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Current status of pesticide practices and management approaches toward the safety and health of Cambodia: A review

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សង្ខិត្តន័យ

ថ្នាំសម្លាប់សត្វល្អិត វាត្រូវបានប្រើប្រាស់យ៉ាងទូលំទូលាយបំផុតនៅពាសពេញពិភពលោក។ នៅក្នុងបណ្តាប្រទេសដែលមានប្រាក់ចំណូលទាបនិងមធ្យម ថ្នាំសម្លាប់សត្វល្អិតត្រូវបានប្រើប្រាស់យ៉ាងទូលំទូលាយបំផុតក្នុងវិស័យកសិកម្ម។ កសិកម្ម គឺជាផ្នែកដ៏សំខាន់បំផុតក្នុងវិស័យសេដ្ឋកិច្ចកម្ពុជា។ ប្រហែលជាង 80% នៃប្រជាជនរស់នៅតាមតំបន់ជនបទ ភាគច្រើន ប្រកបរបរកសិកម្មដើម្បីចិញ្ចឹមជីវិត។ ប្រជាកសិករកម្ពុជាបានប្រើថ្នាំសំយោគគីមីសម្រាប់បាញ់សម្លាប់សត្វល្អិត ដើម្បីការពារកសិផលរបស់ខ្លួនពីការបំផ្លាញរបស់សត្វល្អិតចង្រៃ។ ការកើនឡើងនៃផលិតផលកសិកម្មនិងកំណើនប្រជាជនយ៉ាងឆាប់រហ័ស បាននាំឱ្យមានការកើនឡើងនៃការប្រើប្រាស់ថ្នាំកសិកម្ម ដែលបណ្តាលឱ្យមានការព្រួយបារម្ភអំពីផលប៉ះពាល់អវិជ្ជមានទៅលើបរិស្ថាន និងសន្តិសុខស្បៀងនៅកម្ពុជា។ នៅក្នុងប្រទេសកម្ពុជា សកម្មភាពនៃការប៉ះពាល់និងការពុលកាកសំណល់ថ្នាំគីមីសម្លាប់សត្វល្អិត តាមរយៈការបរិភោគអាហារប្រចាំថ្ងៃ សុទ្ធតែពុំមានការត្រួតពិនិត្យឱ្យបានច្បាស់លាស់។ របាយការណ៍បែបវិទ្យាសាស្ត្រជាច្រើននៅក្នុងប្រទេសកម្ពុជាក៏បាននិយាយអំពីរឿងនេះដែរ ហើយនិយាយទូលំទូលាយជាងនេះទៀតផង។ ដូច្នេះហើយ អត្ថបទស្រាវជ្រាវនេះផ្តល់នូវទិដ្ឋភាពទូទៅនៃការប្រើប្រាស់ថ្នាំសម្លាប់សត្វល្អិតនៅកម្ពុជា នាពេលបច្ចុប្បន្ននេះ និងបង្ហាញចំណេះដឹងអំពីការប្រើប្រាស់ថ្នាំសម្លាប់សត្វល្អិតក្នុងចំណោមកសិករស្រុកស្រែចំការ។ ក្នុងអត្ថបទនេះក៏មាននូវការពិពណ៌នាអំពីការវាយតម្លៃហានិភ័យនៃវត្តមានថ្នាំសម្លាប់សត្វល្អិតនៅក្នុងម្ហូបអាហារដោយផ្អែកលើទីផ្សារក្នុងស្រុកនៃកម្ពុជា។ ដូចគ្នាដែរ អង្គការសុខភាពពិភពលោកបានចាត់ទុកថា ថ្នាំសម្លាប់សត្វល្អិត ដែលកសិករបានប្រើប្រាស់ មានសភាពគ្រោះថ្នាក់ខ្លាំងបំផុត គ្រោះថ្នាក់ខ្លាំង ឬគ្រោះថ្នាក់មធ្យម។ ការសិក្សានេះក៏បានពិភាក្សាផងដែរអំពីវិធីសាស្ត្រគ្រប់គ្រងការប្រើថ្នាំពុលច្រើនមុខលាយគ្នា និងទស្សនវិស័យនាពេលអនាគតសម្រាប់ការប្រើប្រាស់ថ្នាំសម្លាប់សត្វល្អិតនៅកម្ពុជា។ លទ្ធផលនៃការសិក្សា បានលើកឡើងនូវការព្រួយបារម្ភយ៉ាងខ្លាំងទាក់ទងនឹងសុវត្ថិភាពបរិស្ថានធម្មជាតិ និងសុខាមាភាពមនុស្ស។ ទោះបីជាថ្នាំសម្លាប់សត្វល្អិតមួយចំនួនត្រូវបាន

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ហាមឃាត់ក៏ដោយ ប្រជាកសិករស្រុកស្រែចំការ កាគច្រើន នៅតែបន្តប្រើថ្នាំគីមីសម្លាប់សត្វល្អិតទាំងនោះសម្រាប់ដំណាំកសិកម្មរបស់ពួកគេ។ ការសិក្សានេះសូមផ្តល់អនុសាសន៍យ៉ាងទទួចជូនចំពោះរាជរដ្ឋាភិបាលកម្ពុជា ឱ្យបន្តផ្តល់គោលនយោបាយសុខភាពសាធារណៈជាក់ស្តែងស្តីពីការគ្រប់គ្រងការប្រើប្រាស់ថ្នាំសម្លាប់សត្វល្អិត និងការបណ្តុះបណ្តាលពីរបៀបប្រើថ្នាំសម្លាប់សត្វល្អិតឱ្យបានសមស្រប។

ABSTRACT

Pesticides have been one of the most extensively used throughout the world. In low- and middle-income countries, pesticides are extensively used in agriculture. Agriculture is Cambodia's most important economic sector. Around 80% of the population lives in rural areas and is mainly involved in subsistence farming. Cambodian farmers use synthetic pesticides to protect their agricultural products from pest infestation. The increase in agricultural products and the rapid population growth have led to the rise of farming pesticides, which causes concerns about the negative impact on environmental issues and food security in Cambodia. The routes of exposure, toxicity, and pesticide residues in daily food intake are all ambiguous in Cambodia. The scientific reports available in Cambodia could be more extensive and consistent. Therefore, this report provides an overview of the current status of pesticide practices in Cambodia and relates knowledge of pesticide use among local farmers. The contents described the risk assessment of pesticide contamination based on the Cambodian local market. In the same way, the pesticides that farmers use were considered extremely hazardous, highly hazardous, or moderately hazardous by the World Health Organization. This study also discussed the integrated pesticide use management approach and the future perspectives for pesticide practices in Cambodia. The review's findings raised serious concerns regarding environmental safety and human health. Although some pesticides have been banned, most local farmers still use them for agriculture. The study strongly recommends that the Royal Government of Cambodia be provided with a concrete public health policy on pesticide management and suitable training on pesticide applications.

1. Introduction

In agriculture, insects may be classified as destructive pests if the damage it cause to the crops is sufficient to reduce the quality of the harvested product (Kimkhuy & Chhay, 2014). Pesticides are crucial chemical compounds in agriculture since they protect crops from pests or diseases that cause destruction (Umapathi et al., 2022; Popp et al., 2013). The benefits of pesticides include increased food production, higher agricultural yields, and disease control (Lykogianni et al., 2021; Wang et al., 2021). There would be a 78% loss in fruit production, 54% in vegetable production, and 32% in cereal production. Consequently, pesticides significantly improve crop yields, reduce disease, and provide a plentiful supply of high-quality food (Lamichhane, 2017). Two significant pesticide classifications are based on toxicity level and chemical structures (Engel et al., 2011). Many pesticides, such as herbicides, insecticides, fungicides, rodenticides, and herbicides, were used for different target crop threats (Sokcheng et al., 2021). According to the current statistics, 47.5% of pesticide contributions are insecticides at 29.5%, fungicides at 17.5%, and other insecticides at 5.5% (Sharma et al., 2019; Zhang, 2018). One of those pesticides used in agriculture the most frequently is organophosphate, which accounts for approximately 40% of all the pesticides produced and used commercially (Kaushal et al., 2021). According to the Food and Agriculture Organization's previous reports, the agricultural use of pesticides increased from 2,299,979 to 4,122,334 tons worldwide between 1990 and 2018 (Cengiz et al., 2021). In 2019, about 4.19 million tons of pesticides were consumed worldwide, with China consuming the most (1.76 million tons), followed by the US (408 thousand tons), Brazil (377 thousand tons), and Argentina (204 thousand tons) (Pathak et al., 2022).

Besides consumption, China is well known as one of the big pesticide exporters in the world (Yatoo et al., 2022). The World Health Organization's yearly report on Southeast Asia showed a 20% rise in pesticide consumption in emerging nations, including Cambodia, Laos, and Vietnam (Schreinemachers et al., 2015). India is one of Asia's major pesticide-producing countries (Pozo et al., 2011). Between 2010 and 2014, the average annual consumption of Japan was reported (18.94 kg/ ha), followed by China (10.45 kg/ha), Mexico (7.87 kg/ ha), Brazil (6.16 kg/ha), Germany (5.12 kg/ha), France (4.85 kg/ha), UK (4.03 kg/ha), US (3.88 kg/ha), and India (0.26 kg/ha) (Zhang, 2018). With the average world consumption, approximately 2.68 kg were applied per hectare of cultivated land (Manjarres-López et al., 2021). In agrochemical-based agriculture, pesticides are conventionally used to control pest insect populations in paddy fields in many Asian countries (Sarker et al., 2021; Rola & Pingali, 1993). The most dangerous pesticides to the environment are those containing organochlorine pesticides (OCPs), polychlorinated biphenyls (PCBs), aldrin, dieldrin, and dichlorodiphenyltrichloroethane (DDT). OCPs can persist in the environment for more than 40 years in soil, water, fish tissue, and other aquatic biotas (Islam et al., 2022).

The use of pesticides has been on the rise for the past decade, especially in Asian countries where pesticide poisoning is the leading cause of mortality (Jett & Lein, 2006). Improper use of pesticides can generate pesticide resistance by negatively affecting non-target, often beneficial organisms (Guedes & Cutler, 2014). Improper pesticide use is problematic and occurs in many developing countries (Matsukawa et al., 2016; Atreya et al., 2011). Pesticide use will continue to increase as global demand for food increases, with significant growth in low- and middle-income countries (Fox et al., 2021). After applying the improper spray, pesticides contaminate the environment through agricultural applications (Sharma et al., 2021; Ragnarsdottir, 2000), and soil contamination is not a target while using pesticides (Vašíčková et al., 2019). Still, pesticide residues in soil samples or sediments can also

generate pesticide pollution of surface and ground waters (Pérez-Lucas et al., 2019; Hvězdová et al., 2018). Assessment of pesticide residues in soils, most of these studies reported from the US (Marburger et al., 2002), China (Liu et al., 2016), India (Mishra et al., 2012), Brazil (Laabs et al., 2002), South Korea (Park et al., 2020), Japan (Asaoka et al., 2019), or EU countries (Silva et al., 2019). Pesticide contamination is considered of environmental interest because of its potential toxicity and the physicochemical properties that interact with the environment. It could lead to water contamination for human consumption (Barbieri et al., 2020). Contaminated water can cause diarrhea, skin diseases, malnutrition, and even cancer and other diseases related to water pollution (Lin et al., 2022).

The residues of pesticides have found a direction into the underground water system by leaking into the ground, where the agricultural runoff water is disposed (Ali et al., 2021). The residues have been reported to give rise to various short- and long-term health effects in humans, such as carcinogenic, teratogenic, or hepatotoxic (Alarcan et al., 2020; Sharma et al., 2020; Wallace & Djordjevic, 2020). Worldwide, approximately 3 million people are exposed to pesticides annually, with fatalities reaching an alarming rate of 300,000 deaths (Balali-Mood & Saber, 2012). India and Sri Lanka are the two leading countries affected by pesticide poisoning, as reported by epidemiological studies and 1,571 deaths in a particular year (Thunga et al., 2010). Cambodian people face dangers from pesticides and residues accumulated in food products, which can affect most citizens' health (Eliste & Zorya, 2015). Imports of pesticides into Cambodia have increased 285-fold in the last decade, indicating a considerable increase in pesticide use (Kimkhuy & Chhay, 2014). Recently, many pesticides have been imported; for instance, 738,545 tons in Cambodia in 2015 (Matsukawa et al., 2017). Officially, 13,800 more tons of pesticides were imported in 2016 than in 2015 (Flor et al., 2018). Even though the Royal Government of Cambodia has imposed various restrictions on hazardous pesticides, these substances may still be marketed illegally in Cambodia, as they may not be restricted in Cambodia's neighboring countries. The illegal mechanisms of banned pesticide imports in Cambodia remain poorly understood. Not many significant studies have been conducted in Cambodia to evaluate the health risks associated with these pesticides, which commonly include acute neurological disorders. Therefore, this review aims to critically elucidate the current status of pesticide practices in Cambodia and the management approach toward protecting safety and health. Moreover, this review will not only scientifically discuss the improvement of pesticide practices in Cambodia but will also contribute to practical applications in Cambodia for the future.

2. Cambodian farmers' knowledge of pesticide application

Nowadays, Cambodia does not manufacture its agrochemicals; they are mostly imported from Vietnam, Thailand, China, and the European Union. Pesticides import into Cambodia are increasing at an estimated annual rate of 61%, compared to Laos and Vietnam's 55 and 10% rates, respectively (Schreinemachers et al., 2017). A previous study by Schreinemachers et al. (2017) studied how 900 farm households in Cambodia that grow leaf mustard and yard-long beans use pesticides. They used the weekly pesticide application rate per hectare as a proxy for pesticide management practices. Their observational data show that farmers' understanding of pesticide use needs improvement. Moreover, the study discovered that those farmers received advice from friends, neighbors, and particularly from sellers. Likewise, the study conducted by Wang et al. (2011) demonstrated that the levels of OCPs dominated by DDTs and HCH were much higher in Cambodian products than in other countries, with an estimated daily intake (EDIs) of 330 $ng.kg^{-1}.day^{-1}$.

Farmers' pesticide exposure mainly occurs during land preparation for cultivation, storage, mixing, spraying, loading, and cleaning spraying equipment (Ye et al., 2013; Perry & Layde, 1998). Farmers are regularly exposed to high levels of pesticides, usually much more significantly than consumers (Damalas & Koutroubas, 2016). It has been reported that farmers in their district and community have ready access to various chemical inputs at local markets. Occasionally, these commodities are even sold in local stores in their villages. As the package registration labels indicate, most products are imported from licensed agricultural inputs dealers. If the necessary information is translated into Khmer, pesticides from these sources could help reduce the misuse of harmful pesticides. Two categories of pesticide buyers frequent these stores. Farmers who buy pesticides based on experience are in the first group. Farmers ask dealers for pesticides from specific brands or familiar companies that have utilized in previously. The second group involves farmers who need to gain previous knowledge of pesticides. The dealers play the role of consultants for farmers, with brands selecting or mixing pesticides based on the farmer's information. Pesticide dealers occasionally advise combining five different types of pesticides in these mixtures, usually containing three pesticides (Flor et al., 2018).

Local dealers with farmers to share their knowledge of pests, insecticides, and credits for inputs. Many agricultural pesticide products are still labeled in foreign languages, such as Thai, Vietnamese, Chinese, etc., that farmers do not understand. Translation to Khmer can help farmers understand (Pananurak, 2013). Thus, farmers have increased their confidence in retailers over the last few years. Based on the previous findings, 90% received information from pesticide retailers in their decision on pest management, and 60% from the local pesticide retailers (Taylor et al., 2020; Winarto, 2004). In line with the previous study, the farmers often mixed several pesticide products in one spray tank and applied them simultaneously. Some farmers utilized the same product or completely changed the product used each time during the growing season. Some farmers believed their mixed pesticides could enhance rice growth and control pests (Matsukawa et al., 2016). Farmers often use pesticides at the wrong time, in excess doses, and with the incorrect type of pest mentioned on the pesticide packaging label. An inadequate understanding of pesticides exacerbates this improper use due to the lack of a relevant instruction manual written in the native Khmer language (Brown, 2002).

Consequently, many farmers have experienced symptoms of pesticide poisoning (Jensen et al., 2011). The previous research study demonstrates that Cambodian farmers frequently use pesticides as the most practical pest management approach (Matsukawa et al., 2016). Moreover, pesticides were usually applied due to the appearance of pests in the farmers' fields and the types of pesticides used. Their application timing varied according to demographic profile, cultivated crop varieties, and the reason for cultivation. Consequently, the current status of pesticide use in Cambodia revealed that Cambodian farmers' knowledge of pesticide application is still limited. To address this, the Royal Government of Cambodia has issued new regulations restricting the use of hazardous pesticides and has pledged to update available instructions (Ramos-Sanchez, 2017).

3. Pesticide uses in Cambodia's vegetable farming

Vegetable growing in Cambodia has not been thoroughly investigated. The use of pesticides in agriculture has significantly increased in the country by approximately 61% from 2003 to 2012. A study in 2017 reported that 33% of vegetable and fruit exports from Vietnam to European countries exceeded maximum residue limits (MRLs) for pesticide residues (Schreinemachers et al., 2017). Despite being a crucial driver of the country's economic development, around 70% of Cambodia's fresh fruits and vegetables are imported from neighboring countries, primarily Vietnam (Sokcheng et al., 2021). Vegetables are a vital part of the Cambodian diet, with over 96% of the population consuming vegetables on an average of 4.8 days a week. However, market gardening represents only 1.3% of the total agricultural area in Cambodia (Schreinemachers et al., 2017). Phnom Penh's vegetable markets primarily rely on local produce from various Cambodian provinces and significant imports, with Vietnam being the leading supplier. However, Vietnamese vegetables may not be safer than Cambodian vegetables since they rarely undergo food safety inspections (Sokcheng et al., 2021).

Previous studies of pesticide contamination of vegetables in local Cambodian markets have found organochlorine residues (Wang et al., 2011), organophosphate, and carbamate (Neufeld et al., 2010) exceeding the maximum residue limits (MRLs). Among the 13 nations in the region, Cambodia has the most significant pesticide residue on vegetables, especially green vegetables from Kandal province (**Fig.1**) (Wang et al., 2011). According to the Cambodian Center for Study and Development in Agriculture report, farmers around the Mekong River frequently spray vegetables and rice with excessive concentrations of dangerous chemical pesticides (**Fig.2**). According to the Food and Agriculture Organization (FAO) in 2012, the cost of agricultural pesticide imports into Cambodia was estimated at a total cost of USD 890,000 in 2001, which increased to USD 2.2 million in 2006. The price of agrochemical pesticide imports rapidly increased up to USD 629,186 million in 2010 (at least a 285-fold increase in pesticide use in just five years) (**Fig.3**) (Kimkhuy & Chhay, 2014).

4. Pesticide uses in Cambodia's rice farming

Since rice is a significant energy source in worldwide diets and is consumed by more than three billion people (Hoang et al., 2021), it is cultivated in more than 100 countries, with 90% of the total global production in Asia (Wong & Brown, 2021; Fukagawa & Ziska, 2019). The mainland Indochinese of Southeast Asia, Cambodia, was previously categorized as low-income but had more recently transitioned to a lower-middle-income country (Ramstrand et al., 2021; Than, 2019). Rice

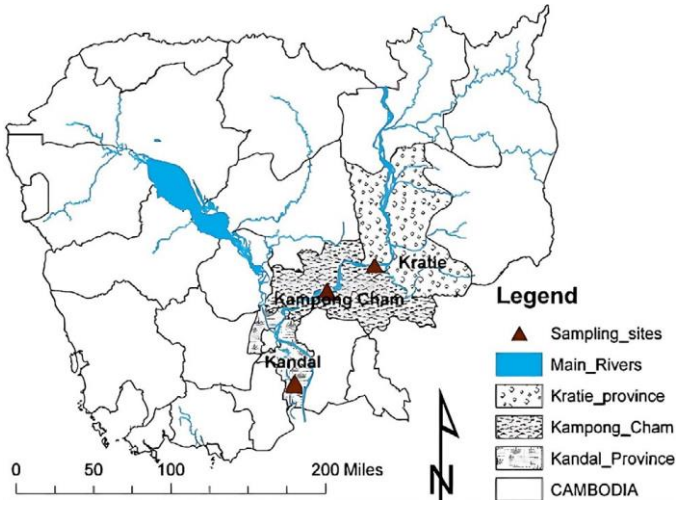

Fig. 1. Map of food sampling sites (Wang et al., 2011).

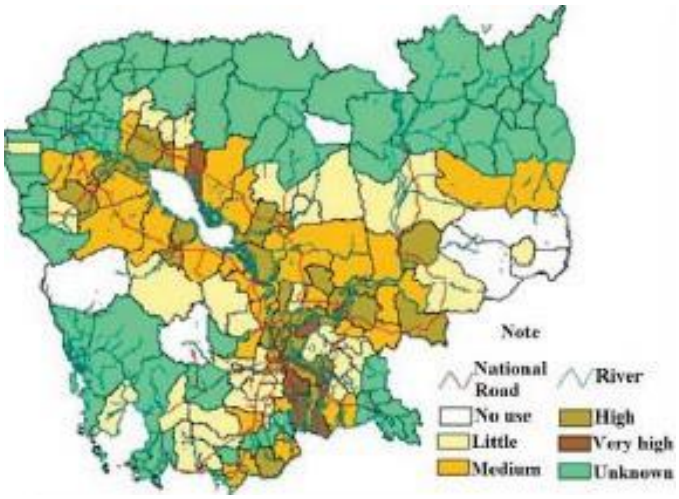

Fig. 2. Map of pesticide usage along the Mekong River (Kimkhuy & Chhay, 2014).

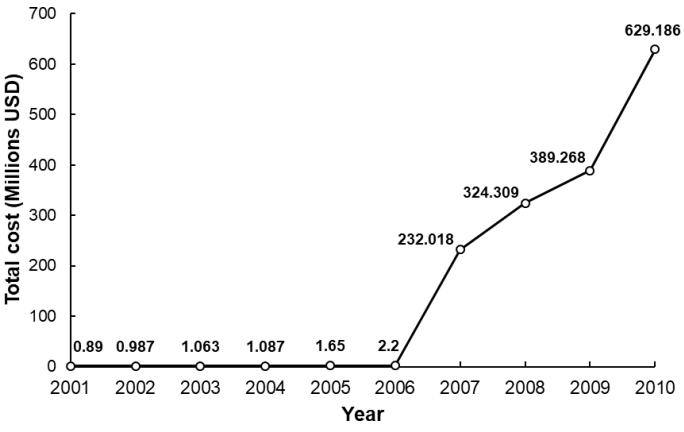

Fig. 3. Cost of agricultural pesticide imports (2001-2010).

farming is Cambodia's most important agricultural product, with 64.2% of the labor force engaged in agriculture (Matsukawa et al., 2016). During 2004-2012, the annual growth in gross agricultural production was 8.7%. Agricultural value added grew by 5.3% during this period (Eliste & Zorya, 2015). Although pesticides are not produced in Cambodia, as was previously stated, the value of pesticide imports into the nation has increased significantly since 1996. The significant illegal pesticide trade across borders (Jensen et al., 2011). According to the previous data from a survey of individual farmers by Flor et al. (2020), their results showed that the farmers mixed different brands of pesticides in one application. As we indicated earlier, pesticides are used to increase crop yields, but their use in Cambodian rice production is critical to efforts to build an effective pest management system. The rice farmers in Cambodia are required to pay more attention to the current status of pesticide usage (Matsukawa et al., 2016).

5. Pesticide residues in agricultural products

Humans can be exposed to pesticides through food in a variety of ways. Pesticide residues in agricultural products represent a severe health problem for consumers. Numerous investigations have shown that developing nations have the highest concentrations of these residues. Furthermore, most highly toxic pesticides banned are still used in most countries (Tudi et al., 2022). According to the toxicity due to pesticide residue in the daily diet, various diseases have been described as being associated with the consumption of food contaminated with pesticide residues above the MRLs in terms of daily intake and acute reference dose (ARD) (Neme & Satheesh, 2016). Monitoring pesticide residues in vegetables from provinces around Tonle Sap Lake was also evaluated (Phat et al., 2022a). Because vegetables are essential to the Cambodian diet, the samples analyzed were the most contaminated with pesticide residues. Hence, the research's findings proposed that the local authority responsible for food safety should be provided with proper regulation and management of pesticide use. It links what has already been achieved by Schreinemachers et al. (2020), who figured out that the extent of pesticide overuse in vegetable production was reported at 73% in Cambodia (Schreinemachers et al., 2020). The result implied that Cambodian farmers were over-spraying pesticides for vegetable production.

Likewise, the previously mentioned work by Van Nguyen et al. (2020) emphasizes that safe agricultural products are a public concern in Cambodia. The study also suggested that since Cambodia is a developing economy, policy measures to address food risk perception should be tailored to the country's situation. In Southeast Asia and South Africa, pesticide import and registration policies must be adequately applied. As a result, the lack of suitable handling and application has caused health issues (Loha et al., 2018). Therefore, there are several solutions to address the pesticide problem, such as safety regulations, campaigns to reduce the use of pesticides, and education and training. The Royal Government of Cambodia plays a vital role in making policies and regulations and encouraging the sustainability of all agricultural activities.

6. Farmer risk assessment

Farmers use all productive methods to ensure high product quality in the face of the ever-increasing demand for food. Furthermore, the previous study on pest management at the community level that collected data in 2016 from five different provinces, including Battambang, Kampong Thom, Prey Veng, Takeo, and Pursat, was demonstrated. The study findings emphasized that farmers most commonly used herbicides and insecticides for each season. Prey Veng and Takeo, mainly, had higher insecticide use per season. In addition, farmers frequently employ a combination of pesticides in a single application, believing this to be more efficient (Flor et al., 2018). In addition, a cross-sectional survey was conducted at Boeung Cheung Ek (BCE) Lake in Phnom Penh in 2010. This 3,200-ha wastewater-fed lake is situated about 5 km north of Phnom Penh. **Table 1** shows the lists of farmers' pesticides in BCE Lake alphabetically by WHO categorization. Insecticides, especially the highly hazardous organophosphates (class Ia/Ib), whose use is banned or restricted, and the moderately hazardous pyrethroids (class II), were widely used by farmers. At least 50% of the pesticides used belonged to the WHO class I + II, followed by the III class (19%), obsolete (6%), and unclassified (25%) (Jensen et al., 2011). As a result, farmers often had mild symptoms such as chest pain, tremors, excessive sweating, blurred vision, and muscle cramps. Dry throat, headache, dizziness, fatigue, joint pain, itchy skin, muscle weakness, and nausea were the most common mild symptoms.

In another research by Kai et al. (2020), the analysis of pesticide residues in sediment from Chhnok Tru, Kampong Chnnag (**Fig.4**) was determined. This study showed four pesticide residue compounds in sediment: chlorfenapyr, fluquinconazole, mevinphos, and oxabetrinil. This study confirmed that sediment is the type of soil that provides beneficial nutrients, and it also has been polluted by the discharge of untreated pesticide residues from agricultural actions. A similar study of residual pesticides around Tonle Sap Lake has shown that chlorine, mefenoxam, metalaxyl, and methamidophos were the central pesticide residues detected in the rainy season. Hexachlorobenzene and mefenoxam were mainly seen in December. The highest concentration in this study was reported for o,*p*'-DDT at Kampong Phluk (16.59 µg/L) in December. Most pesticides were found above regulatory limits for drinking and surface water, indicating that pesticide residues seriously contaminate the lake and make it unfit for human consumption. In terms of threats to human health and pollution of the environment, this problem is of great concern (Phat et al., 2022b).

Another study conducted in Koh Thum district, Kandal province, in the Cambodia upper Mekong delta (**Fig.5**) by Keo et al. (2022) detected the presence of six pesticides in the different water samples, namely hexaconazole, pretilachlor, paclobutrazol, propiconazole, azoxystrobin, and fluquinconazole. This study discovered that seasonal flooding had transferred pesticides from canals and rice fields into groundwater in the rainy season. Therefore, their study clarified that pesticides in groundwater might significantly risk local people using groundwater as a domestic water supply.

Table 1: Pesticides used in Boeung Cheung Ek Lake, Phnom Penh, Cambodia, in 2010. Adopted from Jensen et al., 2011.

Main use	Chemical type	Active ingredient	Reported use %	WHO Classification [a]
Insecticides	Organophosphates	Monocrotophos	11.8	Ib
		Dichlorvos	71.9	Ib
		Mevinphos	11.8	Ia
		Methidathionb	1.1	Ib
		Methamidophos	5.4	Ib
	Pyrazole	Fipronil	1.1	II
	Thiazole	Thiamethoxam	1.1	III
	Neonicotinoid	Imidacloprid	3.2	II
	Pyrethroids	Cypermethrin	93.5	II
	Organochlorine	Endrin	2.2	O
Fungicides	Dithiocarbamates	Mancozeb	44.1	U
		Zineb	48.4	U
		Propineb	64.5	U
	Benzimidazoles	Carbendazim	2.2	U
	Hydroxides	Copper hydroxide	73.1	III
		Copper oxychloride	46.2	III

[a] **Ia**: extremely hazardous, **Ib**: highly hazardous, **II**: moderately hazardous, **III**: slightly hazardous; **U**: unlikely to present acute hazard in normal use, **O**: obsolete

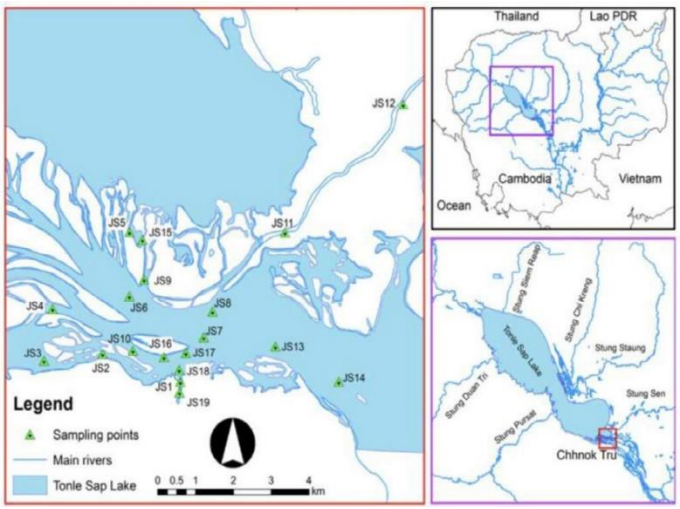

Fig. 4. Map of the study area and the sampling points in different areas in Chhnok Tru (Kai et al., 2020).

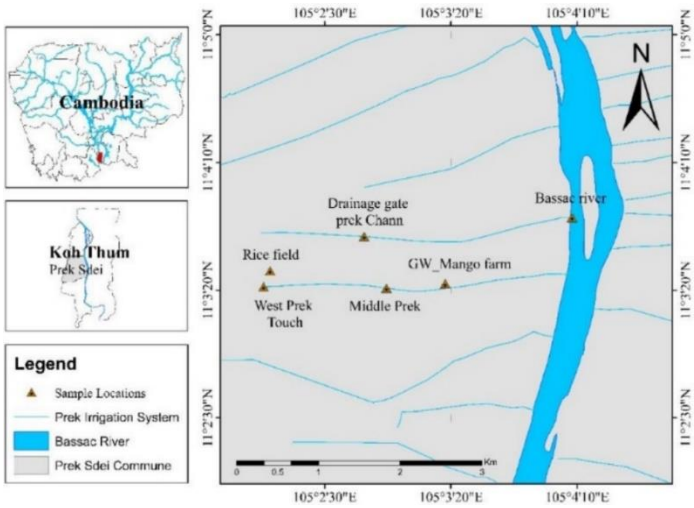

Fig. 5. Sample locations in Koh Thum district, Kandal province (Keo et al., 2022).

A study of pesticide residues in vegetables from provinces around Tonle Sap Lake by Phat et al. (2022a) showed that the yardlong bean from Battambang province was contaminated with a pesticide with nine active compounds detected. Fluquinconazole, dimethametryn, and mevinphos were most frequently seen in the tested samples. Metalaxyl was detected in spinach samples from the Sangker River (67.6 ng/g) and pea eggplant harvested from Chhnok Tru (38.7 ng/g). Pyroquilon was found in 3 tested vegetables, namely, cabbage (109.8 ng/g), yardlong bean (91.4 ng/g) from the Sangker River and eggplant (92.8 ng/g) from Chhnok Tru. The significance of the study presented that vegetables are an essential part of the Cambodian diet. The national summary reports presented in **Table 2** show the pesticide residue. The increased consumption of vegetables and the rapid population growth have led to more usage of agricultural pesticides, which causes concerns about their negative impact on the environment and health safety. These residual pesticides in vegetables sold in local markets pose health risks to farmers and consumers (Phat et al., 2022a). Therefore, Cambodian farmers and consumers are classified as high-risk contacts for detecting local fruit and vegetable pesticide residues.

7. Farmer demographics and safety training

The behavior of farmers in Cambodia is similar to a study by Mengistie et al. (2017), which found that farmers failed to

Table 2: National summary reports on pesticide residue.

Province/region	Pesticide detection	Food items	Pesticide concentration	Reference
Battambang Chhnok Tru	Metalaxyl Pyroquilon Metalaxyl Pyroquilon	Vegetables	67.6 ng/g 109.8 ng/g 38.7 ng/g 92.8 ng/g	(Phat et al., 2022a)
Kampong Phluk	o,p'-DDT	Water	16.59 µg/L	(Phat et al., 2022b)
Koh Thum, Kandal	Paclobutrazol Propiconazole Hexaconazole Fluquinconazole Azoxystrobin Paclobutrazol	Water	- - - - - -	(Keo et al., 2022)
Prek Touch, Kandal	Chloroneb	Water	3.83 µg/L	(Hak et al., 2020)
Chhnok Tru	Chlorfenapyr Fluquinconazole Mevinphos Oxabetrinil	Sediment	- - - -	(Kai et al., 2020)
Kampong Cham Krati Kandal	Organochlorine	Cereals, vegetables, fruits, fish	188 ng/g 25.1 ng/g 103 ng/g	(Wang et al., 2011)

comply with recommendations for safety and storage facilities. For example, farmers have used more than the recommended dosage in the mistaken belief that a higher dosage means more effective pest control. Likewise, the status and use of pesticides in India by Koli and Bhardwaj (2018) mentioned that their practice is based only on knowledge of cereals and other related crops, and there is no certified data on pesticide use on forage crops. In Ghana, pesticides have become a dominant feature of Ghanaian agriculture. Research has found that they use more than the recommended doses and ignore the use of personal protective equipment (Wumbei et al., 2019). In Pakistan and Bangladesh, the studies indicate that farmers were more convenient with the traditional technique and needed better understanding levels regarding the use of pesticides (Riaz et al., 2021; Karim, 2020). For Cambodia's neighboring countries, Thailand, Laos, and Vietnam, their respective studies have shown similar findings that the farmers' decisions about pesticide selection and use were influenced by their technical knowledge, their thoughts on the risks associated with pest management, and their perception of pesticide toxicity (Shattuck, 2021; Salazar & Rand, 2020; Sapbamrer, 2018). Before farmers spray their crops with pesticides, they must know what pests and diseases affect them. Farmers do not just rely on their knowledge; they can use an extensive network to gather pest control information and advice. According to the previous report, the Cambodian farmers' knowledge of pesticides received information related to their pest and disease problems from pesticide shops (52%), friends or neighbors (37%), lead farmers (4%), the Office of Agriculture (4%), NGOs (3%), and TVs and others less than 1% (Sokcheng et al., 2021). Based on these statistics, it is a reason why farmers did not correctly use pesticides. Although the farmers also received training in pest management techniques, the results showed that the high cost of raw materials (30%), their habits (24%), and the additional time commitment (22%) prevented adoption. Therefore, the primary sources of their knowledge of these improved agricultural practices are social networks (i.e., neighbors, friends, or relatives) and advisory services provided by NGOs and the provincial department of agriculture (**Fig.6**) (Sokcheng et al., 2021). As a result, pesticide poisoning was reported by 93% of farmers (Lekei et al., 2014). Contact with pesticides is believed to cause hundreds of thousands of deaths unusually worldwide (Konradsen et al., 2003; Pimentel et al., 1992).

However, as long as people were critical thinking with regulatory information about toxic substances topics, including chemicals and hazardous substances, they were not exposed to potential health risks through consuming fruits and vegetables. Illustration, a recent study of the local fruits and vegetables in Incheon, Korea, elucidated that the fruits and vegetables were 92.1% free from detectable residues. In contrast, 1% of the residue contained exceeded the Korean maximum residue limit (Park et al., 2022). In the European Union, an assessment of pesticides on and in fruits and vegetables in Poland was studied. the highest levels in both vegetables (31 $ng.g^{-1}$ *w/w*) and fruit (9.3 $ng.g^{-1}$ *w/w*). The assessment of consumer health

risk showed a significantly lower Lifetime Average Daily Dose (LADD) of pesticides in this study compared to the Acceptable Daily Intake (ADI) (Witczak et al., 2018).

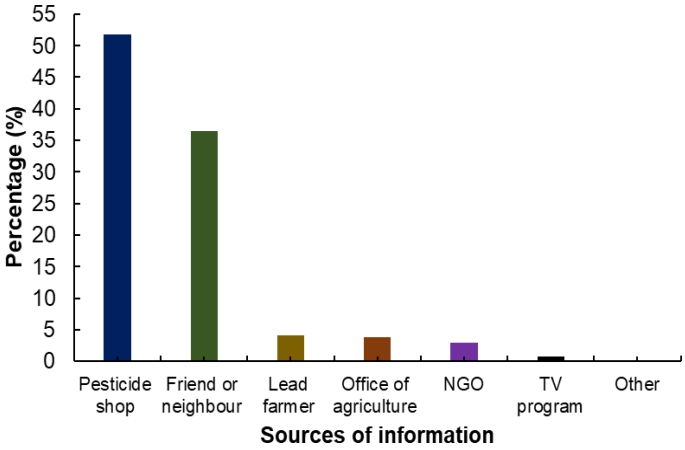

Fig. 6. Sources of information for pest and disease control.

8. Cambodia's pesticide law and regulations

Although the Cambodian government has imposed some restrictions on hazardous pesticides, these substances can still be marketed illegally in Cambodia and neighboring countries. In 1998, Article 4 of Sub-degree 69 "On Standard and Management of Agricultural Materials" stipulated for the first time that agrochemicals of all kinds that can be sold in Cambodia must be registered with a license from the Ministry of Agriculture, Forestry, and Fisheries, even if they were imported or produced in the country. Additionally, Article 6 requires that the manufacture and marketing of products or services likely to harm the health or safety of consumers must be the subject of a prior declaration to the competent institutions and carried out after inspection and approval beforehand by the capable institutions. Storage or disposal of solid waste, and hazardous substances that cause water pollution in public waters should be strictly prohibited (Hernández et al., 2013).

Despite the authority of the Department of Agricultural Legislation, there are limitations to the effective implementation of the regulations (Preap & Sareth, 2015; Kimkhuy & Chhay, 2014; Taylor, 2020; Dinham, 2010). The government published comprehensive rules requiring the registration of pesticides distributed and sold in Cambodia in 2002-2003. This directive included a labeling guideline to ensure farmers could read and understand the packaging instructions. Only licensed dealers could sell pesticides. It was still tricky to handle, and most pesticide labels were in other languages (Singh, 2011). In addition, farmers often use a combination of pesticides in a single application because they believe it is more efficient (Preap & Sareth, 2015). Although instructions for use were often in a foreign language, imported pesticides were often marketed as cheap brands to appeal to low-income farmers. In the previous report of the Ministry of Environment in 2004, 419 pesticides were sold illegally in the country's many markets, with the number increasing to 517 pesticides in 2005 and 757 in 2009. At least 95% of pesticides on the market are labeled in foreign languages (Vietnamese, Chinese, Thai, or English), which makes it very difficult for local farmers to use them correctly (Kimkhuy & Chhay, 2014). As a result, the lack of knowledge and misperceptions about pesticides, the underestimation of risks, and easy access to illegal and hazardous chemical pesticides cause severe problems for farmers.

9. Pesticide practice management approach

Pesticides are essential in countries' efforts to achieve economic growth and meet their development goals (Sharma AK et al., 2020). However, as vital as they are to ensure food security and economic growth, improper and indiscriminate use can be disastrous for human health and the environment (Sabarwal et al., 2018). Pesticides have become a global concern because they cause ecotoxicological problems by killing non-target organisms and polluting soil, air, and water. Only 1% of applied pesticides reach the target, and a large amount becomes available in the environment, affecting non-target species and beneficial organisms (Kaur et al., 2019; Graham-Bryce, 1977). From Cambodian farmers' perspectives, using pesticides to control pests is widely practiced because it is convenient and easy to implement (Matsukawa et al., 2017). Legally imported pesticides must comply with Cambodia's quality and labeling laws, are typically less hazardous, and have packaging translated into Khmer. Illegally imported pesticides, on the other hand, tend to be more dangerous and have labels written entirely in the language of the country of origin. To make farmers more aware of these risks, the government has organized pesticide training courses to better inform farmers about the recommended dosage and the risks associated with the pesticides they purchase. A critical aspect of the pesticide practice management approach is knowledge. The most dangerous practice farmers have performed is mixing different pesticides in one applicator. These are the so-called pesticide "cocktails," which contain an average of more than three pesticides in just one spray (Sokcheng et al., 2021).

The Integrated Pest Management Program (IPM) is a viable way to increase productivity while improving farmers' agroecological knowledge and skills, the Royal Government of Cambodia stressed. The government declared the country's crop production plan, the Integrated Crop Management and Pest Management Program, in an official statement in 1998. Although the efficacy of Integrated Pest Management (IPM) has been effectively demonstrated in Cambodia, farmers have yet to have the same success in dissemination and continued use (Flor et al., 2018). IPM focuses on the education of farmers to enable them to increase agricultural productivity and profitability sustainably, leading to better socio-economic outcomes while safeguarding human and animal health and protecting the natural environment. This activity asks Why has IPM yet to catch on with Cambodian farmers. The traditional farming methods have been thoroughly internalized into daily operations, which is why the short answer to the question was chosen. Therefore, simple solutions are rarely satisfactory when it comes to complex issues. The Ministry of Agriculture, Forestry, and Fisheries in Cambodia has realized the potential negative impact of pesticides on the environment since the 1990s. It has emphasized the need for replacement techniques (Flor et al., 2018).

Attitudes are part of the way of life and are related to farmers' perceptions of pesticide efficacy, including their misperception of pesticide use practices. For example, if farmers believe mixing different pesticides is effective pest control, they will likely use more pesticides. In addition, farmers' lifestyles are reflected in the socio-economic characteristics of people who grow vegetables. Promoting IPM among farmers is an essential conceptual framework, as it will transform traditional behavior and farmers' agricultural safety. Recurring messages include educating farmers about various valuable components of the ecosystem, agricultural biotechnology, understanding the root causes of pest problems, and performing simple tests to evaluate new theories and methods (Heong & Escalada, 1997). For example, well-educated farmers can think analytically and use pesticide application information more effectively (Mengistie et al., 2017; Schreinemachers et al., 2017; Kassie et al., 2013).

Furthermore, the national programs had better encourage more vital technical key messages: healthy crops and environment, using inputs based on ecosystem analysis, inspiring biological control, and pesticide application only as a last choice (Simpson, 1998). Besides the IPM program, Ecologically-Based Rodent Management (EBRM) is another program in Cambodia focusing more on insect management. The EBPM theme concentrates on ideas for rodent pests. It provides examples where research into rodent pests' basic biology and ecology has produced more sustainable and environmentally friendly management strategies (Singleton et al., 1999).

10. Future perspectives for pesticide practices in Cambodia

System-forward in pesticide emission is a critical study. Recent trends and future pesticide challenges are still problematic discussions for future perspectives on pesticide practices in Cambodia. The challenges in implementing IPM programs and adopting IPM practices are closely linked to national policy, social media, psychological factors, extension methods, training and knowledge. The new Cambodian generation should adopt integrated and sustainable agricultural development strategies based on plant science, management technologies, and modern crop protection techniques (Wang et al., 2019; Kimkhuy & Chhay, 2014). In modern agriculture, scientists should try to develop genetically modified crops designed to produce their biopesticides or show resistance to broad-spectrum herbicidal or pest products. This new pest control could reduce the use of chemicals and negatively impact the environment (Bernardes et al., 2015). To further limit the risks and effects of agrochemical usage, the government should take the lead in implementing laws, rules, and regulations regarding environmental protection and responsible pesticide use. The ministry should improve the extension of IPM approaches to cover the majority of farmers in the central-producing provinces. Researchers need to focus more on crop-specific recommendations for sustainable production and environmental protection of crops. The education system should be improved by incorporating ecology and field study principles into the curricula so students can develop applied practical skills in taxonomy, entomology, plant pathology, weed science, horticulture, soil science, and plant breeding (Kimkhuy & Chhay, 2014). A study of Cambodia's agriculture by Eliste and Zorya (2015) strongly recommended that the agrochemical companies ensure that pesticide packaging contains clear and concise instructions, using prominent visual symbols for illiteracy and images of target species.

Instead of synthetic pesticides, Biopesticides in sustainable agriculture were considered the nexus between socially acceptable economic growth and environmental protection (Fenibo et al., 2022; Hanif et al., 2022). Biopesticides are biologically based control agents useful for agriculture pest control (Kumar et al., 2022). According to the previous study, biopesticides are naturally derived products that can control pests and infectious diseases in agriculture (Apurva et al., 2019; Oguh et al., 2019). Biopesticides based on the insecticidal toxins produced by microorganisms are essential for integrated pest management (IPM) practices (Arthurs & Dara, 2019). These eco-friendly features of Biopesticides are remarkable. Therefore, Biopesticide formulations are considered efficient and environmentally.

11. Conclusion

Pesticides are utilized worldwide to increase crop productivity but hurt the soil's quality and biodiversity. Farmers in Cambodia rely heavily on chemical pesticides to protect their crops from pests. Pesticides are commonly used in agriculture in Cambodia. Also, farmers often mix different pesticides in one spray, which is not a good practice. Improper pesticide practices lead to environmental pollution, including soil, water, and food contamination. The current status of pesticide practices in Cambodia is considered more vulnerable to health risks. Cambodia's farmers still need to understand proper pesticide practices better. Moreover, indecorous local pesticide practices ranked Cambodia the first among the 13 countries with the highest pesticide residue on vegetables. Up to this point, little is known about pesticide use practices in Cambodia's agriculture. To address this concrete issue, the Royal Government of Cambodia released the IPM program to farmers to improve their agroecological knowledge and skills. It is implied from the reviewed data that the stakeholders must continually work on the IPM approaches to cover the majority of farmers. This review discusses the current status of pesticide practices and management approaches toward comprehensively protecting Cambodians' safety and health. From an analytical point of view, Cambodia's pesticide practices are primarily based on traditional usage and are incomprehensible.

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Declaration of competing interest

The author has no conflict of interest to declare.

Credit authorship contribution statement

CHEM Chanchao: Conceptualization, Writing-original draft, Writing-review & editing. The author has read and agreed to the published version of the manuscript.

Data availability statement

The datasets generated during the current study are available in the Google Scholar repository, https://scholar.google.com/

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