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Potential Pesticide Misuse in Agriculture Farms from Two Costa Rican Provinces

Posible uso indebido de plaguicidas en explotaciones agrícolas de dos provincias costarricenses

Possível uso indevido de pesticidas em fazendas em duas províncias da Costa Rica

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Abstract

Pesticide misuse by farmers poses hazards to human, animal, and environmental health. **[Objective]** This study aimed to document potential pesticide formulation misuse in agricultural farms. **[Methodology]** Inadequate storage practices, incorrect pesticide selection, and pesticide formulation overuse were documented through interviews and photographs on 13 agricultural farms from the Cartago and Guanacaste provinces of Costa Rica between August 2022 and April 2023. **[Results]** Storage room characteristics in many farms do not comply with safety standards prescribed by the Costa Rican Ministry of Agriculture and Livestock. Different active ingredients with herbicidal, fungicidal, insecticidal, and bactericidal properties are used in crop species for which they are not recommended. These substances include those from the carbamate, pyridine, cyclohexanedione, pyrethroid, conazole, benzothiazinone, oxadiazine, and phthalimide chemical groups in Cartago province, and from the neonicotinoid and pyrethroid chemical groups in Guanacaste province. Many pesticide formulations are utilized in quantities exceeding the manufacturers' recommendations. Among these formulations were bifenthrin, captan, oxamyl, cypermethrin, mancozeb, dimethoate, and deltamethrin in Cartago province, and imidacloprid in Guanacaste province. **[Conclusions]** These substances and their secondary metabolites have the potential to move across different environmental compartments such as water, soil, and air, thereby negatively affecting the health of community members rather than just the farmers applying these formulations. Well-established pesticide education programs based on on-site visits to farmers can enhance awareness about implementing good practices and ensure rational use of these substances, with positive results in non-target organisms such as humans and ecosystem service providers as well as natural and anthropogenic ecosystems.

Keywords: pesticide misuse, storage rooms, product formulation, recommended dose, food crops

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Resumen

El uso indebido de plaguicidas en la agricultura supone un peligro para la salud humana, animal y ambiental. **[Objetivo y Metodología]** En fincas agrícolas de las provincias de Cartago y Guanacaste, en Costa Rica, se documentaron, a través de entrevistas y fotografías, prácticas inadecuadas de almacenamiento, selección incorrecta de plaguicidas y uso excesivo de formulaciones plaguicidas. **[Resultados]** Las características de los cuartos de almacenamiento en muchas fincas no siguen las normas de seguridad para estas instalaciones indicadas por el Ministerio de Agricultura y Ganadería de Costa Rica. Diferentes ingredientes activos con acción herbicida, fungicida, insecticida y bactericida son utilizados en especies de cultivo para las cuales no son recomendados. Entre ellos se encuentran sustancias pertenecientes a los grupos químicos carbamato, piridina, ciclohexanodiona, piretroide, conazol, benzotiazolinona, oxadiazina y ftalimida en la provincia de Cartago; y a los grupos químicos neonicotinoide y piretroide en la provincia de Guanacaste. Muchas formulaciones de plaguicidas se utilizan en cantidades superiores a las recomendadas por sus fabricantes, entre ellas bifentrina, captan, oxamilo, cipermetrina, mancozeb, dimetoato y deltametrina en la provincia de Cartago e imidacloprid en la provincia de Guanacaste. **[Conclusiones]** Estas sustancias y sus metabolitos secundarios tienen el potencial de desplazarse a través de diferentes matrices ambientales, como el agua, el suelo y el aire, y afectar negativamente la salud de miembros de la comunidad y no solo de quienes las aplican. Los programas de educación basados en visitas in situ pueden mejorar la concienciación en la aplicación de buenas prácticas y garantizar un uso racional de estas sustancias, con resultados positivos en organismos no diana como los seres humanos y los entes proveedores de servicios ecosistémicos, así como en los ecosistemas naturales y antropogénicos.

Palabras clave: Uso indebido de plaguicidas; bodegas de almacenamiento; formulación del producto; uso recomendado; cultivos alimenticios.

Resumo

O uso indevido de pesticidas na agricultura representa um perigo para a saúde humana, animal e ambiental. **[Objetivo e Metodologia]** Em fazendas agrícolas das províncias de Cartago e Guanacaste, na Costa Rica, foram documentadas, por meio de entrevistas e fotografias, práticas inadequadas de armazenamento, seleção incorreta de agrotóxicos e uso excessivo de formulações de agrotóxicos. **[Resultados]** As características dos armazéns de muitas fazendas não seguem os padrões de segurança para estas instalações indicados pelo Ministério da Agricultura e Pecuária da Costa Rica. Diferentes princípios ativos com ação herbicida, fungicida, inseticida e bactericida são utilizados em espécies culturais para as quais não são recomendados. Entre eles estão substâncias pertencentes aos grupos químicos carbamato, piridina, ciclohexanodiona, piretroide, conazol, benzotiazolinona, oxadiazina e ftalimida na província de Cartago; e aos grupos químicos neonicotinoides e piretroides na província de Guanacaste. Muitas formulações de pesticidas são utilizadas em quantidades superiores às recomendadas pelos seus fabricantes, incluindo bifentrina, captan, oxamil, cipermetrina, mancozebe, dimetoato e deltametrina na província de Cartago e imidacloprida na província de Guanacaste. **[Conclusões]** Essas substâncias e seus metabólitos secundários têm o potencial de se mover através de diferentes matrizes ambientais, como água, solo e ar, e afetar negativamente a saúde dos membros da comunidade e não apenas daqueles que as aplicam. Programas de educação baseados em visitas in situ podem melhorar a conscientização na aplicação de boas práticas e garantir o uso racional dessas substâncias, com resultados positivos em organismos não-alvo, como seres humanos e entidades prestadoras de serviços ecossistêmicos, bem como em ecossistemas naturais e antropogênicos.

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Palavras-chave: Uso indevido de pesticidas; armazéns de estoque; formulação de produtos; uso recomendado; culturas alimentares.

Introduction

Pesticide formulations are preparations containing one or more active ingredients that, through different chemical or biological mechanisms, destroy, block, or prevent the action of unwanted organisms. These include herbicides, fungicides, acaricides, nematicides, insecticides, and rodenticides (Michalak & Chojnacka, 2014). However, these active ingredients (a.i.) and their secondary metabolites can move into different environmental compartments (air, soil, water), through different processes, such as volatilization (Gan, Yates, Papiernik, & Crowley, 1998), drift (Zimdahl, 2018), runoff (Chen, Guo, & Ngo, 2019), leaching, and biological vectors (Johanif *et al*., 2021).

The United Nations Environment Program (2022) highlights the importance of evaluating human activities, as well as the stakeholders involved in the problem, particularly the sectors related to food production, such as agriculture farms, emphasizing the importance of assessing situations of inadequate farm management practices, to promote appropriate practices through changes in community behavior.

Pesticide misuse by farmers can include inadequate application methods, improper storage practices, poor maintenance of application equipment, overuse, and incorrect pesticide selection (Handford, Elliott, & Campbell, 2015). These issues have been documented on agricultural farms in the Cartago and Guanacaste provinces of Costa Rica.

Methodology

Thirteen participants in both provinces were recruited between August 2022 and April 2023, based on geographic proximity and respondent´s willingness to participate in the research. Ten farms in Cartago province are located in the districts of Llano Grande and San Juan de Chicuá, while three farms in Guanacaste province are situated in the districts of Caballito, San Antonio, and Santa Elena.

Data were collected through structured interviews which gathered information on the types and dosages of pesticides used. Each participant was asked to access agrochemical storage rooms to document, through photographs, information on the plastic or glass container labels about the a.i. in the formulation and their concentrations. The characteristics of storage rooms were compared to the standards recommended by the Costa Rican Ministry of Agriculture and Livestock (MAG for its Spanish acronym).

Each product information sheet for agricultural pesticides was searched and examined to verify whether every a.i. was recommended for the crop to which it had been applied and whether the formulated product was approved for use in Costa Rica and the Central American and Caribbean regions. Additionally, the information provided by participants regarding the dosages used and information from product labels indicating a.i. and concentration was used to calculate agrochemical usage in units of kg ha -1. These calculations were made to determine whether the substances were used at higher dosages than those suggested by the manufacturer.

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Analysis and results

Cartago Province

Observations from various pesticide storage rooms revealed several issues: misplacement of powdered products on lower shelves instead of upper shelves, improper storage of opened powdered pesticide plastic bags (as they were not sealed with a clip or fastener), presence of produce boxes near pesticide formulations in the storage room, out-of-date pesticides, unlabeled pesticide containers, damaged pesticide labels, lack of labels in shelves to classify pesticides, and storage rooms that were not locked, well-ventilated, or sufficiently lit.

Additionally, three a.i. were applied despite not being recommended for use on a particular crop in Costa Rica although they were recommended for that crop in other nations in the Central American and Caribbean region (Table 1). Eight a.i. were applied despite not being approved in any crop in Costa Rica or other nations (Table 2). Seven a.i. were applied in concentrations higher than those suggested by manufacturers (Table 3).

Table 1. *Pesticides applied in agricultural farms in Cartago despite not being recommended for a particular crop in Costa Rica.*

Pesticide Formulation Name and Active Ingredient (A.I.)	Food Crops Recommended for Pesticide Application in Central American and Caribbean Countries	Food Crops Recommended for Pesticide Application in Costa Rica	Crops Applied With Pesticides
Captan ® 50 WP a.i.: captan	Guatemala, Honduras, Nicaragua, Panama and Dominican Republic Coffee (*Coffea arabica*) Potato (*Solanum tuberosum*) Tomato (*Solanum lycopersicum*) Pepper (*Capsicum annum*) Melon (*Cucumis melo*) Watermelon (*Citrullus vulgaris*) Cucumber (*Cucumis sativus*) Onion (*Allium cepa*) Garlic (*Allium sativum*) Avocado (*Persea americana*)	Avocado (*Persea americana*) Onion (*Allium cepa*) Lettuce (*Lactuca sativa*) Tomato (*Solanum lycopersicum*) Carrot (*Daucus carota*)	Potato (*Solanum tuberosum*)
Avaunt ® 30 WG a.i.: indoxacarb	Guatemala, Belice, El Salvador, Honduras, Nicaragua, Panama and Dominican Republic Broccoli (*Brassica oleracea* var. Italica) Cauliflower (*Brassica oleracea* var. Botytis) Brussels sprouts (*Brassica oleracea* var. Gemmifera) Lettuce (*Lactuca sativa*) Pepper (*Capsicum annum*) Corn (*Zea mays*) Tomato (*Solanum lycopersicum*) Apple (*Pirus malus*) Pear (*Malus comunis*) Melon (*Cucumis melo*)	Cabbage (*Brassica oleracea* var. Capitata) Tomato (*Solanum lycopersicum*) Melon (*Cucumis melo*)	Potato (*Solanum tuberosum*)

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Pesticide Formulation Name and Active Ingredient (A.I.)	Food Crops Recommended for Pesticide Application in Central American and Caribbean Countries	Food Crops Recommended for Pesticide Application in Costa Rica	Crops Applied With Pesticides
Decis ® 10 EC a.i.: deltamethrin	Cuba, Guatemala, Belice, Honduras and Dominican Republic Cucumber (*Cucumis sativus*) Melon (*Cucumis melo*) Watermelon (*Citrullus lanatus*) Sesame (*Sesamum indicum*) Squash, Pumpkin, Zucchini (*Cucurbita sp.*) Cabbage (*Brassica oleracea* var. Capitata) Broccoli (*Brassica oleracea* var. Italica) Cauliflower (*Brassica oleracea* var. Botrytis) Pepper (*Capsicum annum*) Tomato (*Solanum lycopersicum*) Potato (*Solanum tuberosum*) Lettuce (*Lactuca sativa*) Celery (*Apium graveolens*) Onion (*Allium cepa*) Garlic (*Allium sativum*) Bean (*Phaseolus vulgaris*) Pea (*Pisum sativum*) Rice (*Oryza sativa*) Corn (*Zea mays*) Sorghum (*Sorghum* sp.) Coffee (*Coffea arabica*)	Rice (*Oryza sativa*) Melon (*Cucumis melo*)	Potato (*Solanum tuberosum*)

Note: derived from research

Table 2. *Pesticides applied in agricultural farms in Cartago despite not being recommended for a particular crop in Central American or the Caribbean*

Pesticide Formulation Name and Active Ingredient (A.I.)	Food Crops Recommended for Pesticide Application in Central American and Caribbean Countries	Food Crops Recommended for Pesticide Application in Costa Rica	Crops Applied With Pesticides
Zetaran ® 76 WG a.i.: ziram	no data (information sheet exclusive for Costa Rica)	Bean (*Phaseolus vulgaris*) Pea (*Pisum* spp.) Broccoli (*Brassica oleracea* var. Italica) Cauliflower (*Brassica oleracea* var. Botytis) Cabbage (*Brassica oleracea* var. Capitata) Melon (*Cucumis melo*) Cucumber (*Cucumis sativus*) Potato (*Solanum tuberosum*) Tomato (*Solanum lycopersicum*) Pepper (*Capsicum annum*)	Onion (*Allium cepa*)
Basagran ® 48 SL a.i.: bentazone	no data (information sheet exclusive for Costa Rica)	Pineapple (*Ananas comosus*)	Potato (*Solanum tuberosum*)
Select ® 12 EC a.i.: clethodim	Guatemala, El Salvador, Honduras, Nicaragua and Panama Cotton (*Gossypium hirsutum*) Soybean (*Glycine max*) Tomato (*Solanum lycopersicum*) Onion (*Allium cepa*) Bean (*Phaseolus vulgaris*) Beet (*Beta vulgaris*) Melon (*Cucumis melo*) Watermelon (*Citrullus lanatus*) Squash, Pumpkin, Zucchini (*Cucurbita sp.*)	Onion (*Allium cepa*) Bean (*Phaseolus vulgaris*) Beet (*Beta vulgaris*)	Potato (*Solanum tuberosum*)

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Pesticide Formulation Name and Active Ingredient (A.I.)	Food Crops Recommended for Pesticide Application in Central American and Caribbean Countries	Food Crops Recommended for Pesticide Application in Costa Rica	Crops Applied With Pesticides
Molto ® 49 EC a.i.: prochloraz + propiconazole	Guatemala, Belice, El Salvador, Honduras, Nicaragua and Costa Rica Rice (*Oryza sativa*) Tomato (*Solanum lycopersicum*)	Rice (*Oryza sativa*) Tomato (*Solanum lycopersicum*)	Potato (*Solanum tuberosum*)
Kasumin ® 2 SL a.i.: kasugamycin	no data (information sheet exclusive for Costa Rica)	Rice (*Oryza sativa*) Cabbage (*Brassica oleracea* var. Capitata) Pepper (*Capsicum annum*)	Potato (*Solanum tuberosum*)
Soprano ® 25 EC a.i.: epoxiconazole + carbendazim	El Salvador, Honduras, Costa Rica and Panama Rice (*Oryza sativa*) Coffee (*Coffea arabica*)	Rice (*Oryza sativa*) Coffee (*Coffea arabica*)	Carrot (*Daucus carota*)
Infinito ® 68,75 SC a.i.: propamocarb + fluopicolide	Guatemala, Belice, El Salvador, Honduras, Cuba and Dominican Republic Tomato (*Solanum lycopersicum*) Potato (*Solanum tuberosum*) Melon (*Cucumis melo*) Cucumber (*Cucumis sativus*) Watermelon (*Citrullus lanatus*) Squash, Pumpkin, Zucchini (*Cucurbita sp.*) Cabbage (*Brassica oleracea* var. Capitata) Onion (*Allium cepa*) Lettuce (*Lactuca sativa*) Citrus fruits (*Citrus* spp.)	Potato (*Solanum tuberosum*) Melon (*Cucumis melo*) Cucumber (*Cucumis sativus*) Watermelon (*Citrullus lanatus*)	Carrot (*Daucus carota*)
Oncol ® 10 GR a.i.: benfuracarb	no data (information sheet exclusive for Costa Rica)	Onion (*Allium cepa*) Pineapple (*Ananas comosus*)	Potato (*Solanum tuberosum*)

Note: derived from research

Table 3. *Pesticides applied in agricultural farms in Cartago in greater amounts than those recommended by manufacturers*

Farm Code	Active Ingredient	Concentration	Recommended Dose (kg/ha)	Used Dose (kg/ha)
CAR 01	bifenthrin	100 g / L	0.013	0.1
CAR 01	cypermethrin	250 g / L	0.075	0.25
CAR 05	captan	500 g / kg	1.2	1.5
CAR 06	oxamyl	240 g / L	0.24	1.2
CAR 08	cypermethrin	250 g / L	0.059	0.19
CAR 09	mancozeb	800 g / kg	1.2	2.4
CAR 12	dimethoate	400 g / L	0.2	0.4
CAR 12	deltamethrin	100 g / L	0.01	0.02

Note: derived from research

Guanacaste Province

Identified inadequate pesticide storage practices included the use of pesticide containers to store water, the misplacement of pesticide containers (scattered on the floor), a lack of infrastructure maintenance (holes on the roofs of storage rooms), the presence of unlabeled pesticide containers, the presence of damaged pesticide labels, and poorly ventilated storage rooms.

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In addition, one a.i. is being applied despite not being indicated for use on a particular crop in Costa Rica, although it is recommended for that crop in other Central American nations (Table 4). Another a. i. is used despite not being recommended in a particular crop in Costa Rica or other countries in the Central American or Caribbean region (Table 5). Furthermore, one a.i. was applied in quantities exceeding the manufacturers' recommendations (Table 6).

Table 4. *Pesticides applied on agricultural farms in Guanacaste despite not being recommended for a particular crop in Costa Rica*

Pesticide Formulation Name and Active Ingredient (A.I.)	Food Crops Recommended for Pesticide Application in Central American and Caribbean Countries	Food Crops Recommended for Pesticide Application in Costa Rica	Crops Applied With Pesticides
Ultraprid ® 35 SC a.i.: imidacloprid	Panama: Tomato (*Solanum lycopersicum*) Rice (*Oryza sativa*) Melon (*Cucumis melo*) Watermelon (*Citrullus lanatus*) Guatemala: Tomato (*Solanum lycopersicum*) Potato (*Solanum tuberosum*) Eggplant (*Solanum melongena*) Pepper (*Capsicum* sp.) Rice (*Oryza sativa*) Common Wheat (*Triticum aestivum*) Corn (*Zea mays*) Rye (*Secale cereale*) Barley (*Hordeum vulgare*) Oat (*Avena sativa*) Sorghum (*Sorghum saccharatum*) Brome grass (*Bromus unioloides*) Raigrass (*Lolium multiflorum*) Banana (*Musa paradisiaca*)	Pineapple (Ananas comosus) Tomato (*Solanum lycopersicum*) Pepper (*Capsicum annum*) Melon (*Cucumis melo*) Watermelon (*Citrullus lanatus*) Orange (*Citrus sinensis*)	Forage Grasses

Note: derived from research

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Table 5. *Pesticides applied on agricultural farms in Guanacaste despite not being recommended for a particular crop in Central American or the Caribbean region*

Pesticide Formulation Name and Active Ingredient (A.I.)	Food Crops Recommended for Pesticide Application in Central American and Caribbean Countries	Food Crops Recommended for Pesticide Application in Costa Rica	Crops Applied With Pesticides
Rimac Cipermetrina ® 25 EC a.i.: cypermethrin	Belice, Guatemala, El Salvador, Honduras, Nicaragua, Costa Rica, Panama and Dominican Republic Cabbage (*Brassica oleracea* var. capitata) Tomato (*Solanum lycopersicum*) Lettuce (*Lactuca sativa*) Rice (*Oryza sativa*) Potato (*Solanum tuberosum*) Papaya (*Carica papaya*)	Cabbage (*Brassica oleracea* var. capitata) Tomato (*Solanum lycopersicum*) Lettuce (*Lactuca sativa*) Rice (*Oryza sativa*) Potato (*Solanum tuberosum*) Papaya (*Carica papaya*)	forage grasses

Note: derived from research

Table 6. *Pesticides applied on agricultural farms in Guanacaste in quantities exceeding the manufacturers' recommendations*

Farm Code	Active Ingredient	Concentration	Recommended Dose (kg/ha)	Used Dose (kg/ha)
GUA 11	imidacloprid	350 g / L	0.05	0.095

Note: derived from research

Adhering to safety standards in pesticide storage rooms decreases the occurrence of incidents such as spills or inhalation of hazardous a.i., as well as the risks of workers experiencing acute and chronic health effects (Kammel, 1991). It also enhances pesticide product control by avoiding practices such as using expired pesticide formulations and mishandling pesticide containers (Paolillo, 2020).

Conversely, exposure to many of these substances has been demonstrated to have negative environmental, animal, and human health effects. Researchers have documented human health effects of active ingredients such as dimethoate (Dogan *et al*., 2011; Reuber, 1984; Silva *et al*., 2021; Wang *et al*., 2013), mancozeb (Axelstad *et al*., 2011; Cecconi, Paro, Rossi, & Macchiarelli, 2007; Perocco, Alessandra Santucci, Campani, & Forti, 1989), cypermethrin (AlKahtane *et al*., 2018; Hu *et al*., 2011; Shukla, Yadav, & Arora, 2002), deltamethrin (Kumar, Amand, Saket, Mukhopadhyay, & Sharma, 2015; Lu *et al*., 2019), and ziram (Kanemoto-Kataoka, Oyama, Ishibashi, & Oyama, 2017; Li, Kobayashi, & Kawada, 2011; Lulla *et al*., 2016) using human cells or model organisms. These include cytotoxic effects (apoptosis, necrosis, oxidative stress); toxicity to DNA and organs such as the liver and kidneys; alteration of immune response, endocrine disruption, and potential development of diseases such as cancer and Parkinson's disease.

Similarly, negative effects due to exposure to active ingredients such as imidacloprid (De Lima E Silva *et al*., 2017; Laycock, Lenthall, Barratt, & Cresswell, 2012; Soares, Jacob, Carvalho, Nocelli, & Malaspina, 2015; Suchail, Guez, & Belzunces,

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2000), deltamethrin (Dai *et al*., 2009; Yadav, Shinde, Patil, Kote, & Kadam, 2023; Yang *et al*., 2029) and dimethoate (Christen, Joho, Vogel, & Fent, 2019; Jepson, Efe, & Wiles, 1995; Martikainen, 1996) on organisms that provide ecosystem services in agricultural landscapes have been demonstrated in different levels of biological organization. This reduces their capacity to provide supporting and regulating ecosystem services such as soil formation, matter decomposition and transformation, pollination, and pathogen and pest control, which implies increases in production costs for farmers.

Technical consultants may advise farmers to use non-recommended pesticides on a given crop to avoid pest resistance to frequently used a.i. It is also possible that pesticide supply stores advise farmers to use non-recommended pesticide formulations to increase sales. The scenarios described above deserve further attention.

Conclusions

Well-established education programs increase awareness regarding the importance of safe pesticide usage (National Association of State Departments of Agriculture Research Foundation, 2014). The Costa Rican Ministry of Agriculture and Livestock has several publications emphasizing the importance of participating in educational programs and understanding aspects such as using the recommended dosage when preparing pesticide mixtures, ensuring that a given pesticide formulation is effective in treating the target pest species, applying pesticides at the appropriate intervals, and reading product labels carefully (Ministry of Agriculture and Livestock, 2010).

It is recommended that Costa Rican stakeholders such as the Ministry of Agriculture and Livestock (MAG for its Spanish acronym) and the Ministry of Environment and Energy (MINAE for its Spanish acronym) facilitate communication channels where farmers can receive accurate information and feedback on product application, clarify doubts regarding technical data sheets and confirm whether the recommended usage explained by agro-commercial store personnel is correct.

Moreover, these institutions can provide farmers with effective educational resources such as on-site visits by community leaders, where farmers can receive technical advice tailored to their needs. The farmers can also receive recommendations on sustainable practices using low-cost technologies, such as tablets, to illustrate concepts and processes and promote awareness through the media.

There is an information gap regarding the human health effects of many active ingredients. Therefore, it is also recommended that stakeholders conduct studies on the health effects of these pesticides to identify those that could pose potential human health and environmental hazards.

The proper use of pesticide formulations by farmers is beneficial for different stakeholders: for consumers, it ensures food security; for farmers, it may result in increased productivity, decreased health risks, and protection against economic losses when produce is exported to foreign nations (Handford *et al*., 2015).

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Conflict of Interest

The authors declare no competing interests.

Author Contribution Statement

All authors declare that they read and approved the final version of this paper. All the authors declare that the final version of this paper was read and approved. The contribution percentages for the conceptualization, preparation, and correction of this paper were as follows: M.S.M. 60 %., J.V.S. 13.3%, F.R.M. 13.3 %, and K.B.P. 13.3 %.

Data availability statement

The data supporting the results of this study will be made available by the corresponding author, M.S.M, upon reasonable request.

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