



RESEARCH ARTICLE

# Pesticide in Indian agriculture: Consumption pattern and farmers perception

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## Abstract

The agricultural sector will need to transform into one that is sustainable more quickly to meet the demands of a growing population with rising incomes. Pests are thought to be growing and spreading quickly in agriculture and forestry ecosystems due to climate change. This study aims to examine the consumption pattern of pesticides in India and to assess the farmers' perception of pesticide use. The consumption of pesticides in India was 52466.45 t in 2022-2023 which has declined from 63284.07 t (2021-2022). The consumption of pesticides was maximum in Maharashtra followed by Uttar Pradesh, Punjab, Telangana and Haryana. In India, pesticide consumption per ha of gross cropped area was 0.322 kg/ha in 2017-18 and declined to 0.289 kg/ha in 2021-22. Jammu & Kashmir leads with rates of 2.097 kg/ha and 3.603 kg/ha in 2022-23 followed by Punjab, Haryana, and Telangana with 0.679 kg/ha, 0.619 kg/ha, and 0.613 kg/ha respectively. Perceived pesticide related environmental and human health impacts influence the farmers' decisions to follow appropriate and sustainable agricultural practices. Farmers are at significant risk of pesticide exposure due to their over-reliance on pesticides, ignorance of safe handling techniques, and limited access to pesticide training which demands prompt action to increase knowledge on those aspects for sustainable pest control, environmental and health protection. The association of mandatory training in the form of seminars and farmers' field schools relating to pesticide application limits, use of personal protective equipment, risks to human health and the environment, enforcement of safety standards and laws for pesticide use and alternative pest management practices with financial support viz., incentives and subsidies may be extremely beneficial.

## Keywords

agriculture; consumption; pattern; perception; pesticides

## Introduction

Globally, the pesticides consumption in agriculture would rise from about 4.3 million t. in 2023 to around 4.41 million mt in 2027 (1). Brazil was the largest pesticide consuming country at 800.65 thousand tonnes. The United States trailed in second with 467.68 thousand t consumed. Worldwide, herbicides make up the greatest percentage at almost 50% followed by fungicides and bactericides at 22.5 % insecticides at 20.4 % and plant growth

regulators at 1.2 %. On the other hand, insecticides account for 51.4 % of the market in India, followed by fungicides and bactericides at 32.6 % and herbicides at 15.8 %. In comparison to Brazil, China, Germany, and the United States, India continuously shown decreased pesticide consumption per unit area (kg/ha) between 1990 and 2021. The amount of pesticides used rose from 2.5 to 4.1 kg/ha in Germany, and from 1.1 kg/ha in Brazil in 1990 to 10.9 kg/ha in 2021. It climbed from 1.1 kg/ha to 1.83 kg/ha in China and from 2.14 to 2.85 kg/ha in the USA. In contrast, India's pesticide consumption decreased from 0.44 kg/ha in 1990 to 0.37 kg/ha in 2021, possibly as a result of the introduction of Bt cotton in 2002 and the ensuing decrease in pesticide use in the cotton crop that uses pesticides (2).

The industrial and service sectors' rapid growth has caused agriculture's share of the Gross Value Added (GVA) to gradually drop to 18.4 % during 2022-23 (3), on the other hand, the sector's significance to the country's economic and social fabric goes much beyond this metric (4). To fulfil the demands of a growing population with rising incomes, India must increase its production of fruits, vegetables, and dairy products in addition to grain crops to provide food security (5). In order to do this, the agricultural sector will need to develop more quickly into one that is sustainable, diversified, competitive, and productive.

For centuries, invading insects and plant pests have posed a serious risk to farmers (6, 7). Pests are thought to be growing and spreading quickly in agriculture and forestry ecosystems due in large part to climate change also (8). Moreover, a significant amount of food production is lost to weeds, plant diseases, and insect pests, among other reasons (9), pesticides, also known as agrochemicals, are essential to maintaining agricultural production. In the developing world, pesticide use is common, and the current crop production system, which places a premium on high agricultural yields, is driving up demand for pesticides (10). Throughout the world, over a thousand chemical and biological pesticides are applied to reduce crop losses (11). In order to reduce the estimated 45% gross loss of crops owing to insect and disease infestation, synthetic pesticides have been widely employed throughout the nation (12). In India, each year, diseases and pests destroy 20–30% of the food that farmers produce, which is valued at approximately Rs. 45000 crore (13). Hence, in the process of developing agriculture, pesticides became an essential tool for protecting plants and increasing crop productivity (14). Pesticides play a crucial role in modern farming, leading to increased output (15). In Indian agriculture, pesticide application is crucially playing its role in reaching the goal because it is one of the foremost procedures followed to protect crops and boost productivity. The nation has been using more pesticides in order to increase agricultural output and meet the food needs of its expanding population. The crop protection chemicals industry is one that is open to innovation and is currently growing quickly. Increased demand for food grains and growing knowledge of agricultural loss from non-use of pesticides are two major factors driving pesticide growth in India. In an effort to minimize crop losses, farmers also typically apply greater

pesticide rates than the dosage advised by experts and extension agents due to the widespread misconception that applying high rates of pesticides is highly effective (16). They are regarded as substantial contributors of diffuse pollution, which may have long-term health consequences for humans. In India, where agriculture plays a central role in the economy, the rampant use of chemical pesticides poses serious risks. Agriculture is one of the human work occupations with the greatest risk levels. Research on agricultural workers' risk perception is frequently referred to as specific risk factors (particularly pesticides), yet risk perception is essential in reducing all types of accidents and occupational diseases (17). Farmers are the main users of pesticides; the degree of awareness and perception about pesticide availability, usage, application methods and its effects intrinsically influence their methods of pest management. Overuse of pesticides was closely linked to farmers' ignorance of pest control and pesticide application (18). Numerous studies expressed that the perceived requirements of farmers were the main determinants of the implementation of alternative methods of controlling pests (19). Nevertheless, the Indian pesticide industry has faced many obstacles, such as the high costs associated with research and development, the threat posed by genetically modified seeds, the need for effective distribution systems, the need to support integrated pest management (IPM), and the widespread presence of counterfeit goods. Given the aforementioned studies, significant questions about the nation's ability to continue its farming industry have been raised. There are undoubtedly ways to use pesticides more wisely, which would reduce the risk of health issues as well as financial losses for farmers. To strengthen the main opportunities including the possibility for increased usage, enormous export potential and product range expansion, it is necessary to trace the consumption pattern of the pesticides in India as well as the perception of farmers towards the pesticide application where the possibilities prevail for sustainable agriculture. The main objectives of the study are to comprehend the pesticide consumption pattern in India and the farmers' perceptions of health risks.

## Materials and Methods

The secondary data used for the analysis were collected from authenticated reports of the Ministry of Agriculture and Farmer's Welfare and the Ministry of Chemicals and Fertilizers, Government of India. The data on state-wise pesticide consumption in India from 2017-18 to 2022-23 were used to derive the recent trend in its consumption pattern. Farmers' perceptions on the level of consuming pesticides and health risks associated with pesticide usage were assessed with a specific focus on the Thondamuthur block of Coimbatore district as it has more area under cultivation of major vegetables such as tomatoes (327.51 ha), small onion (1195.64 ha), bhendi (106.87 ha), and cauliflower (74.95 ha) when compared to other blocks in the district (20) and supplies major vegetables to the market. The detailed survey was conducted by using an interview schedule comprised of close-ended questions (Table 1).

These were in a multiple-choice format so that respondents had to select only the appropriate answers that they thought best described their perception of pesticide usage. The crops tomato, bhendi, onion, and cauliflower selected for the study are heavily treated with pesticides due to their high susceptibility to pests. The survey was conducted in August 2024, with a sample size of 60 farmers who depend on pesticides for pest control. The farmers were selected using stratified random sampling from three villages Narasipuram, Selambanur, and Dhevarayapuram in the Thondamuthur block, with 20 farmers from each village. Prior to conducting the interviews, the interviewers were trained to ensure consistency and accuracy in data collection. The structured interview schedule contains socio-demographic details such as age, gender, education, and monthly income, as well as agricultural practices like crop types, irrigation methods, farm size, and the distance between the fields and farmers' homes. It is necessary to study the farmers' perception because of the tendency of farmers who perceive higher pesticide related risks for the environment and human health to be more likely to adopt pesticide free crop production. The farmer with the high-

est positive perception of the beneficial effects of pesticide free agricultural practices would be more likely to adopt them than the farmer with the lowest perception (20). The farmers' perceptions and practices regarding the safe use of pesticides have been assessed by using a 20-question measure on a five-point Likert scale: Always (5), Often (4), Sometimes (3), Rarely (2), and Never (1). The questionnaire also explored symptoms of pesticide exposure among the participants. The reliability and validity of the interview schedule were tested before data collection. The reliability of the scale used to measure farmer's perceptions of pesticide usage was assessed using Cronbach's Alpha. The analysis revealed a high reliability coefficient of 0.937 across 19 items, indicating excellent internal consistency. This demonstrates that the instrument is reliable for capturing consistent responses from farmers regarding their perception of pesticide usage in Indian agriculture. The analysis was conducted with 60 valid cases, with no exclusions, ensuring a robust evaluation of the scale's reliability. The validity of the scale measuring farmer's perceptions of pesticide usage was evaluated using Pearson's correlation coefficients and significance values. Statements with sig-

**Table 1.** Farmers' perception towards the usage and impact of pesticide application (%)

S.No	Questions	Never	Rarely	Sometimes	Often	Always	Mean	SD
1	Do you select pesticides based on the type of pest affecting your crops?	15.00	20.00	45.00	20.00	0	2.700	0.962
2	Do you read the label on pesticides thoroughly before applying them?	15.00	20.00	45.00	20.00	0	2.700	0.962
3	Do you mix pesticides based on the recommendations of the input dealers?	15.00	20.00	45.00	20.00	0	2.700	0.962
4	Do you use personal protective equipment (PPE) such as masks, gloves, and shoes while spraying pesticides?	31.70	3.30	43.30	0	21.70	2.767	1.466
5	Do you avoid eating or drinking while spraying pesticides?	0	0	35	23.30	41.70	4.067	0.880
6	Do you prefer applying pesticides during the cooler part of the day?	0	0	0	45.00	55.00	4.550	0.502
7	Do you dispose of empty pesticide containers by burying them?	3.30	3.30	55.00	38.30	0	3.283	0.691
8	Are you aware that pesticides can enter the body through inhalation, ingestion, or skin contact?	0	0	63.30	15.00	21.70	3.583	0.829
9	Do you avoid keeping mixed pesticides for later use?	0	0	25.00	30.00	45.00	4.200	0.819
10	Do you believe that pesticides affect the health of animals and pets?	0	0	0	100.00	0	4.000	0.000
11	Are you aware that pesticides can affect the environment?	0	0	0	0	100.00	5.000	0.000
12	Do you take a complete shower immediately after applying pesticides?	0	16.70	25.00	25.00	33.30	3.750	1.099
13	Do you think the overuse of pesticides can lead to long-term health problems for farmers?	0	0	15.00	46.70	38.30	4.233	0.698
14	Do you believe that using pesticides excessively can harm beneficial insects and wildlife?	0	23.3	15.00	25.00	36.70	3.750	1.188
15	Have you noticed any health issues in yourself or your colleagues that you attribute to pesticide exposure?	0	0	100	0	0	3.000	0.000
16	Do you think there should be stricter regulations on pesticide use to protect public health?	0	0	36.70	26.70	36.70	4.000	0.864
17	Are you aware of alternative pest control methods that could reduce reliance on pesticides?	0	16.70	13.30	11.70	58.30	4.117	1.180
18	Do you feel adequately informed about the potential health risks associated with the pesticides you use?	0	61.70	38.30	0	0	2.383	0.490
19	Do you believe that training on safe pesticide application is essential for reducing health risks?	0	0	0	26.70	73.30	4.733	0.446
20	Are you concerned that the cumulative effects of pesticide exposure over time could impact your health?	0	0	0	0	100.00	5.000	0.000

nificance values below 0.05 were considered statistically valid, indicating significant relationships. Statements like "Protective Measures" and "Strict Regulations" exhibited Pearson correlation values above 0.8, confirming their strong validity. Statements like "Health Issues (Colleagues' Pesticide Exposure)" and "Shower After Application" had correlations above 0.9, establishing robust relationships. Statements like "Later Use" and "Overuse Causes Health Issues" showed correlations below 0.5, signifying limited or weak relationships. Statements such as "Disposal" and "Training Safe Practices" showed correlations around 0.5, indicating moderate validity. These relationships are statistically significant but less strong than higher correlations. Descriptive statistical methods, including frequency, percentage, mean, standard deviation, and percentiles, were used to analyze the collected data.

## Results and Discussion

### State-wise pesticide consumption in India

The nation's chemical industry is extremely diverse. The South Asian nation was one of the world's top producers of chemicals, covering thousands of items (21). In India, 299 thousand mt of pesticides were produced in the fiscal year 2022. It was claimed that 104 pesticides are still produced or used in India even though they are prohibited in two or more other nations (22). In India, 318 pesticides were registered and about 51 % of all pesticides used in India were insecticides, whereas 53 % of all pesticides used worldwide were herbicides (23).

The secondary data used for the study were collected from the website of the Directorate of Economics and Statistics, Ministry of Agriculture and Farmer's Welfare and the Ministry of Chemicals and Fertilizers, Government of India. During the period of 2017-18 to 2022-23, the consumption of pesticides in India was high in 2017-18 with 63406 tonnes and low in the year 2022-23 with 52466.45 t which has declined from 63284.07 t in 2021-2022 (Fig. 1) as per the Directorate of Plant Protection, Quarantine & Storage (24) and India is ranked 13<sup>th</sup> in terms of total pesticide use (25). Both total usage as well as per hectare usage of pesticides is very much low in India as compared to other countries and the average data. India uses 0.5 kg of pesticides per hectare, while other nations use up to 17 kg (26).

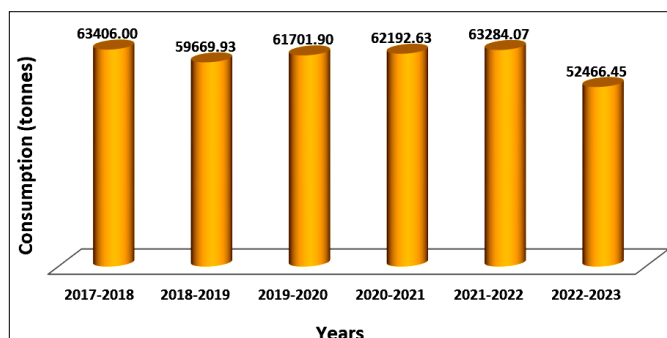


Fig. 1. Pesticide Consumption in India (tonnes).

As per the reported data, the trend in consumption of chemical pesticides has varied from state to state and year to year in the country. The consumption of pesticides

has been found to be maximum in the State of Maharashtra for the specified period from 2017-2018 to 2022-2023 followed by Uttar Pradesh, Punjab, Telangana and Haryana. The lowest level of pesticide consumption was recorded in the state of Arunachal Pradesh in the range of 1.4 t to 5 t for the above period. The state-wise details on the consumption of chemical pesticides during 2017-18 to 2022-23 are presented in Fig. 2.

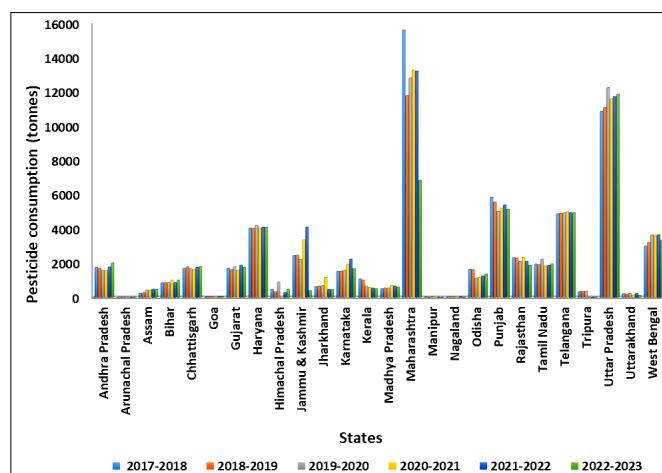


Fig. 2. State-wise Pesticide Consumption in India - 2017-18 to 2022-23.

### Pesticide consumption per ha of gross cropped area (GCA) in India

India used 0.5 kg of pesticides per hectare in 2023; globally, 4.3 million t of pesticides will be used in agriculture in that same year. Some other nations, including China, use pesticides at considerably higher rates than the United States, with an average of over 17 kg/ha (27, 28). In the case of India, there are wide disparities between the pesticide consumption rates among the various states and in contrast, the trend in pesticides per ha for the two period's viz., 2017-18 and 2021-22 goes in parallels with lower variations (Fig. 3). Overall India, pesticide consumption per ha of GCA was 0.322 kg/ha in 2017-18 and declined to 0.289 kg/ha in 2021-22 and the change was about 10.24 %. When it comes to the intensity of pesticide consumption, the state of Jammu & Kashmir leads with rates of 2.097 kg/ha in 2017-18 and 3.603 kg/ha in 2022-23 where many farmers are using large amounts of pesticides to increase their yields because of intense competition and strong demand, which is a result of the farming community's increased tendency towards diversifying their operations through the production of apples in Jammu & Kashmir, vegetables in Assam (29,30,31). In the case of Nagaland, despite the fact that agricultural pests thrive in the Northeastern part of India due to its climate, in recent years, there has been a noticeable rise in the use of pesticides (32).

Punjab, Haryana, and Telangana follow closely behind with 0.679 kg/ha, 0.619 kg/ha, and 0.613 kg/ha in 2022-23. This intensity is mostly caused by the quick conversion of agricultural land into dense orchards, which has increased the need for chemical pesticides.

During the period of 2021-2022, the states viz., Madhya Pradesh (0.022 kg/ha), Rajasthan (0.077 kg/ha) and Bihar (0.116 kg/ha) recorded a low level of pesticide



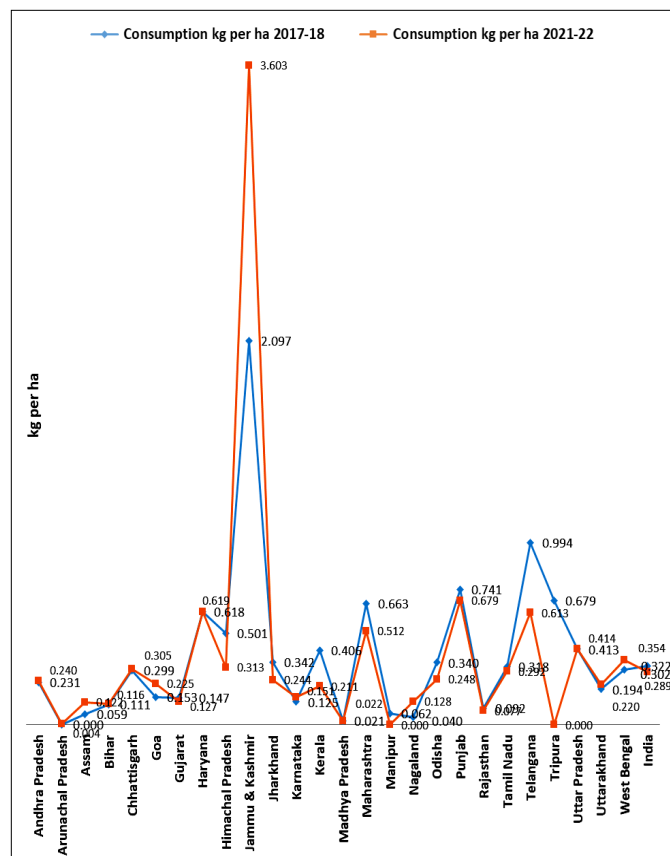


Fig. 3. Pesticide consumption per ha of GCA in India.

consumption per ha of GCA when compared to other states (Table 2). During these five years of pesticide consumption, states like Nagaland, Assam and Jammu & Kashmir increased their pesticide consumption and, Kerala, Telangana and Himachal Pradesh have subsided their consumption of pesticides. The use of bio-pesticides, proper applications of insect-specific chemicals, and genetically-engineered crops are the prime factors for reduction in pesticide use (11, 33).

### Pesticide consumption in Tamil Nadu

Infectious diseases and pests have impeded the growth of the horticulture industry. Due to their nutritive value and natural palatability, vegetables are often targeted by pests and insects. Pest and disease incursions might result in a 30 % reduction in production in Tamil Nadu. To address this issue and ensure the development of high-quality products, large amounts of pesticides and other agro-chemicals are utilized. More than 70 % of vegetable growers in Tamil Nadu only use pesticides to control specific insects and diseases (34). The state stands at 12<sup>th</sup> place in pesticide consumption across the country with 1952 tonnes in 2022-23 (30). While comparing these periods, pesticide consumption in Tamil Nadu was higher in 2019-2020 with 2225 tonnes (Fig. 4).

The pesticide consumption per hectare of gross cropped area in Tamil Nadu is derived for the period from 2017-18 to 2022 -23. The data depicted that pesticide consumption per hectare was 337 g in 2017-18 then declined to 312g in 2022 -23 constituted 7.42 %. In the middle, it attained a higher volume of 375 g in 2019 – 20 which is also synchronized with the total consumption in the state in the same year (Fig. 5).

Table 2. Pesticide consumption per ha of Gross Cropped Area in India (Kg/ha)

States	Consumption (kg/ha)		Percentage Change
	2017-2018	2021-22	
Andhra Pradesh	0.231	0.240	4.04
Assam	0.059	0.122	106.31
Bihar	0.111	0.116	4.55
Chhattisgarh	0.299	0.305	2.11
Goa	0.153	0.225	47.19
Gujarat	0.147	0.127	-13.77
Haryana	0.618	0.619	0.16
Himachal Pradesh	0.501	0.313	-37.37
Jammu & Kashmir	2.097	3.603	71.87
Jharkhand	0.342	0.244	-28.60
Karnataka	0.125	0.151	20.57
Kerala	0.406	0.211	-48.09
Madhya Pradesh	0.021	0.022	2.81
Maharashtra	0.663	0.512	-22.81
Nagaland	0.040	0.128	223.65
Odisha	0.340	0.248	-27.02
Punjab	0.741	0.679	-8.38
Rajasthan	0.092	0.077	-16.87
Tamil Nadu	0.337	0.292	-13.37
Telangana	0.994	0.613	-38.36
Uttar Pradesh	0.413	0.414	0.34
Uttarakhand	0.194	0.220	13.49
West Bengal	0.302	0.354	17.25
India	0.322	0.289	-10.26

Derived from the data collected from Ministry of Agriculture and Farmers Welfare, Government of India.

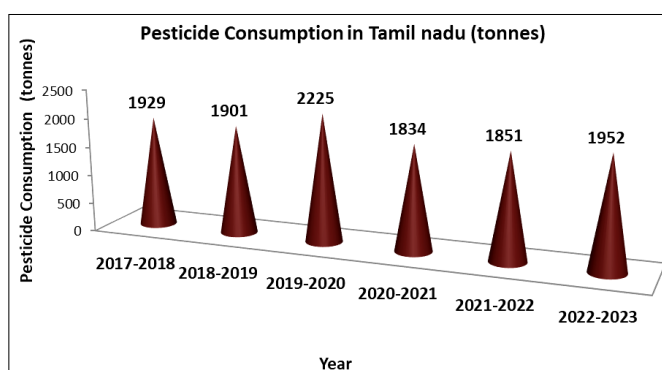


Fig. 4. Pesticide consumption in Tamil Nadu.

### Farmers' perception towards the usage and impact of pesticide application

It is a constant challenge to determine how farmers see the use of pesticides, application techniques, danger, and safety. Since different farmers' perceptions are typically influenced by a variety of factors, such as cultural values, beliefs, attitudes, education, society, and laws and regulations pertaining to the use of pesticides, it is possible to observe divergent views regarding pesticide usage among various categories of farmers. Farmers may benefit greatly from information and guidance from pesticide retailers and authorities, sufficient training, farm field schools,

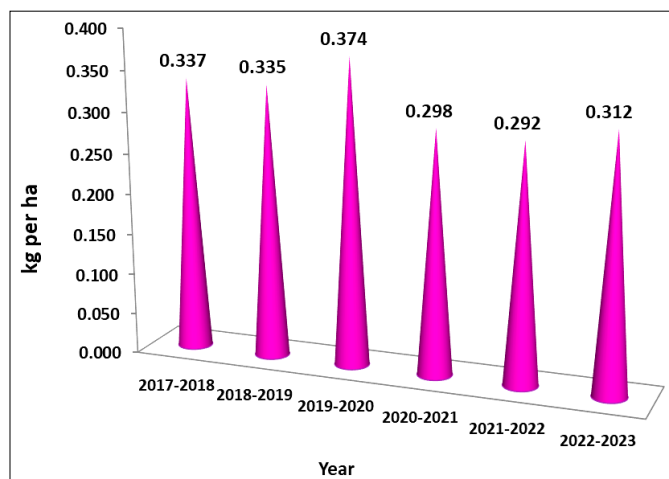


Fig. 5. Pesticide consumption (kg/ha) in Tamil Nadu.

professional advice and their own and neighbours' experiences (35) which can help them make better decisions on pesticide usage and increase their awareness of the dangers associated with using pesticides. It is investigated that perceived pesticide related environmental and human health impacts influence the farmers' decisions (36, 37) to follow appropriate and harmless agricultural practices or organic farming (Hashe) to sustain vegetable production for long term. Multiple responses from the sample farmers against the various questions raised during the interview are categorized below in Table 1. The majority of respondents (45%) selected "sometimes" when selecting pesticides based on the type of pest damaging the crop but may not always have the resources or knowledge to apply them consistently (38). This suggested that while pest identification is crucial, farmers may not always use pest-specific pesticides. Those who choose "never" or "rarely" may be limited by economic constraints or lack the essential insect identification abilities, forcing them to rely on broad-spectrum pesticides rather than pest-specific ones. About 45 % of respondents read pesticide labels thoroughly before using them for "sometimes" as they may not always have the time, literacy abilities, or patience to do so. Other farmers may rely too much on assistance from input dealers or fellow farmers to get information which also coincide with other studies (39, 40).

In India, five pesticides are restricted for use but have been authorized for production, while 49 pesticides are prohibited for usage as of March 2024. The main goal of India's pesticide usage policy governed by the Insecticides Act of 1968 is to control the import, production, sale, and use of pesticides within the nation. It focuses on outlawing highly hazardous pesticides and encouraging safer alternatives considering international standards and working with other nations to ensure responsible pesticide use through mechanisms. However, India's pesticide regulations are regarded as being less strict than those of many developed countries, raising concerns about possible health and environmental risks. Policies to reduce the use of pesticides have been somewhat successful in a number of other countries, especially in the European Union (EU), where strategies such as encouraging Integrated Pest Management (IPM), using pest-resistant crop varieties, and

replacing highly toxic pesticides with less harmful alternatives have resulted in significant reductions in the overall use of pesticides. Nevertheless, there are still issues with ensuring consistent implementation and addressing potential concerns regarding food security and farmer livelihoods (41).

Around 15 % of the farmers "never" mix the pesticides that adhere to dealer advice due to previous negative experiences or a desire for self-determined solutions, which could be motivated by cost-cutting methods or local wisdom. The mean value (2.70) indicates that farmers may selectively adopt input dealers' suggestions, while the SD indicates moderate variability in practices among respondents. A sizable proportion (31.7%) of respondents "never" uses personal protection equipment (PPE) due to the inconvenience, pain, or cost of purchasing PPE. In rural areas, protective gear may be expensive or unavailable, and some farmers may be unaware of the health risks associated with pesticide exposure (42, 43). Farmers who "always" avoid eating or drinking while spraying (41.7%) are likely to have a clear understanding of the risks of ingesting pesticides, possibly from training. Given the substantial health concerns, extension agencies should continue to emphasize the dangers of eating or drinking while applying pesticides to ensure that all farmers use safe methods. The majority of respondents (55%) "always" prefer spraying during low temperatures indicating that pesticides are more effective and safer to apply when temperatures are lower as evaporation is minimized and chemicals remain on plants for longer. Many sample farmers (55%) bury unused pesticide containers for "sometimes" because they consider it as an easy and quick disposal strategy, especially when formal trash disposal facilities are unavailable. They may also be unaware of the environmental concerns associated with burying chemicals as found in the study (44, 45). The majority of individuals (63.3%) are aware that pesticides can enter the body via inhalation, ingestion, or skin contact. All responders (100%) agree that pesticides harm the health of animals and pets, and they are aware of the environmental impact of pesticide use as a result of visible results such as soil degradation, water contamination, or harm to nearby wildlife.

The respondents (58.3%) are "always" likely to be aware of integrated pest management (IPM), organic farming, or biological controls, whether through training programs, community exchanges, or media exposure. In addition to causing major contamination of soil and water, the use of pesticides is often associated with unfavorable consequences, including poisoning and long-term health effects for farmers and farm workers who load, mix, and spray pesticide products as well as clean pesticide clothing or spray equipment (46). Therefore, to lessen the adverse side effects linked to occupational pesticide exposure, suitable exposure reduction methods are needed. Using PPE including face mask, goggles, gloves, hat, protective clothing, boots and respirator when working with pesticide is effective risk-mitigation strategy to prevent pesticide exposure' health problems when handling pesticides can reduce the health consequences on farmers and pesti-

cide operators (47). The majority (61.7%) of respondents are informed "rarely" about the potential health concerns associated with the pesticides they use. It also represents a knowledge gap, since farmers may be not aware of the long-term effects of exposure, particularly if they seek guidance from dealers or peers rather than formal training. None of the respondents claimed to be properly knowledgeable, as evidenced by the mean score of 2.38. The majority of farmers (73.3%) "always" believe training is necessary because they identify gaps in their own or others' understanding of safe pesticide usage. These farmers may have experienced or witnessed the effects of poor pesticide treatment, such as health issues or environmental damage, and consequently place a high emphasis on structured instruction. All respondents (100%) who chose "always" are extremely concerned about the long-term health consequences of pesticide exposure, suggesting a thorough understanding of the cumulative dangers.

## Conclusion

In India, the consumption of pesticides declined to 52466.45 t (2022-2023). Pesticide consumption per ha of the gross cropped area also declined from 0.322 kg/ha in 2017-18 to 0.289 kg/ha in 2021-22 due to the application of bio-pesticides, Integrated Pest Management and genetically engineered crops which led to sustainable agriculture. Hazardous pesticides can be prevented from entering the market by implementing a strong pesticide registration procedure that includes comprehensive safety evaluations, environmental impact analyses, and periodical reviews of pesticide registration based on new scientific findings. All farmers must have access to mandatory pesticide applicator training programs that address safe mixing, application methods, safety equipment usage, disposal techniques, and establishing pest thresholds to reduce needless pesticide use. These programs also help farmers protect themselves. Financial incentives for farmers who utilize Integrated Pest Management techniques and subsidies for the purchase and use of biopesticides, along with financial assistance for biopesticide research and development, will motivate stakeholders to lessen their over-reliance on conventional pesticides. Also, farmers should get education on the enforcement's ability to penalize noncompliant pesticide usage and about infractions related to it.

There is a potential to implement tighter limits on pesticide sales and use and better enforcement of safety standards which include stronger regulations and rigorous monitoring of pesticide application methods. The agriculture and public sectors collaborate to support farmers by creating a unified policy in the above aspects and supporting guidelines for the application of both chemical as well as bio-pesticides.

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## Authors' contributions

AJR conceptualized and formulated the research manuscript. BK helped in the statistical analysis of data. SA helped in the tabulation and editing of the manuscript. NN helped in collecting the data. PPM helped in summarizing and revising the manuscript. ES helped in editing the manuscript. KSB helped in reviewing the manuscript. RM helped in summarizing the manuscript. All authors read and approved the final manuscript.

## Compliance with ethical standards

**Conflict of interest:** Authors do not have any conflict of interests to declare.

**Ethical issues:** None

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