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Monitoring of Organochlorine Pesticide Residues in Summer Season Fruits and Vegetables Using Gas Chromatography and Human Health Risk Assessment.

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Abstract

Organochlorine pesticides (OCPs) continue to pose major food-safety challenges in developing nations owing to their environmental persistence, bioaccumulative character, and adverse toxicological effects. The present investigation was designed to quantify selected OCP residues in commonly consumed summer-season fruits-Pineapple (*Ananas comosus*), Apricot (*Prunus armeniaca*), Peach (*Prunus persica*), Sweet lime (*Citrus limetta*), and Lime (*Citrus aurantifolia*) along with vegetables such as Green Chilli (*Capsicum annuum*), Capsicum (*Capsicum annuum var. grossum*), and Okra (*Abelmoschus esculentus*) procured from local markets of Agra, India. Eight samples were procured and analyzed using GC-ECD techniques. Among the examined pesticides, γ-BHC, β-BHC, chlordane (α, γ) compound, endosulfan-I, methoxychlor, along with trace levels of aldrin and heptachlor were identified in different produce samples. The maximum concentration (0.0134mg/kg) of α-Endosulfan (endosulfan-I) was found in Okra, while methoxychlor exhibited notable levels particularly in Green Chilli and Apricot. Measured concentrations were evaluated against established Maximum Residue Limits (MRLs). Dietary exposure was assessed through Hazard Quotient and Hazard Index calculations. Although the majority of quantified residues complied with international Maximum Residue Limits (MRLs), a few items showed cumulative Hazard Index values nearing the permissible limit, highlighting potential long-term dietary exposure concerns. The outcomes emphasize the need for enhanced surveillance, awareness among consumers and farmers, and strict implementation of pesticide regulations to ensure protection of public health.

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Introduction

India is one of the world's leading agricultural-oriented countries, with a large portion of its population involved in the field of agriculture and associated. The widespread use of chemical pesticides in modern agriculture has significantly increased crop productivity and reduced post-harvest losses.[1] However, the indiscriminate and sometimes unregulated use of pesticides, especially organochlorine pesticides, has raised serious environmental and public health concerns.[2] Organochlorine pesticides (OCPs), including aldrin, dieldrin, heptachlor, and the benzene hexachloride (BHC) isomers persist in environmental matrices for extended periods and progressively build up in living organisms, posing toxic risks to humans and other unintended species.[3,4] Although their application has been globally restricted through agreements like the Stockholm Convention, measurable residues continue to appear in food commodities from several developing regions due to inadequate implementation of pesticide regulatory policies.[5-7] Several studies have reported the continued presence of these residues in agricultural produce across different regions of India.[8,9] Their lipophilic nature allows them to accumulate in fatty tissues, making even trace levels dangerous with chronic exposure.[10]

The consumption of fruits and vegetables contaminated with OCPs may trigger severe health concerns, including hormonal imbalance, neurotoxic responses, reproductive impairments, and possible carcinogenic outcomes.[11,12] Young children exhibit heightened vulnerability because their physiological systems are still developing and their dietary intake relative to body weight is higher.[13]

This study involves the determination of concentrations of twenty organochlorine pesticides in widely consumed summer-season fruits and vegetables sourced from local markets of Agra. Residue quantification was carried out using GC-ECD, an analytical method known for its excellent sensitivity and selectivity toward halogenated pesticides and its suitability for food residue determination.[14,15] Additionally, dietary exposure risks were evaluated through calculations of EDI, ADI, HQ, and HI to gauge the possible non-carcinogenic effects associated with long-term consumption, thereby establishing a comprehensive framework for evaluating consumer risk.[16,17] This research is significant in identifying contamination patterns in fresh produce and contributes to national and international efforts to regulate pesticide use, promote safe agricultural practices, and inform public health policies.[18,19]

Materials and Methods

Chemicals and Standards

All solvents employed in the analytical procedures—n-hexane, acetone, acetonitrile, and dichloromethane were of AR grade and procured from Merck, India. Activated charcoal, silica gel, Florisil and anhydrous sodium sulfate were purchased from Fisher Scientific, United Kingdom. Highly pure chemicals and reagents were selected and procured to ensure accuracy and reliability of the analyses. Certified mixed standards of the twenty targeted OCPs were procured from RESTEK (USA) and preserved under recommended storage conditions. All analytical chemicals and reagents were maintained as per supplier guidelines to ensure quality and stability.

Sample Collection and Preparation

Total eight fresh samples were collected during the peak summer months (April–June 2023) from different local markets of Agra, Uttar Pradesh. The sampling included five fruits—pineapple (*Ananas comosus*), apricot (*Prunus armeniaca*), peach (*Prunus persica*), Sweet lime (*Citrus limetta*), and lime (*Citrus aurantifolia*)—along with three vegetables: green chilli (*Capsicum annuum*), capsicum (*Capsicum annuum* var. *grossum*), and okra (*Abelmoschus esculentus*). Around 250 g of each sample were taken in clean polyethylene bags, and then transported to the lab, where they were refrigerated at 5°C prior to analysis. Before extraction, samples were then washed with tap water for a few minutes, dried with the help of filter paper, and finally chopped into small pieces.

Extraction from Fruits

Extraction of pesticides from all fruits was done using a modified method described in previous studies.[20] Approximately 50 g of fruit sample was ground into a fine paste using a blender and then thoroughly mixed with 50 mL of acetonitrile. This method was then again done three times to ensure complete extraction of the mixture. The acetonitrile extract was filtered using a Buchner funnel to remove all residues. The filtrate obtained was concentrated under reduced pressure to nearly 5 mL and subsequently shifted into a separating funnel. 150 mL saline solution 2% (w/v) was added after that dichloromethane (3 × 50 mL) was added to separate the concentrated extract using a liquid-liquid partitioning process. The dichloromethane layers were then separated collected and passed through a layer of 5 g Na_2SO_4 to absorb the remaining water content. Next, a rotary evaporator was used to evaporate the dichloromethane extract to a volume of 2-5 ml. Finally, the concentrated residue was reconstituted using hexane–acetone mixture (9:1, v/v) of 10 mL

Extraction from Vegetables

Pesticide residues were extracted from each vegetable sample following a modified standard extraction procedure.2[1,22] Approximately 25 g of homogenized vegetable sample was mixed with 15 g of anhydrous Na2SO4 to remove moisture. The mixture was then extracted using 50 mL of acetone on a mechanical shaker for 1 hour to ensure efficient release of pesticide residues. The supernatant was collected under vacuum, and the extraction was repeated three times to ensure optimal residue extraction. The pooled extracts were reduced to roughly 50 mL using a rotary evaporator, followed by liquid–liquid partitioning with n-hexane in a 500 mL separating funnel. The extract was isolated and then filtered through anhydrous Na_2SO_4 to eliminate any remaining moisture. This layer was then evaporated to approximately 10 mL.

Purification Process

The collected samples were subjected to a purification process using columns filled with a mixture of a mixture of silica gel and activated charcoal in a weight ratio of 5:1. The extract was purified by eluting with 50 mL of n-hexane to facilitate the removal of impurities. After elution, the solvent was evaporated until the volume was approximately 5 ml. These concentrated extracts were transferred to GC vials for organochlorine pesticide determination.

Instrumental Analysis

The chromatographic separation was done by using an Agilent 7890A GC system fitted using a ^{63}Ni ECD detector equipped with HP-5 capillary column (30 m lgth, 0.25 mm with interior diameter, 0.25 µm film width). In the oven the temperature program was started at 150°C for the initial one minute, and then gradually increased to 280°C at a rate of 10°C per minute, and the closing temperature was held constant for another 10 minutes. Nitrogen gas act as the carrier as well as the make-up gas, maintaining a steady flow of 30 mL/min throughout the run. The temperatures of both the injector and the detector were maintained at 250°C during analysis. Extract of every sample (2 µL portion) was inserted in split less mode, which helped in achieving better detection of trace-level residues.

Health Risk Assessment

Non-carcinogenic health hazards were evaluated through the Hazard Index (HI), which indicates the combined exposure to multiple pesticide residues present in a single sample. HI values were derived by adding the individual hazard quotients (HQ = EDI /ADI) corresponding to each OCP detected. An HI greater than 1 implies a potential risk of negative health implications.

Results

The chromatographic analysis of the organochlorine pesticide (OCP) standard revealed 20 distinct peaks with well-resolved retention times, confirming the identity and separation efficiency of the compounds. Retention times ranged from 7.192 minutes for α-BHC to 26.777 minutes for Endrin Ketone. All pesticides showed a concentration near 200 µg/mL, indicating accurate standard preparation and instrument calibration. Notably, Endrin (114,555,679 area units) and Dieldrin (112,523,650) exhibited the highest peak areas, reflecting strong detector responses. This standardized chromatogram serves as a reference for comparison with fruit and vegetable samples, validating the method's capability to simultaneously quantify multiple OCPs using GC-ECD with high sensitivity.

Estimation of Organochlorine Pesticide Levels in Selected Fruit and Vegetable Samples

Out of the twenty targeted organochlorine pesticides (OCPs), only a subset was detected in the analyzed summer season produce. The detected compounds included γ-BHC, β-BHC, α- chlordane, γ-chlordane, endosulfan-I, methoxychlor, heptachlor, and aldrin. The residue levels varied depending on the commodity type, with certain fruits and vegetables showing higher contamination levels than others.

Table 1: Details the peak characteristics, retention times, peak areas, and concentrations for the OCP standard mixture.

Peaks	Targeted Pesticides	Ret. time	Area	Concentration (µg/mL)
Hexachlorocyclohexane group (HCH isomers):				
1	α-BHC	7.192	7690122	200.4
2	γ-BHC	8.396	1481212	200.0
3	β-BHC	9.696	5069241	199.9
4	δ-BHC	10.580	65952153	200.8
Cyclodiene Series:				
5	Heptachlor	11.876	44732994	200.8
6	Aldrin	12.011	62032860	200.4
7	Heptachlor-epoxide	13.424	63775778	200.0
8	γ-chlordane	15.152	61627749	200.4
9	α-chlordane	16.748	78485930	200.0
10	Dieldrin	20.273	112523650	200.3
11	Endrin	21.468	114555679	200.0
12	Endrin aldehyde	23.373	59739640	200.0
13	Endrin Ketone	26.777	64579094	200.4
DDT-Derived metabolites:				
14	4,4'-DDE	19.681	76999753	200.0
15	4,4'-DDD	22.384	64014262	200.0
16	4,4'-DDT	23.641	56737299	200.0
Other organochlorines:				
17	Endosulfan-I	18.571	63961322	200.0
18	Endosulfan-II	22.951	70030191	200.0
19	Endosulfan sulfate	24.746	71908605	200.3
20	Methoxychlor	25.042	62186776	200.4

Among the fruits, apricot showed the highest diversity of pesticide residues, with measurable amounts of γ-BHC (0.0056 µg/µL), β-BHC (0.00096 µg/µL), α-chlordane (0.000043 µg/µL), endosulfan-I (0.0104 µg/µL), methoxychlor (0.000014 µg/µL), aldrin, and heptachlor. Peach and Sweet lime also exhibited detectable concentrations of endosulfan-I and α-chlordane, while lime was found to contain γ-BHC, β-BHC, and endosulfan-I. Pineapple presented relatively lower contamination, with γ-BHC and endosulfan-I as the only detected compounds.

Table 2: Detected Organochlorine Pesticides and Concentration (mg/kg) of OC Pesticides residues in summer season Fruit samples by using GC-ECD.

Pesticides	Pineapple	Apricot	Peach	Sweet lime	Lime	MRL
Hexachlorocyclohexane group (HCH isomers):						
α-BHC	"0"	"0"	"0"	"0"	"0"	1.0
γ-BHC	0.00341	0.00564	"0"	"0"	0.00428	1.0
β-BHC	"0"	0.00095	"0"	"0"	0.00062	1.0
δ-BHC	"0"	"0"	"0"	"0"	"0"	1.0

Cyclodiene Series:						
Heptachlor	“0”	0.00005	“0”	“0”	“0”	0.05
Aldrin	“0”	0.000009	“0”	“0”	“0”	0.10
Heptachlor-epoxide	“0”	“0”	“0”	“0”	“0”	0.05
γ-chlordane	“0”	“0”	“0”	“0”	“0”	0.1
α-chlordane	0.00001	0.00004	0.000009	0.00001	0.00013	0.1
Dieldrin	“0”	“0”	“0”	“0”	“0”	0.1
Endrin	“0”	“0”	“0”	“0”	“0”	0.05
Endrin aldehyde	“0”	“0”	“0”	“0”	“0”	0.05
Endrin ketone	“0”	“0”	“0”	“0”	“0”	0.05
DDT-Derived metabolites:						
4,4’-DDE	“0”	“0”	“0”	“0”	“0”	-
4,4’-DDD	“0”	“0”	“0”	“0”	“0”	-
4,4’-DDT	“0”	“0”	“0”	“0”	“0”	-
Other organochlorines:						
α-Endosulfan or (Endosulfan-I)	0.00631	0.01040	0.00761	0.00285	0.00698	2.0
β-Endosulfan or (Endosulfan-II)	“0”	“0”	“0”	“0”	“0”	2.0
Endosulfan sulfate	“0”	“0”	“0”	“0”	“0”	2.0
Methoxychlor	“0”	0.00001	0.00002	“0”	“0”	-

“0”: Not Detected

Among the vegetables, okra was the most contaminated, with a significantly high concentration of endosulfan-I (0.0314 μg/μL) and notable levels of α-chlordane and methoxychlor. Capsicum contained endosulfan-I (0.0072 μg/μL) and α-chlordane, while green chillies had traces of γ-chlordane, endosulfan-I, and methoxychlor.

Table.3: Detected organochlorine Pesticides and Concentration (mg/kg) of OCPs residues in summer season Vegetable samples by using GC-ECD.

Pesticides	Green chilli	Shimla mirch	Okra	MRL
Hexachlorocyclohexane group (HCH isomers):				
α-BHC	“0”	“0”	“0”	0.02
γ-BHC	“0”	“0”	“0”	0.02
β-BHC	“0”	“0”	“0”	0.02
δ-BHC	“0”	“0”	“0”	1.00
Cyclodiene Series:				
Heptachlor	“0”	“0”	“0”	0.02
Aldrin	“0”	“0”	“0”	0.05
Heptachlor-epoxide	“0”	“0”	“0”	0.02
γ-chlordane	0.000005	“0”	“0”	-
α-chlordane	“0”	0.000009	0.00001	-
Dieldrin	“0”	“0”	“0”	0.05
Endrin	“0”	“0”	“0”	0.01

Endrin aldehyde	"0"	"0"	"0"	0.01
Endrin Ketone	"0"	"0"	"0"	-
DDT-Derived metabolites:				
4,4'-DDE	"0"	"0"	"0"	0.50
4,4'-DDD	"0"	"0"	"0"	0.50
4,4'-DDT	"0"	"0"	"0"	0.50
Other Organochlorines:				
α-Endosulfan or (Endosulfan-I)	0.00170	0.00724	0.03138	0.10
β-Endosulfan or (Endosulfan-II)	"0"	"0"	"0"	0.10
Endosulfan sulfate	"0"	"0"	"0"	0.10
Methoxychlor	0.00003	0.00002	0.00001	0.10

"0": Not Detected

Comparison with Maximum Residue Limits

Detected concentrations were compared with Codex Alimentarius and FAO/WHO MRLs for each pesticide. Although most pesticide levels were below their respective MRLs, the frequent occurrence of banned compounds such as aldrin, heptachlor, and methoxychlor indicates potential misuse of restricted pesticides. In particular, the levels of endosulfan-I in okra and apricot approached the upper safety threshold, suggesting environmental persistence or unauthorized use.

Health Risk Analysis

The Hazard Index (HI) and Hazard Quotient (HQ) were used to evaluate the possible health risks connected to the found pesticide residues. These indices were calculated by comparing each pesticide's estimated daily intake (EDI) to its matching acceptable daily intake (ADI). For the majority of analyzed samples, HQ values remained below 1, suggesting negligible health risk at present consumption rates. In contrast, okra and apricot exhibited cumulative HI values that were close to or marginally above 1, indicating the possibility of long-term health concerns, particularly for sensitive populations such as children and individuals with weakened immunity.

Possible Sources and Implications

The detection of banned or severely restricted OCPs in both fruits and vegetables suggests continued use, legacy contamination in agricultural soils, or cross-contamination during storage and transportation. The summer season's high temperatures may also accelerate pesticide degradation, influencing residue patterns. These results call for enhanced awareness among farmers, stricter pesticide usage regulations, and regular surveillance programs to ensure compliance with food safety standards.

Discussion

During the monitoring it has been found that the majority of samples exhibited residue levels below the MRLs established by International Regulatory Agencies. The detection of OCPs such as Endosulfan-I, 4,4'-DDE, 4,4'-DDD, and Heptachlor epoxide indicates their continued presence in the environment, despite long-standing restrictions on their usage. Similar findings have been reported in several studies from India and other developing regions, where the persistence, bioaccumulation potential, and illegal application of OCPs remain a concern.

Table 4: Estimated Intake levels, exposure ratios, and overall health risk of OCPs in fruits (Pineapple and Apricot).

Pesticides	WHO/IPCS ADI (mg/kg/day)	Fruits									
		Pineapple					Apricot				
		EDI		HI		HR	EDI		HI		HR
		CG	AG	CG	AG		CG	AG	CG	AG	
Hexachlorocyclohexane group (HCH isomers):											
α-BHC	0.0005	"0"	"0"	"0"	"0"	"0"	"0"	"0"	"0"	"0"	
γ-BHC	0.0005	3.3011E-06	1.65054E-06	0.006602152	0.00330108	No	5.4569E-06	2.72847E-06	0.01091387	0.005456937	No
β-BHC	0.0005	"0"	"0"	"0"	"0"		9.249E-07	4.62449E-07	0.00184979	0.000924897	No
δ-BHC	0.0005	"0"	"0"	"0"	"0"		"0"	"0"	"0"	"0"	
Cyclodiene Series:											
Heptachlor	0.0001	"0"	"0"	"0"	"0"		4.8851E-08	2.44254E-08	0.00048851	0.000244254	No
Aldrin	0.0001	"0"	"0"	"0"	"0"		9.5088E-09	4.75442E-09	9.5088E-05	4.75442E-05	No
Heptachlor-epoxide	0.0001	"0"	"0"	"0"	"0"		"0"	"0"	"0"	"0"	
γ-chlordane	0.001	"0"	"0"	"0"	"0"		"0"	"0"	"0"	"0"	
α-chlordane	0.001	1.5068E-08	7.53396E-09	1.50679E-05	7.534E-06	No	4.1381E-08	2.06904E-08	4.1381E-05	2.06904E-05	No
Dieldrin	0.0001	"0"	"0"	"0"	"0"		"0"	"0"	"0"	"0"	
Endrin	0.0002	"0"	"0"	"0"	"0"		"0"	"0"	"0"	"0"	
Endrin aldehyde	0.0002	"0"	"0"	"0"	"0"		"0"	"0"	"0"	"0"	
Endrin Ketone	0.0002	"0"	"0"	"0"	"0"		"0"	"0"	"0"	"0"	
DDT-Derived metabolites:											
4,4'-DDE	0.0005	"0"	"0"	"0"	"0"		"0"	"0"	"0"	"0"	
4,4'-DDD	0.0005	"0"	"0"	"0"	"0"		"0"	"0"	"0"	"0"	
4,4'-DDT	0.0005	"0"	"0"	"0"	"0"		"0"	"0"	"0"	"0"	
Other organochlorines:											
α-Endosulfan or (Endosulfan-I)	0.00005	6.1013E-06	3.05065E-06	0.122025875	0.06101294	No	1.006E-05	5.03006E-06	0.20120234	0.10060117	No
β-Endosulfan or (Endosulfan-II)	0.00005	"0"	"0"	"0"	"0"		"0"	"0"	"0"	"0"	
Endosulfan sulfate	0.00005	"0"	"0"	"0"	"0"		"0"	"0"	"0"	"0"	
Methoxychlor	0.1	"0"	"0"	"0"	"0"		1.3844E-08	6.922E-09	1.3844E-07	6.922E-08	No

Child group (CG) / Adult group (AG)

Table 5: Estimated Intake levels, exposure ratios, and overall health risk of OCPs in fruits (Peach and Sweet lime).

Pesticides	**WHO/IPCS ADI (mg/ kg/day)**	**Fruits**									
		Pineapple					**Apricot**				
		EDI		**HI**		**HR**	**EDI**		**HI**		**HR**
		CG	**AG**	**CG**	**AG**		**CG**	**AG**	**CG**	**AG**	
Hexachlorocyclohexane group (HCH isomers):											
α-BHC	0.0005	“0”	“0”	“0”	“0”		“0”	“0”	“0”	“0”	
γ-BHC	0.0005	“0”	“0”	“0”	“0”		“0”	“0”	“0”	“0”	
β-BHC	0.0005	“0”	“0”	“0”	“0”		“0”	“0”	“0”	“0”	
δ-BHC	0.0005	“0”	“0”	“0”	“0”		“0”	“0”	“0”	“0”	
Cyclodiene Series:											
Heptachlor	0.0001	“0”	“0”	“0”	“0”		“0”	“0”	“0”	“0”	
Aldrin	0.0001	“0”	“0”	“0”	“0”		“0”	“0”	“0”	“0”	
Heptachlor -epoxide	0.0001	“0”	“0”	“0”	“0”		“0”	“0”	“0”	“0”	
γ-chlordane	0.001	“0”	“0”	“0”	“0”		“0”	“0”	“0”	“0”	
α-chlordane	0.001	8.867 8E-09	4.433 9E-09	8.867 8E-06	4.433 9E-06	No	1.042 5E-08	5.212 31E-09	1.042 5E-05	5.212 3E-06	No
Dieldrin	0.0001	“0”	“0”	“0”	“0”		“0”	“0”	“0”	“0”	
Endrin	0.0002	“0”	“0”	“0”	“0”		“0”	“0”	“0”	“0”	
Endrin aldehyde	0.0002	“0”	“0”	“0”	“0”		“0”	“0”	“0”	“0”	
Endrin Ketone	0.0002	“0”	“0”	“0”	“0”		“0”	“0”	“0”	“0”	
DDT-Derived metabolites:											
4,4’-DDE	0.0005	“0”	“0”	“0”	“0”		“0”	“0”	“0”	“0”	
4,4’-DDD	0.0005	“0”	“0”	“0”	“0”		“0”	“0”	“0”	“0”	
4,4’-DDT	0.0005	“0”	“0”	“0”	“0”		“0”	“0”	“0”	“0”	
Other organochlorines:											
α-Endosulfan or (Endosulfan-I)	0.00005	7.365 3E-06	3.682 6E-06	0.147 30583	0.073 65292	No	2.759 6E-06	1.379 78E-06	0.055 19123	0.027 59562	No
β-Endosulfan or (Endosulfan-II)	0.00005	“0”	“0”	“0”	“0”		“0”	“0”	“0”	“0”	
Endosulfan sulfate	0.00005	“0”	“0”	“0”	“0”		“0”	“0”	“0”	“0”	
Methoxychlor	0.1	2.440 2E-08	1.220 1E-08	2.440 2E-07	1.220 1E-07	No	“0”	“0”	“0”	“0”	

Child group (CG) / Adult group (AG)

Note: HI < 1 indicates low risk; no sample exceeded the threshold for non-carcinogenic effects.

Table 6: Estimated Intake levels, exposure ratios, and overall health risk of OCPs in fruit and vegetable (Lime and Green chilies).

Pesticides	WHO/IPCS ADI (mg/kg/day)	Fruits & Vegetables									
		Lime					Green chilies				
		EDI		HI		HR	EDI		HI		HR
		CG	AG	CG	AG		CG	AG	CG	AG	
Hexachlorocyclohexane group (HCH isomers):											
α-BHC	0.0005	"0"	"0"	"0"	"0"		"0"	"0"	"0"	"0"	
γ-BHC	0.0005	4.1448E-06	2.0724E-06	0.008289563	0.004144781	No	"0"	"0"	"0"	"0"	
β-BHC	0.0005	6.0194E-07	3.0097E-07	0.001v0388	0.00060194	No	"0"	"0"	"0"	"0"	
δ-BHC	0.0005	"0"	"0"	"0"	"0"		"0"	"0"	"0"	"0"	
Cyclodiene Series:											
Heptachlor	0.0001	"0"	"0"	"0"	"0"		"0"	"0"	"0"	"0"	
Aldrin	0.0001	"0"	"0"	"0"	"0"		"0"	"0"	"0"	"0"	
Heptachlor -epoxide	0.0001	"0"	"0"	"0"	"0"		"0"	"0"	"0"	"0"	
γ-chlordane	0.001	"0"	"0"	"0"	"0"		2.6694E-08	1.33468E-08	2.66936E-05	1.3347E-05	No
α-chlordane	0.001	1.3093E-07	6.5464E-08	0.000130929	6.54643E-05	No	"0"	"0"	"0"	"0"	
Dieldrin	0.0001	"0"	"0"	"0"	"0"		"0"	"0"	"0"	"0"	
Endrin	0.0002	"0"	"0"	"0"	"0"		"0"	"0"	"0"	"0"	
Endrin aldehyde	0.0002	"0"	"0"	"0"	"0"		"0"	"0"	"0"	"0"	
Endrin Ketone	0.0002	"0"	"0"	"0"	"0"		"0"	"0"	"0"	"0"	
DDT-Derived metabolites:											
4,4'-DDE	0.0005	"0"	"0"	"0"	"0"		"0"	"0"	"0"	"0"	
4,4'-DDD	0.0005	"0"	"0"	"0"	"0"		"0"	"0"	"0"	"0"	
4,4'-DDT	0.0005	"0"	"0"	"0"	"0"		"0"	"0"	"0"	"0"	
Other organochlorines:											
α-Endosulfan or (Endosulfan-I)	0.00005	6.7542E-06	3.3771E-06	0.13508425	0.067542125	No	8.7912E-06	4.39562E-06	0.175824915	0.08791246	No
β-Endosulfan or (Endosulfan-II)	0.00005	"0"	"0"	"0"	"0"		"0"	"0"	"0"	"0"	
Endosulfan sulfate	0.00005	"0"	"0"	"0"	"0"		"0"	"0"	"0"	"0"	
Methoxychlor	0.1	"0"	"0"	"0"	"0"		1.5508E-07	7.75414E-08	1.55083E-06	7.7541E-07	No

Child group (CG) / Adult group (AG)

Table 7: Estimated Intake levels, exposure ratios, and overall health risk of OCPs in vegetables (Shimla mirch and Okra).

Pesticides	WHO/IPCS ADI (mg/kg/day)	Fruits & Vegetables									
		Shimla mirch					Okra				
		EDI		HI		HR	EDI		HI		HR
		CG	AG	CG	AG		CG	AG	CG	AG	
Hexachlorocyclohexane group (HCH isomers):											
α-BHC	0.0005	"0"	"0"	"0"	"0"		"0"	"0"	"0"	"0"	
γ-BHC	0.0005	"0"	"0"	"0"	"0"		"0"	"0"	"0"	"0"	
β-BHC	0.0005	"0"	"0"	"0"	"0"		"0"	"0"	"0"	"0"	
δ-BHC	0.0005	"0"	"0"	"0"	"0"		"0"	"0"	"0"	"0"	
Cyclodiene Series:											
Heptachlor	0.0001	"0"	"0"	"0"	"0"		"0"	"0"	"0"	"0"	
Aldrin	0.0001	"0"	"0"	"0"	"0"		"0"	"0"	"0"	"0"	
Heptachlor-epoxide	0.0001	"0"	"0"	"0"	"0"		"0"	"0"	"0"	"0"	
γ-chlordane	0.001	"0"	"0"	"0"	"0"		"0"	"0"	"0"	"0"	
α-chlordane	0.001	5.158 4E-08	2.5791 9E-08	5.158 4E-05	2.579 19E-05	No	7.671 7E-08	3.835 9E-08	7.671 7E-05	3.835 9E-05	No
Dieldrin	0.0001	"0"	"0"	"0"	"0"		"0"	"0"	"0"	"0"	
Endrin	0.0002	"0"	"0"	"0"	"0"		"0"	"0"	"0"	"0"	
Endrin aldehyde	0.0002	"0"	"0"	"0"	"0"		"0"	"0"	"0"	"0"	
Endrin Ketone	0.0002	"0"	"0"	"0"	"0"		"0"	"0"	"0"	"0"	
DDT-Derived metabolites:											
4,4'-DDE	0.0005	"0"	"0"	"0"	"0"		"0"	"0"	"0"	"0"	
4,4'-DDD	0.0005	"0"	"0"	"0"	"0"		"0"	"0"	"0"	"0"	
4,4'-DDT	0.0005	"0"	"0"	"0"	"0"		"0"	"0"	"0"	"0"	
Other organochlorines:											
α-Endosulfan or (Endosulfan-I)	0.00005	3.742 4E-05	1.8711 8E-05	0.748 47362	0.3742 36808	No	0.000 16215	8.107 4E-05	3.242 97306	1.6214 8653	No
β-Endosulfan or (Endosulfan-II)	0.00005	"0"	"0"	"0"	"0"		"0"	"0"	"0"	"0"	
Endosulfan sulfate	0.00005	"0"	"0"	"0"	"0"		"0"	"0"	"0"	"0"	
Methoxychlor	0.1	1.115 3E-07	5.5765 3E-08	1.115 3E-06	5.5765 3E-07	No	7.515 7E-08	3.757 8E-08	7.515 7E-07	3.757 8E-07	No

Child group (CG) / Adult group (AG)

Note - Okra had an HI of 1.62, indicating a potential health risk to adults from chronic exposure to Endosulfan-I. Other vegetables showed HI values well below the critical threshold of 1.

Table 8: Combined Health Risk (HI) of OCPs in Fruits (Summer Season)

Fruits	HI (Children)	HI (Adults)	Risk Level
Apricot	0.2145	0.1072	Low
Peach	0.1473	0.0736	Low
Lime	0.1447	0.0723	Low
Pineapple	0.1286	0.0643	Low
Sweet lime	0.0552	0.0276	Low

Interpretation: All fruits exhibited combined HI values below the threshold of 1, suggesting no immediate health risk for either children or adults based on the detected pesticide levels.

Table 9: Combined Health Risk (HI) of OCPs in Vegetables (Summer Season)

Vegetables	HI (Children)	HI (Adults)	Risk Level
Okra	3.2430	1.6215	High
Shimla mirch	0.7485	0.3742	Moderate
Green chillies	0.1758	0.0879	Low

Interpretation: While most vegetables fell within the safe limit, okra exceeded the HI threshold (HI > 1) in both children and adults. This suggests a notable public health concern, primarily linked to elevated concentrations of Endosulfan-I.

The health risk analysis based on Estimated Daily Intake (EDI) and Hazard Index (HI) revealed distinct risk differences between commodities. Fruit samples showed combined HI values <1 for both adults and children, indicating no immediate health concerns from dietary consumption. Comparatively vegetable samples comparatively higher exposure risk as compare to fruits. Among these, okra demonstrated HI >1 for both children and adults, signifying potential chronic health risks. This elevated risk was mainly attributed to higher concentrations of Endosulfan-I, a pesticide known for endocrine and neurotoxic effects in humans.

Children exhibited higher HI values than adults across most samples due to their underweight and higher diet intake-to-body mass ratio, making them a more vulnerable group to toxic exposure. Although other vegetables such as Shimla mirch and green chili displayed HI values below the threshold of concern, their detection of multiple OCPs suggests potential cumulative effects with long-term consumption.

The continued detection of banned OCPs in the present study highlights gaps in enforcement, monitoring, and public awareness. Environmental persistence due to historical agricultural use, coupled with possible unauthorized applications, likely contributes to their residues in food supply chains. Considering the harmful characteristics of OCPs - including bioaccumulation, environmental stability, and human toxicity—regular surveillance and stringent residue management practices are essential for consumer safety.

Recent studies have highlighted that xenobiotics such as organochlorine pesticides may interfere with anti-aging regulatory pathways, particularly Sirtuin-1 (SIRT1), which plays a crucial role in metabolic regulation and prevention of chronic diseases.[23,24] Organochlorine pesticide residues have been reported as potential SIRT1 inhibitors, and their persistent presence in food commodities may contribute to long-term health implications. Although SIRT1 expression or plasma levels were not evaluated in the present study, the detectable concentrations of organochlorine pesticides observed in summer fruits and vegetables suggest a possible biological relevance that warrants further biomonitoring and molecular-level investigations in exposed populations.

Conclusion

This research demonstrates that summer fruits and vegetables contain trace levels of organochlorine pesticide (OCP) residues. α-Chlordane and endosunfan-I were found in all fruits samples and endosulfan and methoxychlor were found in all vegetable samples. Health risk assessment revealed that okra and Shimla mirch could pose health risks, especially to children, based on their hazard index values. These findings call for increased surveillance and enforcement of pesticide regulations to ensure food safety. Overall, the findings indicate a moderate to high chronic exposure risk, particularly from leafy and fruiting vegetables like okra. Strengthened regulatory controls, good agricultural practices (GAP), and awareness programs for farmers and vendors are necessary to reduce pesticide contamination in food commodities and safeguard public health.

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This research did not involve human participants, animal subjects, or any material that requires ethical approval.

Informed Consent Statement

This study did not involve human participants, and therefore, informed consent was not required.

Permission to Reproduce Material from other Sources

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Author Contributions

- **Jagtendra Singh:** Conceptualization, methodology development, sample collection, laboratory analysis, data curation, writing - original draft preparation, and manuscript editing.
- **Devendra Kumar:** Supervision, project administration, critical review and revision of the manuscript, validation of results, and final approval for publication.

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