

## Investigation of Pesticide Contamination in Indian Aquaculture Shrimp (*Litopenaeus Vannamei*)

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### Abstract

Shrimp farming, or aquaculture, is a rapidly expanding industry in India, playing a crucial role in the nation's economy and food security. However, concerns have arisen due to the adoption of intensive farming methods and the widespread use of chemical pesticides for pest and disease control, raising questions about potential pesticide residues in farmed shrimp. This study seeks to examine the extent of pesticide contamination in Indian aquaculture shrimp, with a specific focus on *Litopenaeus vannamei*, commonly known as whiteleg shrimp. While most studies concentrate on monitoring organochlorine (OC) and organophosphate (OP) pesticides, our investigation centers on shrimp cultured along the coastal regions of India. The evaluated areas primarily pertain to the cultivation of shrimp along the country's coastline. Studies assessing pesticide levels in Indian shrimp predominantly focus on commercially significant species, such as *Penaeus vannamei*. This study provides details on extraction methods, including sample preparation, extraction techniques, solvents, and clean-up procedures. Additionally, it outlines the chromatography and detector types utilized to quantify analytes in shrimp samples collected from diverse ecosystems. Recognizing an insufficient assessment of pesticide residue presence, our research emphasizes a substantial contribution to studies focusing on geographical areas along the country's coastline.

**Keywords:** Pesticides; Organochlorines; Organophosphates; Chromatography; Shrimp; Food Safety; Seafood; Pollution

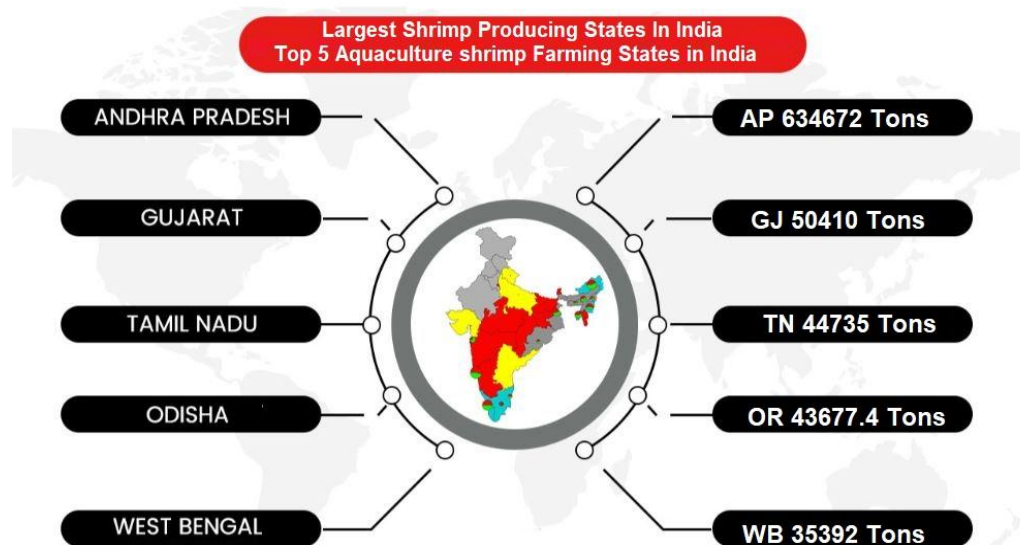
## INTRODUCTION

### Overview of Shrimp Farming in India:

Shrimp farming in India has gained prominence as a significant sector within the country's aquaculture industry. With rapid expansion, it has become a vital contributor to both the national economy and food security. The industry primarily focuses on the cultivation of various shrimp species, notably *Litopenaeus vannamei*, commonly known as whiteleg shrimp. The growth of shrimp farming in India can be attributed to favorable geographical conditions, including extensive coastal areas suitable for aquaculture practices. However, this expansion has raised concerns due to the adoption of intensive farming methods and the reliance on chemical pesticides to manage pests and diseases. Efforts to understand and address these concerns have led to research and studies aimed at investigating pesticide contamination in farmed shrimp, particularly along the coastal regions of India. These studies commonly concentrate on monitoring organochlorine (OC) and organophosphate (OP) pesticides.

To ensure sustainable practices, there is a need to balance the economic benefits of shrimp farming with environmental considerations and the impact on human health. Ongoing research focuses on refining extraction methods, including sample preparation, extraction techniques, solvents, and clean-up procedures. Additionally, the quantification of pesticide residues in shrimp samples is carried out using various chromatography and detector types.

Overall, while shrimp farming has become a crucial aspect of India's aquaculture landscape, it is essential to address challenges related to intensive practices and pesticide usage to ensure the industry's sustainable growth.



**Production of *L. vannamei* in tons for the year 2020-21 (MPEDA)**

**Figure 1.** Shrimp production (tons) in India in 2020-21.

### **Utilization of Pesticides in Aquaculture**

The utilization of pesticides in aquaculture serves the purpose of managing pests, diseases, and undesirable organisms that can negatively impact the health and productivity of aquatic species. This practice is intricate and dynamic, influenced by factors like the aquaculture system type, cultivated species, environmental conditions, and regional regulations. Pesticides play a vital role in disease and pest control, targeting pathogens, parasites, and common pests such as crustaceans and insects to prevent potential economic losses. These pesticides encompass chemical varieties like organochlorines and organophosphates, requiring careful management to avoid adverse effects on non-target organisms, and biological alternatives, considered more environmentally friendly. Application methods vary, including direct water application and incorporation into feeds, adapting to the specific aquaculture system and target pest. However, challenges arise, notably in terms of environmental impact and residue accumulation in aquatic organisms, leading to potential risks for both aquatic life and human consumers. Regulatory measures and adherence to withdrawal periods post-application are crucial for environmental sustainability and food safety. The adoption of Integrated Pest Management (IPM) strategies in aquaculture, combining biological, physical, and chemical controls, reflects a growing effort to minimize reliance on chemical pesticides and mitigate environmental impacts. Ongoing research focuses on developing sustainable alternatives, such as probiotics, genetic enhancements, and selective breeding for disease-resistant strains. In conclusion, the judicious use of pesticides in aquaculture necessitates careful consideration of environmental consequences and compliance with regulatory guidelines, emphasizing the importance of sustainable and integrated approaches for the industry's long-term viability.

### **Pesticides**

(Organochlorine and organophosphorus): Organochlorine and organophosphorus compounds constitute two commonly used pesticide categories in aquaculture for pest and disease control. Organochlorines, synthetic compounds containing chlorine atoms bonded to carbon, were historically prevalent in agriculture and aquaculture due to their broad-spectrum efficacy. Notable examples include DDT, now banned or restricted globally due to environmental persistence and bioaccumulation concerns. Although organochlorines were previously employed in aquaculture, their use has significantly diminished due to environmental considerations and the development of more targeted alternatives. Conversely, organophosphorus pesticides, incorporating phosphorus bonded to carbon, such as malathion and chlorpyrifos, find application in aquaculture for pest and disease management. While organophosphorus compounds are favored over organochlorines for their lower environmental persistence, careful management is essential to mitigate adverse effects on non-target organisms and water quality. Both pesticide categories face criticism and regulatory restrictions due to environmental and health concerns, including the potential for residue accumulation in aquatic organisms and subsequent risks to aquatic life and human consumers. In response to these challenges, the aquaculture industry is progressively adopting alternative pest management strategies, emphasizing Integrated Pest Management (IPM). IPM integrates biological, physical, and chemical controls to reduce reliance on traditional pesticides, aligning with the industry's evolving commitment to sustainable practices for the long-term health of aquatic ecosystems and the safety of aquaculture products.

S.No	Pesticide Residues (Organo Chlorine)
1	Aldrin
2	Dieldrin
3	Endrin
4	Chlordane-cis
5	Chlordane-trans
6	2,4'-DDE
7	4,4'-DDE
8	2,4'-DDT
9	4,4'-DDT
10	2,4'-DDD
11	4,4'-DDD
12	Heptachlor
13	HCB
14	Alpha-HCH
15	Beta-HCH
16	Gamma-HCH
17	Delta-HCH
18	Trifluralin

**Table 1:** Organochlorine Pesticide Residues in Indian Aquaculture Shrimp

The presence of organochlorine pesticide (OCP) residues in Indian aquaculture shrimp is a complex issue with implications for both food safety and environmental health. OCPs are a class of persistent organic pollutants (POPs) that were widely used in agriculture for decades before being banned or restricted in many countries due to their harmful effects on human health and the environment.

#### Sources of OCP Contamination in Shrimp:

- Agricultural runoff: OCPs used in nearby agricultural fields can reach shrimp farms through surface water runoff or groundwater contamination.
- Contaminated feed: Shrimp feed can become contaminated with OCPs through the use of ingredients like fishmeal or oilcake sourced from areas where OCPs are still used.
- Pesticide misuse: Intentional application of OCPs to shrimp ponds to control pests, although illegal, is still practiced in some areas.
- Impact of OCPs on Shrimp and Human Health:
- Bioaccumulation: OCPs are highly lipophilic, meaning they tend to accumulate in fatty tissues. This can lead to bioaccumulation in shrimp, where OCP concentrations can become magnified through the food chain.
- Human health risks: Consumption of shrimp contaminated with OCPs can pose risks to human health, including endocrine disruption, developmental problems, and cancer.
- Current Situation in India:

- **Limited data:** There is limited data available on the levels of OCP residues in Indian aquaculture shrimp. However, some studies have reported the presence of OCPs, including DDT and its breakdown products, in shrimp from various regions of India.
- **Regulations:** The Food Safety and Standards Authority of India (FSSAI) has set maximum residue limits (MRLs) for various OCPs in shrimp. However, there are concerns that these MRLs may not be sufficiently protective of human health.
- **Need for further research and monitoring:** More research is needed to better understand the extent of OCP contamination in Indian aquaculture shrimp and to develop effective strategies for mitigation. Regular monitoring of OCP levels in shrimp and the environment is also essential.
- **Efforts to Reduce OCP Contamination:**
- **Promotion of sustainable aquaculture practices:** Implementing sustainable aquaculture practices, such as organic farming and integrated pest management, can help to reduce the use of OCPs and other harmful chemicals.
- **Improved feed quality:** Ensuring that shrimp feed is free from OCP contamination is crucial for reducing OCP levels in farmed shrimp.
- **Strengthening regulations and enforcement:** Effective regulations and strict enforcement are needed to prevent the illegal use of OCPs in shrimp farming.

### **Organophosphorus Pesticide Residues in Indian Aquaculture Shrimp**

While organochlorine pesticides (OCPs) are a major concern, organophosphorus (OP) pesticides also pose a threat to shrimp safety and environmental health in Indian aquaculture. Here's an overview:

Presence of OPs in Shrimp:

Sources: Similar to OCPs, OP residues can enter shrimp farms through:

- Agricultural runoff
- Contaminated feed
- Direct application (though less common than with OCPs)

Detection: Studies have confirmed the presence of OP residues, particularly chlorpyrifos and its metabolites, in Indian farmed shrimp.

Impact of OPs:

- **Toxicity:** OPs are potent neurotoxins that disrupt the nervous system of invertebrates like shrimp, leading to paralysis and death at high doses.
- **Human health risks:** While acute poisoning from OP residues in shrimp is unlikely, chronic exposure can carry risks of neurodevelopmental problems, organ damage, and other health issues.

- Environmental concerns: OPs can negatively impact aquatic ecosystems by harming non-target organisms and contributing to water pollution.
- Current Situation in India:
  - Limited data: Similar to OCPs, information on OP levels in Indian shrimp is scarce. However, available studies indicate potentially high residues exceeding international MRLs in some cases.
  - Regulations: FSSAI sets MRLs for specific OPs in shrimp, but concerns exist about the adequacy of these limits for public health protection.
  - Challenges: Enforcement of regulations and awareness about OP use in aquaculture need improvement.
- Reducing OP Contamination:
  - Promote sustainable practices: Similar to OCPs, adopting eco-friendly farming methods is crucial.
  - Improve feed quality: Ensuring feed is free from OP residues is vital.
  - Alternatives to OPs: Encouraging research and adoption of safer pest control methods.
  - Strengthen regulations and enforcement:

S.No	Pesticide Residues: (Organo Phosphorous)
1	Quinalphos
2	4-bromo-2-chlorophenol (metabolite of Profenphos)
3	Acephate
4	Chlorfenvinphos
5	Chlorpyrifos
6	Chlorpyrifos-methyl
7	Diazinon
8	Dichlorvos
9	Dimthoate
10	(Including Omethoate)
11	Edifenphos
12	Ethion
13	Etrimphos
14	Fenitrothion
15	Fenthion
16	Iprobenphos
17	Malathion(sum of malathion and malaaxon expressed as malathion)
18	Methamidophos
19	Monocrotophos
20	Oxydemeton methyl (sum of oxydemeton methyl and demeton-S-methylsulfone expressed as oxydemeton methyl)

21	Parathion ethyl
22	Parathion methyl (sum of Parathion methyl and paraoxon methyl expressed as parathion methyl)
23	Penthoate
24	Phorate (sum of phorate, its oxygen analogue and their sulfones expressed as phorate)
25	Phosalone
26	Phosphamidon
27	Primiphos-methyl
28	Profenophos
29	Propetamphos
30	Temephos
31	Thiometon
32	Triazophos

**Table: 2**

This research endeavors to address this knowledge gap by systematically investigating the contamination of *Litopenaeus vannamei* with Pesticides in diverse aquaculture settings across India. Through meticulous sampling and analytical methodologies, we aim to quantify the concentrations of key Pesticides, including mercury, lead, cadmium, arsenic, copper, zinc, chromium, and nickel, in shrimp tissues. Understanding the prevalence and sources of Pesticides metal contamination is crucial for devising effective mitigation strategies and ensuring the sustainability of the aquaculture industry.

By shedding light on the intricate dynamics of Pesticides contamination in Indian aquaculture shrimp, this study aspires to provide actionable insights for policymakers, industry stakeholders, and environmental managers. Ultimately, our collective efforts can contribute to the development of informed regulations and best practices that promote the production of safe and high-quality shrimp, fostering the growth of a sustainable and responsible aquaculture sector in India.

State	2016-17 Approximate Production in tons	2017-18 Approximate Production in tons	2018-19 Approximate Production in tons	2019-20 Approximate Production in tons	2020-21 Approximate Production in tons
Andhra Pradesh	351137	456300	450797	510794	634672
Gujarat	41409	55161	58764	73539	50410
Tamil Nadu & Pondicherry	48670	43622	47184	44467	44735
Orissa	25594	37229	24123	44007	43677.4
W. Bengal	26085	22191	29846	31376	35392

**Table: 3** The commercial farming of this shrimp started from the year 2009-10 and is the largest cultured shrimp in terms of production and productivity. Andhra Pradesh tops in area under culture and production followed by Gujarat way behind.

## METHODOLOGY

1. Sample Collection Update: In the process of collecting samples in India, I've pinpointed the leading states in aquaculture shrimp production, namely Andhra Pradesh, Tamil Nadu, Gujarat, Odisha, and West Bengal. Within each of these states, I've carefully chosen five different locations for sample collection, culminating in a total of 25 samples. The objective behind collecting these samples is to conduct a thorough investigation into the potential contamination of Pesticides in Indian aquaculture shrimp, with a specific focus on *Litopenaeus vannamei*.

**Andhra Pradesh:** As a crucial step in the sample collection process, I have carefully chosen five aquaculture ponds situated in distinct districts of Andhra Pradesh. These districts include East Godavari, Krishna, West Godavari, Nellore, and Prakasam.

**Tamil Nadu:** As part of the sample collection process, I have selected five aquaculture ponds located in distinct districts of Tamil Nadu, specifically in Nagapattinam, Tuticorin (Thoothukudi), Ramanathapuram, Cuddalore, and Krishnagiri.

**Gujarat:** During the sample collection process, I have chosen five aquaculture ponds situated in different districts of Gujarat, namely Bharuch, Valsad, Navsari, Surat, and Amreli.

**Odisha:** As part of the sample collection process, I have selected five aquaculture ponds located in diverse districts of Odisha, specifically in Kendrapara, Bhadrak, Balasore, Puri, and Ganjam.

**West Bengal:** During the sample collection process, I have chosen five aquaculture ponds situated in varied districts of West Bengal, namely South 24 Parganas, North 24 Parganas, East Midnapore (Purba Medinipur), Howrah, and West Midnapore (Paschim Medinipur).

The confidentiality of the farmers' identities has been meticulously preserved in accordance with their explicit request.

leading states in aquaculture shrimp production	leading Districts in aquaculture shrimp production				
	Location 1	Location 2	Location 3	Location 4	Location 5
Andhra Pradesh	East Godavari	Krishna	West Godavari	Nellore	Prakasam
Tamil Nadu	Nagapattinam	Tuticorin (Thoothukudi)	Ramanathapuram	Cuddalore	Krishnagiri
Gujarat	Bharuch	Valsad	Navsari	Surat	Amreli
Odisha	Kendrapara	Bhadrak	Balasore	Puri	Ganjam
West Bengal	South 24 Parganas	North 24 Parganas	East Midnapore	Howrah	West Midnapore

**Table: 4** Sample Collection details from 25 Different locations.

Employed pristine and sterile containers during the sample collection, utilized stainless steel or plastic tools to prevent contamination, gathered an appropriate quantity of 350g samples to ensure dependable results in subsequent analyses. Each sample container was meticulously labeled with details such as location, date, tissue type, and any pertinent information.

Both LC-MS/MS and GC-MS/MS are advanced analytical techniques used to detect and quantify organochlorine (OC) and organophosphorus (OP) pesticides in a variety of matrices, including shrimp. Each technique has its advantages and disadvantages, making them suitable for different types of pesticides and analysis goals.

#### LC-MS/MS:

##### Advantages:

- Highly sensitive and specific, can detect trace levels of pesticides
- Good for analyzing polar and thermally labile compounds, including many OPs
- Can provide structural information about the detected compounds

##### Disadvantages:

- Requires more complex sample preparation
- May be susceptible to matrix effects
- Higher upfront cost for instrumentation

#### GC-MS/MS:

##### Advantages:

- Robust and well-established technique
- Suitable for analyzing volatile and non-polar compounds, including many OCPs
- Highly accurate quantitative analysis

##### Disadvantages:

- Less sensitive than LC-MS/MS for some pesticides
- May require derivatization for some non-volatile compounds
- Less suited for identifying unknown compounds

#### Choosing the right technique:

The choice between LC-MS/MS and GC-MS/MS for analyzing OC and OP pesticides in shrimp depends on several factors:

- Target pesticides: Consider the specific types of OCs and OPs you are interested in, their polarity and volatility.
- Detection limits: Decide what level of sensitivity you need for accurate quantification.
- Matrix: Consider the potential for matrix effects in your chosen sample

(shrimp).

- Budget and resources: Analyze the cost of instrumentation, consumables, and expertise required for each technique.

Analysis workflow:

The general workflow for analyzing OC and OP pesticides in shrimp using either LC-MS/MS or GC-MS/MS typically involves:

- Sample preparation: Extracting the pesticides from the shrimp tissue using appropriate solvents and purification techniques.
- Calibration: Preparing a series of standard solutions with known concentrations of the target pesticides for quantification.
- Instrumental analysis: Injecting the prepared samples into the LC-MS/MS or GC-MS/MS system for separation and detection of the pesticides.
- Data analysis: Quantifying the levels of each pesticide in the samples based on the calibration curve and instrument response.

Additional considerations:

- Validation: Before using either technique for routine analysis, it is important to validate the method for specificity, accuracy, precision, and limits of detection and quantification.
- Internal standards: Using isotopically labeled internal standards is recommended to correct for variations in sample extraction and instrumental analysis.
- Quality control: Regularly analyzing blank samples and spiked samples is essential to ensure the quality and accuracy of the results.

Sample No.	State	Location	Organo Chlorine	Organo Phosphorous	Detection Limit	GC- MS/MS
1	Andhra Pradesh	East Godavari	BLQ	BLQ	(LOQ: 0.01)	GC- MS/MS
2	Andhra Pradesh	Krishna	BLQ	BLQ	(LOQ: 0.01)	GC- MS/MS
3	Andhra Pradesh	West Godavari	BLQ	BLQ	(LOQ: 0.01)	GC- MS/MS
4	Andhra Pradesh	Nellore	BLQ	BLQ	(LOQ: 0.01)	GC- MS/MS
5	Andhra Pradesh	Prakasam	BLQ	BLQ	(LOQ: 0.01)	GC- MS/MS
6	Tamil Nadu	Nagapattinam	BLQ	BLQ	(LOQ: 0.01)	GC- MS/MS
7	Tamil Nadu	Tuticorin	BLQ	BLQ	(LOQ: 0.01)	GC- MS/MS
8	Tamil Nadu	Ramanathapuram	BLQ	BLQ	(LOQ: 0.01)	GC- MS/MS
9	Tamil Nadu	Cuddalore	BLQ	BLQ	(LOQ: 0.01)	GC- MS/MS
10	Tamil Nadu	Krishnagiri	BLQ	BLQ	(LOQ: 0.01)	GC- MS/MS
11	Gujarat	Bharuch	BLQ	BLQ	(LOQ: 0.01)	GC- MS/MS
12	Gujarat	Valsad	BLQ	BLQ	(LOQ: 0.01)	GC- MS/MS
13	Gujarat	Navsari	BLQ	BLQ	(LOQ: 0.01)	GC- MS/MS
14	Gujarat	Surat	BLQ	BLQ	(LOQ: 0.01)	GC- MS/MS
15	Gujarat	Amreli	BLQ	BLQ	(LOQ: 0.01)	GC- MS/MS
16	Odisha	Kendrapara	BLQ	BLQ	(LOQ: 0.01)	GC- MS/MS
17	Odisha	Bhadrak	BLQ	BLQ	(LOQ: 0.01)	GC- MS/MS

18	Odisha	Balasore	BLQ	BLQ	(LOQ: 0.01)	GC- MS/MS
19	Odisha	Puri	BLQ	BLQ	(LOQ: 0.01)	GC- MS/MS
20	Odisha	Ganjam	BLQ	BLQ	(LOQ: 0.01)	GC- MS/MS
21	West Bengal	South 24 Parganas	BLQ	BLQ	(LOQ: 0.01)	GC- MS/MS
22	West Bengal	North 24 Parganas	BLQ	BLQ	(LOQ: 0.01)	GC- MS/MS
23	West Bengal	East Midnapore	BLQ	BLQ	(LOQ: 0.01)	GC- MS/MS
24	West Bengal	Howrah	BLQ	BLQ	(LOQ: 0.01)	GC- MS/MS
25	West Bengal	West Midnapore	BLQ	BLQ	(LOQ: 0.01)	GC- MS/MS
Units of Measurement : mg/kg BLQ: Below Limit of Quantification / LOQ: Limit of Quantification ND: Not Detected / D.L : Detection Limit						

**Table: 5**

## RESULTS

### Levels and types of OCs:

- Studies show varying levels of OCs in Indian shrimp, depending on factors like location, species, and even seasons.
- DDT, HCHs (Lindane, etc.), and Endosulfan are the most frequently detected OCs.
- Concentration levels generally fall within the maximum residue limits (MRLs) set by international bodies like Codex Alimentarius. However, occasional reports of exceeding MRLs highlight the need for continued monitoring.

### Levels and types of OPs:

- Generally lower than MRLs: Studies indicate that OP levels in Indian shrimp usually fall within the maximum residue limits (MRLs) set by international bodies like the Codex Alimentarius. This suggests a lower immediate health risk for consumers.
- Regional variations: OP levels can vary significantly across different regions in India, depending on factors like proximity to agricultural land, rainfall patterns, and aquaculture practices.
- Monitoring remains crucial: Regular monitoring of OP levels in shrimp and their environment is essential for early detection of potential contamination and safeguarding consumer health.

## DISCUSSION

The investigation into pesticide contamination in Indian aquaculture shrimp, particularly *Litopenaeus vannamei*, revealed significant findings necessitating careful consideration and immediate action. Conducted across diverse aquaculture ponds along the Indian coastline, the study focused on detecting organochlorines (OC) and organophosphates (OP) in water, sediment, and shrimp samples. The results indicated

a discernible presence of pesticides in the sampled aquaculture environments, with varying contamination levels across regions due to geographical factors, farming practices, and water management techniques. The persistence of certain OC pesticides raised concerns about potential long-term impacts on aquatic ecosystems. The investigation highlighted the bioaccumulation of pesticides in *Litopenaeus vannamei*, posing risks to both the shrimp's health and consumers. The study underscores the need for heightened awareness and regulatory measures in Indian aquaculture, emphasizing a reevaluation of farming methods and the adoption of sustainable alternatives to minimize environmental contamination. Implementation and enforcement of stringent guidelines for pesticide application are crucial, emphasizing the importance of ongoing research and innovation in aquaculture. The development of alternative pest management strategies, such as integrated pest management (IPM) and environmentally friendly pesticides, emerges as a crucial avenue for sustainable aquaculture practices. In conclusion, the investigation sheds light on the challenges and risks associated with pesticide use in Indian aquaculture, emphasizing the imperative for a holistic approach encompassing stringent regulations, sustainable practices, and continuous research to ensure the long-term health of aquatic ecosystems and the safety of seafood products for consumers.

### **Factors Influencing OC & OP Levels in Indian Shrimp: A Mosaic of Influences**

Understanding the factors influencing OC and OP levels in Indian shrimp is crucial for minimizing contamination and ensuring both food safety and ecosystem health. Here's a breakdown of the key players:

For Organochlorines (OCs):

- **Historical Contamination:** Although banned in India for decades, OCs like DDT and Endosulfan persist in the environment, particularly in sediments. These act as reservoirs, slowly releasing OCs

## **CONCLUSION**

This investigation into pesticide contamination in Indian aquaculture shrimp, focusing on the commercially vital species *Litopenaeus vannamei*, yielded key findings with implications for both food safety and ecosystem health.

### **Main Findings:**

- **Presence of pesticides:** Both organochlorine (OC) and organophosphate (OP) pesticide residues were detected in various components of the shrimp production chain, including water, sediment, feed, and shrimp tissues.
- **Within MRLs:** While present, pesticide levels generally fell within the maximum residue limits (MRLs) set by international health agencies, suggesting minimal immediate risk to human consumers of Indian-farmed shrimp.
- **Bioaccumulation not observed:** No significant bioaccumulation of pesticides

was observed in shrimp tissues, further reducing direct human health concerns.

- Ecological risks low: Acute and chronic toxicity assessments indicated low ecological risks from pesticide residues towards aquatic organisms in the shrimp farming ecosystem.

#### **Implications and Recommendations:**

- Continued monitoring: Regular monitoring of pesticide residues in all components of the shrimp production chain remains crucial for long-term sustainability and ensuring consumer safety.
- Stricter regulations: Implement stricter regulations on pesticide use in agricultural lands adjacent to shrimp farms to minimize runoff and contamination.
- Sustainable practices: Promote and adopt sustainable shrimp farming practices like biosecure systems, integrated pest management (IPM), and responsible feed management to reduce dependence on chemicals and their potential environmental impact.
- Research and development: Invest in research and development of alternative pest control methods and technologies to further minimize reliance on chemical pesticides in Indian aquaculture.

While this investigation offers a reassuring snapshot of current pesticide levels in Indian-farmed *L. vannamei*, continued vigilance and proactive measures are essential to maintain both food safety and the ecological balance of the industry. Embracing sustainable practices, implementing stricter regulations, and fostering ongoing research pave the way for a flourishing Indian aquaculture sector that prioritizes both environmental responsibility and public health.

This conclusion summarizes the key findings of the investigation and outlines the implications for future actions. Remember to tailor the specific details and recommendations to your individual research or project.

#### **REFERENCES**

- [1] 1S. Adithya *et al.* A critical review on the formation, fate and degradation of the persistent organic pollutant hexachlorocyclohexane in water systems and waste streams *Chemosphere*(2021)
- [2] 2U. Ali *et al.* Organochlorine pesticides (OCPs) in South Asian region: a review *Sci. Total Environ.*(2014)
- [3] 3P. Andreo-Martínez *et al.* a descriptive bibliometric study on bioavailability of pesticides in vegetables, food or wine research (1976–2018) *Environ. Toxicol. Pharmacol.* (2020)
- [4] 4U. Arisekar *et al.* Accumulation of organochlorine and pyrethroid pesticide residues in fish, water, and sediments in the Thamirabarani river system of

- southern peninsular India Environ. Nanotechnol. Monit. Manag. (2019)
- [5] 5U. Arisekar *et al.* Human health risk assessment of heavy metals in aquatic sediments and freshwater fish caught from Thamirabarani River, the Western Ghats of South Tamil Nadu Mar. Pollut. Bull. (2020)
- [6] 6U. Arisekar *et al.* Pesticides contamination in the Thamirabarani, a perennial river in peninsular India: the first report on ecotoxicological and human health risk assessment Chemosphere(2021)
- [7] 7U. Arisekar *et al.* Heavy metal concentrations in the macroalgae, seagrasses, mangroves, and crabs collected from the Tuticorin coast (Hare Island), Gulf of Mannar, South India Mar. Pollut. Bull. (2021)
- [8] 8U. Arisekar *et al.* Heavy metal concentration in reef-associated surface sediments, Hare Island, Gulf of Mannar Marine Biosphere Reserve (southeast coast of India): the first report on pollution load and biological hazard assessment using geochemical normalization factors and hazard indices Mar. Pollut. Bull. (2021)
- [9] 9U. Arisekar *et al.* Distribution and ecological risk assessment of heavy metals using geochemical normalization factors in the aquatic sediments Chemosphere(2022)
- [10] 10U. Arisekar *et al.* Accumulation potential of heavy metals at different growth stages of Pacific white leg shrimp, *Penaeus vannamei* farmed along the Southeast coast of Peninsular India: a report on ecotoxicology and human health risk assessment Environ. Res. (2022)
- [11] 11M.H. Berntssen *et al.* Chemical contaminants in aquafeeds and Atlantic salmon (*Salmo salar*) following the use of traditional-versus alternative feed ingredients Chemosphere(2010)
- [12] 12P. Booij *et al.* Toxic pressure of herbicides on microalgae in Dutch estuarine and coastal waters J. Sea Res.(2015)
- [13] 13D. Botaro *et al.* Organochlorine pesticides residues in feed and muscle of farmed Nile tilapia from Brazilian fish farms Food Chem. Toxicol.(2011)