Review

Pesticide Application as a Risk Factor/Behaviour for Workers' Health: A Systematic Review

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Pesticide Application as a Risk Factor/Behaviour for Workers' Health: A Systematic Review

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Abstract: The main objective of this review is to determine the main risks that agricultural workers are exposed to during pesticide application, which may have a harmful effect on their health and on public health. This systematic review was based on the PRISMA guidelines. A search for articles was conducted in the Medline/PubMed, ScienceDirect, and Web of Science databases. Fifteen articles were selected considering their assessment of agricultural workers' knowledge, perceptions, attitudes, practices, and behaviours, identifying the main risks and risk factors for disease associated with the unsafe handling of pesticides. The main risk factors identified were age, education, pesticide safety training, farming experience, and contact with other farmers/intermediaries resulting in pesticide access. The most frequent risk behaviours were: application of pesticides without personal protective equipment (PPE), incorrect disposal of empty packaging and waste, and undervaluation of label information, as well as other unsafe practices. A multidisciplinary and more effective training must be delivered in order to enhance pesticide safe usage. This will empower workers to adopt more conscious and safer behaviours while using pesticides.

Keywords: behaviour; pesticides; food safety; occupational exposure; agricultural workers

1. Introduction

Population growth, as well as the increasing prevalence of pests and problems that affect crop productivity and enhance yield losses, have resulted in more intensive agriculture aimed at producing the necessary amounts of food; consequently, pesticide use has been increasing significantly worldwide (Akter et al. 2018; Kumari et al. 2021; Nascimento and Melnyk 2016). The need to reconsider current agricultural practices and systems is essential, not only to safeguard public health and the environment, but also to protect farmers and agricultural workers who are exposed to these chemicals (Mehmood et al. 2021; Memon et al. 2019; Nath & Deka 2022; Schreinemachers et al. 2020). An excessive and unsafe use of pesticides is perceived, for instance, by the presence of pesticide substances in many food analyses, endangering workers' health and affecting food safety, the environment (negative indirect effects on soil, air and water quality), and public health through the consumption of pesticide-contaminated food (Afshari et al. 2021; Akter et al. 2018; Kumari et al. 2021; Akoto et al. 2013; Hou et al. 2013; Yahia and Elsharkawy, 2014; Kafilzadeh 2015; Ernst et al. 2018; Seenivasan and Muraleedharan 2011; Amirahmadi et al. 2013; Wang et al. 2015).

The factors leading to pesticide contamination and health issues in farmworkers include the use of banned or restricted pesticides, no use of personal protective equipment, unsafe behaviours and practices throughout the pesticide handling process, over-application, undervaluation of label information, inadequate spraying operations in farms, incorrect disposal of empty pesticide containers and residues, insufficient information on hazards, health and environmental effects, and inadequate education and training on pesticides (Afshari et al. 2021; Akter et al. 2018; Kumari et al. 2021; Mardigian et al. 2021; Masruri et al., 2020; Myzabella et al. 2019; Schreinemachers et al. 2020; Sharafi et al. 2018).

Previous studies indicate that the study of farmers' knowledge, attitudes, and practices regarding the use of pesticides is a preliminary step to mitigate pesticide hazards (Yuantari et al. 2015; Bagheri et al. 2018; Bondori et al. 2018). However, such studies, as well as their relationship and impact on safety behaviours, are limited. Evidence shows that occupational safety and health in agriculture is a little-debated topic, as few farmers receive training in occupational health (Afshari et al. 2021; Akter et al. 2018; Bagheri et al. 2018, 2019; Myzabella et al. 2019; Nwadike et al. 2021; Sharafi et al. 2018). Thus, an extensive study on the knowledge, attitudes, perceptions, practices, and behaviours of farmers and agricultural workers is essential to support the authorities who will shape policies and awareness-raising programmes targeted at workers, effectively approaching the safe use of pesticides (Afshari et al. 2021; Akter et al. 2018; Kumari et al. 2021).

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Therefore, this systematic review aimed to determine the main risks that agricultural workers are exposed to and the risk behaviours they adopt while applying pesticides, which may have harmful effects on their health and the environment. At the same time, this study was conducted to identify the level of knowledge and attitudes of agricultural workers regarding the safe use of pesticides; the protective measures and practices taken during all steps of pesticide handling, as well as the inappropriate practices and behaviours of pesticide appliers; the main risk factors influencing the inappropriate use of these products; the health hazards of occupational exposure to pesticides; and the possible effects on food safety through contaminants (residues) and, consequently, on public health.

2. Materials and Methods

This systematic review was based on the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) ® (Page et al. 2021).

The research question was:

What are the main risks and behaviours identified among agricultural workers exposed to pesticides that can potentially trigger health problems and unsafe food?3. Results

This section may be divided by subheadings. It should provide a concise and precise description of the experimental results, their interpretation, as well as the experimental conclusions that can be drawn.

2.1. Eligibility Criteria

The eligibility criteria were defined according to the PICOS methodology guidelines (Cochrane 2020), which assisted in the establishment of the inclusion and exclusion criteria. All studies focusing on farmers' occupational exposure to pesticides, written in Portuguese, Spanish, and English, and available in their full form, were included. Their publication date was also considered: only articles published between the 1st of January 2018 and the 31st of July 2022 were included. Articles were excluded if they were in the following categories: 1) the study population did not consist of agricultural workers or their families; 2) the results only refer to environmental implications resulting from the excessive use of pesticides; 3) the results were related only to health problems in the general population; 4) the results were related to occupational exposure to factors other than pesticide exposure; 5) the study objective was not in the realm of the research interest; and 6) if they were systematic reviews, narratives and meta-analyses.

2.2. Sources of Information, Research, and Study Selection

The search for articles was conducted in three electronic databases: Medline/PubMed, ScienceDirect, and Web of Science. The terms used for the search were: "behavior?or", "practice", "pesticides", "food safety", "occupational* exposure*", "farmworkers", "agricultural workers". The Boolean terms "AND" and "OR" were used to combine the various keywords, thus improving the search strategy and the results. Filters were applied during the search, such as the year of publication, idiom, and articles with free access and online availability, in order to reach a given number of articles related to the research question.

After the search, the selected articles were put through the *Mendeley Reference Manager 2.79.0* ® software to eliminate duplicates. Subsequently, two reviewers (AM and PC) proceeded with the selection process: in the first phase, the titles and abstracts of the articles were analysed by both and classified as potentially relevant or not, according to the inclusion and exclusion criteria; in the second phase, the articles considered relevant were fully and independently studied and a data collection was made. Any possible disagreement was resolved through discussion between the reviewers.

2.3. Data Collection and Extraction

Data from the selected studies were collected after a full reading, and then organized in a detailed table according to the author(s), year of publication, objectives, characteristics of the participants, country/location where the study was conducted, type of intervention, and main results (subdivided into identified knowledge/attitudes, referred behaviours/practices, determining risk factors, and reported side effects). This detailed information is present in Table 2.

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Table 2. Summary of Socioeconomic Characteristics of 15 studies included in the systematic review.

Socioeconomic Characteristics	*Number of Participants*	*Age (years)*	*Sex (%)*		*Education (years)*	*Training received* [(1)] *(%)*		*Experience in agriculture/pesticides (years)*
Akter et al (2018)	101	41,8	**Male**	100	1,9	**Yes**	19,2	11,2
			Female	0		**No**	80,8	
Bagheri et al (2018)	200	52,9	**Male**	100	10,9	**Yes**	27,0	25,5
			Female	0		**No**	73,0	
Mehmood et al (2019)	307	Not specified	Not specified		Not specified	Not specified		Not specified
Memon et al (2019)	260	32,6	**Male**	0	1,5	Not specified		9,7
			Female	100				
Schreinemachers et al (2020)	1000	Not specified	Not specified		Not specified	Not specified		Not specified
Sharafi et al (2018)	311	39,6	**Male**	100	7,8	**Yes**	21,5	17,6
			Female	0		**No**	78,5	
Bakhtawer (2021)	300	33,8	**Male**	93,7	6,9	**Yes**	19	6,8
			Female	6,3		**No**	81	
Nwadike et al (2021)	513	40,6	**Male**	80,6	9,9	**Yes**	91,2	10,3
			Female	19,4		**No**	8,8	
Bagheri et al. (2019)	200	52,9	**Male**	100	10,9	**Yes**	27,0	25,5
			Female	0		**No**	73,0	
Nath et al (2022)	90	Not specified	Not specified		Not specified	Not specified		Not specified
Masruri et al (2020)	380	49,0	**Male**	100	7,1	**Yes**	27,9	16,7
			Female	0		**No**	72,1	
Aniah et al (2021)	150	40	**Male**	34	1,2	**Yes**	59,3	6,2
			Female	66		**No**	40,7	
Mardigian et al (2021)	104	47,7	**Male**	100	10,9	Not specified		Not specified
			Female	0				
Sookhtanlou et al (2022)	370	46,5	Not specified		9,4	Not specified		23,6
Kumari et al (2021)	96	46	**Male**	84,4	Not specified	Not specified		18
			Female	15,6				
Mean*		**Age**	**Male***	73,8	**Education***	**Yes***	42,4	**Experience***
		43,0	**Female***	26,2	7,6	**No***	57,6	15,8

[(1)]: Training received in the use of pesticides that can include training about the side effects of pesticides, banned pesticides, use of recommended dose on labels, commercial names, pesticide storage location, use of PPE, and reentry period after application, among others. *: These values only consider the studies that provide this information (exclude "not specified" studies). Not specified: this data is not included in the study.

2.4. Quality Assessment and Risk of Bias

The methodological quality of the selected studies was independently assessed by two reviewers (AM and PC) using the *Strengthening the Reporting of Observational Studies in Epidemiology* (STROBE) software (Von Elm et al. 2007) and a combination of *STROBE* and the *Cochrane Systematic Review Handbook* (Higgins & Green 2006). According to these tools, the higher the final score, the greater the number of compliant items in the study, thus indicating whether the study has a strong methodological quality or not (da Costa et al. 2013; Silva Martins 2020).

The risk of bias in the selected studies was assessed with the *Risk of Bias in Non-randomized Studies* (ROBINS) for observational studies, developed by Cochrane (Sterne et al. 2016). This instrument considers seven domains, and

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categorises them according to five possible classifications: low risk of bias, moderate risk of bias, severe risk of bias, critical risk of bias, or no information to assess the risk of bias.

3. Results

The database search retrieved 1,704 articles with the selected keywords. **Figure 1** is a flow diagram describing the study selection. A total of 15 articles were included in the study for analysis.

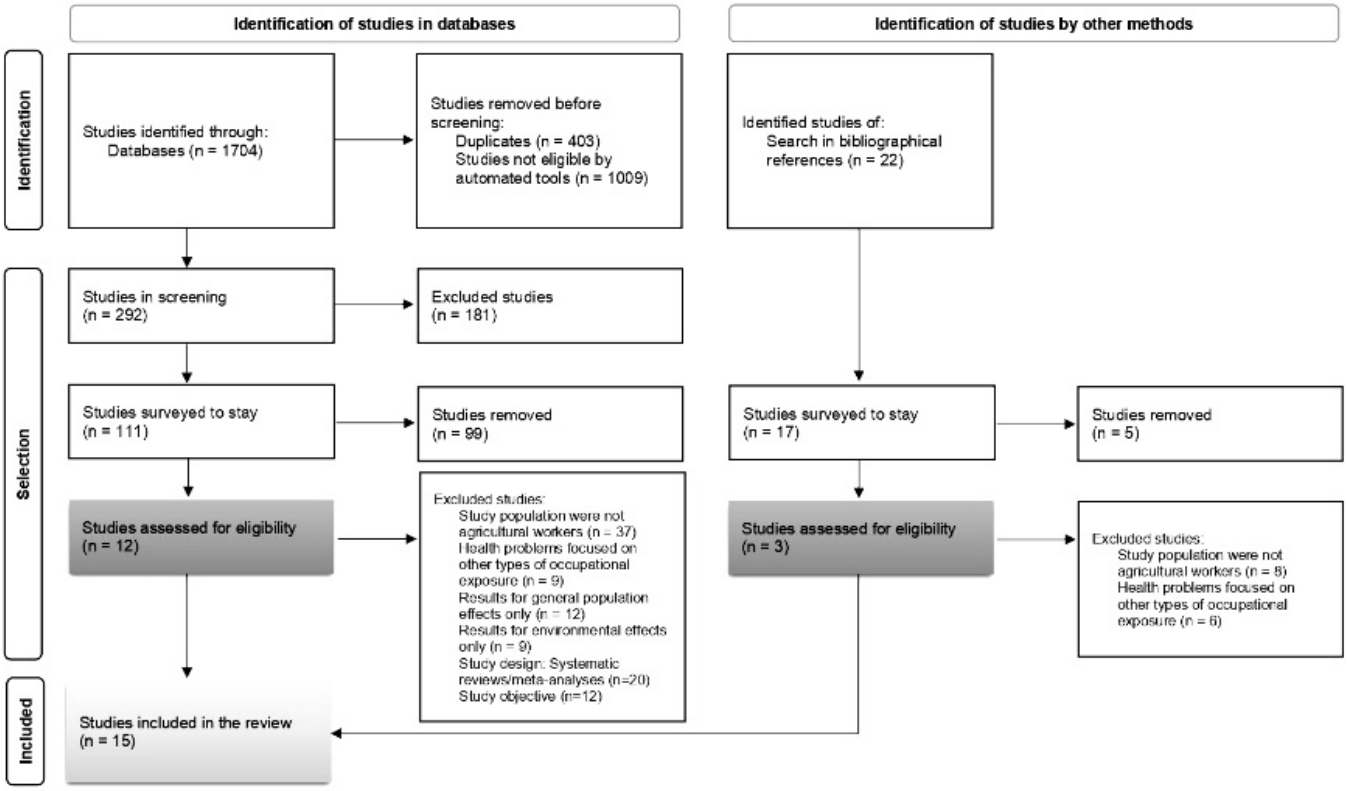

Figure 1. PRISMA 2020 flow diagram for updated systematic reviews, which included the search in databases and other sources.

3.1. General Characteristics of the Studies

The selected studies (Table 1) followed an observational methodology; 4 are case studies (Akter et al. 2018; Bagheri et al. 2018; Memon et al. 2019; Schreinemachers et al. 2020) and 11 are cross-sectional studies (Aniah et al. 2021; Bagheri et al. 2019; Bakhtawer 2021; Kumari et al. 2021; Mardigian et al. 2021; Masruri et al. 2020; Mehmood et al. 2021; Nath and Deka 2022; Nwadike et al. 2021; Sharafi et al. 2018; Sookhtanlou et al. 2022). The duration of these studies ranged from 4 to 16 months. Their intervention involved the completion of a pre-tested and pre-defined questionnaire with several items for a face-to-face interview to the selected farmers/agricultural workers (Akter et al. 2018; Aniah et al. 2021; Bagheri et al. 2018, 2019; Bakhtawer 2021; Kumari et al. 2021; Mardigian et al. 2021; Masruri et al. 2020; Mehmood et al. 2021; Memon et al. 2019; Nath and Deka 2022; Nwadike et al. 2021; Schreinemachers et al. 2020; Sharafi et al. 2018; Sookhtanlou et al. 2022). The completion of this questionnaire was carried out either by themselves or by the responsible of each study. It should be noted that, in all studies, consent to take part in the research was collected from all participants, and their rights were thoroughly explained to them.

The results of the selected studies (Table 1) are in agreement with each other regarding the main risk factors and behaviours influencing the safe handling of pesticides in agriculture. Such studies are from non-European countries (Bangladesh, Iran, Pakistan, India, Cambodia, Laos, Vietnam, Nigeria, Ghana, and Lebanon), which indicates, on one hand, that the issue under study is still very relevant and current in underdeveloped and developing countries and, on the other hand, it reflects the lack of recent information for European countries on this issue.

Table 1. Detailed data of the included studies.

STUDY	OBJECTIVES	PARTICIPANTS/COUNTRY	INTERVENTION	MAIN OUTCOMES			
				Knowledge/Attitudes*	**Practices/Behaviors****	**Risk factors*****	**Reported side effects**
Akter M et al. (2018)	Quantify the knowledge, personal background, and protective behaviors adopted by farmers; identify the factors influencing protective behaviors in pesticide use and recommend improvements in these practices.	**Bangladesh** N= 101 farmers	Application of a standard questionnaire (validated previously) to interview farmers (**with consent**) about their knowledge and practices related to pesticide use through face-to-face interviews with a demonstration of application practices, protective equipment used as well as the storage place of the products with site visits whenever possible (visual evidence). The questionnaire included 30 items on a farmer's knowledge of pesticide use (KNO; seven items), attitude (Atti; five items), past experiences of pesticide poisoning (PE; six items), perceived outcomes (PR; four items), and protective behaviors during pesticide selection, storage, and application (PB; eight items). A Likert school (1 to 5 points) was used to code the responses in the questionnaire.	**Knowledge about pesticides:** Scores indicated a lack of knowledge about pesticide use (read and understand labels/pictograms/hazards of the product and choose the right product for the problem). The scores showed some knowledge of the issues related to linking pesticides to health. Most showed no knowledge that pesticides influence the acceptability and quality of products.	**Preparation and spraying: They** apply more product than the recommended quantity for fear of losing profits (they do not show a tendency to decrease). They do not believe that a reduction in pesticide application can minimize environmental pollution. The most adopted protective behavior among farmers was the correct storage of pesticides, followed by showering after application as well as not eating or smoking during application. Also, it was uncommon to post recent treatment information on the sprayed area as well as apply only the required dose of pesticide. **Protective equipment used and Disposal of empty containers and waste:** The least used practices were the use of adequate personal protective clothing and equipment as well as the correct disposal of waste and empty containers.	**Safe behavior and practices:** Relation (+): Education, level of involvement in agriculture, training in the field. Relation (-): older age, farm size, and years of pesticide application. The safe practices associated with pesticide use are more influenced by the farmer's knowledge/attitudes and previous poisoning episodes.	Headaches, vomiting, dizziness (most frequent), eye irritation (60%), and skin irritation (50%).

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				Knowledge/Attitudes*	Practices/Behaviors**	Risk factors***	Reported side effects
Bagheri A et al. (2018)	To study the use of pesticides as well as the associated health risks and determine the protective behaviors of apple producers.	**Arbadil, Iran** N= 200 farmers	Application of a questionnaire (previously validated) completed face-to-face by the farmers (**with consent**) with questions related to socio-economic data, farming experience, household size, residence, marital status, level of education, function in agriculture, pesticide toxicity problems, safety and behaviors, use of PPE and pesticide handling practices. Farmers were asked to report only health complications caused by pesticide handling.	**Knowledge about pesticides:** Some producers presented training in the area; however, the training was more directed to the quantity to apply of products than to the safety matter regarding the use of pesticides.	**Preparation and Spraying:** Part of the producers store pesticides in warehouses, however, some still store this type of product at home (8.5%). Due to the proximity of the farm, 8.0% of the producers indicated that they prepare the grouts for spraying in their own kitchen. Most of the farmers (71.5%) stated that they prepare the sprays in the orchards or near the water points. Washing hands with hot water and soap after spraying, not eating or drinking, not smoking during spraying, changing clothes, and taking a shower after spraying were considered by almost all farmers. Keeping pesticides in safe places and using eco-friendly/low-toxic pesticides were the least considered behaviors. **Disposal of empty containers and waste:** Almost one in three farmers (32.8%) reported that they 'dump' the empty containers in their orchards. Similarly, some farmers (30.2%) reported that they usually bury the empty containers and others burn the empty containers (17%) or throw them into irrigation canals, regardless of their destination (10%). Another part washes and uses them to water domestic animals (10%).	**Influence on protective behaviors:** Relation (+): education and training. Relation (-): agricultural experience and age.	17% of farmers have been hospitalized for pesticide poisoning. **Most frequent symptoms:** irritated eyes and blurred vision.

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				Knowledge/Attitudes*	Practices/Behaviors**	Risk factors***	Reported side effects
Mehmood Y et al. (2019)	To analyze the factors determining the use of personal protective equipment by producers and to assess how pesticide residues and containers are disposed of.	**Pakistan** N= 307 farmers	Application of a questionnaire (previously validated) to interview farmers (**with consent**) on information on socio-economic and farm issues, financial situation, access to finance for agriculture, costs for health protection as well as farmers' understanding of the use of toxic chemicals and taking safety measures in this regard.	Not specified	**Type of pesticides handled:** Various pesticides of categories Ib, II, and III (highly hazardous, moderately hazardous, and slightly hazardous respectively) according to the WHO pesticide risk classification. **Preparation and Spraying:** While spraying, the protective equipment that workers use the most are: a hat/cover (33.2%), mask (28.7%), and socks/boots (12.7%). However, it is not common for them to use rubber gloves, goggles, and applicator suits. The study revealed that workers use at least one piece of personal protective equipment. **Protective equipment used: They** only used PPE during the spraying periods. Most farmers used trousers, long-sleeved blouses/shirts, and gloves; however, they do not wear glasses or applicator suits. **Disposal of empty packaging and waste:** 53% disposed of pesticide containers by throwing the containers onto fields or bushes as solid waste, while 18% of respondents reused empty pesticide containers for domestic or agricultural purposes. A small percentage (7%) sold empty containers to street vendors. About a fifth (21.8%) of farmers set the empty containers on fire and/or buried them. There was no collection by the recycling system in place in any of the cases.	**Safe behavior and practices (use of PPE):** Relation (+): Education, level of involvement in agriculture, training in the field, diversified income, access to finance. Relation (-): Age, health effects occurred, income, protective equipment costs.	Sweating, hypersalivation, dizziness, headache, skin and eye irritation, blurred vision (more frequent).

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Memon Q et al. (2019)	To assess the health problems and associated costs arising from exposure to pesticides and to analyze the use of protective equipment by female workers.	**Southern Pakistan** N = 260 cotton pickers	Application of a pre-tested questionnaire to interview the workers with questions related to the socio-economic status of cotton pickers, source of income, awareness of pesticide hazards, health problems occurring in cotton harvesting (considered by respondents to be a result of exposure to pesticides during harvesting), personal protection practices adopted during harvesting and health facilities.	Not specified	**Type of pesticides handled:** Various pesticides of category II (moderately hazardous) according to the WHO pesticide risk classification. **Protective equipment used:** the majority did not use any type of PPE. Some workers indicated that they protect their face with some material (e.g., towel or scarf), use gloves and wear shoes during harvesting.	**Use of protective measures:** Relation (+): younger age, higher level of education/training. Relation (-) with illiteracy and higher experience in harvesting and health treatments.	**Short-term:** skin and eye injuries, headaches, stomach aches and fever (more frequent)
Schreinemachers P et al. (2020)	Quantify the excessive use of pesticides in production systems.	**Cambodia, Laos, and Vietnam** N= 1000 families	Application of a pre-tested questionnaire to interview workers (**with consent**) with questions related to crop production, pesticide use, the distinction between beneficial and harmful arthropods to crops, and questions related to spraying practices and pesticide handling.	Not specified	**Preparation and Spraying:** In Vietnam, 100% of producers over-applied (above the optimal amount for profit) pesticides, in Cambodia about 73% and in Laos, the percentage of over-application was 75%. This reflects unnecessary costs for producers.	**Appropriate use of pesticides:** Relation (+): when female gender as responsible for pest management, previous training in the area as well as contact with official entities. Relation (-): advice with pesticide sellers, belief in (over)effectiveness of pesticides, more recent experience in agriculture.	Not specified

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Sharafi K et al. (2018)	To assess the knowledge/attitudes of farmers and determine the risk factors affecting the use of pesticides and consequently causing effects on their health.	**Kermanshah** N= 311 farmers	Application of a pre-tested questionnaire adapted from two previous ones for face-to-face completion by farmers with questions on socio-economic characteristics and farming practices, including age, gender, education level, types of crops and products, type and amount of pesticide used and income; farmers' knowledge, attitudes and practices on pesticide use and risks and practices used for pesticide/residue disposal.	**Knowledge about pesticides:** Most did not have certified training in the area. Most farmers were aware that several pesticides have been banned in recent years, however, only about 18% of them knew that this was due to their high toxicity. Few had the information that pesticides had residues. Only about 15% and 29% of farmers were aware of the risks of pesticides to human health and the environment respectively. While the majority believed that pesticides do not have any adverse effect on human health, environment, or agricultural produce. Most of the respondents did not know (24.4%) or had no idea (24.8%) how to deal with the risks of pesticides. However, they indicated that reducing the dose (42.4%), using personal protection (30.5%), and using low-risk products (14.8%) can reduce the risk associated with pesticides.	**Type of pesticides handled:** various pesticides of categories Ib, II and III (highly hazardous, moderately hazardous, and slightly hazardous respectively) according to the WHO pesticide risk classification. 61% of farmers used pesticides based on their own experience without reading the instructions. **Preparation and Spraying:** Most farmers (62.7%) wash their hands and face after application. **Protective equipment used:** Only about 18% of farmers use personal protective equipment for the body (face and hands). **Disposal of empty packaging and waste:** Most of the farmers (52.7%) claimed that they stored the surplus pesticides for another use. About 16% of the farmers employed the surplus pesticide/wash residues on the treated land or on uncultivated land, which, means unnecessary use of pesticides. About 10% of the farmers were dumping the wastes into rivers and other waterways. Most of them (41.2%) dispose of the packaging with waste. None of them dispose of the empty containers properly, using a specific program for their collection and recycling.	**Prevalence of health implications:** Relation (+): training in the area or higher level of education. Relation (-): age over 65 years, untrained farmers applying highly toxic pesticides.	Skin irritation and dizziness (most frequent symptoms).

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Bakhtawer S (2021)	To assess farmers' knowledge/attitudes and practices in the use of insecticides against pests.	**Punjab, Pakistan** N=300 farmers	Application of a pre-tested questionnaire to interview workers face-to-face (with consent). The first part is related to the socio-demographic characteristics of respondents, such as gender, marital status, age, level of education, agricultural area, irrigation method, agricultural experience, and working hours they spend on the crops. The second part is related to farmers' perceptions about which insecticides are more effective and which they use more, which crop and pest are most frequently mentioned, methods of preparing the dose to apply considering the pests encountered, knowledge about alternative pest control methods, biological agents or natural enemies. The third part referred to the respondents' attitudes and practices regarding their protection during spraying, use of personal protective equipment, and participation in training in the area.	**Knowledge of pesticides:** only 7% have some qualification acquired in the area and 12% have training on the use of insecticides. Most of them get the name of the products and use them for pests only following the indications of the agricultural technician. Little knowledge was revealed about integrated pest management and the biological pest control method. **Preparation and Spraying:** 42% of respondents understand the label instructions when preparing for spraying. **Alternative to insecticides:** 63% did not know of its existence while 37% were aware of it. 68.6% had no knowledge about integrated pest management. 65.3% of the respondents did not know any information about the biological pest control method.	**Type of pesticides handled:** various pesticides of category II (moderately hazardous) according to the WHO pesticide risk classification. **Preparation and Spraying:** 42% of respondents understand the label instructions while preparing for spraying. 22% of respondents were able to prepare an adequate dose, while 15% of respondents followed the pesticide application plan. **Protective equipment used:** the most used measures are the use of rubber gloves (44%), mask (41%), and/or covering the face with some material (e.g.: cloth). **Disposal of empty containers and waste:** 50.33% of the respondents bury the empty containers and 14% of the respondents burn them, while 31.67% throw them in the rubbish without any processing. Only 3.67% of the respondents proceed to collection centers for the disposal of empty insecticide containers.	**Safe practices in the use of insecticides:** Relation (+): level of education and consequently knowledge about pest control procedures, interpretation of product labels, frequency and quantity of product to be applied, use of personal protective equipment, and appropriate disposal of empty containers and waste.	Not specified

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Nwadike C et al. (2021)	Assess farmers' knowledge/attitudes and safe practices in pesticide use.	**Northern Nigeria** N= 524 farmers	Application of a pre-tested questionnaire to face-to-face interviews with workers (with consent). Data collected include socio-demographic characteristics, knowledge about frequently used/purchased pesticides, pesticide exposure routes, pesticide control methods, storage and disposal, use of PPE, attitudes towards the hazardous effect of pesticides, farmers' practices during pesticide application, and health problems associated with pesticide use. The factors considered include farmers' knowledge of safety during pesticide application, on-farm handling, and possible health/environmental and safety effects of the most adopted practices during and after pesticide use on farms. Farmers' attitudes about pesticide use and associated impact were measured using a 5-point Likert scale.	**Knowledge about pesticides:** 58.8% were able to identify inhalation as the most likely route of entry of pesticide residues into the human body. The oral route (ingestion) was identified as the second most possible route of exposure (54.5%). 60.3% said they were aware of secondary routes of pesticide exposure, including ingestion of contaminated food and drinking water contaminated with pesticides, etc. Limited knowledge of the risk classification of each pesticide according to WHO classification. High knowledge of the safe application of pesticides as well as a high knowledge of the safe use of personal protective equipment. Knowledge on how to dispose of pesticide residues and expired products and on the safe storage of pesticides received slightly lower scores. High knowledge was found on practices to avoid during pesticide preparation and application (e.g., eating and/or drinking and smoking).	**Preparation and Spraying:** 87.9% said they read the product safety data sheet/packaging label before applying the product on their plots. An unsafe practice for worker safety and health observed was: 32% of respondents stated that during pesticide application when one of the nozzles of the sprayer is clogged, they use their mouth to proceed to unblock it. **Protective equipment used:** the most used measures are the use of rubber gloves, masks, and applicator suits. **Disposal of empty packaging and waste:** 30.6% of participants use empty pesticide containers for other agricultural or domestic uses, thus exposing farmers to potential health problems associated with this practice.	**Safe practices in the use of pesticides:** Relation (+): gender, experience, and agricultural practice do not influence the use of empty containers for other household purposes. A higher educational level positively influences reading product labels before use as well as other safety practices. Relation (-): older age and low educational level influence the use of empty containers for other domestic purposes as well as the use of protective equipment and the use of the mouth to unclog sprayer nozzles.	Headaches, dizziness, skin and eye irritation, coughing, nausea, and vomiting.

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STUDY	OBJECTIVES	PARTICIPANTS/COUNTRY	INTERVENTION	MAIN OUTCOMES			
				Knowledge/Attitudes*	Practices/Behaviors**	Risk factors***	Reported side effects
Bagheri A et al. (2019)	To assess the knowledge/attitudes and perceptions of apple producers regarding the use of pesticides.	**Ardabil, Iran** N= 200 farmers	Application of a pre-tested questionnaire to interview workers face-to-face (**with consent**). Data collected include basic demographic characteristics of farmers, main pests in apple plantations, trust, and use of information sources on pesticides, knowledge, attitudes, and perceptions related to pesticide use, and adoption of safety practices by farmers in the use of these products using a 5-point Likert scale.	**Knowledge of pesticides:** Low knowledge regarding pest control management. The score reveals a moderate level of knowledge of pesticides among the respondents namely on environmental problems arising from over-application as well as for the effects on existing "healthy" crops. Most of the respondents perceived that spraying is harmful to the health of the applicators who do not protect themselves during spraying and that spraying should be carried out only by skilled personnel. The scores indicated a positive perception of the overall implications of pesticide use (e.g., they did not agree that decreasing spraying means decreasing profits).	**Type of pesticides handled:** fungicides, herbicides, insecticides, and acaricides. **Preparation and spraying:** Most rely on pesticide dealers as a trusted source of information for correct product application. Most farmers stated that they wash their hands with soap and water after spraying while a large proportion stated eating and drinking during spraying. Also, many of the farmers stated that they do not smoke during spraying. 75% indicated that they do not read pesticide labels.	**Correct knowledge, attitudes, and perceptions about pesticide use:** Relation (+): credible and official information sources as well as younger age and naturally acquired professional experience. The level of personal and family literacy also positively influences knowledge, attitudes, and perceptions. Relation (-): previous experience of poisoning.	Not specified

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STUDY	OBJECTIVES	PARTICIPANTS/COUNTRY	INTERVENTION	MAIN OUTCOMES			
				Knowledge/Attitudes*	Practices/Behaviors**	Risk factors***	Reported side effects
Nath A et al. (2022)	To assess the knowledge/attitudes and practices of people regarding pesticide use and the occurrence of acute toxicity symptoms.	**India** N= 90 farmers	Application of a pre-tested questionnaire to interview farmers face-to-face.	**Knowledge about pesticides:** 82.2% used chemical pesticides and most recognized them as harmful.	**Type of pesticides handled:** 52% belong to WHO class II (moderately hazardous), 8% belong to class III (slightly hazardous) and 4% belong to class Ib (highly hazardous). **Protective equipment used:** 75.7% reported not using any individual protection measures. 13.51% stated that they did not use differentiated work clothes or wash them separately despite applying pesticides.	**Knowledge, attitudes, and correct practices on the use of pesticides:** Relation (-): lack of adequate knowledge, risky behavior during handling; inappropriate storage and disposal of pesticides.	**Episodes of acute poisoning from pesticide use:** headache, nausea, irritated eyes, vomiting, decreased breathing, disturbed vision, and excessive sweating.

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STUDY	OBJECTIVES	PARTICIPANTS/COUNTRY	INTERVENTION	MAIN OUTCOMES			
				Knowledge/Attitudes*	Practices/Behaviors**	Risk factors***	Reported side effects
Masruri B et al. (2020)	To determine the knowledge and practices of farmers towards the use of pesticide insurance.	**Iran** N= 380 farmers	Application of a pre-tested questionnaire to interview workers face-to-face (**with consent**). The questions included topics on farmers' knowledge of pesticide safety as well as their practices in this regard. The topics were rated using a 5-point Likert scale.	**Knowledge about pesticides:** 92.1% of them reported that they had not participated in any training on pesticide safety. 41.6% of the farmers had a low level of knowledge and 58.4% had a moderate level of knowledge about pesticide side effects, storage, transport, and disposal conditions as well as precautions when handling toxic products. Most of the farmers studied had good knowledge about the prohibition of eating and drinking at the application site, as well as the use of personal protective equipment such as masks. On the other hand, only about 40% of the workers knew about the prohibition to reuse empty containers for other purposes and about the prohibition to burn them.	**Precautionary measures in the storage, transport, and disposal of pesticides:** 62.6% of the participants had a moderate practice and 37.4% of them had a good practice in this regard. **Protective equipment used:** only 58.2% of the farmers always washed their clothes after spraying, 29.5% always wore gloves and 1.6% boots, 7% always wore safety glasses, and 17.6% protective masks. 1.6% of the farmers always used appropriate clothing. Another part of the farmers indicated that it is not a common practice to use the protection equipment listed.	**Knowledge and safe practices in the use of pesticides:** Relation (+): age, experience, and level of education/training.	Not specified

STUDY	OBJECTIVES	PARTICIPANTS/COUNTRY	INTERVENTION	MAIN OUTCOMES			
				Knowledge/Attitudes*	Practices/Behaviors**	Risk factors***	Reported side effects
Aniah P et al. (2021)	To assess farmers' actual knowledge and practices regarding the use of pesticides and evaluate the ways in which they are obtained.	**Ghana** N= 150 farmers	Application of a pre-tested questionnaire to interview workers face-to-face (**with consent**). Questions include individual characteristics such as age, gender, educational level, farm size, duration of pesticide application, and knowledge and understanding of the safe use of pesticides.	**Knowledge about pesticides:** About 95% of the farmers did not have adequate knowledge of the environmental and health implications of pesticide use. 59.3% were trained on the use of personal protective equipment. 53% of the farmers are, however, unable to adequately understand the correct meaning of pictograms. Farmers show low knowledge regarding the toxic effects of pesticides.	**Type of pesticides handled:** the pesticides identified belong to WHO class II (moderately hazardous) and class Ib (highly hazardous). **Preparation and Spraying:** most farmers (91.5%) reported that they do not read the label of pesticides before use. 77%, revealed that some of the pesticides they buy do not even have labels or instructions. Farmers usually use much more than the recommended dose of the various pesticides they handle. **Protective equipment used**: 3.3% of farmers wore gloves and masks and less than 2% wore boots. While most of the farmers (90.2%) wore jackets and long sleeve shirts. **Storage:** 63% of farmers stored their pesticides inside their own homes, while the rest (37%) stored their pesticides in a warehouse or a no-food zone. **Disposal of empty packaging and waste:** Most farmers (over 90%) indicated that they disposed of empty packaging by burying it in the soil or burning it.	**Health effects:** Relation (+): between pesticide use and eye irritation as well as between pesticide use and headache, vomiting, and nausea.	Generalized discomfort, vomiting, headaches, nausea, and eye irritation. 96.7% of respondents reported having suffered pesticide poisoning at least once.

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Mardigian P et al. (2021)	Assessing farmers' practices and determining risk factors that incorrectly affect pesticide use	**Lebanon** N= 146 farmers	Application of a pre-tested questionnaire to interview workers face-to-face (**with consent**). The questions include socio-demographic characteristics, of the farm and questions related to usual practices in pesticide application.	**Knowledge about pesticides:** Most farmers indicated that they did not know the active substances of the pesticides they use. However, they relied on their own education, research, and experience to obtain information on the safe use of pesticides. 59.6% agreed that exposure to pesticides could result in short-term and long-term health effects. When asked about possible long-term health effects of pesticide exposure, almost half of the respondents (49%) mentioned at least one associated disease (cancer, depression and neurological deficits, respiratory diseases, gastrointestinal disorders, reproductive disorders, skin problems, eye problems, and kidney failure). Only 58.7% of respondents believed that pesticides could have negative effects on the environment, the rest were unaware of the issue.	**Type of pesticides handled:** the choice of pesticides as well as the indications for the safe use of pesticides is made by the suppliers (family/friends). **Preparation and Spraying:** 87.5% of respondents said that they respect the recommended dose on the package label during the application, both themselves and their workers. 74.6% of farmers indicated that they have increased the use of pesticides because of environmental issues or because of issues related to the loss of effectiveness of a certain amount of product, pest resistance to the product, and/or beliefs that higher doses have more effectiveness). 85.4% said they monitored wind direction before spraying. Most reported not eating/drinking (95.8%), nor smoking (87.5%) during spraying activities. In addition, 93.7% said they shower and change clothes immediately after spraying. **Protective equipment used**: 41.4% reported mixing the different pesticides using their hands without protection or a stick and only 36.5% reported wearing gloves during mixing. **Willingness to use fewer toxic products:** when asked about the possibility of using a less toxic product with equal efficacy, 87% of respondents were willing to switch, motivated mainly by the price difference. The remaining indicated that they did not want to switch as they were satisfied with the product and would only do so on the advice of the current supplier.	**Safe practices in the use of pesticides:** Relation (-): Costs of products influence the choice of products. A belief that pesticides are currently ineffective and therefore do not cause problems due to dermal contact (devaluation of toxicity). **Willingness to use a safe pesticide:** Relation (+): younger age and education.	Death of one of the workers due to poisoning caused by exposure to pesticides.

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STUDY	OBJECTIVES	PARTICIPANTS/COUNTRY	INTERVENTION	MAIN OUTCOMES			
				Knowledge/Attitudes*	Practices/Behaviors**	Risk factors***	Reported side effects
Sookhtanlou M et al. (2022)	Analyze the health risks for farmers arising from the use of pesticides.	**Ardabil. Iran** N=370 farmers	Application of a pre-tested questionnaire to interview workers face-to-face (**with consent**). The questions include sociodemographic and occupational characteristics of potato growers, questions related to the rate of pesticide use per area, and questions regarding protective measures and behaviors adopted throughout all stages of pesticide use. The topics were evaluated using a 5-point Likert scale.	Not specified	**Type of pesticides handled:** pesticides used were mostly in WHO class II (moderately hazardous). Most of the respondents (39.4%) belonged to the group of potato growers who were exposed to high health risks, while 30.8% and 29.8% of the groups were exposed to moderate and low health risks respectively. **Preparation and Spraying:** 74.6% of farmers used pesticides in excess and only 24.6% used within the allowed levels or below the recommended levels. The main protection measures adopted by farmers include determining the type of pesticide appropriate for the pest/disease, "checking their production and expiry dates", "preparing pesticides outside the house", "wearing boots" and "changing the suit after pesticide application". **Dangerous behaviors:** buying pesticides from unreliable outlets, not carefully reading instructions on pesticide labels, not paying attention to selecting an appropriate sprayer that is compatible with the pesticide/crop, and unsafe disposal of pesticide packaging and waste (burying, burning, etc.).	**Safe pesticide uses behaviors and practices:** Relation (-): age. Education, farm income, knowledge/perception of seriousness, and awareness of adopting safe behaviors as well as perceived benefits and beliefs influence (in both directions) the adoption of safe behaviors during pesticide use and contribute to the increase in the list of health risks for producers.	Not specified

Kumari D et al. (2021)	To assess farmers' knowledge and safety practices regarding pesticide use and the health effects associated with this exposure.	**North India** N= 96 workers	Application of a questionnaire based on the WHO standard protocol (1982) for pesticide exposure surveys to face-to-face interviews with workers (**with consent**). Questions include socio-demographic characteristics; types, amount, frequency of pesticide application, knowledge/information, practices in pesticide use; familiarity with WHO label risk classification, and self-reports on experiences of health effects from pesticide application.	**Knowledge about pesticides:** Most farmers (97%) showed knowledge of the harmful effects of pesticides. Almost all farmers agreed that direct ingestion of pesticides was toxic however only 31% expressed an understanding of the risk of poisoning by consuming food (e.g., vegetables and fruits) with pesticide residues. 57% of respondents believed that empty pesticide containers could be reused after washing. Only 24% of applicators had certified training in pesticide spraying. **Interpretation of the risk classification defined by the WHO:** The data indicate that 59% of respondents identified the WHO classifications on pesticide containers, but only very few respondents knew what the information meant. Of the four categories (excluding the most recent U), only 18% of respondents knew the meaning of the red category and 6% knew the meaning of the green color category. However, no one could explain the meaning of the yellow and blue color categories on pesticide containers. About 76% of the participants were not aware of these classifications.	**Type of pesticides handled:** the most used pesticides were fungicides and insecticides in class II (moderately hazardous) and Ib (highly hazardous). **Preparation and Spraying:** most pesticide applicators (92%) always wash their hands and 96% always change their clothes after use. Eating during and at the spraying site was practiced by 17% of respondents while 51% always drank water on site. Most respondents (> 65%) stored pesticides and related products in their own homes. Pictures taken confirmed this fact and indicated that products are handled with bare hands without gloves (15%). Only 32% followed the proper mixing procedure. **Protective equipment used**: 53% of respondents always wore long-sleeved shirts, 37% always wore hats and 48% always wore masks while handling pesticides. **Disposal of empty packaging and waste:** Most respondents burn (65%) and about 12% were seen burying the empty packaging. No one used the practice of handing over the packaging to an entity responsible for waste management and recycling recommended by FAO/WHO.	Lack of knowledge about the effects of pesticides and lack of understanding of the WHO-defined pesticide toxicity classification is associated with an increased likelihood of unsafe practices in pesticide use.	Eye and skin irritation.

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STUDY	OBJECTIVES	PARTICIPANTS/COUNTRY	INTERVENTION	MAIN OUTCOMES			
				Knowledge/Attitudes*	Practices/Behaviors**	Risk factors***	Reported side effects
				Only the red color classification was interpreted as dangerous.			

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3.2. Socioeconomic Characteristics of the Studies

The participants were mainly male farmers (73.8%), farm workers, and/or their relatives, with an average age of 43 years old (implying that farmers are in middle age) (Table 2). Most participants were involved in the farming of apples, onions, turmeric, chilies, condiments, garlic, potatoes, coriander, cotton, mustard, beans, wheat, corn, barley, beet, rapeseeds, tomatoes, chickpeas, pistachios, soybeans, maize, cowpeas, groundnuts, among other vegetables and fruits. Their educational level ranged from illiterate to college graduates. The average length of education is 7.6 years, suggesting that most participants completed only their elementary education (Table 2). The average experience in agriculture and use of pesticides is 15.8 years, which points to a significant experience in this field (Akter et al. 2018; Aniah et al. 2021; Bagheri et al. 2018, 2019; Bakhtawer 2021; Kumari et al. 2021; Mardigian et al. 2021; Masruri et al. 2020; Mehmood et al. 2021; Memon et al. 2019; Nath and Deka 2022; Nwadike et al. 2021; Schreinemachers et al. 2020; Sharafi et al. 2018; Sookhtanlou et al. 2022).

3.3. Knowledge, Attitudes, and Perceptions

Considering the results for knowledge, attitudes, and perceptions of farmers/agricultural workers on the safe use of pesticides, we could perceive, in most studies (60%), a poor knowledge on the toxic effects of pesticides and toxicity classifications (Akter et al. 2018; Aniah et al. 2021; Bagheri et al. 2019; Bakhtawer 2021; Kumari et al. 2021; Masruri et al. 2020; Nath and Deka 2022; Nwadike et al. 2021; Sharafi et al. 2018). A large part of the studies indicated a lack of knowledge on reading and interpreting labels/pictograms and on product selection considering the problem/pest detected (Akter et al. 2018; Aniah et al. 2021; Bakhtawer 2021; Kumari et al. 2021; Mardigian et al. 2021; Nath and Deka 2022; Nwadike et al. 2021; Sharafi et al. 2018). Only 42.6% of farmers took training in the use of pesticides, with most of it focusing on the amount of pesticide to be applied rather than safety in pesticide use, suggesting that more than half have been applying pesticides for a few years without training (Aniah et al. 2021; Bagheri et al. 2018; Bakhtawer 2021; Kumari et al. 2021; Masruri et al. 2020; Sharafi et al. 2018). In the selected studies, there was also a significant percentage of farmers who are unaware of the health and environmental risks of pesticide over-application and inappropriate disposal of pesticide waste (Akter et al. 2018; Aniah et al. 2021; Bagheri et al. 2019; Bakhtawer 2021; Kumari et al. 2021; Mardigian et al. 2021; Masruri et al. 2020; Nath and Deka 2022; Sharafi et al. 2018). Some producers were able to identify the routes of entry of pesticides into the human body and singled out the reduction of the used dosage, the use of PPE, and the use of less toxic pesticides as active measures to reduce the risk associated with occupational exposure (Nwadike et al. 2021).

3.4. Practices and Behaviours

The practices and behaviours of producers during pesticide handling are identified in the selected studies (Akter et al. 2018; Aniah et al. 2021; Bagheri et al. 2018, 2019; Bakhtawer 2021; Kumari et al. 2021; Mardigian et al. 2021; Masruri et al. 2020; Mehmood et al. 2021; Memon et al. 2019; Nath and Deka 2022; Nwadike et al, 2021; Schreinemachers et al, 2020; Sharafi et al, 2018; Sookhtanlou et al, 2022):

(1). 33.3% refer overapplication of products for more effective control or because their experience indicates so.

(2).Inadequate disposal of pesticide containers and waste was reported in 53.3% of the studies (e.g., burning, burying, washing them near water courses, use of containers for domestic and agricultural purposes, left along farms, among others).

(3).Lack of information and signalling (a warning signboard or red flag) on the recently sprayed areas and conditions to re-enter the same.

(4).Storage of pesticides at their homes (46.7%).

(5).Preparation of pesticides or mixtures in houses, orchards, or near irrigation points with bare hands or sticks (26.7%).

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(6).Preparing and spraying pesticides without considering/reading the information on the product's label (safety precautions, recommended dosage, disposal of empty containers, weather conditions, targeted pest problem, among others) was a practice described in 40% of the studies.

(7).Almost 70% of the studies point to the fact that farmers do not yet wear appropriate PPE during pesticide use (masks, gloves, long-sleeved shirts, and boots).

(8).Eating, drinking, and/or smoking during or at the place of application/preparation of pesticides seems to be a common practice, according to 46.7% of the studies.

However, some studies reveal an increasing consideration of abandoning these practices, which might lead to a change of behaviours (Akter et al. 2018; Bagheri et al. 2018, 2019; Bakhtawer 2021; Kumari et al. 2021; Mardigian et al. 2021; Masruri et al. 2020; Sharafi et al. 2018; Sookhtanlou et al. 2022).

3.5. Risk Factors

The selected studies refer a set of factors that negatively influence the adoption of safe practices/behaviours by agricultural workers during pesticide handling: advanced age, more work experience, lower educational level, and lack of training in safety (Akter et al. 2018; Aniah et al. 2021; Bagheri et al. 2018, 2019; Bakhtawer 2021; Kumari et al. 2021; Mardigian et al. 2021; Masruri et al. 2020; Mehmood et al. 2021; Memon et al. 2019; Nath and Deka 2022; Nwadike et al. 2021; Schreinemachers et al. 2020; Sharafi et al. 2018; Sookhtanlou et al. 2022).

3.6. Health Effects of Occupational Pesticide Exposure

Occupational pesticide exposure affected the health of workers, with the most reported symptoms being short-term effects, since the long-term health effects depend on more concrete and solid data, and these studies are based only on self-reports. Thus, the most frequent symptoms identified in 60% of the selected studies are: headache, nausea, vomiting, dizziness, excessive sweating, hypersalivation, blurred vision, and skin and eye irritation (Akter et al. 2018; Aniah et al. 2021; Bagheri et al. 2018; Kumari et al. 2021; Mehmood et al. 2021; Memon et al. 2019; Nath and Deka 2022; Nwadike et al. 2021; Sharafi et al. 2018).

Most studies refer the importance of developing intensive training programmes on occupational safety specific to pesticides, in order to increase the workers' literacy and contribute to safer practices and behaviours, food safety, preservation of the environment and public health (Akter et al. 2018; Aniah et al. 2021; Bagheri et al. 2018, 2019; Bakhtawer 2021; Kumari et al. 2021; Mardigian et al. 2021; Masruri et al. 2020; Mehmood et al. 2021; Memon et al. 2019; Nath and Deka 2022; Nwadike et al. 2021; Schreinemachers et al. 2020; Sharafi et al. 2018; Sookhtanlou et al. 2022).

3.7. Quality Assessment and Risk of Bias

In view of their results, these studies were regarded as having a good methodological quality, according to the STROBE criteria and the STROBE and Cochrane Systematic Review Handbook compilation. The results for the risk of bias are, according to the Risk of Bias in Non-randomized Studies (ROBINS): 4 studies presented a low risk of bias, 10 had a moderate risk, and 1 a severe risk.

4. Discussion

The negative implications of the improper use of pesticides have been reported in several studies over time. (Afshari et al. 2021; Dalmolin et al. 2020; de Graaf et al. 2022; de Moura et al. 2020; de-Assis et al. 2021; Gillezeau et al. 2019; Giulioni et al. 2021; López-Gálvez et al. 2019; Lucero & Muñoz-Quezada 2021; Matich et al. 2021; Mehmood et al. 2021; Memon et al. 2019; Myzabella et al. 2019; Negatu et al. 2021; Panis et al. 2021; Passos et al. 2022; Perry et al. 2020; Rani et al. 2021; Schreinemachers et al. 2020; Sharafi et al. 2018; Varghese et al. 2021; Wahlang 2018; Zúñiga-Venegas et al. 2021). However, these implications do not result only from their use, but from a set of factors that include the wrong knowledge, attitudes, perceptions, beliefs, practices, and behaviours of

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producers, posing a threat to their health, the safety of food items, the environment, and public health (Aniah et al. 2021; Bagheri et al. 2019; Akter et al. 2018).

Some studies agree that the inappropriate use of pesticides occurs particularly at the stages of storage, spraying, and disposal of empty containers. This improper behaviour, reported in the selected literature, is due to factors such as limited education, awareness, and training that negatively influence the adoption of safe behaviours during this process (Bakhtawer 2021; Mardigian et al. 2021; Sharafi et al. 2018; Masruri et al. 2020).

Other studies refer that inadequate or unsatisfactory training on pesticide safety essentially occurs because it is not provided by official entities (Nath and Deka 2022; Sharafi et al. 2018; Aniah et al. 2021; Bakhtawer 2021). Evidence shows that most of the information on pesticide safety is transmitted to farmers and agricultural workers by friends, relatives, pesticide sellers (not always qualified to do so) or through unreliable sources (Nath and Deka 2022; Sharafi et al. 2018; Aniah et al. 2021; Bakhtawer 2021).

A lack of knowledge when choosing and buying pesticides is one of the risk factors most often associated with unsafe behaviours in pesticide use, as they allow producers to contact and trust intermediaries with scarce knowledge on the products (e.g., pesticide sellers without adequate training) and, consequently, to have access to unlimited products without labels and instructions on the recommended dosage and appropriate use (Aniah et al. 2021; ANIPLA 2016; DGAV 2021; Mardigian et al. 2021; Masruri et al. 2020; Morgado Gomes 2018; Paixão et al. 2016; Santos & Almeida 2016; Serapicos Vilarinho 2019; Sookhtanlou et al. 2022; Teixeira 2014).

Bagheri et al. (2018) and other authors affirm that a lack of proper monitoring and regulations has led to more adverse effects of pesticides and their residues in developing countries, when compared to developed countries. Although in developed countries the regulations and laws for selling and purchasing these products are significantly effective, there are still countries where such laws are unclear or not yet enforced, and this opens a window of opportunity to the free market (easily accessible these days) and more attractive prices that result in more risks to health and the environment (Aniah et al. 2021; Bakhtawer 2021; Mardigian et al. 2021; Nwadike et al. 2021; Barizon et al., 2020; Garcês et al., 2020; Knauer, 2016; Lopes et al., 2010; Nascimento & Melnyk, 2016). For instance, in Portugal, Law no. 26/2013 of 11 April regulates the activities of distribution, sales, and application of plant protection products for professional use, with the aim of promoting the sustainable use of pesticides while reducing their risks and effects on human health and the environment. Furthermore, this law establishes that all pesticide users must be qualified to do so, and when this is the case, they are given a card, renewable every 10 years, and only those holding this card can apply such products. Sellers, as well as pesticide retailers, must also have the qualifications referred in the legislation to be considered legally recognized technicians and sales operators (ANIPLA, 2016; Teixeira, 2014).

The risk factors "education" and "training" identified in so many of the selected studies, as well as other studies, are two of the main enhancers of dangerous practices among farmers and agricultural workers, such as "using bare hands without gloves to mix pesticides". According to the literature, this happens because they are unaware of the harmful effects of the products they are handling and the consequences of their attitude to their health (Akter et al. 2018; Bagheri et al. 2018, 2019; Bakhtawer 2021; Kumari et al. 2021; Mardigian et al. 2021; Masruri et al. 2020; Mehmood et al. 2021; Memon et al. 2019; Nath and Deka 2022; Nwadike et al. 2021).

Some studies on the effectiveness of interventions to promote pesticide safety refer that education and training are also important precursors of safe behaviours. This is also proved by some of the selected studies, in which a positive association is found between a higher level of education and training and the implementation of safe pesticide behaviours and practices, such as the use of PPE, the correct storage of products, and a proper disposal of pesticide waste and packaging (Akter et al. 2018; Bagheri et al. 2018, 2019; Bakhtawer 2021; Kumari et al. 2021; Mardigian et al. 2021; Masruri et al. 2020; Mehmood et al. 2021; Memon et al. 2019; Nath and Deka, 2022; Nwadike et al. 2021). On the other hand, the same studies indicate that age and farming experience are negatively associated with pesticide safety, i.e., older farmers adopt less adjusted practices and behaviours than younger

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farmers, and few of them are willing to adopt them in their day-to-day life (Bagheri et al. 2019; Masruri et al. 2020; Memon et al. 2019; Nath and Deka, 2022). This may be due, according to evidence, to a low level of education, lack of knowledge on the toxicity and risks of pesticides, beliefs that an increased use of these products will lead to greater productivity, and the fact that they have not yet experienced a real health implication after so many years of exposure (questioning safety concerns and continuing to rely on behaviours they have adopted so far) (Bagheri et al. 2019; Mehmood et al. 2021; Akter et al. 2018; Mardigian et al. 2021).

However, some studies point to a need of investing in multidisciplinary awareness and training programmes featuring experiences of other farmers, with videos and photographs, small focus, and discussion groups, which, at the same time, are adapted to the educational level of this population, in order to facilitate learning; only then the training and awareness programmes can have the desired effects and contribute to the knowledge of workers (Bagheri et al. 2018, 2019; Bakhtawer 2021; Kumari et al. 2021; Nwadike et al. 2021; Sharafi et al. 2018). The reason to wear PPE in times of excessive heat is an example of something to be adjusted to the educational level; this will be better understood if it is explained that, by doing this, they will be reducing contact with one of the main routes of entry - the skin - of pesticide residues into the human body (Mardigian et al. 2021; Nath and Deka 2022; Bakhtawer 2021; Bagheri et al. 2018; Akter et al. 2018).

Studies have also suggested that it is of extreme importance and priority that these programmes cover all phases of pesticide use, including the correct disposal of empty packaging and pesticide residues, according to the guidelines of the Food and Agriculture Organization of the United Nations (FAO) (e.g. triple washing and delivery to a waste management and recycling centre) - a rather uncommon practice in current studies which, if implemented, will contribute to the reduction of risks to human and animal health, and to the environment (Bagheri et al. 2018; Kumari et al. 2021). In Portugal, there are regulations aimed at controlling the conditions and safety procedures of pesticide waste management systems, dictating how the delivery of packaging waste or surplus waste to the reception centres should be carried out. This regulation also provides guidelines on the reporting of their collection for subsequent reuse or disposal (ANIPLA 2016; DGAV 2021; Morgado Gomes 2018; Paixão et al. 2016; Rocha Matias 2015; Santos & Almeida 2016; Serapicos Vilarinho 2019; Teixeira 2014).

In contrast, in the countries where the studies were conducted (in developing countries), the most common packaging disposal practices include burying, burning, leaving them on farms, or throwing them out into waterways. Others use packaging for domestic purposes such as washing clothes, transporting food, storing water, or as toilet bowls. These practices reinforce the idea that it is extremely important to explain the risks of food and water contamination with pesticides, as well as the dangers of contacting with its residues (Bagheri et al. 2018; Bakhtawer 2021; Kumari et al. 2021; Mardigian et al. 2021; Masruri et al. 2020; Mehmood et al. 2021; Nath and Deka 2022; Sookhtanlou et al. 2022).

It is also essential to discourage the storage of these types of products in houses - a practice mentioned by many farmers - since this puts not only the worker but also his/her entire family and especially children at risk (Masruri et al. 2020; Nwadike et al. 2021).

The unnecessary application of (excess) pesticide in treated areas and the application of a higher than recommended dosage is, unfortunately, common and a high-risk behaviour that may result in several reported problems, including damage on quality products due to the presence of unwanted residues that may affect food safety and, consequently, jeopardize their marketing, as well as enhanced pest resistance and deposition of harmful substances on soil and water resources, which threatens human and animal health. Producers should be encouraged to spray the recommended dosage and use residues to spray on untreated land, or proceed to a more efficient management by defining the correct application rate before purchase and preparation (Bagheri et al. 2018; Bakhtawer 2021; Kumari et al. 2021; Nwadike et al. 2021; Schreinemachers et al. 2020; Sharafi et al. 2018; Sookhtanlou et al. 2022).

Training programmes on pest management have been associated, in several studies, with a positive influence on the safe use of pesticides, as they allow farmers to increase their knowledge on

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alternative methods to toxic chemical control, and also assist them in the identification of pests – a knowledge lacking in most of them. This should be encouraged, as it drives farmers to adopt more responsible and appropriate procedures for the use of chemicals, as well as more sustainable approaches to the economy, the community and the environment. Hence the importance of addressing these topics in training (Kumari et al, 2021; Nath and Deka2022; Sookhtanlou et al. 2022; Bagheri et al. 2018; Bakhtawer 2021; Sharafi et al. 2018; Mehmood et al. 2021; Nwadike et al. 2021).

Regarding the health implications of occupational exposure to pesticides, the most reported and evidence-based symptoms are headaches, nausea, vomiting, dizziness, eye and skin irritation (self-reported data only indicate health impacts) (Kumari et al. 2021; Nath and Deka 2022; Memon et al. 2019; Mehmood et al. 2021; Bagheri et al. 2018; Nwadike et al. 2021; Bhandari et al., 2019). However, the studies refer that only a small percentage ever went to the hospital after experiencing these short-term symptoms of intoxication - the literature justifies this by stating that workers regard these symptoms as 'normal' and part of an episode that occurs after spraying, rather than an episode of intoxication, with symptoms corresponding to the adverse effects of pesticide use. Once again, the lack of information on the effects of unsafe spraying and the health risks of recurrent spraying endanger the safety and life of workers, who devalue these symptoms (Kumari et al. 2021; Nath and Deka 2022; Memon et al. 2019; Mehmood et al. 2021; Bagheri et al. 2018; Nwadike et al. 2021).

As for the long-term effects, it is essential to determine whether the diseases arise from occupational exposure to pesticides or other external factors. Therefore, more studies are needed to determine the root cause and cautiously expose the long-term health effects associated with pesticide use (Kumari et al. 2021; Mehmood et al. 2021; Nath and Deka 2022; Prudente et al. 2018).

On the subject of PPE, the studies found that, contrary to what would be desired, this is still a significantly undervalued practice by producers, even among those who handle highly toxic products, translating into small percentages of use of adequate equipment during preparation and spraying with pesticides. The most used equipment consists of long sleeve shirts, trousers, and some items to protect the face (e.g.: scarf) - not always a mask (Bagheri et al. 2018; Bakhtawer 2021; Kumari et al. 2021; Masruri et al. 2020; Mehmood et al. 2021; Memon et al. 2019; Nath and Deka 2022; Nwadike et al. 2021; Sharafi et al. 2018).

The selected studies, as well as others, suggest that this absence may be due to the high costs of this type of equipment, as well as the discomfort caused by the climatic conditions experienced in the studied locations (higher temperatures and humidity). These studies revealed that the educational level, access to training in the area, financing from local institutions and a source of income not only dependent on agriculture was positively associated with the use of PPE, while encouraging farmers to adopt new protective measures and providing them with more tools to deal with risks, as well as an increased financial freedom (Masruri et al. 2020; Nath and Deka 2022; Nwadike et al. 2021; Bakhtawer 2021; Memon et al. 2019; Akter et al. 2018; Bagheri et al. 2018).

There is also a need to rethink agricultural practices in order to encourage more sustainable farming and to strengthen farmers' knowledge on pest management, composting, resource conservation, and fertilization. This will enable a change in farmers' attitudes, perceptions, and practices and will certainly contribute to a more conscious and safe use of pesticides (Kumari et al. 2021; Nwadike et al. 2021; Sookhtanlou et al. 2022; Akter et al. 2018, Aniah et al. 2021).

Determining the factors that influence safety in pesticide handling is the first step to build comprehensive policies that ensure security for both health and the environment (Kumari et al. 2021; Mehmood et al. 2021; Sookhtanlou et al. 2022).

5. Limitations

This study has limitations that should be acknowledged for a better evaluation of the main findings. The selected studies are based on self-reported symptoms and safety practices that are limited, requiring studies with objective and quantitative measures to validate this information. Another limitation of this systematic review is the fact that it's based solely on observational studies, due to the lack of experimental studies that meet the eligibility criteria and answer the research question. The selected studies were mostly conducted in developing countries from Asia and Africa

(associated with a low level of literacy and precarious work conditions), preventing us to have a representative sample of the European and global reality on this topic - this may be due to their year of publication, as well as their exclusion criteria. However, a search conducted at the European Agency for Safety and Health at Work indicated the absence of recent studies from Europe and other continents on the knowledge and practices of farm workers regarding the use of pesticides, with works aimed only at providing information to workers on the safe use of pesticides. Another inherent limitation is the presence of a significant number of studies with a moderate risk of bias and one having a severe risk of bias, requiring greater caution in the analysis of their results, in order to improve the methodological aspects of further research.

6. Conclusions

The knowledge, attitudes, and perceptions of farmers, as well as their practices and behaviours, are influenced by several factors. This influence translates into different effects, both positive and negative. The educational level and training on pesticides allow farmers to better understand and interpret pesticide labels/instructions; they inform them on the risks of pesticide use and, consequently, exposure; they equip them with knowledge on pesticide storage, preparation, and application; they encourage better health protection behaviours, such as the use of proper PPE (mask, clothes, hat, and gloves); they elucidate them on the correct way to dispose of pesticide waste and empty containers; and teach new ways of fighting against pests. However, other factors are associated with opposite effects on farmers. Examples are age, farming experience, and contact with other farmers and intermediaries, which have a negative influence on farmers' knowledge and attitudes regarding pesticide risk, thus increasing the adoption of unsafe behaviours while applying these products, with harmful effects on human and environmental health. The influence of personal background or previous episodes of pesticide poisoning is not unanimous and, therefore, needs further research.

There is a need of developing multidisciplinary and comprehensive programmes to improve and increase literacy on pesticide safety, bearing in mind factors such as the educational level of farmers, and featuring contents such as the correct methods for a safe storage and application of pesticides, the importance of PPE, the relevance of personal hygiene during and after pesticide use (e.g. taking a shower after spraying, washing clothes separately and not eating, drinking and/or smoking), and an introduction to the health and environmental risks of pesticides, presenting other pest control strategies and encouraging safe procedures for the disposal of pesticide residues and empty containers.

This will empower workers to adopt more conscious and safer behaviours while using pesticides and, consequently, contribute to a healthier life and to the protection and safety of the produced food (products without harmful substances to health), as well as to the sustainability of agriculture, preservation of the environment, and promotion of public health.

Authors should discuss the results and how they can be interpreted from the perspective of previous studies and of the working hypotheses. The findings and their implications should be discussed in the broadest context possible. Future research directions may also be highlighted.

Author Contributions: For research articles with several authors, a short paragraph specifying their individual contributions must be provided. The following statements should be used "Conceptualization, X.X. and Y.Y.; methodology, X.X.; software, X.X.; validation, X.X., Y.Y. and Z.Z.; formal analysis, X.X.; investigation, X.X.; resources, X.X.; data curation, X.X.; writing—original draft preparation, X.X.; writing—review and editing, X.X.; visualization, X.X.; supervision, X.X.; project administration, X.X.; funding acquisition, Y.Y. All authors have read and agreed to the published version of the manuscript." Please turn to the CRediT taxonomy for the term explanation. Authorship must be limited to those who have contributed substantially to the work reported.

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Data Availability Statement: We encourage all authors of articles published in MDPI journals to share their research data. In this section, please provide details regarding where data supporting reported results can be found, including links to publicly archived datasets analyzed or generated during the study. Where no new data were created, or where data is unavailable due to privacy or ethical restrictions, a statement is still required.

Suggested Data Availability Statements are available in section "MDPI Research Data Policies" at https://www.mdpi.com/ethics.

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