Human Health and Environmental Risk Perceptions Related to Pesticide Use in Algerian Market Gardening

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Summary

A random survey was performed in Ain Naga and Doucen of Biskra (Southeast Algeria) during 2016/2017 and 2017/2018 crop seasons to assess the environmental and human health risks posed by pesticides applied in Algerian market gardening systems, and to identify products with lower risks. Therefore, the Quebec Pesticide Risk Indicator "IRPeQ" is used to compute risk indices of 24 different active substances widely used and potentially hazardous. Data for these calculations of the Human Risk Index (HRI) and Environmental Risk Index (ERI) values are sourced from global databases of pesticides' properties. Data reveal that the Human Risk Index, formulations based on triadimntol exhibited the highest value (HRI = 4580), while formulations of Acarol 10 WP® and Hexizox® based on Hexythiazox displayed the lowest value (HRI = 20). Regarding the Environmental Risk Index, formulations containing tefluthrin and fenbutatin oxide registered the highest value (ERI = 462), whereas Maneb (a.s.) had the lowest value (ERI = 33). Mopistop® and Score® formulations are therefore identified as the most favourable products, ensuring both safe and sustainable production.

Key words

market gardening, pesticides, human health, environment, risk indices

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Introduction

Algeria's economic growth depends on agriculture, which contributes to nearly 70% of the total food consumption (FAO, 2015). Market gardening plays a crucial role in providing a range of crops across the country, contributing to both small and large-scale agricultural yields and serving as an important source of household income (Yarou et al., 2017). Additionally, agrochemical treatment serves as a rapid and cost-effective solution for managing pests, diseases and weeds (Tudi et al., 2021).

Algeria has been both an importer and large user of plant protection products (PPPs) such as pesticides, experiencing a 3.5-fold increase since 2000 (Laouar and Dugué, 2019). This increase in PPP usage aligns with the stated agenda of enhancing cropland productivity. Nevertheless, concerns regarding the toxicological and ecotoxicological impacts of these inherent agrochemicals have arisen (Foughalia et al., 2022; Anaduaka et al., 2023).

It should be noted that more than 99% of pesticide inputs are wasted and fall off the target (Tudi et al., 2021; Soudani et al., 2020b). Instead, they disperse into the air and become more toxic through their metabolites, leading to various risks (Boukhalfa, 2016; Tsaboula et al., 2016; Boukhalfa et al., 2018; Hlihor et al., 2019; Tudi et al., 2021). These risks include contamination of soil and water resources, loss of biodiversity and disruption of ecosystem functionality (WHO/FAO, 2018; Srivastav, 2020; Zaller, 2020; Galani et al., 2020; Tudi et al., 2021). Furthermore, PPPs can cause neurological and hormonal imbalances, pregnancy abortion, cancer and other long-term illnesses (Toumi et al., 2018; Zaller, 2020; López-Dávila et al., 2021). These risks to human well-being arise mainly from the consumption of fresh food products, which even when washed are contaminated with pesticide residues adhering to the surface and/or seeping into the interior (Park et al., 2015; Toumi et al., 2022).

Therefore, poisoning accidents, chronic symptoms and occupational exposures associated with PPPs have been increasingly recorded worldwide. Some countries as Southern Benin (Gouda et al., 2018), Iran (Neghab et al., 2014), Burkina Faso (Naré et al., 2015), Indonesia (Yuantari et al., 2015), Tunisia (Bouagga et al., 2016), Pakistan (Damalas and Khan, 2017), Belgium (Toumi et al., 2017) and in the Dominican Republic (Hutter et al., 2018), Côte d'Ivoire (Mouroufie, 2020), Morocco (Berni et al., 2021), Ethiopia (Loha et al., 2022), and Nigeria (Madaki et al., 2023) largely suffer from such symptoms. While there are 275 484.84 inhabitants working in rural areas of Biskra, i.e., 36.65% (ANIREF, 2021), the reported health outcomes related to PPPs use have been modest (Belhadi et al., 2016, Bettiche, 2017; Soudani et al., 2020a; Bettiche et al., 2021; Soudani et al., 2022).

Significantly, these risks are mostly caused by farmers' lack of awareness and inability to comply with Good Agricultural Practices (GAPs) before and after the application of PPPs (FAO/WHO, 2016). In the long-term, this could worsen as regulations governing the approval, supply and application of PPPs remain antiquated, and government assessment of PPPs impacts on health and the environment is either lengthy or absent (Omran and Negm, 2020).

Records compiled by Soudani et al. (2022), obtained from measurements relating to the Treatment Frequency Index (TFI) and Phytosanitary treatment Pressure Index (PPI) undergone in Ain Naga and Doucen, indicated high levels of PPPs usage and phytosanitary pressure on vegetables, and therefore, use of indicators is of interest.

At present, numerous models and approaches have been developed to evaluate and quantify risks associated with pesticide use (PPPs). The purpose of designing these models and approaches is to support policymakers and stakeholders in mitigating the impacts of PPPs (Zhan and Zhang, 2012; Tsaboula et al., 2016; López-Dávila et al., 2021).

Among these tools, the Canadian Health and Environment IRPeQ model, which is based on overall risk index measurements, allows for the optimization of the management of pesticide products, defines crop hazards, and identifies pesticides with the lowest potential risk to human health and the environment (Samuel et al., 2012).

We should stress the fact that, so far, no assessment studies using the IRPeQ model have been conducted in Algeria. Therefore, this study was undertaken to assess the potential risks related to some commonly employed PPPs in market gardening systems produced in Biskra Southeastern Algeria, and to highlight those products with lower risks.

Materials and Methods

Study Areas

Biskra, southeast Algeria, extends over 21 671 km² from Chott Melghir to Erg in the southwest. It has a Saharian bioclimatic zone, and from 2007 to 2017, it had a mild winter with an average annual rainfall of 123.40 mm and an average annual temperature max of 40.16 °C, min of 6.96 °C (National Meteorological Office, 2018). Its geographical coordination is between 34° 51' North and 5° 44' East (Sedrati, 2011), and this emplacement makes it ideal for growing crops throughout the region. The communes of Ain Naga (Ziban East) and Doucen (Ziban West) regularly supplied vegetables to local and national markets and were selected as study areas.

Survey Methodology

This study uses a dataset from an investigation carried out by Soudani et al. (2020a) and Soudani (2022). The original surveys, including 7 pages and 60 questions, targeted farmers in the study areas of Biskra, southeastern Algeria. Data was collected over two agricultural seasons (2016/2017 and 2017/2018).

Fourteen relevant questions were carefully extracted from the original questionnaire to undertake our study-specific analysis. These questions were designed to capture three key areas: (i) farmer's background information (6 questions), (ii) overall information about farms (1 question), and (iii) farmer's phytosanitary knowledge (7 questions). Interviews were conducted in local Arabic with a randomly selected group of 96 market gardeners.

Data Collection

For the purpose of this study, seventy plant protection products are selected, which include 67 single commercial formulations and 3 binary formulations. These PPPs are extensively used in market gardening in the study areas, as reported by Soudani (2022) in a previous study. These selected PPPs consist of twenty-four active substances belonging to different chemical groups, and their identification was based on the WHO classification (2020).

Data Processing

To calculate the Quebec pesticide risk indicator "IRPeQ", which comprises two components: health (HRI) and environment (ERI), global databases on pesticide properties such as Agritox Database, PPDB Database, the European Union Pesticide Database and SAgE Pesticide have been used. These databases provide detailed information on the physicochemical and toxicological properties of the listed active substances (a.s.). Also, the scientific names of pests and diseases are determined by referring to the EPhytia website (https://ephytia.inrae.fr/en/Home/index).

Calculation of the Canadian Pesticide Risk Index "IRPeQ"

Toxicological Risk Index (TRI)

The calculation of the toxicological risk index (TRI) is based on the summation of certain criteria for each active substance (a.s.), as given by equation 1. The criteria include short-term toxicity endpoints such as LD_{50} oral, LD_{50} dermal, LD_{50} inhalation, skin and/or ocular irritation and skin sensitization and long-term toxicity endpoints including carcinogenesis, endocrine disruption, neurotoxicity and reproductive and developmental effects (Samuel et al. 2012; Le Bars et al. 2020). The total is then multiplied by the Environmental Persistence and Bioaccumulation Factor (EPBF), as expressed by equation 1.

$$TRI = [\sum \text{Acute risks} + (\text{Chronic risks} \times EPBF)]^2 \quad (1)$$

Health Risk Index (HRI)

The health risk index (HRI) considers both the short-term toxicity and long-term effects resulting from the use of PPPs. This index is computed using the toxicological risk index (TRI), the weighting factor relative to formulation type (FPf) and the compensation factor for commercial preparation (FCP), as indicated in equation 2.

$$\text{HRI active substance.p} = (TRI \times FPf \times FCP) / 10 \quad (2)$$

Environmental Risk Index (ERI)

To quantify the environmental risk index (ERI) of the different pesticides used in the crops of the studied areas, ecotoxicological effects were considered. This includes the potential effects on aquatic organisms (A), the potential effects on terrestrial invertebrates (T) (including birds (O)) and certain physicochemical parameters, such as bioaccumulation (B), soil persistence (P) and mobility (M) (Equation 3), as mentioned by Samuel et al. (2012), Bouagga et al. (2016) and Le Bars et al. (2020).

$$\text{ERI active substance.p} = [1{,}75 \times (T + O) + A + M + P + B + 1]^2 \quad (3)$$

All indices are calculated using Microsoft Excel 2013.

Results

Socio-Demographic Profile

The market gardeners interviewed in the two study communes (Ain Naga and Doucen) were mostly men 94(98%), while only two (2%) were females. Their ages ranged from 25 (3%) to 86 (1%) years old. In addition, over half of them had limited education (28% illiterate and 29% primary level). As for their farming skills, 75% of the market gardeners lacked formal training, while 50% relied on their own personal experience, which ranged from zero to 19 years in this profession.

Crops Produced

Figure 1 displays seven major vegetable varieties produced in the study areas. These crops mainly belong to three botanical families: Solanaceae (tomato, pepper, chilli, eggplant), Cucurbitaceae (watermelon, cucumber), and Fabaceae (*Vicia faba* L.). Tomatoes (*Lycopersicum esculentum* Mill.) dominate, accounting for 66% of the crops. Peppers (*Capsicum frutescens* L.) are also significant, representing 61%, followed by eggplants (*Solanum melongena* L.) at 21%.

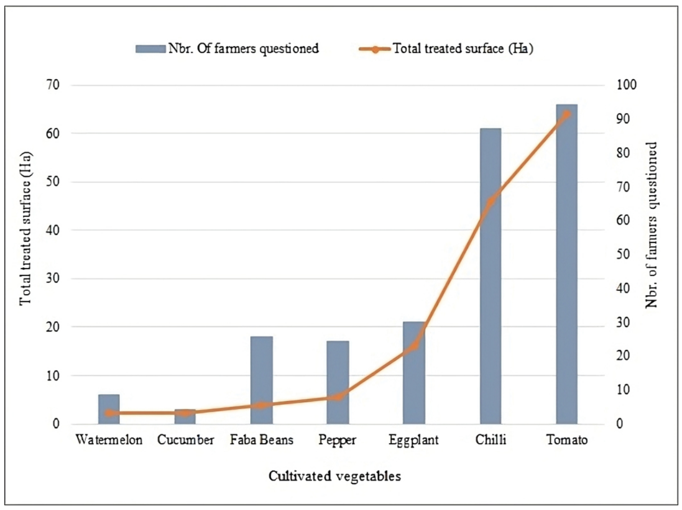

Figure 1. Main market vegetables produced and inventoried in the study areas

The Main Phytosanitary Problems

Table 1 summarizes the major phytosanitary problems affecting all seven identified vegetable crops. For the insects' pest category, 53% of respondents cited whitefly, and 30% mentioned Greenhouse whitefly. Regarding the diseases that affect the listed vegetables, the most commonly mentioned were Bacterial soft rot (44%), Grey mold (31%) and Bean Common Mosaic Virus (48%). Concerning the viral diseases, 46% of respondents did not report any, either because they failed to identify them or were unaware of any symptoms observed on their crops.

Phytosanitary Products Used

Table 2 shows a list of pesticides, including twenty-four active substances (a. s.). This list comprises 14 insecticide-acaricides, 8 fungicides, a nematicide, a bactericide, and a rodenticide. These pesticides are the most commonly applied substances to the seven vegetable crops grown in the study areas.

Table 1. Major phytosanitary problems quoted by market gardeners questioned at the study areas

Phytosanitary problems		Crops affected	Nbr. of farmer citations (%)
Insect pests	Greenhouse whitefly	Eggplant/tomato/chilli/pepper	29 (30%)
	Whitefly (*Bamisia tabaci; Trialeurodes vaporarium*)	Eggplant/tomato/chilli/pepper	52 (53%)
	Leafminers (*Tuta absoluta*)	Eggplant/tomato/chilli/pepper	14 (15%)
	Mites (*Tetranychus* spp.; *Aculops lycopersici*)	Tomato/watermelon/chili/pepper	8 (8%)
	Aphids	Eggplant/Faba beans/tomato/watermelon/chilli/pepper	4 (4%)
Bacterial diseases	Bacterial soft rot (*Pectobacterium carotovorum*)	Pepper/chilli	42 (44%)
	Bacterial wilt (*Ralstonia solanacearum*)	Tomato/chilli/pepper	26 (27%)
	Bacterial speck (*Pseudomonas syringae* pv.)	Tomato	15 (16%)
	Bacterial canker (*Clavibacter michiganensis* subsp. *michiganensis*)	Tomato	6 (6%)
	Bacterial speck of tomato (*Pseudomonas syringae* pv. *tomato*)	Tomato	3 (3%)
	Not reported or not identified	/	4 (4%)
Fungal diseases	Gray mold (*Botrytis cinerea*)	Eggplant/cucumber/Faba beans/chilli/pepper	30 (31%)
	Powdery mildew or white mold (*Leveillula taurica*)	Eggplant/cucumber/Faba beans/pepper/chilli/watermelon/tomato	24 (25%)
	Anthracnose, black dot root rot	Pepper/chilli/ tomato	22(23%)
	Early blight (*Early blight tomatophila*)	Tomato	13 (14%)
	Late blight, Downy mildiou (*Phytophthora infestans*)	Eggplant/tomato/pepper	7 (7%)
Viral diseases	Bean Common Mosaic Virus (BCMV)	Faba Beans	46 (48%)
	Cucumber mosaic virus cmv	Cucumber	3 (3%)
	Watermelon mosaic virus	Cucumber/watermelon	2 (2%)
	Downy mildew on cucurbits	Cucumber	1 (1%)
	Not reported or not identified	/	44 (46%)

All substances identified by the WHO (2019) have been classified as extremely hazardous (two of the a.s. listed in Table 2), very hazardous (three of the a.s.), moderately hazardous (12 of the a.s.), slightly hazardous (three of the a.s.) and very unlikely (three of the a.s.), or fumigant (one of the a.s.). The substances were registered and authorized for use in Algeria, except for eight substances that were not authorized and have been removed from the European registration system due to concerns about their safety for human health and the environment, as specified in Reg. (EC) No 1107/2009 (repealing Directive 91/414/EEC) (Table 2).

These eight unauthorized a.s. can be found individually or as a mixture in twenty PPPs formulations, accounting 28.57% of the identified pesticides. The a.s. include diazinon, fenbutatin oxide, imidacloprid, thiacloprid as the active substances in eight insecticides, hexaconazole, mancozeb, triadimenole as the active substances in ten fungicides, and chlorophacinone in the Hunterpate pesticide. Acetamiprid, cypermethrin, abamectin and mancozeb, collectively representing 41.43% of the total PPPs identified, are the most commonly used pesticides.

Table 2. Pesticides used in market gardening at the study areas

Active substances	WHO recommended classification of pesticides 2019	European Regulation 1107/2009 status	Pests/Diseases	Nbr. of farmers citing (%)
1,3-Dichloropropene	FM	In waiting	Nematodes	3
Abamectin	Ib	Approved	Spider mites/ Thrips/ Leafminer	76
			Spider mites/ Leafminer	
Acetamiprid	II	Approved	Pepper aphids/ Leafminer/ Whitefly/ Moths (noctuids) /Aphids/	38
			Thrips	
			Whitefly / Aphids	
Cypermethrin	II	Approved	Wireworms (*Agriotes* spp.)/Noctuid	34
			Whitefly and Noctuid	
			Whitefly/ Pepper midge/ Noctuid/ Aphids/ Wireworms	
Deltamethrin	II	Approved	Noctuid / Soil Noctuid / Whitefly	13
Diazinon	II	Not Approved	Aphids/ Leafhoppers	19
Emamectin Benzoate	Ib	Not found	Spider mites / Moths (noctuids) of Tomato	18
			Noctuid	
			Spider mites/ Moths (noctuids)	
Fenbutatin oxide	III	Not Approved	Spider mites	10
Hexythiazox	U	Approved	Spider mites	22
Imidacloprid	II	Not Approved	Whitefly	19
			Whitefly /Leafminers/ Aphids	
Indoxacarb	II	Approved	Eudemis / Leafhoppers, Noctuid	12
			Eudemis / Leafhoppers	
Oxamyl	Ia	Approved	Nematodes/Spider mites /Aphids/ Whitefly/ Leafminers /Thrips	2
			Nematodes	
Tebufenpyrad	II	Approved	Spider mites	15
Thiacloprid	II	Not Approved	Whitefly/ Aphids	15
Tefluthrin	Ib	Approved	Soil insects	4
Thiacloprid + Deltamethrin	II	Not Approved+Approved	Aphids / Whitefly	1
Acetamiprid + Cypermethrin	II	Approved	Aphids/ Leafminers	1
Azoxystrobin		Approved	Powdery mildew /Early blight /Downy mildiou	10
Bromuconazole	II	Approved	Powdery mildew	12
Difenoconazole	II	Approved	Powdery mildew / Early blight	11

Continued. Table 2

Active substances	WHO recommended classification of pesticides 2019	European Regulation 1107/2009 status	Pests/Diseases	Nbr. of farmers citing (%)
Hexaconazole	III	Not Approved	Powdery mildew	18
			Rust / Powdery mildew	
Hymexazol	III	Approved	Pythium/ Fusarium	11
Mancozeb	U	Not Approved	Early blight / Downy Downy mildiou / Rust	30
Maneb	U	Non Found	Downy mildiou /Rust	15
			Downy mildiou/ Mold	
			Powdery mildew / Rust	18
			Powdery mildew	
Azoxystrobin+Dif-enoconazol	U+II	Approved	Downy Downy mildiou /Powdery mildew / Early blight	1
Chlorophacinone	Ia	Not Approved	Rats and mice	2

Additionally, 76% of market gardeners reported using abamectin, which is the main compound found in eleven insecticides (accounting for 15.71% of the total PPPs identified) commonly used against mites, thrips and leaf miners. Similarly, the fungicide mancozeb (presenting 7.14% of the total PPPs identified) is extensively used to control early blight, downy mildew and rust.

Quebec's Plant Protection Product Risk Indices "IRPeQ"

Toxicological Risk Index (TRI)

About 58 percent of the a.s. identified exhibit an acute risk greater than the chronic risk. The TRI values obtained ranged from 11 449 to 81 (Table 3). When comparing the short-term toxicity and the long-term toxicity, fourteen (a.s.) showed higher acute toxicity risk values. These include triadiminol (TRI =11 449) from the fungicides class, imidacloprid (TRI = 11 342) from the insecticides class, and 1,3-dichloropropene (TRI = 4 900) from the nematicides and bactericides class.

Further, triadimenol and imidacloprid (a.s.) display the highest tissue persistence factor (Fper = 2.5). Furthermore, chlorophacinone (TRI = 1 936) from the rodenticide class, tefluthrin (TRI = 1 225) from the insecticide class and mancozeb (TRI = 1 156) from the fungicide class are among the nine (a.s) with the highest chronic toxicity risk. Only azoxystrobin (a.s.) (TRI = 81) from the fungicide class exhibits a lower toxicity risk value.

Health Risk Index (HRI)

The theoretical HRI for an a. s. varies from 1 to 2 420. The higher the number, the greater the health risk it represents (SAgE pesticide, 2022). However, in practice, the HRI values range between 1.25 and 1 560 (Samuel et al., 2012).

In this study, the obtained HRI values range from 20 to 4,580 (Table 3), indicating a higher risk to health. Therefore, there are four products (Prod.65, 66, 67, and Prod.68) based on triadimntol (a.s.), which record the highest value (HRI = 4580). Among all the pesticides inventoried, Prod.41 and Prod.42, insecticides based on Hexythiazox (IRS = 20) (a.s.), display the lowest HRI value.

Environmental Risk Index (ERI)

Similarly, the theoretical reference value for ERI range from 1 and 961 or higher, and the higher the number, the greater the environmental risk it represents (SAgE pesticide, 2022). The ERI values obtained in this study vary from 33 to 462, indicating significant environmental concern, as shown in Table 3.

The results reveal that the two insecticide formulations, namely Prod. 37 and Prod. 69, based respectively on fenbutatin oxide and tefluthrin, have a maximum ERI of 462. On the other hand, all fungicides inventoried based on maneb (a.s.) have a minimum ERI of 33 (Table 3).

Identifying Low-Risk Pesticides

According to the Sage pesticides guidelines, the HRI and ERI indices cannot be directly compared as they are not based on the same formula. However, their calculation can assist in identifying and distinguishing between more risky and less dangerous products (SAgE pesticide 2022).

As a result, each PPP listed in table 3, is composed of any of these substances: abamectin, acetamiprid, cypermethrin, emamectin benzoate, fenbutatin oxide, hymexazol, imidacloprid and indoxacarb, and has different recommended doses with corresponding ERIs. Among the ten identified PPPs featuring abamectin, which exhibit significant acute and chronic hazards (TRI = 1849, HRI = 185), only Prod. 12 (25-35 mL/hL) records lower ERI values of 121. Therefore, selecting PPPs with a lower dosage can minimize the associated risk.

Table 3. Toxicity, health and environmental risk indexes of listed active substances

Active substances	Commercial formulation name	Acute toxicity	Chronic Toxicity	Fper	TRI	FPf	FCP	HRI	Ecotoxicological			Physico-chemical			ERI
									T	O	A	M	P	B	Active substance-p
1,3-Dichloropropene (N)	Prod. 1	34	36	1	4900	2	2	1960	4	4	4	2	0	0	400
Abamectin (I)	Prod. 2	19	24	1	1849	2	1	185	4	2	4	0	0	0	210
	Prod. 3														
	Prod. 4														
	Prod. 5														
	Prod. 6														
	Prod. 7														
	Prod. 8														
	Prod. 9														
	Prod. 10														
	Prod. 11														
	Prod. 12								2	2	4	0	0	0	121
Acetamiprid (I)	Prod. 13	11	8	1	361	2	1	36	2	2	4	0	0	0	121
	Prod. 14														
	Prod. 15														
	Prod. 16														
	Prod. 17														
	Prod. 18														
	Prod. 19														
	Prod. 20														
	Prod. 21								2	1	4	0	0	0	86
Azoxystrobin (F)	Prod. 22	9	0	2,5	81	2	2	32	4	0	4	3	4	0	306
Bromuconazole (F)	Prod. 23	4	10	2,5	841	2	1	122	4	0	4	1	3	1	255
Chlorophacinone (R)	Prod. 24	26	9	2	1936	1	2	387	4	4	4	0	2	0	400
Cypermethrin (I)	Prod. 25	27	12	1,5					4	1	4	0	2	2	281
	Prod. 26								4	0	4	0	1	2	186
	Prod. 27	27	12	1,5	2025	1	2	405	4	0	4	0	0	2	160
	Prod. 28														
	Prod. 29														
Deltamethrin (I)	Prod. 30	18	0	1,5	324	2	0,9	57	4	0	4	0	0	2	166
Diazinon (I)	Prod. 31	17	0	1,5	289	2	1,4	83	4	4	4	1	0	0	388

Continued. Table 3

Active substances	Commercial formulation name	Acute toxicity	Chronic Toxicity	Fper	TRI	FPf	FCP	HRI	Ecotoxicological			Physico-chemical			ERI
									T	O	A	M	P	B	Active substance-p
Difenoconazole (F)	Prod. 32	8	4	2,5	324	2	0,9	57	0	0	4	0	2	2	62
Emamectin Benzoate (I)	Prod. 33	18	16	1	1156	2	1	246	4	2	4	0	0	0	210
	Prod. 34														
	Prod. 35								4	1	4	0	0	0	163
	Prod. 36														
Fenbutatin Oxide (I)	Prod. 37	19	0	2,5	361	2	2	144	4	2	4	0	4	3	462
	Prod. 38								2	0	4	0	3	3	171
Hexaconazole (F)	Prod. 39	4	8	2,5	576	2	1	115	4	0	4	1	4	2	333
	Prod. 40														
Hexythiazox (I)	Prod. 41	4	4	1,5	100	2	1	20	4	0	4	0	0	0	124
	Prod. 42														
Hymexazol (F)	Prod. 43	20	12	1	1024	2	1	205	4	2	4	2	1	0	308
	Prod. 44								4	0	4	1	0	0	158
	Prod. 45														
Imidacloprid (I)	Prod. 46	24	33	2,5	11342	2	1	2268	4	2	4	3	3	0	413
	Prod. 47								4	1	4	3	3	0	331
	Prod. 48								4	0	4	3	3	0	262
	Prod. 49														
Indoxacarb (I)	Prod. 50	18	20	1	1444	2	1	289	4	4	4	0	0	1	361
	Prod. 51								4	2	4	0	0	1	240
Mancozeb (F)	Prod. 52	21	13	1	1156	2	2	462	4	0	4	0	0	0	121
	Prod. 53														
	Prod. 54														
	Prod. 55														
	Prod. 56														
	Prod. 57														
Maneb (F)	Prod. 58	20	40	1	3600	2	2	1440	0	1	4	0	0	0	33
	Prod. 59														
	Prod. 60														
Oxamyl (I)	Prod. 61	14	0	1	196	2	2	78	4	4	4	2	0	0	400
	Prod. 62														

Continued. Table 3

Active substances	Commercial formulation name	Acute toxicity	Chronic Toxicity	Fper	TRI	FPf	FCP	HRI	Ecotoxicological			Physico-chimical			ERI
									T	O	A	M	P	B	Active substance-p
Tebufenpyrad (I)	Prod. 63	16	24	1	1600	2	1	320	2	0	4	0	0	1	72
Thiacloprid (I)	Prod. 64	17	12	1	841	2	2	336	4	0	4	0	0	2	162
Triadimenol (F)	Prod. 65	7	40	2,5	11449	2	2	4580	2	0	4	0	0	0	56
	Prod. 66														
	Prod. 67														
	Prod. 68														
Tefluthrin (I)	Prod. 69	29	4	1,5	1225	1	2	245	4	2	4	4	3	0	462

Prod: Product (Commercial formulation)

I = Insecticide (including acaricide); F = Fungicide; N: Nematicide (including bactericide); R= Rat poison

Fper = Persistence factor; TRI = Toxicological Risk Index; FPf = Factor relative to formulation type; FCP = Compensation factor for commercial preparation; HRI = Health risk index; T = Impact on terrestrial invertebrates; O = Impact on birds; A = Impact on aquatic organisms; M = Mobility; P = Persistence in soil; B = Bioaccumulation; ERI: Environmental risk index.

While some (a.s.) may pose a high health risk, they can be less toxic to the environment. This applies to the tebufenpyrad-based insecticide (Prod. 63) and to the maneb- based fungicides (a.s.) (Prod. 58, Prod. 59, and Prod. 60).

On the other hand, formulations containing the triadimenol-based fungicides (Prod. 65, Prod. 66, Prod. 67, and Prod. 68) are highly toxic to human health (HRI = 4 580; TRI = 11 449) and classified as slightly toxic to the environment (ERI = 56) (Table 3).

Conversely, some other PPPs may present a lower health risk, but pose a danger to the environment. This is the case for the insecticides Prod.30, Prod.41, Prod.42, Prod.61, and Prod.62. Particularly, azoxystrobin-based fungicide (Prod. 22) is slightly toxic to human health (HRI = 32; TRI = 81) and classified as dangerous to the environment (Table 3).

Furthermore, formulations used by farmers, such as Prod. 21 (10-12.5g/ha) (acetamiprid) recommended for controlling whiteflies and aphids, and Prod. 32 (0.3-0.5 l/ha) (difenoconazole) used to combat Powdery mildew and Early blight, pose minor health and environmental hazards.

Discussion

As part of this study, we have collected some intriguing and relevant insights. According to the local farmers questioned in the study areas, they frequently use a broad variety of PPPs in market gardening crops. Insecticides and fungicides are the two major categories applied to control pests such as whitefly, bacterial soft rot of pepper and botrytis fungal disease.

Referring to the most recent study by Soudani et al. (2022), concerns about the use of PPPs on tomatoes, eggplants, and chilli peppers cultivated in Doucen commune (1 220 ha) compared to Ain Naga commune (2 500 ha) have been highlighted. The study indicates that Doucen commune undergoes PPP treatment intensities that are 3.6 times higher, and phytosanitary pressure levels that are 2.5 times higher than those in Ain Naga commune. Specifically, high average values of Frequency Treatment Index (TFI) (≥ 10) were recorded on farms in Ain Naga (Mansoria, Nebka, Feidh Sala, Ghemoug, Djalaya and Safl Tadjdid) and Doucen (Berouth, Noumer, Tamda and Elmarhoum), reflecting a very high degree of phytosanitary pressure (IPP ≥ 2.1), particularly in Mansoria and Nebka in Ain Naga, and Berouth and Tamda in Doucen.

In this study, farmers questioned tend to cultivate the same crops or closely related species belonging to the botanical families of *Solanaceae, Cucurbitaceae* and *Fabaceae* continuously on small-scale farms during successive growth and seeding cycles. This practice puts their crops at a higher risk from pests and diseases. Therefore, under favourable conditions, the resulting damages caused by pests and diseases can vary from slight leaf spotting to almost complete crop loss, thereby impacting products quality and leading to significant reductions in yield.

According to Brooker et al. (2023), intensive agriculture involves a high dependency on chemical inputs (pesticides and fertilizers) and reduces the functionality of ecosystems. Yet, cultural heterogeneity and crop rotations can provide flexibility and sustainability to soils and the environment, while also decreasing the threat and spread of pests and diseases (Sanad et al., 2019; Yu et al., 2022; Brooker et al., 2023).

Moreover, farmers questioned have limited education and are untrained, relying heavily on local knowledge or outdated personal experience to deal with crop issues. All these factors have significant and adverse implications for their follow-up of GAPs before and after applying PPPs application. For instance, they often apply pesticides in quantities exceeding the recommended doses, sometimes even up to 10 fold higher, as reported by Soudani et al. (2020b).

Further, farmers believe that mixing different varieties of products would increase effectiveness and decrease pests' appearance, corresponding to Padmajani et al. (2014), Halimatunsadiah et al. (2016), Soudani et al. (2020a). However, randomly mixing pesticides with insufficient awareness of their specific properties is dangerous. For example, mixtures containing both insecticides and fungicides can be harmful and fatal to bees (Johnson et al., 2013; Milford et al., 2022). Moreover, the failure to adhere to recommended rates and application intervals often leads to the development of pest resistance and/or the use of more poisonous substances (Agnandji et al., 2018). Consequently, such behaviours increase the risks to human health and the environment related to pesticides use.

The above results broadly support the work of Soudani et al. (2020a), who reported that 72% of farmers experienced one or more symptoms indicative of a significant level of pesticide poisoning. Complaints most frequently encountered were respiratory problems (28%), skin-related symptoms (16%), eye problems (9%), fatigue and headaches (6%) and gastrointestinal problems (3%).

In this regard, the current study attempted to employ the Canadian model "IRPeQ" model in order to calculate indices of hazard for the environment (ERI) and health (HRI) for the listed PPPs based on the applied dose per hectare. Noteworthy, a direct comparison between the HRI and ERI indexes is not possible. However, aspects associated with the use of PPPs, such as application rate, treatment pattern and crop height, are all factored into the ERI index (SAgE pesticide, 2022).

Importantly, farmers desiring short-term profit regularly apply various types of PPPs but often hesitate between several products. Such an approach can facilitate the classification of PPPs according to their risk indices and enable the selection of the appropriate products to use.

Pesticide formulations based on triadimenol have the highest toxicological and health risks and can cause numerous potential hazards. These include outcomes such as impaired fertility, adverse effects on unborn babies and infants (Bozdogan, 2014), classification as a probable or possible carcinogen and neurotoxic substance to humans, as well as demonstrated teratogenicity in rats (Chu et al., 2016). Furthermore, triadimenol is known to be persistent in the environment and exhibit higher levels of toxicity (Chu et al., 2016).

Imidacloprid is a widely used broad-spectrum neonicotinoid insecticide that can contaminate water, soil and air (Almeida et al., 2021; Butcherine et al., 2022). According to the Pest Management Regulatory Agency (PMRA), imidacloprid is classified as a "persistent" substance with high leachability (Anderson et al., 2015). It has serious effects on humans, mammals and terrestrial communities by disrupting carboxylesterase activity (Tao et al. 2019; Wen et al. 2020). In addition, it is highly toxic to bees (Bonmatin et al., 2005) and other non-target organisms (Ansoar-Rodríguez et al., 2015). However, aquatic insects, fish, algae, amphibians, and molluscs, are relatively less sensitive to it (Anderson et al., 2015).

Moreover, formulations based on chlorophacinone, tefluthrin and mancozeb have the highest chronic toxicity risk. Approximately 38% of questioned market gardeners confirmed applying products based on mancozeb. Thus, consuming fresh commodities and/or drinking water that is directly or accidentally contaminated with mancozeb poses a risk to human health (Runckle et al., 2017; Asparch et al., 2020). Additionally, it can expose the ecosystem, including avian species, non-target mammals, arthropods and soil microorganisms. It poses moderate to high toxicity to various freshwater fish species and invertebrates (EFSA, 2020; Asparch et al., 2020).

As reported by Ochoa and Maestroni (2018) and Soudani et al. (2020b), imidacloprid, hexaconazole, triadimenol, cypermethrin, mancozeb and abamectin, have all been identified as highly leachable and capable of contaminating groundwater, presenting a significant environmental risk.

In cases where multiple products of different brands contain the same active substance but in varying concentrations, it is necessary to consider the levels of these active substances (Le Bars et al., 2020). This is applicable to abamectin, which is the most widely used (a.s.) identified by the majority of farmers (76%) and carries acute and chronic risks, especially when applied beyond the recommended dose. Similar to the findings of Le Bars et al. (2020), these risks can be reduced by either choosing products with lower rates of the active substance or switching to a pesticide with an active substance of lower risk.

As computing HRI and ERI indexes have also allowed recognition of pesticides that pose less risk, this may require favouring a single index over others depending on the particularity of an environment, such as water resources and/or the scarcity of safer product options.

Therefore, PPPs formulations Prod. 21and Prod. 32 were found to be more likely to ensure safe and sustainable production. Unfortunately, many commercially available and widely marketed PPPs do not comply with these requirements. Further, the use of unapproved PPPs has health repercussions for both vegetable growers and consumers, as their misuse leads to the contamination of soil and water resources (Le Bars et al., 2022).

In agreement with Lamichhane et al. (2015), Ahoungninou et al. (2019), Falahzadah et al. (2020), Khan et al. (2020) and Foughalia et al. (2022), there is a strong need to encourage farmers to reduce their reliance on chemicals and shift to biocides and/or to adopt an integrated pest management approach (IPM). Additionally, many (a.s.) that have negative impacts on human health and the environment are banned or being replaced by the European Union (Parra-Arroyo et al., 2020, Sarkar et al., 2021, López-Dávila et al., 2021).

Therefore, our results may contribute in assisting decision-makers in removing products based on toxic (a.s.) from the national plant protection index of PPPs for agricultural use, and/or replacing them with less toxic alternatives. Also, updating and revising current regulations should be considered.

Conclusion

The objective of this study was to use “IRPeQ” risk assessment tool to identify and select safer products among several widely applied PPPs in market gardening. Upon calculating the TRI, HRI and ERI indices, we found some important insights about the careful selection of PPPs and the feasibility of managing the risks associated with their use. We expect that these findings will be considered prior to any final approval for the use of PPPs on crops. This is particularly relevant given the growing number of new pesticides entering the Algerian market every year and the heavy reliance of farmers on these chemicals to safeguard crops.

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CRediT authorship contribution statement

Hassina Hafida Boukhalfa and Khaoula Toumi: Conceived the project and supervising the work and critically reviewing the draft. **Nafissa Soudani:** Conceptualization, investigation, Data analysis, Original draft preparation. **Amina Soudani:** Contributed to the investigation and data collection.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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