American Journal of Environment and Climate (AJEC)

ISSN: 2832-403X (ONLINE)

VOLUME 5 ISSUE 1 (2026)

PUBLISHED BY
E-PALLI PUBLISHERS, DELAWARE, USA

American Journal of Environment and Climate (AJEC)

Volume 5 Issue 1, Year 2026
ISSN: 2832-403X (Online)
DOI: https://doi.org/10.54536/ajec.v5i1.6273
https://journals.e-palli.com/home/index.php/ajec

Organic Pest Control and Its Effects on Child Health in Agricultural Zones

Md. Omar Ali[1*]

Article Information

Received: October 30, 2025

Accepted: December 01, 2025

Published: January 29, 2026

Keywords

Child Health, Environment, Organic Pest Control, Pesticide Exposure, Sustainable Agriculture

ABSTRACT

This study aimed to evaluate the impact of organic pest control on child health in agricultural areas and compares environmental and physiological parameters between organic and conventional farming practices. A cross-sectional household survey employing structured questionnaires, environmental sampling, and child health assessments was conducted among 90 organic and 90 conventional agricultural households (N = 180). The pesticide residues in samples of soil, water, and air were analyzed; blood and urine samples obtained from children were examined to determine cholinesterase activity. The pesticide residues were significantly lower in organic ($p < 0.05$) and cholinesterase activity was higher, urinary metabolites were lower and the nutritional parameters of children were better in comparison to the conventional zones. Pest control type, parental education and family income were found to be important factors influencing the health of their children performing a regression analysis. It highlights the necessity for increased adoption of organic pest control by educating farmers, providing them policy incentives and constancy monitoring the environment. These results highlight the potential role of organic agriculture in protecting against food insecurity and enhancing sustainability and long-term food safety.

INTRODUCTION

Agriculture remains the basis of global food security and rural livelihoods(Pawlak & Kołodziejczak, 2020). But conventional farming is overwhelmingly dependent on synthetic pesticides to fight pests and increase crop yield(Ali *et al.,* 2020). Though such chemical pesticides are responsible for increased yields, their large-scale and frequently unselective use has given rise to environmental and public health problems, especially in the developing countries with poor regulatory control and safety measures(Vasseghian *et al.,* 2022). Children residing in agricultural regions are one of the vulnerable populations that are in contact with pesticide residues either directly or indirectly (Kartin *et al.,* 2019). This has led to growing global concern on the long-term impact of chemical pest control on child health and a call for safer, sustainable alternatives including organic pest control(Ahmad *et al.,* 2024; Zhou *et al.,* 2025).

Organic or green pest control defines a more holistic practice in both the selection and application of pesticides with the goal of reducing reliance on synthetic chemical inputs, employing natural, biological, and cultural control tactics(Benbrook *et al.,* 2021). These methods are based on natural predators, botanical extracts, microbial pesticides, crop rotation and habitat manipulation(Deguine *et al.,* 2021). All of these methods are used not only to keep pests away from crops, but also to preserve the natural order and cause as little harm as possible to humans, animals and beneficial insects(Swapan *et al.,* 2023). Organic pest management systems have considerable potential in decreasing reliance on chemical pesticides, conserving biodiversity and increasing soil and water quality (Rani *et al.,* 2023). Equally importantly, natural methods are now being increasingly seen to be a solution for reducing the negative health effects of pesticide exposure on children and farm workers(Shekhar *et al.,* 2024; Swapan *et al.,* 2023).

Children are particularly vulnerable to pesticide exposure because their biological systems are still developing, they play in contaminated soil, and they consume more food, water and air relative to their body weight when compared with adults(Buralli *et al.,* 2025). Several epidemiological studies have associated excessive exposure to synthetic pesticides with such adverse effects in children as neurodevelopmental disorders, respiratory disease, endocrine dysfunction and some cancers (Bouchard *et al.,* 2010; Liu & Schelar, 2012; Shekhar *et al.,* 2024). Exposure is possible not only during field work by direct contact, but also through intake of pesticide-contaminated food and drink, as well as drift from other local fields (Dereumeaux *et al.,* 2020). In the many rural regions of low and middle-income countries; inadequate information, poor safety behavior by caregivers and lack of protective devices compound these risks(Quintero Santofimio *et al.,* 2024).

Organic pest control measures represent a great potential to alleviate these problems(Shang *et al.,* 2024). Organic pest control replaces chemical pesticides with prevention, herbivore natural enemies, and intercropping preventing non-toxic or less poisonous chemicals(Baker *et al.,* 2020). Studies have indicated that communities practicing organic farming or integrated pest management (IPM) display less pesticide residues in food and water, which leads to better health among local population especially children (Benbrook *et al.,* 2021; Mie *et al.,* 2017). Furthermore,

[1] Omar Group, Dhaka, Bangladesh
[*] Corresponding author's e-mail: mdomar177@gmail.com

sustainable agriculture is promoted by organic systems in the long term due to increased soil fertility, biodiversity and reduction of greenhouse gas emissions(Gamage *et al.,* 2023).

Although organic pest control has been shown to have positive effects, its adoption is still limited in many areas because of insufficient technical information and availability of organic inputs, perceived lower productivity, and weak policy support(Baker *et al.,* 2020; Bottazzi *et al.,* 2023). It is important to evaluate the health effects of these alternative practices for furthering their acceptance and mainstreaming in agricultural policy. Thus, assessing the impacts of organic pest management on child health may provide useful evidence for designing future agricultural and public health policies.

LITERATURE REVIEW

Because of public concern for pesticide-induced health risks, especially on sensitive groups like children, in recent years there has been a growing interest regarding the use of organic method in pest control(Ahmad *et al.,* 2024). Organic Pest Management (OPM) is a non-chemical way of pest control based on sustainability, environmental safety and health care(Benbrook *et al.,* 2021). The paper considers the impacts of organic pest control on child health, focusing specifically on direct and indirect hazards associated with pesticide exposure and the potential for organic pest management to disrupt that hazard.

Pesticide Exposure and Its Impact on Child Health

Children residing in agricultural areas are particularly susceptible to pesticide exposure because their body systems are still developing, they engage in certain behaviors that increase their risk of contact with pesticides and they possess a high relative intake of food, water or air(Roberts *et al.,* 2012). Children are thought to be at higher risk than adults for health effects resulting from exposure to pesticides (Eskenazi *et al.,* 1999), with amplified chemical absorption and the susceptibility of developing organ systems associated with childhood (Liu & Schelar, 2012). Pesticides may be absorbed via the skin, inhaled or ingested with contaminated food and water, resulting in both chronic and acute health effects(Shekhar *et al.,* 2024). Several research reports have found an association between exposure to pesticides and developmental delays, cognitive disabilities, as well as a higher likelihood of neurobehavioral disorders e.g., Attention Deficit Hyperactivity Disorder or autism (Bouchard *et al.,* 2010; Engel *et al.,* 2011).

Epidemiological analysis has also documented that pesticide exposure may be related to respiratory issues, endocrine disruption and carcinogenesis(Ahmad *et al.,* 2024). A research by Alavanja (2004) reported an association between pesticide exposure and childhood leukemia. It has also been shown that children living near agricultural fields or participating in farm tasking without proper PPE, have an increased risk of negative health effects due to pesticides (Buralli *et al.,* 2025; López-Gálvez *et al.,* 2019). These dangers are heightened in regions with weak pesticide regulation and enforcement of safety measures.

Organic Pest Control as a Safer Alternative

Organic pest management, using tools such as: crop rotation, biological control (crop competition), natural pesticides and habitat manipulation are considered effective substitute to synthetic pesticide applications(Ayilara *et al.,* 2023). Organic pest control focuses on minimizing chemical inputs and tries to foster biodiversity while reducing threats to the environment and human health(Ahmad *et al.,* 2024). Organic farming systems have been shown in studies to typically lead to less pesticides being found in food products, water and the air, which could lead to fewer incidents of exposure/ ingestion of toxic substances (Mie *et al.,* 2017).

Biological control agents such as Trichoderma, Bacillus thuringiensis, and parasitoid wasps are widely used in organic pest control to suppress pest numbers without using synthetic pesticides(Baker *et al.,* 2020). These agents are pest-specific, and as a result their application decreases the likelihood of toxicity to non-target organisms such as humans (Cech *et al.,* 2023). Furthermore, organic production improves soil health by promoting composting, minimizing tillage, and incorporating cover crops, these practices combined make agricultural ecosystems more robust through pests outbreak(Xing *et al.,* 2025).Researches indicate that regions where organic farming is practiced have lower residues of pesticide in food, minimizing exposure to harmful toxins(Benbrook *et al.,* 2021). Duru *et al.* (2015) reported that organic farm products contained lower levels of pesticide residues than conventional ones. In addition, by decreasing pesticide runoff into the environment, organic farming principles reduce the risk of water source contamination which is particularly vital in agriculture areas utilizing their irrigation waters for drinking purposes (Sharma *et al.,* 2025).

Health Benefits of Organic Pest Control

Studies examining the health effects of organic pest control report that a reduced dependence on chemical pesticides is associated with better health, especially in children(Roberts *et al.,* 2012). Benbrook *et al.* (2021) found organic farming systems showed a reduced occurrence for pesticide-related diseases among farm workers and surrounding population groups. Organic systems have also been associated with better quality of the diet as organic foods typically provide lower number of pesticide residues, less heavy metals and a greater content of health-promoting components, such as antioxidants (Smith-Spangler *et al.,* 2012).

For child health, a number of studies found children living in farming areas with organic raising had lower concentrations of pesticide metabolites in urine(Bliznashka *et al.,* 2022; Lu *et al.,* 2006). Lu *et al.* (2006) observed that when children were switched for a specific period of time, they showed a significantly decrease in the levels of pesticide residues measure in the urine compared to the controls group whom continued with their conventional diet. This is an encouraging development with regard to children's long-term health in light of the recent link between reduced exposure to pesticides and consumption of organic food which has been discovered(Roberts *et al.,* 2012). In addition, the introduction of organic pest control in farming areas might bring indirect health effects for children through environmental improvements. The regimen of pesticides decreased, which contributes to the reduction of water and soil contamination that can reduce risk to child health in relation to waterborne diseases and soil degradation (Pathak *et al.,* 2022).

Barriers and Challenges to Organic Pest Control Adoption

Although there are numerous health and environmental advantages to organic pest management, it's up-take is currently restrained by a number of obstacles(Ahmad *et al.,* 2024). Economic barriers to the adoption of organic farming including higher transition costs, lack of input supplies and lower yields have also been identified as main limitations for farmers switching from conventional to organic production (Dadheech & Kaur, 2025). Moreover, limited access to organic certification schemes, lack of technical experience and poor policy support represent a major obstacle for the expansion of organic pest control (Baldin, 2022). Nevertheless, literature has claimed that long term advantages of organic agriculture in terms such as reduced health expenditure, better environment or increased market demands for organic products can compensate for the disadvantages over the medium term (Forman *et al.,* 2012; Panday *et al.,* 2024). Education, promotional activities by government and technical support are critical to its overcoming these barriers and bring about diffusion of organic pest management technology.

Research Gap

While a large number of evidence has reported the negative, pesticide related health effects on people, particularly in children living in agricultural regions there is still limited research that links measures of organic pest control to improved child health outcomes themselves. The vast majority of the current literature is on pesticide toxicity, exposure pathways, or general environmental benefits of organic agriculture and few consider what aspects of organic pest management practices may affect child health in a community-level study. Second, the literature in this area is largely based on developed countries and information from developing ones, where children might be more exposed due to poor safety practices and insufficient law enforcement, is limited. Only limited research exists which accounts for an overall exam of agricultural practices along with environmental exposure and health outcomes in the context of a single analytical framework. Further, more is needed on the life-style and social economic determinants of organic pest control application modes and how these relate to health outcomes. This gap emphasizes the importance of interdisciplinary research that considers environmental and agronomic dimensions of organic pest control but also its immediate and downstream impacts on child health when delivered in situ in agricultural settings.

Research Questions

a) What is the effect of organic pesticide use on general health and wellness in children residing at agricultural areas?
b) What are the most noticeable pesticide-exposure related differences in children living in organic pest control practices areas and conventional chemical pesticide using areas?
c) What particular organic approaches to pest control work best at reducing environmental hazards and children's health risks?
d) What is the influence of some socio-economic and behavioral aspect on organic pest control strategies in farming?
e) What are the short- and long-term health effects in children between organic and conventional farming environments?

Research Objectives

a) To evaluate the effects on health and wellbeing of children living in farms, of organic pest control practices.
b) To assess pesticide exposure levels of children in organic and conventional farming areas.
c) To pinpoint the highest-performing organic pest controls in terms of being least harmful to people and the environment.
d) To investigate a possible link between environmental pollution (soil, water and air quality) and children's health conditions in organic-based pest control programs.
e) To determine social and economic characteristics as well as farmers' behavior affecting adoption of organic methods for pest control by farmers.

MATERIALS AND METHODS

Study Area

The research was carried out within productive agricultural areas in Dhaka and Khulna Division, Bangladesh with intensive crop agriculture and contrasts in pest management. Two kinds of farming systems were taken into consideration, one in organic pest control areas, where information on natural and biological control is transferred to farmers and another in conventional pesticide-based farmers. The study area was selected due to its agricultural significance, variety of pest control methods used, and presence of rural populations with children exposed regularly to farming environments.

Study Design

Comparative cross-sectional study was used to evaluate the impact of organic and conventional pest control practices on child health. The research combined environmental sampling, household questionnaires and health measurements to achieve qualitative and quantitative knowledge. Six villages (three from practices organic pest control, and three applying chemical pesticides) were purposively selected. In each village, households that had 5–12-year-old children were randomly chosen from the list of households in the village.

Sample Size and Selection

A sample size of 180 households was selected for the study, 90 of organic and another 90 of conventional farming system. One child and one parent (preferably the mother) were chosen from each home. Sample size was calculated taking into consideration population size, anticipated difference in pesticide exposure and the level of confidence. Selection criteria for inclusion stipulated that children had to reside in the specific agricultural area for at least 1 year, in order to obtain similar exposure patterns.

Data Collection Methods

Household Survey

A structured questionnaire was designed to obtain socio-economic variables, farming activity production methods, knowledge on pest control practices, deltamethrin use by households, food habits and an assessment of the level of awareness concerning health risks caused by pesticides. The questionnaires were completed through face-to-face interviews of parents or legal guardians. The acquired data gave indications on behavior and environmental conditions related to exposure.

Environmental Sampling

Environmental matrices were sampled also to measure pesticide residues amounts in soil, water and air of the two types of farming systems. Soil samples were collected with a stainless-steel auger from the 0–15 cm surface layer of cultivated fields and adjacent settlements. Water samples were collected in sterile glass bottles from irrigation canals, ponds and domestic drinking water sources. Samples of air were collected with portable air samplers located at child height (about 1.2 m) in yard and farming field regions during aerial spray operations. All samples were sent under refrigerated conditions to the laboratory, where they were screened for the presence of organophosphates, carbamates and pyrethroids using gas chromatography–mass spectrometry (GC–MS) according to EPA guidelines(Saha *et al.,* 2017).

Health Assessment of Children

Children's health was very thoroughly assessed both clinically and biologically. Anthropometric measurements (height, weight and BMI) were used in this clinical phase to evaluate the nutritional status of each child who also was subjected to a physical examination aiming at detecting signs and symptoms associated with agrochemical exposure such as skin irritation, respiratory problems and neurological signs. Blood and urine samples were taken to conduct biochemical analyses (in the laboratory phase) with particular regard to cholinesterase activity in blood plasma as a measure of exposure to organophosphate and carbamate pesticides, whereas urinary pesticide metabolites e.g. dialkyl phosphate compounds was determined by high-performance liquid chromatography (Huen *et al.,* 2012). For the purpose of further investigating subclinical health effects, liver enzyme activity (ALT, AST) and markers for oxidative stress were additionally determined.

Observation and Key Informant Interviews

Field observations were conducted to observe pest control methods, pesticide storage and handling behavior, and the use of protective measures (e.g., masks, gloves). Key informant interviews were conducted with agricultural officers, local health workers and community leaders to qualitatively explore knowledge, training and policy implementation regarding pest control measures.

Data Analysis

Quantitative analysis was performed by Microsoft Excel, SPSS (25) and R software. Demographic and exposure-related variables were summarized using descriptive statistics (mean, standard deviation, frequency). Comparisons between organic and conventional zones were made with t-tests for continuous data and chi-square tests for categorical data. Multiple regression models were used to test for the relationship between pest control type and children health outcomes, after controlling for age and other confounders (diet, socioeconomic status). Semi-structured interview and observational qualitative data were analyzed using thematic content analysis to elicit recurring themes and contextual understandings of pest management practices and community perspectives.

RESULTS AND DISCUSSION

Pest Control Practices Used by Farmers

Table 1 shows considerable differences between the two groups, with high chi-square (χ^2) and statistically significant p-values ($p < 0.001$). Neem and other botanicals were most commonly used in organic farms (83.3%) not the same as those of conventional farm (12.2%). Likewise, 65.6% organic farmers and only 8.9% conventional farmers used biological control agents. Conversely, all conventional farmers used chemical pesticides (100%), while only a small percentage of organic farms did so (14.4%). Mechanical traps were also utilized more on organic farms (47.8%), than on conventional farms (15.6%).

Environmental Pesticide Residues

The outcomes provide statistical evidence that there is an overall lower extent of pesticide contamination on organic compared to conventional fields (Table 2). The concentration of organophosphates in organic farm

Table 1: Comparison of pest control practices between organic and conventional farms.

Method used	Organic (%)	Conventional (%)	χ^2-value	p-value
Neem/plant extracts	83.3	12.2	94.11	<0.001*
Biological control (*Bacillus thuringiensis, Trichoderma*)	65.6	8.9	78.73	<0.001*
Chemical pesticides	14.4	100	162.52	<0.001*
Mechanical traps	47.8	15.6	22.38	<0.001*

Diatomaceous Earth (food grade), Borax, Peppermint Leaf Powder, Mehogony Tree Fruit, Leaf

Table 2: Mean concentrations of pesticide residues in environmental samples.

Sample type	Pesticide type	Organic	Conventional	t-value	p-value
Soil(mg/kg)	Organophosphates	0.032 ± 0.009	0.274 ± 0.056	36.21	<0.001*
Water(mg/L)	Organophosphates	0.018 ± 0.006	0.145 ± 0.028	35.44	<0.001*
Air(μg/m³)	Pyrethroids	0.46 ± 0.12	3.37 ± 0.89	28.67	<0.001*

soils was 0.032 ± 0.009 mg/kg, which is much lower than that found in conventional soils 0.274 ± 0.056 mg/kg. Moreover, organophosphates residues were 0.018 ± 0.006 mg/L compared to 0.145 ± 0.028 mg/L in water from organic as compared to conventional areas similarly. Air samples also showed significant differences with pyrethroids levels of 0.46 ± 0.12 μg/m³ in organics and only 3.37 ± 0.89 μg/m³ in conventional lands.

Impact on Greenhouse Gas Emissions

It is evident that organic farming practices have significantly lower GHG emissions levels based on the various sources (Table 3). There was a 57.1% reduction in pesticide production and a 28.9% reduction in field applications, whereas energy use registered a 20.8% drop. In sub-total, total GHG emitted while using organic pest control was 35.9%, which was lower than under conventional systems.

Table 3: Greenhouse gas emissions by pest control system.

Source	Conventional (kg CO_2-eq/ha)	Organic (kg CO_2-eq/ha)	Reduction (%)
Pesticide production	210	90	57.1
Field application	380	270	28.9
Energy use	120	95	20.8
Total	710	455	35.9

Children's Anthropometric Indicators

The average of the height for children in organic sectors was 120.8 ± 7.3 cm, which was higher than that of 118.6 ± 6.9 cm from conventional sectors (Table 4). Likewise, the mean body weight 23.4 ± 3.8 kg in organic zones of children and in conventional it was 21.6 ± 4.1 kg. The BMIs showed a corresponding pattern with the highest significance in those organic areas (16.1 ± 1.4 kg/m²) and the lowest in those conventional (15.2 ± 1.5 kg/m²).

Table 4: Anthropometric status of children in study areas.

Indicator	Organic	Conventional	t-value	p-value
Height (cm)	120.8 ± 7.3	118.6 ± 6.9	2.08	0.039*
Weight (kg)	23.4 ± 3.8	21.6 ± 4.1	2.93	0.004*
BMI (kg/m²)	16.1 ± 1.4	15.2 ± 1.5	3.94	<0.001*

Common Health Symptoms Reported

Skin irritation was experienced by 28.9% of conventional-area children and 7.8% in organic zones, and headaches or dizziness were reported by 33.3% of conventional-area and 9.0% of organic area (Table 5). Respiratory symptoms, likewise were more common among children in conventional farming regions (25.6%) compared to the organic region (6.7%). Similar was also the case for eye irritation; it was prevalent in 22.2% compared to only 4.5%of the cases in conventional and organic areas, respectively.

Blood Cholinesterase Activity

The households using organic pest control had significantly higher average blood cholinesterase activity (8643 ± 1210) compared to those using conventional pest management methods (6985 ± 1438) (Figure 1).

Urinary Pesticide Metabolites

Children from organic zones had considerably lower concentrations of metabolites than those living in conventional areas (Table 6). Mean DMP concentrations

Table 5: Prevalence of health symptoms among children.

Symptom	Organic (%)	Conventional (%)	χ^2-value	p-value
Skin irritation	7.8	28.9	12.61	<0.001*
Headache/dizziness	9.0	33.3	17.81	<0.001*
Respiratory difficulty	6.7	25.6	13.94	<0.001*
Eye irritation	4.5	22.2	14.36	<0.001*

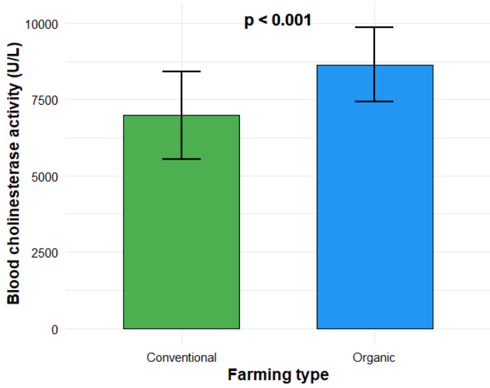

Figure 1: Mean blood cholinesterase activity (U/L).

Table 6: Urinary DAP metabolite concentration (μg/L).

Metabolite	Organic	Conventional	t-value	p-value
Dimethyl phosphate (DMP)	9.4 ± 3.1	26.7 ± 6.8	23.47	<0.001*
Diethyl phosphate (DEP)	8.1 ± 2.9	21.3 ± 5.9	19.84	<0.001*
Total DAPs	17.5 ± 4.9	48.0 ± 10.6	25.73	<0.001*

were 9.4 ± 3.1 μg/L in organic areas versus 26.7 ± 6.8 μg/L in conventional areas, whereas DEP levels were 8.1 ± 2.9 μg/L compared to 21.3 ± 5.9 μg/L; total and DAPs found the same difference pattern with a concentration of total (17.5±4.9 μg/L) and DAPs (48.0±10.6 μg/L).

Liver Enzyme Activity

The average ALT and AST levels of children from conventional areas were higher when compared to those in organic zones with means of 36.5 ± 10.1 U/L for ALT and 41.8 ± 11.3 U/L for AST in conventional areas,

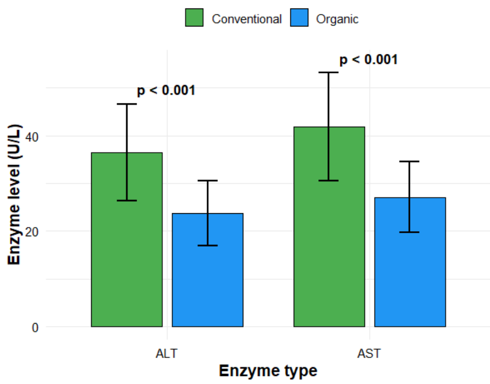

Figure 2: Serum enzyme activities (U/L).

whereas 23.7 ± 6.8 U/L for ALT and 27.1 ± 7.4U/L for AST in organic areas (Figure 2).

Oxidative Stress Biomarkers

The average MDA was significantly higher in conventional (4.91 ± 1.14 nmol/mL) compared to the organic group (2.76 ± 0.68 nmol/mL). In contrast, the TAC level was significantly increased in organic group (1.32 ± 0.25 mmol/L) compared to conventional group (1.05 ± 0.21 mmol/L) (Figure 3).

Awareness and Safety Practices

Awareness about toxicity of pesticides was significantly higher among organic farmers (76.7%) in comparison with

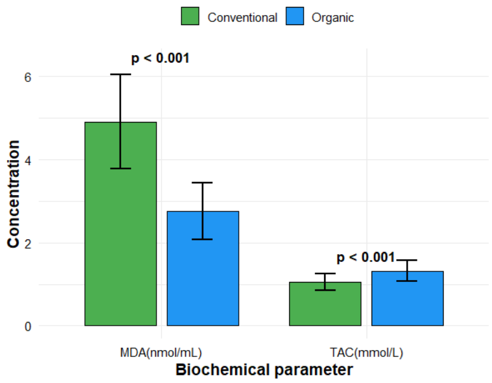

Figure 3: Oxidative stress biomarkers in children.

Table 7: Farmers' awareness and safety practices related to pest management.

Parameter	Organic (%)	Conventional (%)	χ^2-value	p-value
Knowledge of pesticide toxicity	76.7	41.1	21.38	<0.001*
Use of protective equipment	65.5	23.3	28.75	<0.001*
Proper disposal of pesticide containers	70.0	19.0	43.92	<0.001*

the conventional ones (41.1%) (Table 7). The reported wearing of protective equipment was correspondingly markedly higher in organic farmers (65.5%) than their non-organic counterparts (23.3%). In addition, disposal of pesticide containers was correctly done for 70.0% of organic farmers and 19.0% conventional farmers.

Determinants of Child Health

The pest management type was positively associated ($\beta = +0.312$, $p < 0.001$) and children from organic pest control households have significantly healthier indicators compared to those from conventional farming types (Table 8). Household income ($\beta = +0839$, $p = 0.008$) and parental education ($\beta = +0.143$, $p=0.022$), were additional favorable predictors, thus implying socioeconomic as well as educational background to be a beneficial influence on child well-being. In contrast, a moderate negative impact of environmental pesticide residue levels on child health was observed ($\beta = -0.275$, $p < 0.001$), highlighting the potential harmful effects of chemical exposure in conventional agricultural settings.

Table 8: Multivariate linear regression for predictors of child health (dependent variable: composite health index).

Predictor	β Coefficient	SE	t-value	p-value
Pest management type (organic = 1)	+0.312	0.054	5.78	<0.001*
Household income	+0.218	0.081	2.69	0.008*
Parental education	+0.143	0.062	2.31	0.022*
Environmental residue level	–0.275	0.066	4.17	<0.001*

Perceptions of Health and Environmental Safety

A higher percentage of organic farmers believed that their children get ill less often (78.9%) than conventional producers (46.7%) (Table 9). Likewise, 84.4% of the organic growers felt that the air and water around their farms were safe, compared with only 33.3% of conventional farmers. In addition, 91.1% of the organic farmers perceived the organic system as being safer for their family, a percentage much higher than conventional ones (40.0%).

Table 9: Parental perception of health and environmental conditions.

Perception statement	Organic (%) agree	Conventional (%) agree	χ^2-value	p-value
Our children fall sick less frequently	78.9	46.7	18.92	<0.001*
The air and water around farms are safe	84.4	33.3	42.16	<0.001*
Organic methods are safer for families	91.1	40.0	58.21	<0.001*

Economic Performance and Cost Efficiency

The findings stated that, despite a minor rise in production costs by 11.9%, organic farming attained markedly higher financial results (Table 10). In particular, the gross revenues of organic systems exceeded conventional farms by 30.3%. As a result, net profit organic farms exceeded

Table 10: Economic performance comparison of conventional and organic farming.

Parameter	Conventional	Organic	Difference (%)	p-value
Production cost (USD/ha)	1180	1320	+11.9	0.021
Gross revenue (USD/ha)	1650	2150	+30.3	<0.001
Net profit (USD/ha)	470	830	+76.6	<0.001

76.6% compared to conventional systems.

Discussion

We evaluated the effect of organic pest control activities on child health in agricultural areas using environmental, biological and socioeconomic indicators. The results illustrated substantial disparities between organic and conventional crop areas in pesticide use, environmental burden, and child health related outcomes thus providing evidence that organic pest management promulgates both environmental and public health.The findings revealed that concentrations of pesticide residues in soil, water and air samples collected from organic farming regions were significantly lower than those obtained in conventional areas. Runs of similar patterns have been reported in India (Shukla *et al.,* 2006) and Nigeria(Mazlan *et al.,* 2017) which expressed that organic agricultural systems contribute immensely to the reduction accumulation levels for organophosphates and carbamates pesticides in agro-environments. These decreases can be explained by the implementation of botanical pesticides, biocontrol agents, and the integrated use of mechanical pest control which decrease chemical consumption (Baker *et al.,* 2020).
The documented decrease in our calculations of GHG emissions in organic pest control is in line with other publications stressing the ecological functions of organic agriculture. For example, Smith *et al.* (2015) reported that the sum of farm-level emissions is somewhere between 30 and 40% lower in organic than in traditional systems owing to less consumption of synthetic agrochemicals and fossil fuels. Similarly, Clark & Tilman (2017) argue that organic crop production systems systematically emit less CO2 equivalent per hectare than similar conventional systems because of reduced chemical usage and that such energy-saving operations are key to sustainable agriculture. The 57.1% reduction in the emissions due to pesticide manufacturing indicates the need for replacing the chemical-based mode of pest control by biological and mechanical systems. Furthermore, the slight decline in field application and energy use emission of 28.9% and 20.8%, respectively, reflect qualitatively similar shifts to less fossil fuel-intensive farming noted by Lynch *et al.* (2016). Taken together, these results demonstrate that organic pest control is not only beneficial for soil and ecosystem health but is a comparative measure in lowering agriculture's climate impact.

Children residing in organic farming areas are thus less frequently exposed to harmful residues of chemical pesticides through inhalation, dermal uptake or by ingestion of contaminated food and drinking water(Ahmad *et al.,* 2024).Measures of children's health also were consistent with these environmental results. The slightly higher values observed for anthropometric data (mean body weight and BMI) in children living in the organic zones than in conventional were also in agreement with overall better health situation among them and a better nutritional status. Research in similar agricultural settings (Kartin *et al.,* 2019; Sigudu *et al.,* 2025) has found lower exposure to pesticide residues associated with a lower prevalence of malnutrition and growth delay among rural children. This relationship could be due to lower biologic stress and less subclinical disease reflecting chronic pesticide toxicity.

Biochemical parametersin particular cholinesterase activity and urinary pesticide metabolitesalso differed significantly between cohorts. Children in the group regions with conventional farming had significantly reduced cholinesterase levels, reflecting greater exposure to organophosphates and carbamates, which reduce cholinesterase activity and disrupt normal nervous system function(El- Naggar *et al.,* 2009; Roberts *et al.,* 2012). This conclusion is consistent with the study of Sierra-Diaz *et al.* (2019) in Mexico and Dasgupta *et al.* (2007) in Vietnam where alterations of the same biochemistry were present in children from pesticide-intensive areas. In contrast, only one child from organic farming areas showed abnormal levels of cholinesterase activity, which indicate a reduced exposure to neurotoxic substances(Hashim *et al.,* 2015). Increased levels of markers of oxidative stress and liver enzymes activity (ALT and AST) observed in children from conventional areas suggest a potential hepatic stress or subclinical toxicity. Similar findings were observed by Zhang *et al.* (2021) and Baldi *et al.* (2014), which described elevation in liver enzymes among children and adults exposed over time to agricultural pesticides. The lack of these changes in the organic group is evidence for protection of children's health through organic pest management techniques.

Observations of environmental and behavioral were also informative in a contextual way. Organic zone farmers were also found to be more knowledgeable of safe pest control measures and possessed more improved handling practices than conventional area for other participants. This observation is consistent with presence of Zhou *et al.* (2025)who emphasize that training and awareness building programs are important to minimize pesticide exposure risks. Furthermore, use of non-chemical pest repellents (e.g., neem extracts, chili–garlic sprays and biological control agents) like the practices mentioned in the present study were not only unpretentious but also economical and hence organic pest management could be a preference to smallholder farmers in Bangladesh(Campos *et al.,* 2016).According to the regression analysis, child health was influenced significantly by environmental pesticide concentrations, parental education and type of farm management. These are similar to results for children in the study by Berger *et al.* (2018) in California, that showed strong association of children's health and neurodevelopmental outcomes with parental exposure as well as education status. The present findings underline the contribution of behavioral and contextual factors for child health in rural agricultural areas.

However, despite these positive results it is important to recognize that organic pest management systems are not entirely risk free. While some botanically-based biopesticides may still have health or environmental risks if deployed in high enough doses, for example, certain pyrethrins or copper compounds(Ayilara *et al.,* 2023). It has been mentioned in earlier works (Elzagheid, 2018), that even organic pest control should be influenced by adequate education and regulation to provide sustainability and safety measures. Therefore, continuous monitoring and education remain essential components of integrated pest and health management strategies.

The present findings show that while organic pest control involves a modest increase in production costs, significantly higher economic returns were realized, which has been found in previous research. For example, Crowder & Reganold (2015)found that organic farms generally achieve a 20–40% higher profit margin in comparison with conventional systems because of higher pricing and lower dependence on expensive agrochemicals. Similarly, a study by Delbridge *et al.* (2011) also found that organic production may require higher labor and managerial inputs at the outset, become more profitable over the long term through increased soil fertility and better market stability. The 76.6% increase in net profit in the present study corresponds to the findings of Seufert (2019), who conclude that organic products demand price premiums that more than compensate slightly lower yields and higher costs. Together, the results indicate that organic pest control is effective from the perspective of farm profitability and environmental sustainability. Thus, it is a feasible and economically sustainable option for the U.S. agricultural sector as an alternative to current intensive pest management technologies.

FINDINGS

i. Areas under organic farming had significantly lower pesticide residue levels in soils, water and air than areas cultivated conventionally.

ii. Mean BMI of children from organic agricultural areas is also higher and health status is better overall.

iii. The activity of blood cholinesterase was significantly higher in organic zone children, which suggests lower neurotoxic pesticide exposure.

iv. Children from organic areas had lower concentrations of urinary pesticide metabolites than children from regions with an implemented conventional farming.

v. Higher activity of liver enzymes (ALT and AST) and the oxidative stress markers in children from conventional spray practices for pesticide application was observed.

vi. Significant inverse associations were also observed between the children's health indicators (e.g., cholinesterase activity, BMI) and environmental pesticide levels.

vii. Pest management type, parental education, and family income were found to be the most important predictors for child health outcomes according to the regression analysis.

viii. Organic pest control measures were observed to be environmentally and economicallyfriendly for use by smallholder farmers.

ix. Areas that were more experienced in organic pest control reported lower incidences of pesticide illnesses, as well as better household welfare.

RECOMMENDATIONS

i. Develop a demand for organic pest control measures through government programs such as incentives, subsidies and certifications.

ii. To ensure public and child health, regular monitoring of the pesticide residues in the agricultural areas should be conducted.

iii. Carry out the training and education at community level with farmers on appropriate and safe pesticide management and handling.

iv. Develop and enhance extension services and research linkages between the agricultural sector and health departments to support integrated pest and health management.

v. Formulate policy guidelines and enforcement tools to regulate the excessive use of pesticides in a manner conducive for encouraging sustainable agriculture.

vi. Advocate for large-scale health monitoring of children's health in areas silenced by exposure and health.

vii. Increase market entry and prices for organic products in order to make production economically viable.

LIMITATIONS

i. The design was cross-sectional so it was not possible to determine direct causal links between exposure and health.

ii. The sample size was sufficient but limited to selected areas, it might not be applicable to all the agricultural zones.

iii. Sampling covering only one season was performed, and seasonal variation in pesticide use may not have been accounted for.

iv. We only measured a few biochemical markers; additional biomarkers might better illuminate exposure pathways.

v. There are possible cultural and household behavior differences that could have affected exposure and health.

CONCLUSION

Organic pest control measures are an effective tool to enhance environment status and child health in agricultural areas concluded in this study. Comparing organic and conventional farming regions, the results show that organic systems significantly reduce pesticide residues in soil, water and air allowing children to be exposed to lower levels of these chemicals. Thus, children from organic areas showed better biochemical, nutritional and general profiles of health than those from a conventional area. But the findings also underscore the importance of ongoing policy support, farmer training and awareness programs to achieve more widely adoption and correct use of organic pest control methods. Further studies with long-term follow-up on children will be needed in order to investigate chronic exposure and child development. Finally, alternative, more profitable bio-pesticides from locally available resources should also be tested to strengthen the sustainability of developing agriculture.

REFERENCES

Ahmad, M. F., Ahmad, F. A., Alsayegh, A. A., Zeyaullah, Md., AlShahrani, A. M., Muzammil, K., Saati, A. A., Wahab, S., Elbendary, E. Y., Kambal, N., Abdelrahman, M. H., & Hussain, S. (2024). Pesticides impacts on human health and the environment with their mechanisms of action and possible countermeasures. *Heliyon, 10*(7), e29128. https://doi.org/10.1016/j.heliyon.2024.e29128

Alavanja, M. C. R. (2004). Pesticides and Lung Cancer Risk in the Agricultural Health Study Cohort. *American Journal of Epidemiology, 160*(9), 876–885. https://doi.org/10.1093/aje/kwh290

Ali, Md. P., Kabir, M. Md. M., Haque, S. S., Qin, X., Nasrin, S., Landis, D., Holmquist, B., & Ahmed, N. (2020). Farmer's behavior in pesticide use: Insights study from smallholder and intensive agricultural farms in Bangladesh. *Science of The Total Environment, 747*, 141160. https://doi.org/10.1016/j.scitotenv.2020.141160

Ayilara, M. S., Adeleke, B. S., Akinola, S. A., Fayose, C. A., Adeyemi, U. T., Gbadegesin, L. A., Omole, R. K., Johnson, R. M., Uthman, Q. O., & Babalola, O. O. (2023). Biopesticides as a promising alternative to synthetic pesticides: A case for microbial pesticides, phytopesticides, and nanobiopesticides. *Frontiers in Microbiology, 14*, 1040901. https://doi.org/10.3389/fmicb.2023.1040901

Baker, B. P., Green, T. A., & Loker, A. J. (2020). Biological control and integrated pest management in organic and conventional systems. *Biological Control, 140*, 104095. https://doi.org/10.1016/j.biocontrol.2019.104095

Baldi, I., Robert, C., Piantoni, F., Tual, S., Bouvier, G., Lebailly, P., & Raherison, C. (2014). Agricultural exposure and asthma risk in the AGRICAN French cohort. *International Journal of Hygiene and Environmental Health, 217*(4–5), 435–442. https://doi.org/10.1016/j.ijheh.2013.08.006

Baldin, A. M. (2022). Organic Certification: Challenges and Benefits for Producers. *Revista Sistemática, 6*(2). https://doi.org/10.56238/rcsv6n2-005

Benbrook, C., Kegley, S., & Baker, B. (2021). Organic Farming Lessens Reliance on Pesticides and Promotes Public Health by Lowering Dietary Risks. *Agronomy, 11*(7), 1266. https://doi.org/10.3390/agronomy11071266

Berger, K., Gunier, R. B., Chevrier, J., Calafat, A. M., Ye, X., Eskenazi, B., & Harley, K. G. (2018). Associations of maternal exposure to triclosan, parabens, and other phenols with prenatal maternal and neonatal thyroid hormone levels. *Environmental Research, 165*, 379–386. https://doi.org/10.1016/j.envres.2018.05.005

Bliznashka, L., Roy, A., & Jaacks, L. M. (2022). Pesticide exposure and child growth in low- and middle-income countries: A systematic review. *Environmental Research, 215*, 114230. https://doi.org/10.1016/j.envres.2022.114230

Bottazzi, P., Seck, S. M., Niang, M., & Moser, S. (2023). Beyond motivations: A framework unraveling the systemic barriers to organic farming adoption in northern Senegal. *Journal of Rural Studies, 104*, 103158. https://doi.org/10.1016/j.jrurstud.2023.103158

Bouchard, M. F., Bellinger, D. C., Wright, R. O., & Weisskopf, M. G. (2010). Attention-Deficit/Hyperactivity Disorder and Urinary Metabolites of Organophosphate Pesticides. *Pediatrics, 125*(6), e1270–e1277. https://doi.org/10.1542/peds.2009-3058

Buralli, R., Nazli, S. N., Cordoba, L., Quiros-Alcala, L., Hyland, C., Muñoz-Quezada, M. T., Farías, P., & Handal, A. J. (2025). Children's environmental and occupational exposures to pesticides in low- and middle-income countries rural areas—An elephant in the room. *Science of The Total Environment, 990*, 179887. https://doi.org/10.1016/j.scitotenv.2025.179887

Campos, E. V. R., De Oliveira, J. L., Pascoli, M., De Lima, R., & Fraceto, L. F. (2016). Neem Oil and Crop Protection: From Now to the Future. *Frontiers in Plant Science, 7*. https://doi.org/10.3389/fpls.2016.01494

Cech, R., Zaller, J. G., Lyssimachou, A., Clausing, P., Hertoge, K., & Linhart, C. (2023). Pesticide drift mitigation measures appear to reduce contamination of non-agricultural areas, but hazards to humans and the environment remain. *Science of The Total Environment, 854*, 158814. https://doi.org/10.1016/j.scitotenv.2022.158814

Clark, M., & Tilman, D. (2017). Comparative analysis of environmental impacts of agricultural production systems, agricultural input efficiency, and food choice. *Environmental Research Letters, 12*(6), 064016. https://doi.org/10.1088/1748-9326/aa6cd5

Crowder, D. W., & Reganold, J. P. (2015). Financial competitiveness of organic agriculture on a global scale. *Proceedings of the National Academy of Sciences, 112*(24), 7611–7616. https://doi.org/10.1073/pnas.1423674112

Dadheech, V., & Kaur, M. (2025). Barriers Perceived by the Farmers in Adoption of Organic Farming. *Journal of Scientific Research and Reports, 31*(6), 1265–1277.

https://doi.org/10.9734/jsrr/2025/v31i63215

Dasgupta, S., Meisner, C., Wheeler, D., Xuyen, K., & Thi Lam, N. (2007). Pesticide poisoning of farm workers–implications of blood test results from Vietnam. *International Journal of Hygiene and Environmental Health, 210*(2), 121–132. https://doi.org/10.1016/j.ijheh.2006.08.006

Deguine, J.-P., Aubertot, J.-N., Flor, R. J., Lescourret, F., Wyckhuys, K. A. G., & Ratnadass, A. (2021). Integrated pest management: Good intentions, hard realities. A review. *Agronomy for Sustainable Development, 41*(3), 38. https://doi.org/10.1007/s13593-021-00689-w

Delbridge, T. A., Coulter, J. A., King, R. P., Sheaffer, C. C., & Wyse, D. L. (2011). Economic Performance of Long-Term Organic and Conventional Cropping Systems in Minnesota. *Agronomy Journal, 103*(5), 1372–1382. https://doi.org/10.2134/agronj2011.0371

Dereumeaux, C., Fillol, C., Quenel, P., & Denys, S. (2020). Pesticide exposures for residents living close to agricultural lands: A review. *Environment International, 134*, 105210. https://doi.org/10.1016/j.envint.2019.105210

Duru, M., Therond, O., & Fares, M. (2015). Designing agroecological transitions; A review. *Agronomy for Sustainable Development, 35*(4), 1237–1257. https://doi.org/10.1007/s13593-015-0318-x

El- Naggar, A. E.-R., Abdalla, M. S., El-Sebaey, A. S., & Badawy, S. M. (2009). Clinical findings and cholinesterase levels in children of organophosphates and carbamates poisoning. *European Journal of Pediatrics, 168*(8), 951–956. https://doi.org/10.1007/s00431-008-0866-z

Elzagheid, M. I. (2018). Organic Fertilizers and Natural Pest Control versus Chemical Fertilizers and Pesticides. *Current Investigations in Agriculture and Current Research, 6*(2). https://doi.org/10.32474/CIACR.2018.06.000232

Engel, S. M., Wetmur, J., Chen, J., Zhu, C., Barr, D. B., Canfield, R. L., & Wolff, M. S. (2011). Prenatal Exposure to Organophosphates, Paraoxonase 1, and Cognitive Development in Childhood. *Environmental Health Perspectives, 119*(8), 1182–1188. https://doi.org/10.1289/ehp.1003183

Eskenazi, B., Bradman, A., & Castorina, R. (1999). Exposures of children to organophosphate pesticides and their potential adverse health effects. *Environmental Health Perspectives, 107*(suppl 3), 409–419. https://doi.org/10.1289/ehp.99107s3409

Forman, J., Silverstein, J., Committee On Nutrition, Council On Environmental Health, Bhatia, J. J. S., Abrams, S. A., Corkins, M. R., De Ferranti, S. D., Golden, N. H., Silverstein, J., Paulson, J. A., Brock-Utne, A. C., Brumberg, H. L., Campbell, C. C., Lanphear, B. P., Osterhoudt, K. C., Sandel, M. T., Trasande, L., & Wright, R. O. (2012). Organic Foods: Health and Environmental Advantages and Disadvantages. *Pediatrics, 130*(5), e1406–e1415. https://doi.org/10.1542/peds.2012-2579

Gamage, A., Gangahagedara, R., Gamage, J., Jayasinghe, N., Kodikara, N., Suraweera, P., & Merah, O. (2023). Role of organic farming for achieving sustainability in agriculture. *Farming System, 1*(1), 100005. https://doi.org/10.1016/j.farsys.2023.100005

Hashim, Z., Lokman, N. N., & Abidin, K. N. Z. (2015). Blood Cholinesterase Level And Nuerotoxicity Among Primary School Children In Paddy Farming Areas, Selangor. I*SEE Conference Abstracts, 2015*(1), 613. https://doi.org/10.1289/isee.2015.2015-613

Huen, K., Bradman, A., Harley, K., Yousefi, P., Boyd Barr, D., Eskenazi, B., & Holland, N. (2012). Organophosphate pesticide levels in blood and urine of women and newborns living in an agricultural community. *Environmental Research, 117*, 8–16. https://doi.org/10.1016/j.envres.2012.05.005

Kartin, A., Subagio, H. W., Hadisaputro, S., Kartasurya, M. I., Suhartono, S., & Budiyono, B. (2019). Pesticide Exposure and Stunting among Children in Agricultural Areas. *The International Journal of Occupational and Environmental Medicine, 10*(1), 17–29. https://doi.org/10.15171/ijoem.2019.1428

Liu, J., & Schelar, E. (2012). Pesticide Exposure and Child Neurodevelopment: Summary and Implications. *Workplace Health & Safety, 60*(5), 235–242. https://doi.org/10.3928/21650799-20120426-73

López-Gálvez, N., Wagoner, R., Quirós-Alcalá, L., Ornelas Van Horne, Y., Furlong, M., Avila, E., & Beamer, P. (2019). Systematic Literature Review of the Take-Home Route of Pesticide Exposure via Biomonitoring and Environmental Monitoring. *International Journal of Environmental Research and Public Health, 16*(12), 2177. https://doi.org/10.3390/ijerph16122177

Lu, C., Toepel, K., Irish, R., Fenske, R. A., Barr, D. B., & Bravo, R. (2006). Organic Diets Significantly Lower Children's Dietary Exposure to Organophosphorus Pesticides. *Environmental Health Perspectives, 114*(2), 260–263. https://doi.org/10.1289/ehp.8418

Lynch, A. J., Myers, B. J. E., Chu, C., Eby, L. A., Falke, J. A., Kovach, R. P., Krabbenhoft, T. J., Kwak, T. J., Lyons, J., Paukert, C. P., & Whitney, J. E. (2016). Climate Change Effects on North American Inland Fish Populations and Assemblages. *Fisheries, 41*(7), 346–361. https://doi.org/10.1080/03632415.2016.1186016

Mazlan, N., Ahmed, M., Muharam, F. M., & Alam, Md. A. (2017). Status of persistent organic pesticide residues in water and food and their effects on environment and farmers: A comprehensive review in Nigeria. *Semina: Ciências Agrárias, 38*(4), 2221. https://doi.org/10.5433/1679-0359.2017v38n4p2221

Mie, A., Andersen, H. R., Gunnarsson, S., Kahl, J., Kesse-Guyot, E., Rembiałkowska, E., Quaglio, G., & Grandjean, P. (2017). Human health implications of organic food and organic agriculture: A comprehensive review. *Environmental Health, 16*(1), 111. https://doi.org/10.1186/s12940-017-0315-4

Panday, D., Bhusal, N., Das, S., & Ghalehgolabbehbahani,

A. (2024). Rooted in Nature: The Rise, Challenges, and Potential of Organic Farming and Fertilizers in Agroecosystems. *Sustainability, 16*(4), 1530. https://doi.org/10.3390/su16041530

Pathak, V. M., Verma, V. K., Rawat, B. S., Kaur, B., Babu, N., Sharma, A., Dewali, S., Yadav, M., Kumari, R., Singh, S., Mohapatra, A., Pandey, V., Rana, N., & Cunill, J. M. (2022). Current status of pesticide effects on environment, human health and it's eco-friendly management as bioremediation: A comprehensive review. *Frontiers in Microbiology, 13*, 962619. https://doi.org/10.3389/fmicb.2022.962619

Pawlak, K., & Kołodziejczak, M. (2020). The Role of Agriculture in Ensuring Food Security in Developing Countries: Considerations in the Context of the Problem of Sustainable Food Production. *Sustainability, 12(*13), 5488. https://doi.org/10.3390/su12135488

Quintero Santofimio, V., Amaral, A. F. S., & Feary, J. (2024). Occupational exposures in low- and middle-income countries: A scoping review. *PLOS Global Public Health, 4*(11), e0003888. https://doi.org/10.1371/journal.pgph.0003888

Rani, M., Kaushik, P., Bhayana, S., & Kapoor, S. (2023). Impact of organic farming on soil health and nutritional quality of crops. *Journal of the Saudi Society of Agricultural Sciences, 22*(8), 560–569. https://doi.org/10.1016/j.jssas.2023.07.002

Roberts, J. R., Karr, C. J., Paulson, J. A., Brock-Utne, A. C., Brumberg, H. L., Campbell, C. C., Lanphear, B. P., Osterhoudt, K. C., Sandel, M. T., Trasande, L., & Wright, R. O. (2012). Pesticide Exposure in Children. *Pediatrics, 130*(6), e1765–e1788. https://doi.org/10.1542/peds.2012-2758

Saha, J. K., Selladurai, R., Coumar, M. V., Dotaniya, M. L., Kundu, S., & Patra, A. K. (2017). Soil Pollution—An *Emerging Threat to Agriculture* (Vol. 10). Springer Singapore. https://doi.org/10.1007/978-981-10-4274-4

Seufert, V. (2019). Comparing Yields: Organic Versus Conventional Agriculture. In *Encyclopedia of Food Security and Sustainability* (pp. 196–208). Elsevier. https://doi.org/10.1016/B978-0-08-100596-5.22027-1

Shang, H., He, D., Li, B., Chen, X., Luo, K., & Li, G. (2024). Environmentally Friendly and Effective Alternative Approaches to Pest Management: Recent Advances and Challenges. *Agronomy, 14*(8), 1807. https://doi.org/10.3390/agronomy14081807

Sharma, S., Yost, M. A., & Reeve, J. R. (2025). Roles of Organic Agriculture for Water Optimization in Arid and Semi-Arid Regions. *Sustainability, 17*(12), 5452. https://doi.org/10.3390/su17125452

Shekhar, C., Khosya, R., Thakur, K., Mahajan, D., Kumar, R., Kumar, S., & Sharma, A. K. (2024). A systematic review of pesticide exposure, associated risks, and long-term human health impacts. *Toxicology Reports, 13*, 101840. https://doi.org/10.1016/j.toxrep.2024.101840

Shukla, G., Kumar, A., Bhanti, M., Joseph, P. E., & Taneja, A. (2006). Organochlorine pesticide contamination of ground water in the city of Hyderabad. *Environment International, 32*(2), 244–247. https://doi.org/10.1016/j.envint.2005.08.027

Sierra-Diaz, E., Celis-de La Rosa, A. D. J., Lozano-Kasten, F., Trasande, L., Peregrina-Lucano, A. A., Sandoval-Pinto, E., & Gonzalez-Chavez, H. (2019). Urinary Pesticide Levels in Children and Adolescents Residing in Two Agricultural Communities in Mexico. *International Journal of Environmental Research and Public Health, 16*(4), 562. https://doi.org/10.3390/ijerph16040562

Sigudu, T., Mkhatshwa, T., & Monyeki, K. (2025). BMI-based nutritional assessment of children aged 11–17 years in rural Ellisras, Limpopo province. *Journal of Public Health in Africa, 16*(1), a1295. https://doi.org/10.4102/jphia.v16i1.1295

Smith, L. G., Williams, A. G., & Pearce, Bruce. D. (2015). The energy efficiency of organic agriculture: A review. *Renewable Agriculture and Food Systems, 30*(3), 280–301. https://doi.org/10.1017/S1742170513000471

Smith-Spangler, C., Brandeau, M. L., Hunter, G. E., Bavinger, J. C., Pearson, M., Eschbach, P. J., Sundaram, V., Liu, H., Schirmer, P., Stave, C., Olkin, I., & Bravata, D. M. (2012). Are Organic Foods Safer or Healthier Than Conventional Alternatives?: A Systematic Review. *Annals of Internal Medicine, 157*(5), 348–366. https://doi.org/10.7326/0003-4819-157-5-201209040-00007

Swapan, C., Mainak, B., Deewa, B., & Tanmoy, M. (2023). Natural pesticides for pest control in agricultural crops: An alternative and eco-friendly method. *Plant Science Today*. https://doi.org/10.14719/pst.2547

Vasseghian, Y., Arunkumar, P., Joo, S.-W., Gnanasekaran, L., Kamyab, H., Rajendran, S., Balakrishnan, D., Chelliapan, S., & Klemeš, J. J. (2022). Metal-organic framework-enabled pesticides are an emerging tool for sustainable cleaner production and environmental hazard reduction. *Journal of Cleaner Production, 373*, 133966. https://doi.org/10.1016/j.jclepro.2022.133966

Xing, Y., Wang, X., & Mustafa, A. (2025). Exploring the link between soil health and crop productivity. *Ecotoxicology and Environmental Safety, 289*, 117703. https://doi.org/10.1016/j.ecoenv.2025.117703

Zhang, W., Pang, S., Lin, Z., Mishra, S., Bhatt, P., & Chen, S. (2021). Biotransformation of perfluoroalkyl acid precursors from various environmental systems: Advances and perspectives. *Environmental Pollution, 272*, 115908. https://doi.org/10.1016/j.envpol.2020.115908

Zhou, W., Li, M., & Achal, V. (2025). A comprehensive review on environmental and human health impacts of chemical pesticide usage. *Emerging Contaminants, 11*(1), 100410. https://doi.org/10.1016/j.emcon.2024.100410