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Inventory and Impact Assessment of Pesticides on Merja Zerga's (Morocco) Environment Using Pressure Indicators

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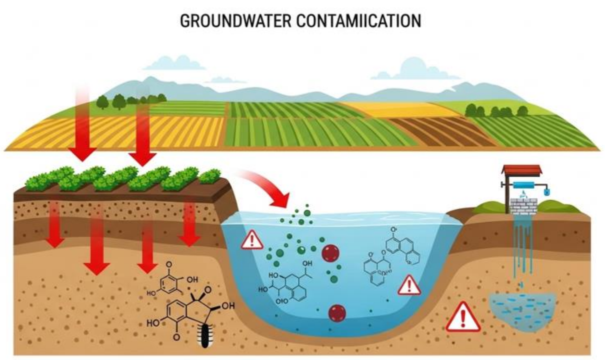
Graphical abstract



Abstract

This study analyzed the agricultural and phytosanitary practices, the intensity of pesticide use, and the associated health risks to humans on 100 farms with a total surface area of 555 hectares in the irrigated Gharb plain, the Merja Zerga area, over the 2016–2018 period. Information on the pesticides, active substances, application patterns, and amounts used was collected from questionnaires sent to farmers and surveys of 71 retailers of pesticides. Phytosanitary pressure was assessed using the Treatment Frequency Index (IFT), comparing applied and recommended doses, whereas health risk to applicators was assessed using the IRTH indicator (considering toxicity, formulation, and application method) through the OLYMPE platform. The survey identified 109 types of pesticides (containing 77 active ingredients), of which fungicides were the most abundant, representing 50%. A remarkably high mean application rate of 13.6 kg/ha was recorded, totaling 7569.8 kg, of which the largest portion was fungicides. Banana cultivation, which represented just 8% of the area cultivated, presented the highest application rate of 47.5 kg/ha and an IFT of 38. In contrast, citrus and avocado crops presented the highest IRTH values of 6269.5 and 6076, respectively, indicating high risk to applicators. Tomato cultivation also presented high pesticide pressure (IFT=11) together with a significant applicator risk (IRTH=4931). Conversely, export-oriented crops like strawberries and raspberries exhibited substantially lower application rates, IFTs (≈5), and applicator health risks (raspberry IRTH=283.5). These findings highlight the urgent need to promote sustainable agricultural practices, especially Integrated Pest Management (IPM), for high-input crops destined for the domestic market to mitigate environmental and health issues.

Keywords: Pesticide Use, Human Health Risk, Treatment Frequency Index (IFT), IRTH Indicator, Gharb Plain, Morocco.

1. Introduction

Merja Zerga, a key agricultural zone in Morocco's Gharb plain, faces severe environmental issues from intensive farming and heavy pesticide use. Upstream farming causes pesticide and nutrient runoff, degrading water quality in the lagoon and threatening human and ecosystem health (Hajjioui *et al.*, 2021; Bouzekry *et al.*, 2022). Watercourses draining into Merja Zerga show poor water and sediment quality with alarming pollutant and metal levels, risking fisheries and locals (Bouzekry *et al.*, 2022). Local fauna exhibit heavy metal bioaccumulation (Fan *et al.*, 2020), and invasive species, alongside pollution, reduce endemic aquatic vegetation (Mghili *et al.*, 2020; Mountassir *et al.*, 2021). Fish production has declined due to pollution, reduced freshwater and fishing pressure, affecting biodiversity and local economies (Boubou *et al.*, 2025). Agricultural expansion and hydrological changes have reduced wetland area, altered water flow, and increased salinity (Baloch *et al.*, 2022).

The use of pesticides in Morocco requires integrated regulation and risk assessment. As noted by Ouakhssase *et al.* (2024), monitoring pesticide residues in food, water, and soil is essential for European Union compliance and public health risk assessment, noting links with chronic exposure and a range of diseases, including cancers, cardiovascular disease, reproductive problems, and musculoskeletal disorders (Ouakhssase *et al.*, 2024). In the Saïss Plain, farmers who had not received appropriate training showed evidence of acute pesticide exposure, while banned pesticides found in groundwater-risked cancer in children, thus pointing to the need for educating farmers (Duca *et al.*, 2024).

In Merja Zerga, monitoring of environmental alterations involves simulation models and remote sensing for determining effects (Hafiane *et al.*, 2024). These measures, coupled with programs promoting greater water efficiency, reduced pesticide use, and better wastewater treatment, are designed to prevent further degradation (Baloch *et al.*, 2022; Hajjioui *et al.*, 2021). A multi-faceted approach is needed for addressing water pollution, loss of biodiversity, and ecosystem degradation resulting from intensive production (Hafiane *et al.*, 2024).

The purpose of this study is to provide a complete list of pesticides used in Merja Zerga and to assess their environmental implications using the Treatment Frequency Indicator (IFT) and Risk Indicator of Toxicity to Human Health (IRTH). The findings are presented to highlight the urgent need for sustainable use and regulation measures designed to reduce environmental and health risks. In identifying widespread pesticides and respective effects on different crops, this research provides vital observations, with emphasis on the need for better pesticide control and stronger regulations for maintaining environmental balance and protecting human health in the area.

2. Materials and methods

2.1. Study Area Description

Merja Zerga is a wetland under the Ramsar Convention located within the plain of Gharb in Morocco. It has a Mediterranean climate that predominates due to oceanic conditions and causes relatively mild winters, while the more inland areas have semi-arid conditions (**Figure 1**). The site in study consists of a total area of land equal to 555 hectares and harbors different agricultural areas that include Mnassra, Souk Tlet, Sidi Mohamed Lehemer, Larbaa Souk, and Lalla Mimouna.

Figure 1. Location of the Merja Zerga study area on the Atlantic coast of Morocco.

2.2. Field Surveys and Sampling

The field surveys covered 100 farming businesses and 71 pesticide dealers over the 2016/2017 and 2017/2018 cropping seasons. The main aim in these surveys was to identify different types of pesticides, amounts, and application techniques. The data collection process included:

- Farm Surveys: Detailed questionnaires were administered to farmers to gather information on pesticide types, active ingredients, application rates, crop types, and farming practices.
- Reseller Surveys: Interviewing pesticide resellers provided important insights into pesticide distribution and sales trends in the region.
- Pesticide Inventory Surveys and Resellers.

The pesticide inventory included 109 different types, which represented 77 different active ingredients. The survey questionnaires were aimed at collecting data on:

- The active ingredients and commercial names of agrochemicals.
- Recommended doses and administration frequencies
- Varieties of crops and rotational practices.

2.3. Analytical Methods

The IFT is defined as the quotient of the dose used (DA) and the authorized dose (DH) assigned to the product.

Methodology for computation:

$$\text{IFT}\left(\text{Treatment}\right) = \left(\text{applied Dose / Dose approved}\right) \text{ * the proportion of the treated plot} \quad (1)$$

$$\text{IFT plot} = \Sigma\left(\text{DAT / DHT}\right) = \Sigma\ \text{IFT}\left(\text{Treatment}\right) \quad (2)$$

$$IFT\ \left(Operations\right) = \Sigma\ \left(IFT\ plot\ *\ Surface\ Treated\right) / \Sigma\ surface\ plots \quad (3)$$

$$\text{IFT}\left(\text{Region / Nation}\right) = \text{Avg IFT plots / }\Sigma\text{surface plots} \quad (4)$$

To calculate the IRTH it is necessary first to determine the IRT that results from the use of three given parameters that have already been calculated using the scientific data obtained in the analysis of the Etophy 2007 platform (Samuel *et al.*, 2007).

$$\text{IRT} = \left[\Sigma\ \text{Risks acute} + \left(\Sigma\ \text{* Chronic hazards RSBF}\right)\right] \quad (5)$$

$$\text{IRTH product} = \Sigma\left(\text{IRTma * FPS * fpa * FCP}\right) \quad (6)$$

$$\text{IRTH treatment} = \Sigma\left(\text{IRTH product * Surface treated}\right) \quad (7)$$

$$\text{Operation IRTH} = \Sigma\text{IRTHtraitement} \quad (8)$$

2.4. Data Analysis Tools and Software

Data analysis was performed using the OLYMPE platform (**Figure 2**), which allows pressure indicators to be calculated and the risk of toxicity to be assessed. The platform integrates data collected from field surveys and includes statistical analysis tools along with the visualization of results.

2.5. Instrumental Analysis by LC-MS/MS and GC-MS/MS

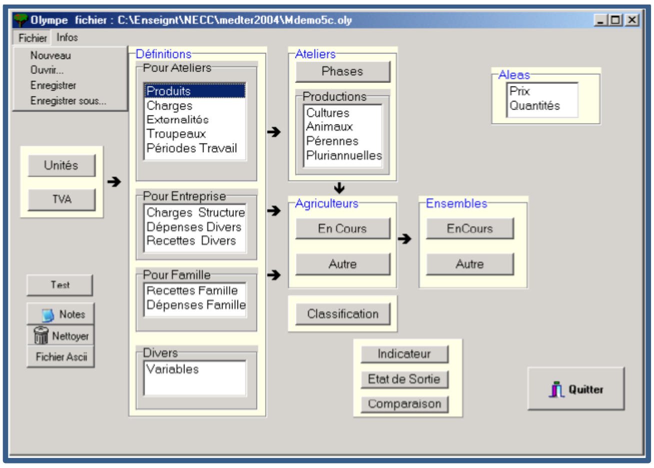


Figure 2. Olympe main interface.

3. Results and discussion

This study examined agricultural and phytosanitary practices on 100 farms covering a total surface area of 555 hectares in the Moroccan Gharb plain, which is characterized by fully irrigated (drip, sprinkler, or gravity) and diverse cropping systems. The findings reveal trends of intensive farming practices together with a high reliance on chemical pest control methods. The major land uses observed were citrus groves (mostly oranges, extending over 132 hectares) and tomato cultivation (115 hectares), followed by strawberry (78 hectares, i.e., 14%), avocado (11 hectares), and high-value crops like banana (around 8%) and raspberry (around 5%), as detailed in **Table 1**. Similar trends were found for the Souss-Massa and Tadla areas, where citrus and tomato are also identified as major crops, with reports of intensive pesticide use practices (Sadik *et al.*, 2022).

3.1. Inventory of Pesticides Used

Analysis of pesticide use, based on farm surveys and retailer interviews, identified 105 distinct pesticide types (containing 77 active ingredients) being used, drawn from the 1312 nationally registered brands. Fungicides constituted the largest category (54 types, 50%), followed by insecticides (35 types, 32%) and herbicides (20 types, 18%) (**Figure 3**). The marked dominance of fungicides (54 types used out of 537 nationally registered, with Mancozeb, Copper, Metalaxyl, Thiophanate-methyl, and Carbendazim being prominent active ingredients - **Table 2**) is strongly indicative of the challenges posed by fungal diseases and nematodes, likely exacerbated by the prevalent irrigation practices favouring humid conditions. Many of these fungicides offered broad-spectrum utility across both vegetable and fruit crops. Insecticide use (35 types identified out of 365 nationally registered), primarily featuring active ingredients like Abamectin, Cypermethrin, and Chlorpyrifos-ethyl (**Table 2**), was concentrated on vegetables and bananas. Herbicide diversity and use were comparatively lower (20 types used out of 237 nationally registered, with 2,4-D and MCPA common - **Table 2**), possibly offset by farmers employing manual weeding, although herbicides were still applied across various crops including strawberries and tomatoes. This detailed inventory can be compared with other studies that have cataloged pesticide use in different agricultural areas of Morocco, such as Meknes region, whene 74 commercial preparations were identified, including 14 insecticides, 23 fungicides, 26 herbicides, 3 insecticide-acaricides, and 1 nematicide, with several classified as carcinogenic by international standards (Khadda *et al.*, 2021). In groundnut cultivation in the Loukkos plain, 20 commercial products with 17 active ingredients were used, dominated by herbicides (71%), followed by fungicides (22%) and insecticides (7%) (Abbou *et al.*, 2022).

Table 1: Distribution of cultivated crops by area in (ha) and (%).

Category	Crop	Cultivated Area (ha)	Percentage (%)
Industrial Crops	Sugarcane*(Saccharum officinarum)*	37	7
Vegetable Crops	Eggplant*(Solanum melongena)*	13	2
Vegetable Crops	Cauliflower(*Brassica oleracea* var. *botrytis)*	4	1
Vegetable Crops	Pepper*(Capsicum annuum)*	20	4
Vegetable Crops	Melon*(Cucumis melo)*	10	2
Vegetable Crops	Tomato*(Solanum lycopersicum)*	115	21
Forage Crops	Forage Maize*(Zea mays)*	12	2
Fruit Crops	Banana*(Musa spp.)*	46	8
Fruit Crops	Citrus*(Citrus spp.)*	132	24
Fruit Crops	Strawberry*(Fragaria × ananassa)*	78	14
Fruit Crops	Raspberry*(Rubus idaeus)*	25	5
Fruit Crops	Avocado *(Persea americana)*	63	11
Total		555	100

Table 2. Key characteristics of the primary pesticides (Fungicides, Insecticides, Herbicides) used on surveyed farms.

Fungicide Trade Name	Fungicide Active Ingredient	Insecticide Trade Name	Insecticide Active Ingredient	Herbicide Trade Name	Herbicide Active Ingredient
Acrobat cu	Copper oxychloride + Dimethomorph	Acaritouch	Propylene glycol monolaurate	Afalon 50 wp	Linuron
Acrobat mz wp	Mancozeb	Acramite 480 sc	Bifenazate	Al Fahd mix	2,4-D (ammonium salts) + MCPA
Acrobat wg	Mancozeb + Dimethomorph	Actara 25 WG	Thiamethoxam	Arzin 75 wg	Metribuzine
Actamyl 70 wp	Thiophanate-methyl	Arrivo 25 EC	Cypermethrin	Atlantis	Iodosulfuron-methyl-sodium
Agrezate	Mancozeb	Avaunt 150 EC	Indoxacarb	Boxer	Prosulfocarb
Aliette Flash	Fosetyl-Aluminium	Berlina	Abamectin	Daka 50 wp	Linuron
Antracol 70 wp	Propineb	Coragen	Chlorantraniliprole	El Afrit 200	2,4-D (butylglycol ester)
Armetil m	Mancozeb + Metalaxyl	Cypermethrine 25	Cypermethrin	Faucil	Linuron
Artea 330 EC	Propiconazole + Cyproconazole	Decis expert	Deltamethrin	Gallant super	Haloxyfop-R-methyl
Balear 720 sc	Chlorothalonil	Dursban 4	Chlorpyrifos-ethyl	Gramoxone	Paraquat
Banco plus	Chlorothalonil	Dursban 75 WG	Chlorpyrifos-ethyl	Hussar evolution	Fenoxaprop-P-ethyl + Iodosulfuron-methyl-sodium + Mefenpyr-diethyl
Champion	Copper hydroxide	Express	Thiamethoxam	Imidafor 4	Glyphosate + Ammonium salt
Cobox	Copper	Karaté 2	Lambda-cyhalothrin	Lumax 537.5 SE	Mesotrione + S-metolachlor + Terbuthylazine
Coragen	Chlorantraniliprole	Karaté 5 ec	Lambda-cyhalothrin	Matecor	Metribuzine
Cropzim 500 sc	Carbendazim	Kendor 70 wp	Imidacloprid	Menjel 24 EC	2,4-D (butylglycol ester)
Cuivrol 50% wp	Copper	Lannate 20L	Methomyl	Mustang 306 SE	2,4-D (acid equivalent) + Florasulam
Cuivroxine	Copper oxyquinolate	Lannate 25 ec	Methomyl	Ovni XL	Glyphosate + Oxyfluorfen
Cupra-50	Copper oxide	Limocide	Orange Oil	Printazol 75	2,4-D + MCPA
Cuprene 50	Copper oxychloride	Mesurool 50 WP	Mercaptodimethur	Prolinuron	Linuron
Cuprozin	Copper	Mocap 10 G	Ethoprophos	Topik 080 EC	Clodinafop-propargyl + Cloquintocet-mexyl (safener)
Curator	Azoxystrobin + Chlorothalonil	Pilori 480 EC	Chlorpyrifos-ethyl		
Daconil 720 Sc	Chlorothalonil	Pirate 50 sc	Chlorantraniliprole		
Difcor 250 ec	Difenoconazole	Pride 200 sc	Fenazaquin		
Dithan M 45	Mancozeb	Proclaim 05 SG	Emamectin benzoate		

Equation pro	Famoxadone	Promethion	Dimethoate
Flare gold	Copper + Metalaxyl-M	Robust 48 ec	Chlorpyrifos-ethyl
Flint 50 WG	Trifloxystrobin	Rugby 10 G	Cadusafos
Folio gold 537,5	Metalaxyl-M	Salvador 25 wp	Methomyl
Fongicuivre	Copper	Synergy	Chlorpyrifos + Cypermethrin
Fungomil 72 wp	Mancozeb	Takumi 20 wg	Flubendiamide
Galben M	Benalaxyl + Mancozeb	Tarique 25 ec	Cypermethrin
Gardner	Difenoconazole	Ustaad	Cypermethrin
Impact RM	Flutriafol + Carbendazim	Valmec	Abamectin
Laskor 50 PM	Carbendazim	Vertico 18 EC	Abamectin
Mancofil	Mancozeb	Vertimec 18 EC	Abamectin
Maneb 80	Maneb		
Maxil m	Mancozeb + Metalaxyl		
Miracle	Myclobutanil		
Ortiva 25 EC	Azoxystrobin		
Pelt 44 PM	Thiophanate-methyl		
Pride 200sc	Fenazaquin		
Pyrus	Pyrimethanil		
Ridomil Gold MZ 68 WG	Mancozeb + Mefenoxam		
Rugby 10g	Cadusafos (10%)		
Score 250 ec	Difenoconazole		
Signum WG	Boscalid + Pyraclostrobin		
Switch 62.5 WG	Cyprodinil + Fludioxonil		
Systhane 12 E	Myclobutanil		
Teldor 50WG	Fenhexamid		
Thiogri 70	Thiophanate-methyl		
Topas 100 ec	Penconazole		
Turbo ZM	Mancozeb		
Uthane 80% WP	Mancozeb		
Vydate 10g	Oxamyl		

3.2. Pesticide Application Patterns

Quantitatively, a total of 7569.8 kg of pesticides was employed over the 555 hectares of the study region representing a very high average application rate of 13.6 kg/ha per farm. Such an average is very high when compared to both regional as well as international standards that generally range from 0.3 to 2 kg/ha, and only a handful of countries or regions approach double-digit application levels (Khadda *et al.*, 2021; Abbou *et al.*, 2022; Bouziri *et al.*, 2021). These results support previous apprehensions about potential pesticide contaminants in the Merja Zerga catchment region due to intensive farming activities (Mghili *et al.*, 2020). Out of the pesticides used, fungicides comprised the largest proportion by unit farm area (mean 5.7 kg/ha), followed by insecticides (mean 4.4 kg/ha), and followed in turn by herbicides (mean 3.5 kg/ha), highlighting the highly vital role that fungal disease management plays within the larger context of chemical input usage.

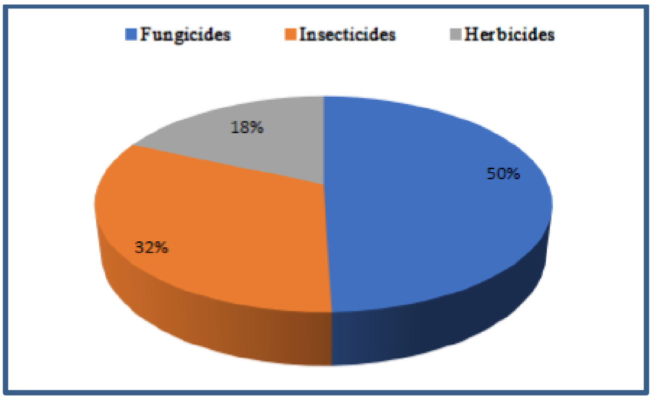


Figure 3. Proportional distribution of pesticide types used.

Significant variations in pesticide intensity were observed between crops, highlighting specific drivers of the high overall usage. Banana cultivation, despite occupying only 8% of the area, exhibited the highest application rate at 47.5 kg/ha and accounted for 28.9% (2185 kg) of the total pesticide quantity used (**Figures 4, 5**). Citrus, while receiving a lower rate (16.7 kg/ha), covered a larger area and thus consumed the highest absolute quantity of pesticides at 2204.4 kg (29.1% of total) (**Figure 4, 5**). These two crops together are clearly major contributors to the region's pesticide burden. In contrast, strawberry production, covering 78 ha, used significantly less pesticide (average 6.3 kg/ha, totalling 6.5% or 491.4 kg) (**Figure 4, 5**). This difference suggests that factors such as crop susceptibility and potentially market destination influence application rates, with the lower use on strawberries possibly linked to stricter regulations for export markets. In a study from southern Morocco, citrus was identified as one of the most pesticide-intensive crops, with farmers applying multiple treatments per season, especially insecticides and fungicides (Bouziri *et al.*, 2021). This aligns with our finding that citrus had the highest absolute pesticide use.

Despite the lack of specific data on banana cultivation in Morocco, worldwide studies reveal that pesticide use in banana cultivation is significantly high. In Ecuador, for example, banana plantations have the highest rates of pesticide application per hectare due to their vulnerability to fungal disease epidemics (Garcia-Ballesteros *et al.*, 2023).

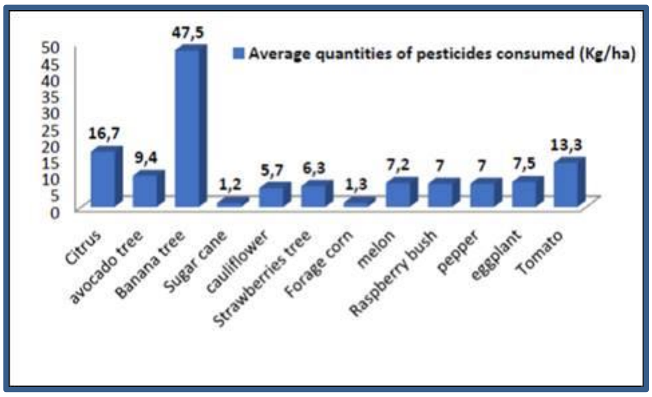


Figure 4. Mean pesticide application rates for major crops on surveyed farms in surveyed (Kg/ha).

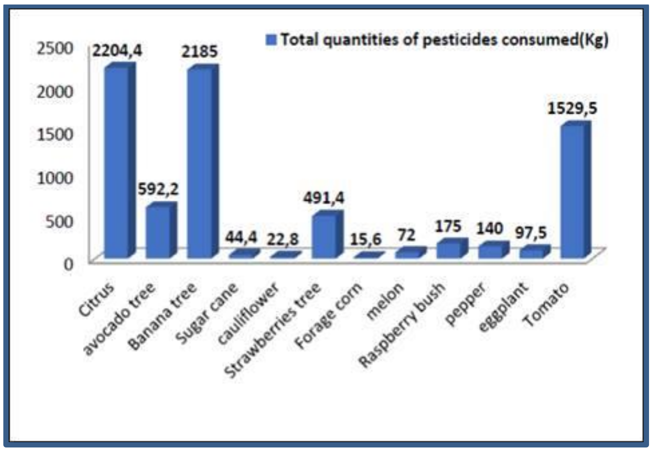


Figure 5. Aggregate pesticide consumption by crop type across all surveyed farms in (Kg).

3.3. Phytosanitary Pressure and Toxicity Indicators

Quantitative differences identified are reflected in the assessed phytosanitary pressures through the Treatment Frequency Index (IFT). Banana production showed the greatest pressure (IFT = 38, **Figure 6**), highlighting its high need for frequent and high-dose use of fungicides and insecticides. These results confirm the results of other studies carried out in Morocco that demonstrate pervasive patterns of risky practice, high levels of residues, and the need for stricter regulation and farmer education to counter associated risks (Berni *et al.*, 2021; Aberkani *et al.*, 2022; Ouakhssase *et al.*, 2024). Tomatoes also showed impressive pressure (IFT = 11), but are prone to pests and have a high contribution to the overall pesticide pressure; this level of pesticide pressure is rather exceptional when comparing to many global practices (Winans *et al.*, 2019). The same pattern has also occurred in other areas of intensive tomato production (Guo *et al.*, 2021; Srinivasulu & Ortiz, 2017). Export-oriented products like strawberries and raspberries showed low pressures in marked contrast (IFT ≈ 5 for both), in line with the result of earlier studies (El-Sheikh *et al.*, 2023; Choubbane *et al.*, 2022) and due to presumably better technical management techniques and compliance with the mandatory phytosanitary standards for exportation.

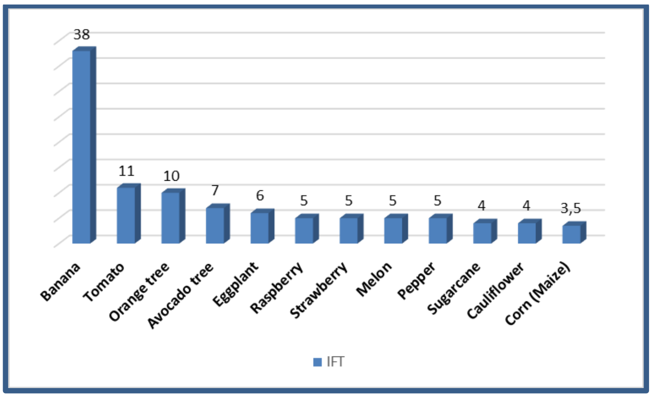


Figure 6. Comparison of pesticide treatment intensity across major crops, measured by the Treatment Frequency Indicator (TFI).

Potential human health toxicity risk to applicators (IRTH), based on pesticide types and application practices, also varied substantially. Citrus (IRTH = 6269.5) and avocado (IRTH = 6076) presented the highest risks, attributed not only to the use of toxic herbicides, insecticides, and fungicides but critically also to the application method involving spraying trees (adjustment factor Fa=2), International studies (e.g., Iran, China) also report high human health risks for citrus applicators, especially when using air-blast or tree spraying methods. Pesticide residues in citrus can exceed safety thresholds, and acute exposure risks are particularly high for children (Taghizadeh *et al.*, 2023; Tang *et al.*, 2023). Banana cultivation carried a significant, though slightly lower, risk (IRTH = 5697), linked to toxic ingredients used in its intensive treatment schedule; in Costa Rica and the Canary Islands, banana cultivation is associated with heavy pesticide use and significant health risks for workers, including increased rates of cancer and neurobiological dysfunctions (Brühl *et al.*, 2023; Mendez *et al.*, 2018). Tomato ranked fourth (IRTH = 4931). Consistent with pressure and quantity findings, export crops registered lower risks (Raspberry IRTH = 283.5, Strawberry IRTH = 3171, **Figure 7**), suggesting that regulatory compliance likely influences the choice towards less hazardous products or safer practices.

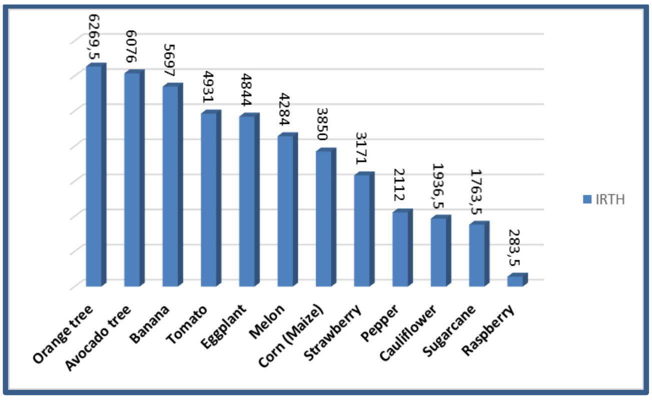


Figure 7. Comparison of potential human health risk from pesticide use across major crops, measured by a toxicity risk indicator.

Most crops had a positive relationship between phytosanitary pressure (IFT) and risk of toxicity for the application (IRTH) (**Figure 8**). Crops that required a high number of treatments, such as Banana, Citrus, Avocado, and Tomato, generally presented a higher risk. Raspberry was the exception; it presented moderate pressure (IFT ≈ 5), but minimal toxicity risk. It implies that a lower number of treatments reduces the risk but switches the products implemented.

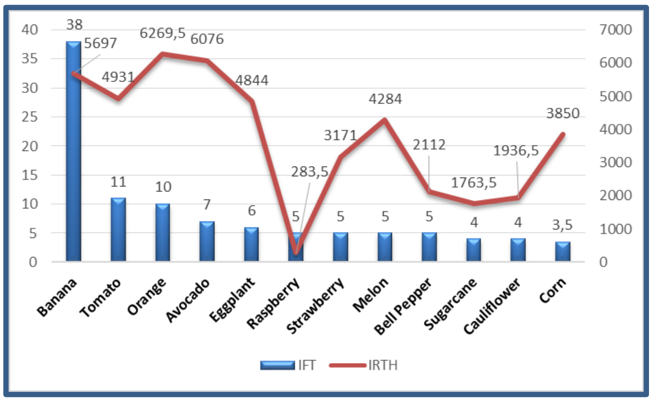


Figure 8. Comparative analysis of pesticide application frequency and associated human health risk for major crops.

This comprehensive assessment presents a situation marked by the widespread use of pesticides on the farms of the Gharb plain, motivated by the management demands linked to the production of bananas, citrus fruits, and tomatoes. This results in higher total rates of pesticide application, increased treatment frequencies, and greater potential health risks for the applicators relative to target norms and past local studies. In contrast, the comparatively lower risk and intensity of export crops like strawberries and raspberries suggest that market pressures and regulation have the potential to promote more sustainable pesticide application practices. These findings underscore the urgency to promote and establish more sustainable pest management practices, specifically the use of Integrated Pest Management (IPM), for intensive crops to address the attendant environmental and human health issues. While the present study provides valuable insights, it is derived from data obtained using a survey; hence, future studies should encompass direct environmental monitoring and pesticide residue analysis, as well as socio-economic analysis of the agricultural systems.

4. Conclusions

This study, conducted on 100 farms covering 555 hectares in the Gharb plain of Morocco, examined agricultural practices, pesticide use, and health risks for applicators. The results show intensive pesticide use, especially fungicides, in banana and citrus farming, with application rates well above international standards, leading to significant toxicity risks for workers. Tomato farming also contributes to high pesticide pressure. In contrast, export-oriented crops like strawberries and raspberries showed lower pesticide use, suggesting that strict regulations and improved practices influence safer pesticide applications. The study highlights the urgent need for a shift to integrated pest management strategies to reduce environmental and health risks, promoting low-input agricultural systems.

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