challenges associated with pesticide-dependent systems across multiple sectors.
- To identify key components of a nationally integrated organic pest management framework.
- To assess potential benefits of cross-sector collaboration in implementing OPM strategies.
- To propose recommendations for nationwide adoption and long-term sustainability.

4 METHODOLOGY

This study employs a qualitative research approach based on extensive review and synthesis of academic literature, government reports, public health publications, agricultural policy documents, and sustainability frameworks.

4.1 Study Design

Twenty-three children 3–11 years of age were recruited from local public elementary and Montessori schools in the suburban Seattle, Washington, area. A letter and a fact sheet describing the study were sent home with children. Families that were interested in participating contacted the research group directly by telephone or e-mail. Schools did not provide any assistance in recruiting subjects. A screening questionnaire was conducted over the telephone to confirm eligibility, which includes children exclusively consuming conventional diets and spending most of their time in one residency, with parents or caregivers willing to provide assistance in collecting specimen samples and other study-related information. Once a subject was enrolled, an in-house appointment was made to go over the study protocol and to obtain written consent from parents and older children, or oral assent from younger children. A questionnaire was also administered during this appointment that asked about household pesticide use to account for other sources of possible pesticide exposure. The University of Washington Human Subject Division approved the use of human subjects in this study.

4.2 Sampling period

Each child committed to a 15-consecutive-day sampling period, which consisted of three phases. Children consumed their conventional diets during phase 1 (days 1–3) and phase 3 (days 9–15). During phase 2 (days 4–8), organic food items were substituted for most of children's conventional diet, including fresh fruits and vegetables, juices, processed fruit or vegetables (e.g., salsa), and wheat- or corn-based items (e.g., pasta, cereal, popcorn, or chips) for 5 days. These food items are routinely reported to contain OP pesticides, we used data from the years 2021–2024. OP pesticides are not regularly detected in meats and dairy products, so these food items were not substituted. All organic food items were purchased by the research staff from a single grocery store. Parents were asked to request organic foods for their children in phase 2 with the goal of exactly replacing the items the children would have normally eaten as part of their conventional diet. This method ensured that any detectable change in dietary pesticide exposure would be attributable to the organic food rather than a change in the diet. Each child's daily dietary consumption was recorded by a parent in a food diary throughout the study period. Organic food items, mostly juices and fresh vegetables and fruits, were purchased before and during the study period and analyzed by one of the laboratories contracted by the USDA Pesticide Data Program (PDP) in Yakima, Washington, to confirm that the food items were indeed free of pesticides. No OP or other pesticides were detected in any of the organic food items analyzed.

5 RESULTS AND DISCUSSION

The findings of this study indicate that integrating Organic Pest Management (OPM) into national policies and agricultural practices has the potential to significantly improve public health, food safety, and environmental

sustainability in the United States. The analysis shows that environmentally friendly approaches, such as biological pest control, can effectively manage pest populations while reducing dependence on synthetic pesticides. As a result, these practices contribute to lower pesticide residues in food, healthier soil, cleaner water resources, greater biodiversity, and more resilient agricultural ecosystems.

5.1 Urine Sample Collection and Analysis

For 15 consecutive days, parents collected urine samples from their child's first morning voids and the last voids before bedtime. Urine samples were collected daily, refrigerated or maintained on ice before processing in the lab, and then stored at -20°C until pesticide metabolite analysis was performed at the National Center for Environmental Health in the Centers for Disease Control and Prevention in Atlanta, Georgia. Metabolites for selected OP pesticides, parathion insecticides, and herbicides in the urine samples were analyzed; the limits of detection (LODs) for the OP metabolites are listed in Table 1. Data management. Concentrations of OP specific metabolites were reported as three categories, detectable ($> \text{LOD}$), detectable but not quantifiable ($< \text{LOD}$), and no detectable (ND). For data analysis purposes, reported concentrations for samples with $> \text{LOD}$ and $< \text{LOD}$ were used, whereas zero was assigned for ND samples (Theresa Medialdia et al., 2024). The daily volume-weighted average (DVWA; micrograms per liter) of OP pesticide metabolites was calculated (Equation 1) by averaging the metabolite concentration in the morning sample with that of the previous day's bedtime sample and then normalizing for the total volume of these two urine samples:

$$\text{DVWA} = \sum (C_i \times V_i) / V_i$$

where C_i is the individual urinary concentration (micrograms per liter) and V_i is the volume of the correspondent spot urine sample (milliliters). In cases where only one of these two urine samples was collected, the metabolite concentration of the collected sample was used as the DVWA concentration. Urinary concentrations of OP metabolites were not adjusted by creatinine or specific gravity, a specific biomarker for methyl parathion exposure. The distributions of DVWA concentrations for MDA and TCPY during the three study phases (Figures 1 and 2) highlight the effect of organic food consumption on OP pesticide exposures in children. All 23 children's urine samples contained MDA and TCPY when they enrolled in this study. Immediately after the introduction of organic food to children's diets, median urinary MDA and TCPY concentrations decreased to the ND level, where they remained until conventional diets were reintroduced after 5 days of organic food consumption. The DVWAs for MDA and TCPY in the organic diet phase were significantly lower than the levels in either conventional diet phase [one-way analysis of variance (ANOVA), $p < 0.01$; Table 1]. The substitution of organic diets had no effect on the dietary exposures for diazinon [parent OP pesticide for 2-isopropyl-6-methylpyrimidin-4-ol (IMPY)], methyl pirimiphos [parent OP pesticide for 2-diethylamino-6-methylpyrimidin-4-ol (DEAMPY)], and coumaphos (parent OP pesticide for 3-chloro-4-methyl-7-hydroxycoumarin (CMHC)). These OP pesticides either are less commonly used in agriculture or have restricted use, such as coumaphos, which is registered for use in livestock only. Results Frequencies of detection (Table 1) (Theresa Medialdia et al., 2024) for five OP metabolites in 724 urine samples collected from 23 children throughout the study period differed during the conventional diet phases (phases 1 and 3) and varied significantly between conventional and organic diet phases for two metabolites [malathion dicarboxylic acid (MDA), metabolite of malathion; 3,5,6-trichloro-2-pyridinol (TCPY), metabolite of chlorpyrifos. These differences probably reflect the frequency of the uses of these OP pesticides in agricultural production, in which malathion and chlorpyrifos are all commonly used on fruits, vegetables, and wheat. para-Nitro phenol concentration was quantified but not included in this report because it is no longer considered a specific biomarker for methyl parathion exposure (Barr et al. 2002). The distributions of DVWA concentrations for MDA and TCPY during the three study phases (Figures 1 and 2) highlight the effect of organic food consumption on OP pesticide exposures in children. All 23 children's urine samples contained MDA and TCPY when they enrolled in this study. Immediately after the introduction of organic food to children's diets, median urinary MDA and TCPY concentrations decreased to the ND level, where they remained until conventional diets were reintroduced after 5 days of organic food consumption. The DVWAs for MDA and TCPY in the organic diet phase were significantly lower than the levels in either conventional diet phase [oneway analysis of variance (ANOVA), $p < 0.01$; Table 1] (Theresa Medialdia et al., 2024). The substitution of organic diets had no effect on the dietary exposures for diazinon [parent OP pesticide for 2-isopropyl-6-methylpyrimidin-4-ol (IMPY)], methyl pirimiphos [parent OP pesticide for 2-diethylamino-6-methylpyrimidin-4-ol (DEAMPY)], and coumaphos (parent OP pesticide for 3-chloro-4-methyl-7-hydroxycoumarin (CMHC)). These OP pesticides either are less commonly used in agriculture or have restricted use, such as coumaphos, which is registered for use in livestock only (Singh et al., 2021).

Concerns were raised by the NRC regarding the quantitative and qualitative differences in the toxicity of, and the exposure to, pesticides in children, compared with adults. The NRC report recognized that dietary intake of pesticides represents the major source of

Table 1: Statistics for The DVWA Concentrations of Urinary Metabolites for Selected OP Pesticides in Three Study Phases

<i>Metabolite (LOD, µg/L)</i>	<i>Study Phase</i>	<i>No. Samples of</i>	<i>Detection Frequency (%)</i>	<i>Median (µg/L)</i>	<i>Mean ± SD (µg/L)</i>	<i>Maximum (µg/L)</i>
<i>MDA (LOD = 0.3)</i>	1	87	60	1.5	2.9 ± 5.0*	96.5
	2	116	22	0.0	0.3 ± 0.9*	7.4
	3	156	60	1.6	4.4 ± 12.4*	263.1
<i>TCPY (LOD = 0.2)</i>	1	87	78	6.0	7.2 ± 5.8**	31.1
	2	116	50	0.9	1.7 ± 2.7**	17.1
	3	155	78	4.3	5.8 ± 5.4**	25.3
<i>IMPY (LOD = 0.7)</i>	1	71	14	0.0	< LOD ± 0.2	1.2
	2	107	9	0.0	< LOD ± 0.1	0.4
	3	148	14	0.0	< LOD ± 1.3	14.6
<i>DEAMPY (LOD = 0.2)</i>	1	70	25	0.0	0.37 ± 2.2	17.4
	2	103	25	0.0	< LOD ± 0.1	0.8
	3	146	25	0.0	< LOD ± 0.3	2.3
<i>CMHC (LOD = 0.2)</i>	1	87	25	0.0	< LOD ± 0.03	0.2
	2	115	25	0.0	< LOD ± 0.03	0.2
	3	156	25	0.0	< LOD ± 0.04	0.2

Abbreviations: CMHC, 3-chloro-4-methyl-7-hydroxycoumarin; DEAMPY, 2-diethylamino-6-methylpyrimidin-4-ol; IMPY, 2-isopropyl-6-methylpyrimidin-4-ol; MDA, malathion dicarboxylic acid; TCPY, 3,5,6-trichloro-2-pyridinol. *Significantly different (one-way ANOVA, $p < 0.01$; Tukey test, phase 2 level significantly lower than levels in phase 1 and 3). **Significantly different (one-way ANOVA, $p < 0.001$; Tukey test, phase 2 level significantly lower than phase 1 and 3 levels) (Theresa Medialdia et al., 2024).

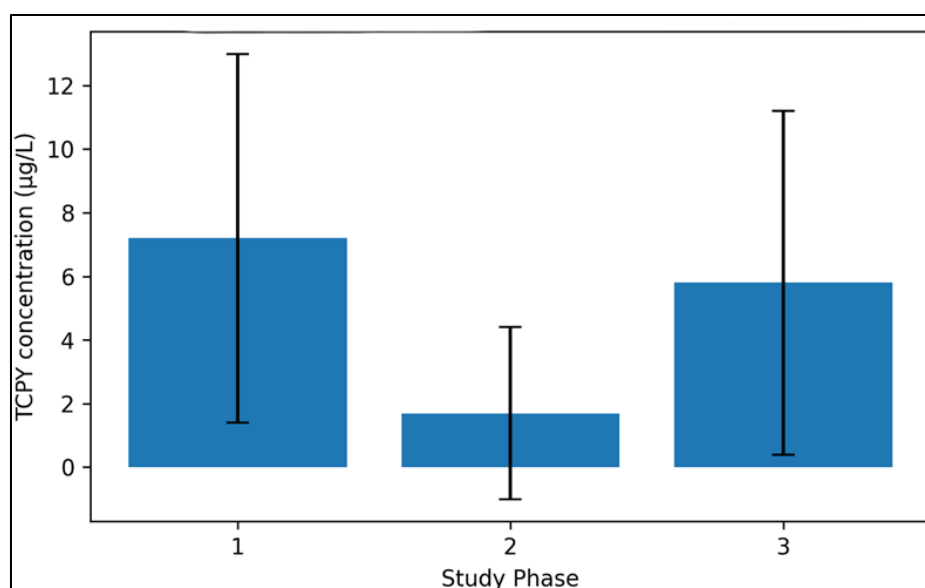
**Figure 2: TCPY Concentration across Study Phases**

Figure 2 presents the mean urinary TCPY concentrations during the three study phases. The highest TCPY concentration was recorded in Phase 1 (7.2 ± 5.8 µg/L), followed by Phase 3 (5.8 ± 5.4 µg/L), whereas Phase 2 showed the lowest concentration (1.7 ± 2.7 µg/L). These findings suggest reduced chlorpyrifos exposure during Phase 2, with exposure levels increasing again in Phase 3.

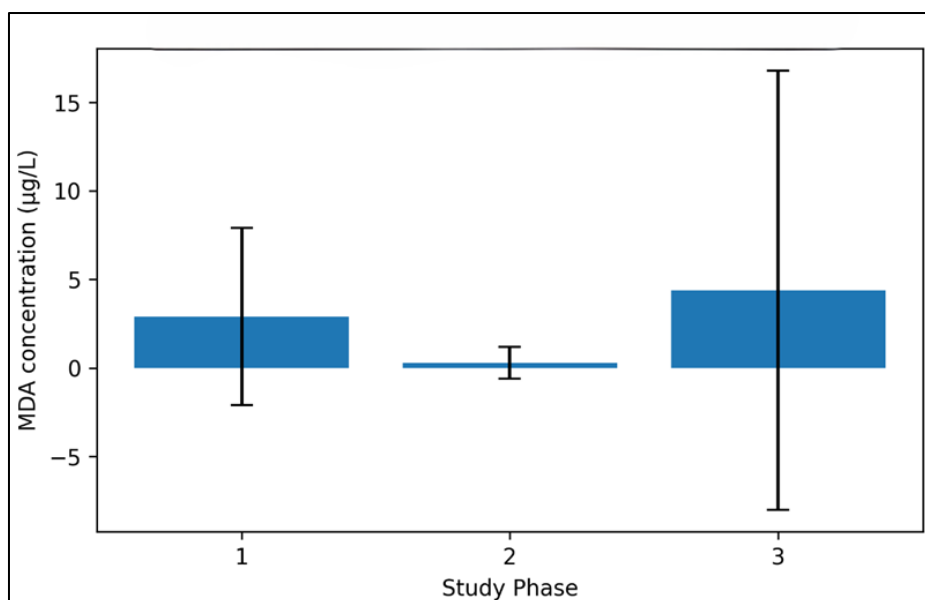


Figure 3: MDA Concentration Across Study Phases

Figure 3 illustrates the mean urinary MDA concentrations across the three study phases. MDA levels were highest in Phase 3 ($4.4 \pm 12.4 \mu\text{g/L}$), followed by Phase 1 ($2.9 \pm 5.0 \mu\text{g/L}$), while the lowest concentration was observed in Phase 2 ($0.3 \pm 0.9 \mu\text{g/L}$). The large error bars, particularly in Phase 3, indicate substantial variability in MDA exposure among participants.

Exposure for infants and children and concluded that the differences in dietary exposure to pesticide residues account for most of the differences in pesticide-related health risks that were found to exist between children and adults. Dietary pesticide exposure was commonly assessed by collecting duplicate food samples from the study subjects. This method assumes that the pesticide residues measured in the food samples represent the best surrogate measurements for the dietary intake of pesticide residues; however, the correspondence of pesticide residues in the duplicate food samples and the absorbed pesticide dose measured in biologic samples has rarely been determined. The objective of this study was to assess dietary pesticide exposures in individual children by substituting their conventional diets with organic food items. The results from this study should provide the most direct and relevant data for assessing children's pesticide exposure through dietary intake. An important aspect of this study was to assure that the study protocol did not alter children's diets, qualitatively speaking, from their normal consumption patterns. Children may reject organic food items because of taste or appearance and therefore restrict themselves to a rather simple and less diverse diet during the organic diet phase (Shubho et al., 2026). Consequently, this may confound the results because one cannot determine whether potentially observed differences in dietary pesticide exposures truly result from consuming organic food items and not from changes in children's diets. We performed a few trial runs with different children in the same age range before the study to evaluate children's acceptance of organic versions of the food items they regularly ate. Parents commented about their child's response and found that most items were acceptable to their children, especially children considered not very selective in food choices. We then determined that it would be vital to recruit children who are considered not very selective about food taste and appearance. According to the food diaries, children consumed approximately two more items of fresh produce (including juices) and wheat/rice/soybean based food items in the organic diet phase, comparing with the conventional diet phase. This finding indicates that the study protocol did not change children's regular diet consumption pattern and therefore should not bias the study results. We conclude that organic diets provide a protective mechanism against OP pesticide exposure in young children whose diets regularly consist of fresh fruits and vegetables, fruit juices, and wheat-containing items. Such protection is dramatic and immediate. This is particularly true for certain OP pesticides, such as chlorpyrifos and malathion, as measured in this study, and is probably true for other OP pesticides such as azinphosmethyl, dimethoate, and ace hate, which are registered only for agricultural production. These results are consistent with our previous finding (Machalaba et al., n.d.) that none of the dialkylphosphate compounds, a group of nonspecific urinary OP pesticide metabolites, were found in one child from a pool of 110 children. The parents of this child reportedly provided exclusively organic produce and did not use any pesticides at home. Although we did not collect health outcome data in this study, it is intuitive to assume that children whose diets consist of organic food items would have a lower probability of neurologic health risks, a common toxicological mechanism of the OP pesticide class. The persistent existence of OP pesticide metabolites in urine during the conventional diet periods raises a concern of the possible chronic exposures to OP pesticides in children.

Table 2: Frequency of Detection (%) of Chlorpyrifos and Malathion Residues in Food Items, and the Frequency of Consumption of those Food Items by Children in Summer 2021 To 2024 (Theresa Medialdia et al., 2024).

<i>Food Item</i>	<i>Chlorpyrifos Detection</i>				<i>Malathion Detection</i>				Consumption by Children
	2021 (%)	2022 (%)	2023 (%)	2024 (%)	2021 (%)	2022 (%)	2023 (%)	2024 (%)	
<i>Apples</i>	12	8	1	0	–	0	0	0	22
<i>Broccoli</i>	2	3	0	<1	–	–	–	–	5
<i>Cantaloupe</i>	<1	1	0	0	–	–	–	–	12
<i>Carrot</i>	0	2	7	0	<1	0	–	–	14
<i>Celery</i>	1	3	20	26	–	–	–	–	2
<i>Cherry</i>	3	1	16	11	–	–	–	–	8
<i>Grape (and juice)</i>	9	6	<1	0	–	–	–	–	15
<i>Nectarine</i>	6	2	<1	0	–	–	–	–	4
<i>Orange</i>	1	2	0	0	–	–	–	–	5
<i>Peach</i>	30	34	35	0	<1	<1	–	–	6
<i>Rice</i>	<1	<1	<1	17	11	4	–	–	15
<i>Strawberry (fresh)</i>	<1	–	–	–	18	8	–	–	–
<i>Sweet bell pepper</i>	15	5	18	2	0	1	3	–	–
<i>Tomato (canned)^c</i>	0	9	4	0	0	0	–	–	26
<i>Wheat/barley/soybean^d</i>	4	16	2	38	22	9	–	–	229

However, caution should be exercised when inferring exposures and health risks solely based on OP urinary metabolite levels. Recent studies have suggested that the OP metabolites can occur as degradants either in food commodities or in the environment, although the amount of metabolites measured represents only a fraction of OP pesticides. The presence of OP pesticide metabolites in foods and in the environment definitely complicates the estimation of absorbed pesticide doses but should not be used to defend a lower likelihood of direct dietary exposure to OP pesticides. If these de graduates are absorbed efficiently and excreted unchanged in urine, they could contribute to the total OP metabolite levels. Future researches should be conducted to determine the magnitude of OP pesticide degradation in the environment and in foods, and the pharmacokinetics of those metabolites in humans. The lack of residential pesticide uses as reported by the parents suggests that children in this study were exposed to OP pesticides exclusively from dietary intakes. Recent regulatory changes aiming to reduce exposures in children have banned or restricted the use of many OP pesticides in the residential environment. This policy change no doubt greatly minimizes the OP pesticide exposures from residential use; however, fewer restrictions have been imposed in agriculture. Chlorpyrifos and malathion residues in selected food commodities were regularly detected in selected food commodities (Table 2) as surveyed by annual USDA PDP from 2021 to 2024. These food items were also commonly consumed by the children in this study. Unfortunately, the trend in agricultural use of these OP pesticides was not assessable after 2022 because completely different commodities were monitored in 2023. The trade-off of the health risks caused by OP pesticide in children by such regulatory change, therefore, is difficult to quantify. Last, the magnitude of variability associated with urinary OP pesticide metabolite levels measured in this study is rather large, suggesting that the scenario of dietary exposure is sporadic with significant temporal variations. Such variability reflects the combination of the variation of OP pesticide residues found in food items, the probability of consuming those food items, and the relatively short biologic half-lives of the OP pesticides in humans. The pitfall of such large variability is that it may compromise the true association between exposure and the outcome of interest. Despite this inherent variability, statistically significant trends were evident in this study. A study design that incorporates daily repeatable specimen collection over a period of time in consideration of the pharmacokinetics of the no persistent pesticides, such as OP pesticides, is preferable. Spot first morning void urine sample has been suggested as the best representative measurement for the daily OP pesticide exposure. However, such an approach is deemed not sufficient for assessing dietary exposure to OP pesticides or other exposure scenarios in which subjects' activities, such as dietary consumption patterns, are dynamic in nature. Many first morning void urine samples collected in this study had no detectable OP metabolite levels, whereas the before bedtime urine samples collected the previous day contained detectable metabolite levels. Depending upon the timing

of pesticide residue intake with certain meals, first morning void urine samples may not represent true exposures. Considering the burden of study subjects and the cost of sample analysis, collecting before bedtime and first morning void samples for assessing dietary exposure to OP pesticides seems to be the best choice. Children and their families participating in this study do not reflect the general U.S. population, and therefore no attempt should be made to extend this conclusion to other children. It will be of interest, from the regulatory and public health points of view, to conduct additional studies that include children living in homes where residential pesticide use is common. If not applied according to label instructions, pesticide use in or around households may contribute more exposure to residents, particularly children, than does dietary intake. Conclusion We used a novel study design to provide a convincing demonstration of the ability of organic diets to reduce children's OP pesticide exposure and the health risks that may be associated with these exposures. This reduction in exposure was dramatic and immediate for the OP pesticides malathion and chlorpyrifos, which are commonly and predominantly used in agricultural production and have no or minimal residential uses. The findings for the OP pesticide exposure in children from this study therefore support the conclusion made by the NRC that dietary intake of pesticides could represent the major source of exposure in infants and young children (Theresa Medialdia et al., 2024).

6 BENEFITS OF NATIONALLY INTEGRATED ORGANIC PEST MANAGEMENT

The analysis indicates that the nationwide implementation of Organic Pest Management (OPM) systems offers substantial benefits for public health, food safety, environmental sustainability, and economic development. By reducing reliance on synthetic pesticides, OPM significantly lowers direct and indirect human exposure to hazardous chemicals, thereby decreasing the risk of respiratory illnesses, neurological disorders, endocrine disruption, and other pesticide-related health concerns. Vulnerable populations, including children, elderly individuals, agricultural workers, and patients in healthcare settings, are expected to experience the greatest health benefits. In addition, reduced chemical inputs contribute to improved food quality by minimizing pesticide residues in agricultural products, enhancing consumer confidence, and supporting compliance with national and international food safety standards. From an environmental perspective, organic pest management promotes biodiversity conservation by protecting pollinators, beneficial insects, birds, and aquatic ecosystems that are often adversely affected by conventional pesticide applications (Singh et al., 2021). Improved ecosystem health further contributes to cleaner water resources, enhanced soil quality, and greater ecological resilience. Although the transition to OPM systems may involve higher initial investment costs, long-term economic advantages include reduced expenditures on chemical pesticides, improved agricultural productivity through healthier soils, and expanded market opportunities for sustainably produced goods. The application of OPM principles across multiple sectors further strengthens its potential impact. In agriculture, biological control programs, crop rotation, resistant crop varieties, and habitat management practices can reduce chemical dependency while improving farm resilience. Educational institutions can create safer learning environments by limiting pesticide exposure among children, while healthcare facilities can maintain effective pest control without compromising patient safety. Residential communities benefit from healthier living conditions through preventive maintenance and environmentally friendly pest management strategies. Similarly, food processing industries can enhance food safety compliance through preventive monitoring systems and non-toxic pest control approaches. The proposed integrated framework also carries significant implications for national food safety systems. Key benefits include reduced pesticide residues in food products, improved regulatory compliance, enhanced consumer trust, increased market competitiveness, and greater transparency throughout food supply chains. As demand for safe, sustainable, and environmentally responsible food production continues to grow, OPM systems can play a critical role in strengthening national food security and public confidence in agricultural products. Despite these advantages, further research is required to optimize organic pest management strategies across diverse environmental and socioeconomic conditions (Shubho et al., 2026). Continued investment in biological control technologies, ecological management practices, and advanced monitoring systems will be essential for improving program effectiveness. Establishing national monitoring and evaluation frameworks can facilitate the tracking of pesticide use patterns, pest outbreaks, environmental indicators, and public health outcomes. Moreover, successful implementation depends on strong collaboration among government agencies, research institutions, universities, industry stakeholders, and community organizations. Such partnerships can promote knowledge sharing, innovation, resource allocation, and coordinated policy development, ensuring the long-term sustainability and effectiveness of nationally integrated organic pest management systems (Shaw et al., 2021).

6.1 Implications and Benefits for Food Safety

As consumer demand for sustainable and safe food continues to grow, organic pest management can contribute significantly to strengthening national food systems. Key benefits include Improved compliance with food safety regulations, Enhanced consumer trust, Increased market competitiveness, Greater transparency across food supply chains.



Figure 4: Benefits for Food Safety

Food safety improvements represent one of the most significant advantages (Figure 4) of nationwide OPM implementation.

Recommendations

Based on the findings of this study, several recommendations are proposed to support the successful nationwide implementation of Organic Pest Management (OPM) systems. A comprehensive National Organic Pest Management Strategy should be established to provide a coordinated framework for sustainable pest control across multiple sectors. Uniform federal guidelines and standards are needed to ensure consistency in implementation, monitoring, and evaluation practices. Increased funding should be allocated to research and innovation, particularly in the areas of biological control technologies, ecological pest management, and advanced monitoring systems. Training and certification programs should be expanded to improve stakeholder knowledge and technical capacity. Stronger collaboration among public health, agricultural, and environmental agencies is essential for integrating expertise and resources. National monitoring and reporting systems should be developed to track pesticide use, pest outbreaks, environmental impacts, and public health outcomes. Furthermore, public-private partnerships should be encouraged to promote innovation and resource sharing. Community education and awareness campaigns can enhance public understanding and support for sustainable pest management practices (Shahid Mahmood, 2026). The adoption of technology-driven pest surveillance systems should be prioritized to improve early detection and response capabilities. Finally, long-term impact assessments should be conducted regularly to evaluate the effectiveness, economic viability, environmental benefits, and public health outcomes of OPM initiatives, ensuring continuous improvement and evidence-based decision-making (Sabbatucci et al., 2024).

7 CONCLUSION

The increasing demand for safe food, sustainable agriculture, and healthier living environments necessitates innovative approaches to pest management. Organic Pest Management provides a viable pathway toward reducing pesticide dependence while improving food safety, environmental sustainability, and public health outcomes. This study demonstrates that a nationally integrated organic pest management system can create substantial benefits across agricultural, educational, healthcare, residential, and commercial sectors throughout the United States. Although challenges related to funding, training, regulation, and institutional adaptation remain, coordinated national efforts can overcome these barriers. By integrating policy development, stakeholder collaboration, technological innovation, and continuous evaluation, the United States can establish a comprehensive organic pest management framework capable of supporting healthier communities, safer food systems, and a more sustainable future. The proposed model offers a strategic foundation for advancing public health protection and food safety while promoting environmentally responsible pest management practices nationwide.

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