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Pesticide Use Knowledge among Vegetable Growers in Bangladesh: Implications for Sustainable Agriculture, Farmer Health, and Environmental Integrity

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Abstract

In Bangladesh, pesticides are frequently used in vegetable production to control pests and diseases with little consideration of their impact on the environment and human health, and their use remains largely uncontrolled despite the existence of several pesticide control rules and regulations. Against this backdrop, the study examined traditional practices, knowledge, behavior, and propensity for pesticide usage, as well as the impact of these chemicals on farmers' health and the environment. Data were collected through a questionnaire survey, Focus Group Discussions (FGDs), and Key Informant Interviews (KIIs) in the study villages. The health impact was illustrated through graphical presentations generated using the Statistical Package for the Social Sciences (SPSS), while a likelihood ratio test was used to examine links between health problems and factors such as pesticide use frequency, training level, education, and protective coverings. Results indicate that 60% of farmers apply pesticides, insecticides, and fungicides daily or weekly without necessary protective measures, and 68% rely on personal experience and fellow farmers' advice rather than Bangladesh guidelines. Harvesting often occurs within 2-5 days of pesticide application, especially for vegetables like long beans and eggplant, leading to health issues including gastric problems, headaches, nausea, skin problems, and diarrhea. Over-pesticide use also adversely affects the environment, depleting soil fertility and contaminating water. Addressing these challenges requires strengthening farmer training and awareness programs, including community-based initiatives such as Uthan Boithok, and promoting organic and sustainable farming practices that encourage the safe use of pesticides while safeguarding both farmer health and the environment.

Keywords: Pesticide use, Health hazard, PPE, Environmental contamination, Vegetable production

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1. Introduction

The issue of environmental degradation has become pertinent in recent years (Ali et al., 2024), with agriculture playing a substantial role in this process. From the beginning of the sixth decade of the last century, the world agricultural system started to be modernized, and chemical inputs increased manyfold (Rahman et al., 2021). Pesticides are pivotal in global agriculture, significantly boosting crop yields and protecting against pest-induced losses (Damalas and Eleftherohorinos, 2011); approximately 40% of potential crop losses are averted annually through the application of around 5 billion kg of insecticides worldwide (Oerke, 2006). Despite this crucial role, the persistent nature and high toxicity of pesticides raise concerns for human health and the environment, and also lead to increased production costs and unintended consequences as pests develop resistance over time (Carvalho, 2006; Gavrilescu et al., 2015). The World Health Organization (WHO) has highlighted the long-term health risks associated with pesticide exposure, including cancer, neurological disorders, reproductive impairments, and respiratory and skin problems (WHO, 1990). Sharma et al. (2010) and Zhang et al. (2015) note that pesticides play a vital role in meeting the ever-increasing global food demand by boosting productivity, but that their widespread use poses challenges to sustainable agriculture by contaminating essential resources such as air, water, and food. Developing nations, particularly farmers in rural regions, bear the brunt of pesticide-related illnesses and fatalities, accounting for 99% of such cases annually (Miller 2004; Zhang et al. 2011). According to estimates from WHO (2009), at least 300,000 individuals die each year from pesticide poisoning, with low- and middle-income nations accounting for 99% of these deaths, VVand the World Bank estimated that 355,000 people died in 2008. However, according to FAO (2005), which cited new data from Sri Lanka, pesticide poisoning may cause as many as 300,000 annual deaths in the Asia-Pacific region alone (Gyawali, 2018). Moreover, estimates from the UN Environmental Program and the World Health Organization indicate that three million farm workers in poor nations suffer severe pesticide poisoning each year, with over 18,000 losing their lives (Miller, 2004). Numerous pesticides have been shown or are believed to be endocrine-disrupting chemicals, substances that interfere with the endocrine system's normal function and may cause illness or abnormalities in both the organism and its progeny (McKinlay et al., 2008); breast cancer risks, for instance, is greater among women living in areas where agricultural pesticide use has been rising (Reynolds et al., 2005). Pesticides and other organic contaminants also have wide-ranging, often interconnected ecological effects on ecosystems as well as individual organisms; Swedish research, for example, identified pesticide use as one of the main factors influencing biodiversity loss. According to WWF, the rise in sickness, malformations, and tumors among commercial fish species in heavily contaminated regions of the North Sea and UK coastal waters since the 1970s is consistent with consequences linked to pesticide exposure (FAO, 1996). Pesticide-induced groundwater contamination is likewise a global issue: the USGS reports that at least 143 distinct pesticides and 21 transformation products, representing all major chemical classes, have been detected in groundwater (Kole and Bagchi, 1995, cited in Aktar et al., 2009). Due to improper application and handling by untrained farm workers, most pesticides use in poor nations such as Nepal is linked to negative impacts on human health and the environment (Naidoo et al., 2010). Research from Vietnam suggests that approximately 80% of pesticides used in Vietnamese agriculture are applied improperly, which raises production costs, reduces bioefficacy, and increases the environmental hazard load (Nguyen, 2014).

Bangladesh, a densely populated nation heavily reliant on agriculture, illustrates the complex interplay between pesticides, agricultural practices, and their consequences. With limited land resources, Bangladesh depends heavily on pesticides, and agriculture contributes significantly to the GDP (13.3% in 2018-2019) (BBS, 2020a). Bangladesh is now the third-largest vegetable producer in the world, with an anticipated 19.7 million metric tonnes (MT) produced in 2020–2021(BBS, 2022). Vegetables, essential components of a healthy diet, are particularly susceptible to pests, necessitating intensive pest management; a myriad of vegetable species are cultivated on approximately 470,414 hectares of land in Bangladesh, with an annual growth rate of 2.8% (BBS, 2010). Government initiatives, such as providing free pesticides before 1974 and substantial subsidies thereafter, have contributed to the intensified use of pesticides among vegetable growers (Amin and Bashu, 2004); although use began in 1951, it remained low until the 1960s. Some 242 trade names of pesticides and 84 active compounds in different formulations have since been registered for crop and vegetable protection in the country (Ara et al., 2014), indicating a massive increase in use. Pesticide consumption in Bangladesh is reported to have surged from 758 metric tons in 1960 to 48,690 metric tons in 2008, reflecting growing dependence on these chemical interventions (Islam et al., 2016; Miah et al., 2014). However, the excessive use of pesticides, including prohibited ones, raises concerns about their impact on both human health and the environment (IRIN, 2010). Reports from Bangladesh have documented extremely high concentrations of organophosphate and carbamate pesticides in soil and water (Chowdhury et al., 2012; Shammi et al., 2014), and the widespread use of organophosphate insecticides has led to a disturbing finding that 900 farmers out of every 100,000 suffer from pesticide poisoning (Dasgupta and Meisner, 2005). A lack of proper awareness, insufficient self-protection measures among farmers, and excessive pesticide application all contribute to these alarming statistics (Goldner et al., 2010). The World Bank's findings highlight the common issue of excessive pesticide use among vegetable cultivators in Bangladesh, particularly those involved in bean and eggplant farming (Dasgupta and Meisner, 2005). Moreover, highly toxic pesticides, both permitted and prohibited, are frequently employed by Bangladeshi farmers, contributing to significant health and environmental impacts (Meisner, 2004; Robinson et al., 2007; Shammi et al., 2020). More than 47% of Bangladeshi farmers growing Boro (winter rice), potatoes, beans, eggplant, cabbage, sugarcane, and mangoes have also been found to overuse pesticides. This overuse is a potentially dangerous issue for both the environment and farmers' health, since only 4% of farmers have received official training in pesticide use or management, and more than 87% freely acknowledge taking little to no precautions while applying pesticides (Dasgupta, 2007). Although data from around the world indicate several connections between agricultural practices and products and environmental health concerns, public policy initiatives have frequently targeted agriculture and health separately (Sarkar et al., 2012), Even though the importance of occupational health and safety has grown in recent years (Cecchini et al., 2018). This overuse of pesticides, coupled with a lack of knowledge and protective behavior among vegetable farmers, creates a substantial impact on both health and the environment that remains largely undocumented in Bangladesh. Against this backdrop, this study tried to assesses pesticide usage in vegetable farming, including practices, health risks, and farmer perceptions of pesticides' environmental impact, and develops targeted recommendations for safer pesticide use and environmental protection.

2. Materials and methods

Both primary and secondary data were used in this investigation. Primary data were gathered through a questionnaire survey, focus group discussions, and Key-informant discussions in two agrarian villages—one in Godagari Upazila, Rajshahi district, and the other in Manirapur Upazila, Jashore district purposively chosen for their intensive vegetable-growing characteristics (Fig.1). These villages are known for producing a wide range of vegetables, including okra (Abelmoschus esculentus), cauliflower (Brassica oleracea var botrytis), eggplant (Solanum melongena), tomato (Lycopersicon esculentum), bitter gourd (Momordica charantia), pumpkin (Cucurbita pepo), cucumber (Cucumis sativus), white spot arum (Amorphophallus), radish (Raphanus sativus), chili (Capsicum annuum L.), cabbage (Brassica oleracea var. capitata), long beans (Vigna unguiculata), papaya (Carica papaya), and others.

A total of 191 respondents, purposefully chosen from among active vegetable growers, pesticide dealers, and retailers, were used for the questionnaire survey and FGDs, while agricultural officers, local leaders, and school teachers served as key informants. Various statistical tools, including descriptive and analytical statistics, were then used to process and interpret the data. Descriptive statistics were used to display the frequency distribution and percentages of the variables, while analytical statistics such as likelihood ratio tests demonstrated the relationship between distinctive characteristics of vegetable growers — including gender, education, training, precautions taken, and health risks. Finally, the impact of pesticide contamination on the environment was examined using a binary logistic regression model, since this technique predicts a dichotomous outcome, such as whether perceived environmental quality is changing (yes/no), and is appropriate where linear regression would violate its error assumptions and yield out-of-range probabilities (Hosmer et al., 2013; Peng et al., 2002).

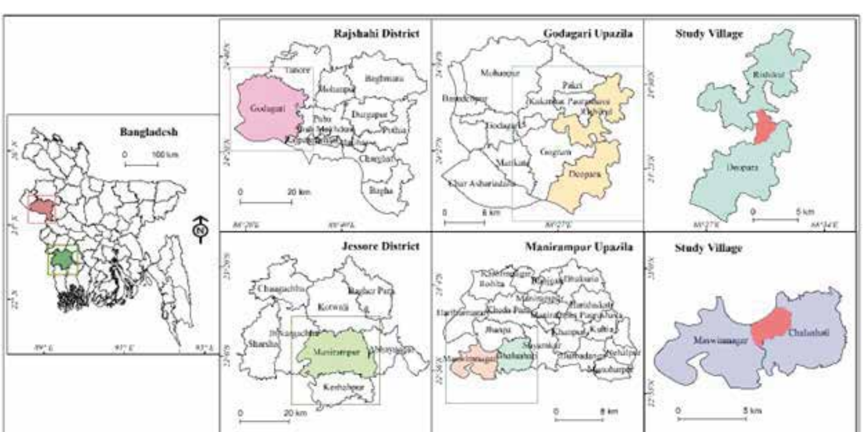


Fig 1. Study area map

3. Results and discussions

In most situations, the relationship between pesticide use and its effects on the environment and human health depends on the demographics of the farmers, primarily their age, sex, and educational attainment (Shammi et al., 2020; Nguyen, 2017). In light of this perspective, the following is a visual representation of the examination of farmers' demographic patterns:

3.1 Demographic profile and experiences of the vegetable growers

The demographic details of the vegetable growers who participated in the study's interviews are shown in Figure 2. The information sheds light on the participants' age groupings, education levels, gender distribution, and pesticide use experiences.

3.1.1 Gender Similar trends were seen in the research area, where males predominate in agricultural practices. Only 2.09 percent of respondents were female, while 97.91 percent of respondents were male.

3.1.2 Age The interviewed growers were distributed across various age groups. Ages 30 to 40 made up the largest age group (37.20%), followed by those over 40 (28.80%).

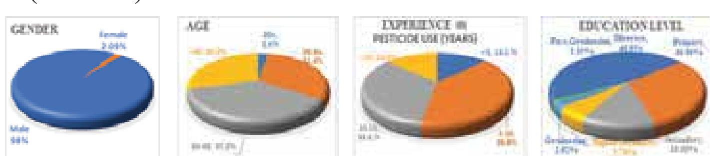


Fig 2. Demographic Characteristics of the interviewed vegetable growers

3.1.3 Experience in Pesticide Use The participants' duration of pesticide use experience varied. 39.80% of the largest group had five to ten years of experience. However, a startling number of people (13.6%) have worked with pesticides for more than 15 years. Additionally, 33.5% have 10–25 years of pesticide application experience.

3.1.4 Education Level The vegetable growers' levels of education also differed. A sizable portion of farmers are illiterate (46.60%), followed by those with lesser levels of education (30.89%), primarily primary education. Numerous studies have found that farmers' perceptions of the health risks associated with chemical pesticide use are influenced by factors such as age, agricultural experience, education level, farm size, yield, average income, and membership in agricultural organizations (Liu et al.,2021; Bakhsh et al., 2017). Ghalavandi et al. (2018) stressed the importance of proper knowledge and education for handling pesticides safely at every stage, including purchase, storage, composition, spraying, and correct waste disposal. Janmaimool and Watanabe (2014) similarly validated the impact of prior experience, attitude, mental norm, perceived ability to regulate risk, and sociodemographic characteristics (age, gender, education, socioeconomic level, and membership in organizations) on health-risk perception, while Ahmadipour and Nakhei (2024) showed a significant relationship between education and pesticide-related health risks.

3.2 Tradition of pesticide use and knowledge of the vegetable growers

Agrochemicals, such as pesticides and chemical fertilizers, are prevalent in agriculture, especially among intensive and small farm holders like those in Bangladesh, a densely populated nation whose society is highly dependent on the agricultural economy (BBS 2016; BBS 2020b; WB 2016a). Farmers' answers to questions on their knowledge and pesticide usage behaviors are shown in Table 1. About 48% of farmers use pesticides only when required to control pests, while 34% and 18% use pesticides daily and weekly, respectively; frequency also varies by vegetable variety, with farmers who grow eggplant and long beans heavily responsible for the frequent use of pesticides, often applying an excessive dose in the belief that increased application leads to increased output. Similar results were reported in previous World Bank research showing that pesticide abuse is common among Bangladeshi vegetable growers, particularly those who raise eggplant and beans (Dasgupta and Meisner 2005). The most commonly used pesticide input (42.93%) was insecticides; rodenticides (3.14%) were less common than fungicides (31.41%) and herbicides (22.51%), and over 85% of farmers use both fungicides and insecticides, with overdosing remaining common. Farmers' decisions about pesticide use are influenced by a number of factors; 40.31% relied mostly on recommendations from other farmers, and 28.80% on their own experience, while proposals from pesticide retailers (16.75%) were also important, and labeling guidelines (8.38%) and recommendations from agricultural authorities (5.76%) had a smaller impact, with very few farmers following agriculture officers' suggestions. According to similar results from an earlier study (Chowdhury et al. 2013a), most Bangladeshi farmers base their pesticide selections on their own experience and the recommendations of pesticide merchants rather than official guidance. Farmers also had varying preferences regarding when to apply pesticides: application before an attack (24.60%) and after the severe stage of an attack (1.04%) were less common than application at the primary stage of attack

(31.93%) or when needed (42.41%) — though even this more appropriate practice remain underused. Most respondents (94.90%) preferred spraying, with only 5.09% choosing granular approaches, and 30.37% of farmers sprayed pesticides on an empty stomach, while 69.63% did so on a full stomach, suggesting that many farmers continue to disregard the correct way to apply pesticides. The interval between final spraying and harvesting is similarly important: most respondents reported intervals of 2–5 days (38.21%) and 5–10 days (28.78%), with smaller shares reporting intervals of less than 2 days (20.41%) or more than 10 days (12.56%) — a pattern likely linked to the 84.19% of farmers who lack adequate training on pesticide use and its effects on human health. By comparison, a previous study of small-scale commercial vegetable growers in Vietnam found that 54.8% of vegetables had a preharvest interval of 8 to 15 days, while 31.4% had fewer than 7 days (Nguyen et al. 2017).

Table 1. Pesticide use tradition among vegetable growers

Variables	Response (%)	Variables	Response (%)
Pesticide usage frequency		**Pesticide usage types**	
Daily	34.03	Insecticides	42.93
Weekly	18.33	Fungicides	31.41
Used when needed	47.64	Herbicides	22.51
		Rodenticides	3.15
Pesticide application based on		**When should pesticides be**	
Personal experience	28.80	**applied?**	24.60
Agricultural officer's	5.76	Before Attacking	31.93
suggestion	8.38	Primary Stage of Attacking	1.06
Labeling instruction	40.31	Following the Severe Stage of	42.41
Fellow farmer's suggestion	16.75	Attacking	
Pesticide retailer's suggestions		When needed	
Prefer method of pesticide		**Pesticide application with**	
applications	5.09	Empty stomach	30.37
Granular	94.91	Full Stomach	69.63
Spray			
Interval Between Spraying		**Training received?**	
and Harvesting		Yes	15.81
<2	20.41	no	84.19
2-5	38.21		
5-10	28.78		
>10	12.56		

3.3 The behavior of vegetable growers during pesticide application

Although behavior is shaped by a complex array of factors that are far from well understood or consistent across situations, attitudes toward the environment influence behavior, which in turn is shaped by information and knowledge. Table 2 shows vegetable growers' behavior regarding pesticide application: the majority (76.97%) do not take safety measures during pesticide application, while those who do use partial cover with towels on the face (37.41%), masks (22.45%), or full shirts (40.14%). Yang et al. (2014) note that protective measures taken before, during, or after pesticide application are thought to effectively reduce farmers' risk, yet 71% of farmers in a comparable survey did not use sufficient protective clothing, with the majority of those who did relying on a complete shirt and a towel over the face (Nguyen et al. 2017). A study of the Moghan Plain region of Iran likewise found that roughly half of farmers used little personal protective equipment, with a long-sleeved shirt the most common item work, and personal protective equipment use rising alongside farmers' negative opinions of pesticides (Bondori et al., 2018). After pesticide use, farmers took a range of precautions, including changing dress (23.04%), washing hands with water only (38.22%), washing hands with mud and water (11.51%), washing hands with soap (19.89%), taking a shower (5.25%), and doing nothing (2.09%). A major concern, however, was the handling of used pesticide bottles and packets and the disposal of remaining pesticides: research results indicate that a majority of growers (76.96%) leave pesticide bottles and packets in the field after use, while 13.08% burn them and 9.96% preserve them for further use; regarding disposal of the remaining pesticide, 53.49% of respondents spray it continuously until finished, 30.01% unload it on the ground, and 16.50% keep it for the next spray. Similar findings were made in an earlier study conducted in Oman, where applicators' (workers from South Asia, including Bangladesh) practices for handling partially used pesticides were shown to be problematic, with 81.1% storing them in other areas of the house and 14.9% storing them in their bedrooms, and personal protective equipment (PPE) such as nose masks and eye protection was hardly ever employed when applying pesticides (Esechie and Ibitayo, 2011).

Table 2. Pesticide use behavior among vegetable growers

Variables	Total responses (%)	Variables	Total responses (%)
Taking safety measures during spray?		**Types of safety cover taken**	
Yes	23.03	Towel on face with a few cloths	37.41
No	76.97	Mask with normal cloth	22.45
		Full shirt only	40.14
Preventive precautions conducted immediately following pesticide use		**Pesticide bottle and packet after use**	
Change dress	23.04	Burned	13.08
Wash hands with only water	38.22	Left in the field	76.96
Wash hands with mud and water	11.51	Preserve for further use	9.96
Wash hands with soap	19.89		
Take shower	5.25		
Do nothing	2.09		

Disposal technique of the remained pesticides			
Unloaded on the ground	30.01		
Kept for the next spray	16.50		
Until finished, spray continuously	53.49		

3.4 Trends of pesticide use among vegetable growers

Pesticides are essential to sustaining high output in vegetable growing, protecting crops from pests and diseases (Khatun et al., 2023; Mahugija et al., 2017; Tudi et al., 2021). To cultivate traditional and new rice types, potatoes, spices, vegetables, and cotton, farmers frequently use pesticides in place of fertilizers (Rahman, 2013), and with limited land available to feed a large population,. Bangladesh depends heavily on intensive application of chemical inputs to boost crop yield. Fig. 3 illustrates trends in different types of pesticide usage in Bangladesh from 2000 to 2018, categorized into Rodenticides, Herbicides, Fungicides, Insecticides, and Total Use. Total pesticide use rose rapidly from 15632.24 MT to a high of 48690.19 MT in 2008, before declining to 37,187.28 in 2018 — still well above the 2000 level. Insecticides use grew sharply from 13,430.71 MT in 2000 to 30,115.18 MT in 2008, peaking alongside total use, but then declined consistently after 2008, reaching 14,838.29 MT in 2018, while fungicide use grew steadily from 1,220.06 MT in 2000 to 16,087.97 MT in 2018, indicating the growing importance of fungal disease control in agriculture; rodenticides remained negligible, highlighting a limited focus on rodent control. Vegetable growers were also asked during the survey about their perception of the pesticide use trend: 76% of farmers (Fig.4) said that pesticide use in vegetable farming had increased significantly over the years, while 19% said it was decreasing. A similar result has been reported in numerous studies.: Islam et al. (2015, cited in Begum et al. 2025) note an alarming rise in pesticide use in Bangladesh, driven by a significant increase in vegetable output, with over 37,000 MT applied in 2022 compared to 19,000 MT in 2000.

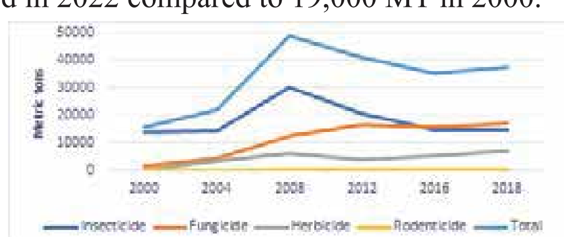


Fig. 3. Total pesticide consumption from 2000 to 2018 in Bangladesh (Mt)

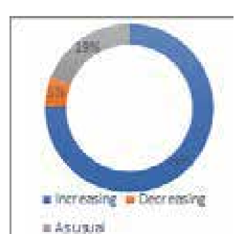
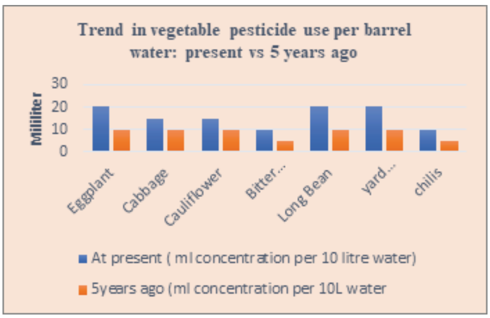


Fig 4. Farmer's perception on pesticide use propensity in vegetable farming

Source: Bangladesh Crop Protection Association

Similarly, the data in Fig.5 show that pesticide use has increased for all vegetables over the past five years, in both concentration per 10 liters of water and total volume per acre. Vegetables like eggplant, long bean, and yard-long bean now use double the previous amount and even for crops like bitter gourd and chilis, where acreage use remained low, concentration levels have risen. This trend highlights a notable intensification of pesticide application in the study area.



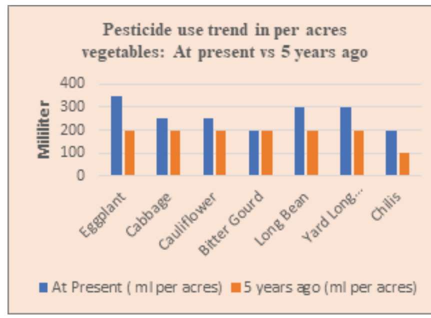


Fig 5: Trend of pesticide usage in the vegetables of the study area.

Moreover, Table 3 presents information on various pesticides used by farmers in the study area, including their common names, active ingredients, WHO hazard classifications, and application targets. Most insecticides, like Alco 550 EC and Heron 5 EC, are moderately hazardous (Class II), while some, like Goldazim 500 SC and Amistar 250 SC, are classified as low hazard (Class U); abamectin-based pesticides are marked with UK guidelines, indicating special handling instructions, and a few entries, like Upperclem and Amistar, lack WHO classifications. The table also includes the herbicide Roundup 480 SC, targeting weeds, with a Class III (slightly hazardous) rating. Though the table presents commonly used pesticides and their hazard classifications, field observations during the survey also revealed the use of banned pesticides like Ultima 40 WG and Diazinon 14G. The presence of these restricted or prohibited chemicals raises serious concerns about a lack of awareness, weak regulatory enforcement, and unsafe farming practices in the study area — concerns reinforced by other studies finding that a significant number of pesticides used in Bangladesh appear on lists of banned or restricted substances (such as dichlorvos, dicrotophos, disulfoton, ethyl parathion, methyl parathion, mercury compounds, monocrotophos, phosphamidon) under international agreements such as the Stockholm

Convention, the Basel Convention, and the Rotterdam Convention (Chowdhury et al., 2018; Meisner, 2004; Begum et al., 2025).

Table 3: Different types of pesticides used by farmers of the study area

Common name	Active ingredients	WHO class	Application
Alco 550 EC	Chlorpyrifos 50% and cypermethrin 5%	ii	Maggots, sap-sucking, and soil-dwelling pests
Goldazim 500 SC	Carbendazim 50%	U	Red rust, Sigatoka, powdery mildew
Heron 5 EC	Lufeneuron	ii	Jab insects, bed bugs, brown insect
Toximite 1.8 EC	Abamectin	UK	Spiders
Salvenation 32.5 SC	Abamectin	UK	Late blight
Upperclem 5 SG	Emamectin benzoate		Insects, aphids, and fruit borers
Amistar 250 SC	Azoxystrobin	U	Vegetable, rice, cotton, and tree nut diseases, including leaf spots, blights, and powdery mildew.
Roundup 480 SC	Glyphosate	iii	Weeds

3.5 Health Impacts of Pesticide Use on Farmers: Symptoms, Treatment, and Contributing Factors

Farmers in the study area experienced a variety of health issues during or after using pesticides. Gastric issues were the most commonly reported health problem among farmers, with 39.3% of respondents experiencing it, while headaches and nausea were also relatively common, affecting 19.9% and 14.7% of farmers, respectively; skin problems, diarrhea, and poisoning were reported to a lesser extent but remain noteworthy at 8.4%, 9.9%, and 7.8%, respectively. Similarly, a survey in Oman noted that skin irritation (70.3%), burning (39.2%), headache (33.8%), vomiting (29.7%), and salivation (21.6%) were health symptoms related to pesticide exposure (Esechie and Ibitayo 2011). These health problems appear to be compounded by farmers' tobacco use while spraying: a significant proportion of farmers (36.1%) reported using tobacco during pesticide spraying,, most commonly by smoking with other forms of tobacco use accounting for the remainder. However, a major concern is that most farmers (65.4%) did not visit a health facility when experiencing pesticide-related health problems, and self-treatment was the most common approach, used by 54.5% of farmers, while village doctors and community clinics were used to a lesser extent, at 18.3% and 12.0%, respectively (Table 4).

Table 4: Farmers' health issues and their treatment techniques

Variables	Total responses	Variables	Total responses
Farmers experienced health		**Visit the health complex**	
problems	39.3	Yes	34.6
Gastric	19.9	No	65.4
Headache	14.7		
Nausea	8.4		
Skin problem	9.9		
Diarrhea	7.8		
Poisoning			
Addiction during spray		**Pesticide-related health**	
Smoking	36.1	**issues treatment method**	
Remain of tobacco	13.6	Self-treatment	54.5
Betel leaf	4.2	Village doctor	18.3
No addiction	46.1	Community clinic	12.0
		Napa, omeprazole	6.3
		Health complex	8.9

Table 5 shows the results of a likelihood ratio test examining the relationship between farmers' characteristics and the occurrence of health problems due to pesticide use, evaluating how factors like gender, age, education, training, protective measures, and frequency of pesticide use are statistically associated with pesticide-related health issues. The results also reveal that education level, training, protective measures, and frequency of pesticide use have a significant association with farmers' health problems during or after pesticide application. Education showed a strong influence at the $p<0.01$ level, indicating that better education may reduce health risks, while training and use of protective measures were highly significant ($p<0.001$), suggesting their critical role in minimizing health issues. Frequency of pesticide use also showed a strong association with health outcomes ($p<0.001$), highlighting the danger of repeated exposure. Gender was only marginally significant ($p=0.036$), and age was not significantly associated ($p=0.083$). These findings align with Nguyen et al. (2017), who also identified education, protective equipment, and pesticide frequency as major influencing factors.

Table 5: Relationship Between Farmers' Characteristics and Health Problems from Pesticide Use

Farmer's characteristics	Likelihood ratio test		
	Value	df	P value
Gender	11.935	5	.036
Age	23.051	15	.083
Education level	40.03	18	.01
Training	35.406	5	<0.001
Types of Protective Measures	29.96	10	0.001
Frequency of pesticide use	35.19	10	<0.001

Significant association at $p<0.01$ and $p<0.001$ levels respectively

3.6 Farmers' perception of the impact of pesticides on vegetable farming and the environment

Table 6 summarizes vegetable growers' perceptions of the environmental impacts of pesticide use, while Table 7 presents the results of a binary logistic regression model identifying which of these perceptions significantly influence the belief that overall environmental quality is declining. Most farmers reported experiencing soil fertility loss (68.1%), water contamination (67.0%), pest resistance (63.9%), and pest incidence (62.8%) due to pesticide use, consistent with earlier research showing that pesticides increase vegetable production but that their overuse creates a serious problem for agriculture and the environment (Kapka-Skrzypczak et al. 2011; Shorma et al. 2014). However, the regression analysis revealed that only air contamination, perceived by 41.8% of respondents, was positively and significantly associated with the perception of environmental degradation ($B = 0.853$, $p = 0.009$). In contrast, perceptions of water contamination ($B = –1.036$, $p = 0.003$), reduced soil fertility ($B = –0.762$, $p = 0.027$), and developing pest resistance ($B = –0.922$, $p = 0.006$) showed significant but negative associations, suggesting an inverse or complex relationship, while pest incidence, although commonly reported, was not statistically significant ($p = 0.663$). The overall model was statistically significant ($–2LL = 231.26$, Nagelkerke $R^2 = 0.213$), indicating modest explanatory power. These findings suggest that while farmers widely recognize several environmental impacts from pesticide use, they conceptually separate specific agricultural issues from broader environmental degradation, likely reflecting overlapping or interrelated perceptions. This highlights the importance of targeted awareness and education to align farmers' understanding of specific pesticide effects with overall environmental outcomes, and underscores the need to address water, soil, and air quality impacts in pesticide management. Similar arguments have been made in previous research: according to Swedish research, pesticide use is one of the most important factors affecting biodiversity, and according to WWF, since the 1970s, the North Sea and the coastal waters of the United Kingdom have experienced an increase in sickness, malformations, and tumors in commercial fish species, consistent with consequences known to be caused by chemical exposure (FAO 1996). Glotfelty and Schomburg (1989) also note that every application of pesticides results in some drift, even when using ground-based equipment, so that air, water, and soil — the most vital components of the ecosystem— can all be contaminated by pesticides, altering the quality of the ecosystem.

Table 6: Perception of the vegetable growers on the environmental impacts of pesticide use

Variables	Frequency	Yes (%)	Mean	SD
Increasing insect incidence?	120	62.8	.63	.48
Increasing insect resistance?	122	63.9	.64	.48
Decreasing soil fertility?	130	68.1	.68	.46
Is air contamination increasing?	79	41.4	.59	.49
Is water contamination increasing?	128	67.0	.67	.47

Table 7: Result of the Binary Logistic Regression

Do You Think Environmental Quality is Changing Due to Pesticide Contamination? (Dependent variable)

Variables in the equation

Explanatory variables	B	S.E.	Wald	df	Sig.
Increasing pest incidence	.147	.339	.189	1	.663
Water pollution	-1.036	.348	8.893	1	.003
Air contamination	.853	.328	6.764	1	.009
Reducing soil fertility	-.762	.344	4.890	1	.027
Developing pest resistance	-.922	.339	7.418	1	.006
Constant	.949	.391	5.890	1	.015

-2 log likelihood=231.26, Nagelkerke R Square=.213, level of significance=0.0

3.7 Measures to improve farmers' safety behavior and pesticide-related

environmental issues

In Bangladesh, where agriculture plays a pivotal role in the livelihoods of a densely populated society, addressing the prevalent use of pesticides and fertilizers is of paramount importance (BBS 2016; BBS 2020b; WB 2016a). Recognizing that farmers are key stakeholders in mitigating environmental pollution and safeguarding their own health as well as that of their families, it is imperative to address their perceptions of pesticide-related risks. To enhance knowledge and promote safer pesticide practices in rural areas, the following recommendations are suggested:

3.7.1 Education and Training: Implement targeted educational programs for farmers and retailers on pesticide use, handling, and safety. Collaborate with agricultural extension services to provide regular training sessions that emphasize the proper application of pesticides and the associated risks. These programs should also underscore the importance of adhering to safe pre-harvest intervals.

3.7.2 Awareness Campaigns: Launch public awareness campaigns in rural communities to inform farmers about the potential negative impacts of pesticides on human health and the environment. Use a variety of media channels, including radio, television, and community meetings, to disseminate information about safe pesticide practices and their benefits.

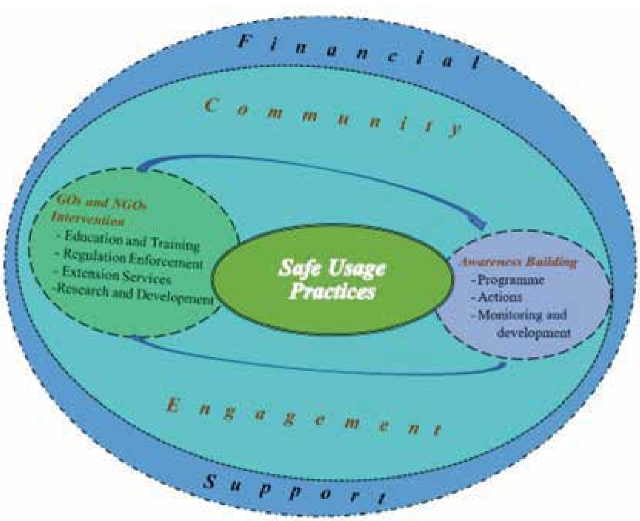


Fig 6: Safe Usage Practices Framework

3.7.3 Safe Usage Practices: Emphasize the adoption of safe pesticide usage practices, including the use of protective clothing, equipment, and recommended dosages. Promote the implementation of Integrated Pest Management (IPM) techniques, which reduce reliance on chemical pesticides (Fig 6).

3.7.4 Regulation and Enforcement: Strengthen the enforcement of existing pesticide regulations, such as the Pesticides (Amendment) Act, 2009, in Bangladesh. Develop more stringent legislation where necessary to address gaps and ambiguities in pesticide control. Increase penalties for non-compliance and ensure that regulatory agencies have adequate resources for monitoring and enforcement.

3.7.5 Extension Services: Strengthen and upgrade agricultural extension services to offer continued assistance to farmers with timely information, training, and technical advice. The DAE carries out programs such as Integrated Pest Management (IPM) and the Farmer Field Schools (FFS), which educate farmers in the field on the appropriate use of safe pesticides and the sustainable production of field crops, as well as help promote environment-friendly practices more broadly. These services need to be extended to strengthen their education on sustainable, environmentally friendly farming techniques, including organic farming, crop rotation, and biopesticides.

3.7.6 Financial Support: Seek funding from both government and non-government sources to support farmer training programs and the implementation of safe pesticide practices. Encourage the private sector to invest in research and development of safer, more eco-friendly pesticides.

3.7.7 NGO and Donor Interventions: Collaborate with non-governmental organizations (NGOs) and donor-funded initiatives like UTHAN BOITHOK (yard meeting) and Integrated Pest Management (IPM) to further promote responsible pesticide use. These organizations can play a significant role in providing resources, expertise, and advocacy for sustainable agriculture.

3.7.8 Research and Development: Invest in research and development efforts to identify and promote low-toxicity, eco-friendly alternatives to highly and moderately toxic pesticides. Encourage local universities and research institutions to engage in research that benefits both farmers and the environment.

3.7.9 Monitoring and Reporting: Establish a robust monitoring and reporting system for pesticide residues in agricultural produce. This will help to ensure compliance with safety standards and enable timely corrective actions when contamination is detected.

3.7.10 Community Engagement: Engage local communities and farmers in discussions and decision-making processes related to pesticide use and environmental protection. Encourage community-driven initiatives to reduce pesticide risks and promote sustainable farming practices.

4. Conclusion

The study reveals that pesticides are the predominant method used for pest management in Bangladeshi vegetable farming, yet they are widely viewed as hazardous, posing risks to the environment, crop quality, and consumer health. Alarmingly, the findings show that farmers are significantly exposed to these risks while also jeopardizing the broader ecosystem. Pesticide contamination of the environment and its adverse health effects on farmers are pressing concerns that stem from a lack of training, excessive reliance on pesticides, limited awareness of pesticide risks, low literacy rates, and insufficient knowledge of personal protective equipment. Addressing these issues demands the promotion of personal protective equipment (PPE), comprehensive training in pesticide application, and a concerted effort to improve education. Correcting pesticide handling practices, tightening monitoring of banned pesticides, and developing extensive training programs are all pivotal to raising farmers' awareness of the risks pesticides pose to their health and the environment. Effective regulation of pesticide use, promotion of non-chemical or organic pest control methods, and streamlining the process for banning harmful pesticides are indispensable steps toward sustainable vegetable farming. Realizing a future of sustainable agriculture in Bangladesh will require directing financial support toward alternative practices such as organic vegetable farming and the adoption of integrated pest management (IPM) strategies. The government must play a central role in providing pesticide application training and must also work with NGOs to help ensure farmers' safety. Given the health and environmental consequences of chemical pesticides, a paradigm shift in agriculture is urgently needed — one centered on substantially reducing chemical pesticides use, to the benefit of public health, the ecosystem, and the wider economy. This study contributes to the existing literature by offering a comprehensive assessment of pesticide use practices, farmers' knowledge and awareness, associated health and environmental impacts, and the socio-economic determinants of pesticide dependence in Bangladeshi vegetable farming. Future research should focus on evaluating the long-term health and environmental impacts of pesticide exposure, as well as assessing the effectiveness and adoption of integrated pest management (IPM) and other sustainable pest control alternatives among farmers.

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