MEDDOCS Open Access Publisher

ISSN: 2639-4391

Annals of Epidemiology and Public Health

Open Access | Review Article

Pesticide Occurrence in Food, Water, and Human Biomonitoring in Lebanon-A Health Repercussion

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Received: Dec 20, 2022

Accepted: Jan 12, 2023

Published Online: Jan 16, 2023

Journal: Annals of Epidemiology and Public Health

Publisher: MedDocs Publishers LLC

Online edition: http://meddocsonline.org/

Keywords: Pesticides; Health impacts; Food residue; Lebanon; Banned pesticides; Environmental pollution; Water resources; Biological monitoring

Abstract

The regular use of plant protection products in modern agriculture improved the quality and quantity of yield products. Exposure to pesticides through water, food, or breathing polluted air has become a significant public health burden. In Lebanon, agriculture activities are not tightly controlled; many farmers do not respect the proper pesticide handling measures, and banned pesticides are illegally smuggled into the country through unsecured borders. This article overviewed all published papers between 2012 and 2022 regarding pesticide occurrence in Lebanon's environmental matrix, food residue, biomonitoring studies, and their health repercussions. We conclude that pesticide levels in the surface and groundwater increased over time. Prohibited pesticides and high maximum residue levels were detected in water, organic, and conventional fruit and vegetable samples. Human biomonitoring studies disclose minor residues from the organochlorine pesticide family prohibited in Lebanon since 1982. Knowledge, Attitude, and practice survey in Lebanon approved pesticide malpractice, illiteracy, and lack of safety measures among farmers. The health effect of pesticides is undoubtedly well-known and confirmed. Hence, epidemiological studies are still scarce in Lebanon. Solutions to this burden lie in the cooperation between all the stakeholders. Law enforcement, continuous monitoring programs, and implementing Good agriculture practices (GAP) are essential for a new sustainable and safe agriculture paradigm.

Introduction

Agrochemical concept usage has been a concern for many years worldwide and has a vast scope of many studies [1]. Understanding pesticides' pros and cons are very efficacious in evaluating costs and benefits at all levels. According to the lancet commission on pollution and health, "pollution is costly"; 16% of all deaths in the world is related to environmental pollution, with 92% of these cases occurring in low to middle-income countries and among the vulnerable population such as children, premature babies, and fetuses [2]. Pesticides or plant protection products (PPPs) are a general word that defines many groups of chemicals used to prevent pests such as insects, fungi, and opportunistic weeds from damaging agricultural products [1]. Although the agriculture sector is the leading pesticide consumer, these chemicals also have many uses other than protecting crops, such as in sports arenas, outdoor playgrounds, household disinfectants, and building materials such as paints, glues, and plastics to prevent mites [3,4]. In addition, pesticides are essential in protecting public health from infectious diseas-

Cite this article: Akkouch N, Halwani J. Pesticide Occurence in Food, Water, and Human Biomonitoring in Lebanon- A Health Repercussion. A Epidemiol Public Health. 2023: 6(1): 1101

es transported by mosquitoes, such as the Zika virus, West Nile virus, Chikungunya virus, Dengue, and Malaria [5].

Plant protection products protect crops, improve productivity, and ensure food security [6]. For instance, "in India, a 1.8 % increase in pesticide use in agriculture was accompanied by a 1% increase in crop yield per hectare" [7]. The global pesticide consumption is currently more than 2 million tons, with the Asia continent being the top contributor [8]. Demographic growth poses more pressure on national governments to increase food production; between 1900 and 2000, the world population increased to about 6.1 billion. By 2003, the population had grown another billion [6], and according to the current growth pattern, the world population is estimated to reach 9.15 billion by 2050 [9] and 11 billion in 2100 [10]. Advanced countries such as the US, the EU, and Australia have regulated the use of pesticides by creating a pesticide registration legislative tool. It aims to approve their safety through scientific-based risk assessment [10]. Furthermore, even after approval, these countries continue to monitor, surveil, and conduct field studies to measure the allowed Maximum Residue Level (MRL) on the crop and in many environmental aspects [11]. The Environmental Protection Agency (EPA) in the USA elaborates on the cumulative risk assessment of some groups of pesticides. It determined the "reasonable certainty of no harm," which accepts some remaining trace of pesticides on the food [12]. Unfortunately, this is not the case in the developing world. Low- to middle-income countries still use banned pesticides due to poverty, deficient regulations, and lack of knowledge [13,14,8]. Forty-two thousand six hundred thirty-six tonnes of prohibited pesticides were exported to the third world after being banned in developing countries [15]. Safer options exist, such as policy updates [12], implementing more scientific research and field studies on biopesticides as an alternative to conventional pesticides [16], implementing educational training and workshops for agriculture farmers to ensure a safe handling process [17], and finally halting the export of banned pesticides from developed to developing countries [15].

Plant protection products (PPPs) practice in Lebanon

Lebanon is a small, Middle Eastern country on the Mediterranean Sea. It is characterized by a subtropical climate, a high proportion of agricultural lands, and a significant amount of water resources compared to other countries in the same area [18]. The agriculture sector is one pillar of the economy in Lebanon, with the Bekaa and Akkar governorates constituting the most contribution due to their soil fertility and significant plains areas [19]. More than 49% of agriculture farms in Lebanon misuse pesticides [20]. Farmers in one agriculture area in the north of Lebanon indicated using plant protection products 100 times higher than the advisable dose [21]. Weak law enforcement, minimal resources, poverty, and lack of knowledge are all attributed to the misuse of hazardous chemicals and to effect on the environment and human health at a larger scale [13]. Many studies have been done across Lebanon which confirmed the presence of toxic and banned pesticides in the soil [22], rivers [23,24,25], and groundwater [26,27,25,28]. Human biomonitoring studies assessed pesticide residue in breast milk [29], human serum [30,31], and umbilical cord blood [32]. Fruits, vegetables, and honey were assessed for types and levels of pesticides [33, 34, 35, 38]. No published assessment on pesticide residues in animal products such as dairy, meat, eggs, chicken, and fish [39,22]. Studies that link acute or chronic pesticide exposure to human health do not exist in Lebanon, except for one old case-control study that linked pesticide exposure in occupational settings to the increased percentage of Asthma and respiratory allergies [39], Furthermore, one recent cross-sectional study found a statistical significance between wells water ingestion and the increased risk of Parkinson's and Alzheimer's disease among a population living in a heavily agricultural area [40].

Although Lebanon has a wealth of natural resources, the country suffers from significant environmental pollution [41], water shortage, population growth, climate change, and economic inflation [42,18]. Lebanon ranked first in cancer incidence among the Arab countries [43], and 40% of death related to heart attacks and cancer in Lebanon were linked to air pollution [41]. Lebanon's population grew from approximately 4,953,000 in 2010 to 6,825,445 in 2020, mainly due to Syrian immigrants' movement from Syria to Lebanon. Lebanon's agriculture sector struggles to ensure the needed resources such as energy, seeds, pesticides, fertilizers, and labor [19]. However, along with the extensive use of pesticides and fertilizers, Lebanon cannot secure safe and enough food for its people, "90% of cereal is imported to Lebanon" [44]. Therefore, this review aims to gather and summarize all the findings regarding plant protection product occurrence, random use, and its repercussion on the environment and the health of Lebanon's population. This paper also intends to urge Lebanon regulatory authorities and the community, including NGOs, pesticide retailers, agriculture farmers, and consumers, about the seriousness of the problem to find quick solutions and preserve human health and the ecosystem in Lebanon.

Methodology

The literature review was initiated by searching scientific databases such as Google Scholar, Science Direct/ Elsevier, and PubMed. Keywords include plant protection products, health impacts, Lebanon, agriculture farmers, banned pesticides, environmental pollution, water resources, biological monitoring, biomarkers, pesticide metabolite, pesticide residues, safety, policy, and food security. Every article related to this subject and published between 2012 and 2022 was included in this review. This paper mainly focuses on previous studies' abnormal findings, limitations, gaps, and suggested solutions.

Research findings in lebanon

In Lebanon, pesticide use is not tightly regulated [13,45]. Clear pesticide registration policies, field trials, and scientific research are scarce. Unregistered pesticides are used arbitrarily to protect crops, and all this is due to defective law enforcement and lagging government [33]. Assessment studies detected banned pesticides and high maximum residue levels (MRLs) in fruits and vegetables [33,45,37,46] prepared meals [47], organic harvest [48]and water [49,22,24].

Pesticide residue in food samples

Although no official research was done in Lebanon by the responsible authorities such as the Ministry of Public Health or the Ministry of Agriculture, assessment studies were implemented by many academic institutions [22], such as the Lebanese University, the American University of Beirut, and the Beirut Arab University. The European Union report on residues in food specifies an MRL of 0.01 mg/kg of nearly 690 pesticide types [50].

In 2015 a study aimed to test pesticide types and levels of

locally sold fruits in Lebanon's north. Banned pesticides such as Chlorothatonil (Organochlorine) and Zineb fungicides were detected. Trifluralin (herbicide) was also disclosed, which was legal to use then in Lebanon; however, it was prohibited in Europe and many other advanced countries [34].

In 2016 Nasreddine et al. assessed pesticide residues from prepared meals in two different areas of Lebanon, Greater Beirut and Keserwan. The values and types of pesticides were compared to the acceptable daily intakes (ADIs). Phased-out organochlorines such as Dieldrin and Aldrin were detected in the Lebanese meal. Many tested fruits and vegetables disclosed three to four types of pesticides. Diazinon (organophosphate) reached 50.3% of the ADI in the urban diet and 61.9% in the semirural diet [47]. Even though the residue level in this study did not exceed the acceptable daily intake, we cannot deny the persistent risk that could precipitate due to pesticide accumulation from other sources and the unpredictable synergetic effect of mixing chemicals [51].

In 2019 El Hawari et al. assessed the types and levels of pesticides in Lebanese apples; 77% of the tested apples had pesticide residue, with 61% being above the maximum residue limits (MRL). All detected pesticides were legal to use in Lebanon except for cypermethrin [45] which was banned in Lebanon since 2014 although still used due to illegal smuggling and weak law enforcement. Chlorpyrifos was the most detected pesticide, and although it is still used in many countries, some studies related the exposure to this pesticide to the increased risk of many cancers, such as colorectal, lung, and breast, in addition to the risk of liver damage [52, 51].

Another study was implemented in Lebanon by Mohamad Abou Zeid et al. in 2020 to highlight the urgent need to activate the pesticide registration process for minor crops (the loquat) to avoid pesticide misuse. The Ministry of Agriculture registered one type of pesticide, the difenoconazole (fungicide), to use on this type of fruit, which forced the farmers, in case of pest resistance, to try mixing many types of unregistered pesticides to manage and control pests. One hundred twenty-eight samples of loquat were analyzed for pesticide types and residue levels, and fifty-one samples had pesticide residues. Forty-eight samples out of the 51 had traces of banned pesticides, such as cypermethrin, dimethoate, methomyl, and many more [33]. Although minor crop registration is a global problem, the registration process should be activated, and more studies should be implemented to encourage good agriculture practices and decrease pesticide overuse and misuse. A further study by Mohamad Abou Zeid highlighted other issues in Lebanon; the required time between spraying pesticides and harvesting crops. In 2020, an assessment was implemented in the south of Lebanon on three commercial formulations of penconazol (fungicide) dissipation rate in greenhouse-cultivated tomatoes [53]. The dissipation rate of penconazol was the same for the three studied formulas. The author urged the responsible authorities to implement field trials on the dissipation rate and the residue levels of registered pesticides and to advise the farmers on the importance of respecting the preharvest interval to protect their and consumers' health.

In 2021, the glyphosate (organophosphate herbicide) level was assessed in 164 bread and flour product samples in Beirut and Mount Lebanon. International studies claimed that the extensive use of glyphosate is responsible for the deterioration of health in the USA and the increase of modern diseases such as type two diabetes, obesity, cancer, and autoimmune disease [54,55,51]. Glyphosate exposure is also linked in a meta-analysis and a systematic review to increasing the risk of Hodgkin's Lymphoma and Multiple Myeloma [56]. In Lebanon, it was revealed that all flour-content food contained an accepted glyphosate daily value. However, they highlighted the need for follow-up and re-evaluation since people's exposure could happen through other types of food, and the actual exposure cannot be estimated through one type of food [35].

In 2021, vine leaves pesticide traces were assessed by Salem Hayar et al.; 24 samples of 17 brands of vine leaves were analyzed for type and level of pesticide residues. Dry preserved vine leaves had a higher value than the ones in pickling solutions or stuffed. Twenty of the 33 detected were approved for use in Lebanon; 13 detected pesticides were banned in Lebanon. Many samples exhibit a mixture of up to 13 types of pesticides [57].

Another shocking finding in 2021 by Jana Dwaidy et al. The pesticide occurrence in organic and conventional cucumber samples and lemons was compared. Four types of chemical pesticides were detected in the organic lemon, and just one type was detected in the conventional lemon.

It was revealed that the organic cucumber had six pesticides, whereas the conventional cucumber had eight pesticides. Four cucumber samples from each category (organic and non-organic) exceeded the maximum residues level set by the European Union [58]. Many people in Lebanon are defrauded by buying organic products contaminated with chemical pesticides.

In 2022, Salma Khazaal et al. assessed the pesticide types and levels of four hundred and seventy-eight samples of 49 food items. Fifty-eight pesticides were detected, whereas five were prohibited (Carbendazim, Dimethoate, Thaimethoxame, Trifluralin, and thiacloprid). Eighty-one percent of the food samples were contaminated with synthetic pesticides, and 69% were above the accepted maximum residue level established by the European Union [37]. The last paper was also published in 2022 by Wissam Sahyoun et al. this research intended to quantify the pesticide traces in 58 fruit samples and vegetables obtained from Lebanon and many other countries. Regarding Lebanon, it was found that some samples of tomato and cucumber cypermethrin (pyrethroid insecticide) residue exceeded the levels set by European legislation. The author also compared the levels of pesticides in many scenarios. Washed versus non-washed or peeled fruits and vegetables. According to the findings of this paper, washing and peeling could be beneficial in decreasing the pesticide traces on many fruits and vegetables [46].

Regional distribution of pesticide residues in lebanon water resources

The United Nations (UN) recently declared that 64% of Lebanon's population is facing a critical water shortage. Water waste, pollution, evaporation, drought, and excessive demand due to Syrian refugee overpopulation are responsible for Lebanon's water scarcity [59]. More than 50% of Lebanon's surface and groundwater, the primary sources for agricultural activity and people's daily use, are polluted and undrinkable [18]. Banned and dangerous pesticides, fertilizers, non-treated municipal sewage -and heavy metals such as Nickel and Cadmium were detected in many water bodies across the country [39,23,26,24] According to the Environmental Quality Standard, the accepted level of one pesticide in water should not exceed 0.1 ug/L, and the total level of pesticides found in water should be less than

0.5ug /l [60]. There is no continuous assessment concerning water pesticide levels. Most groundwater assessment studies in Lebanon were implemented in hot spot agricultural areas, especially in the north (Akkar valley) and the south (Bekaa valley), in addition to river assessments across the country, such as the Litani, Hasbani, and Abu Ali. Academic bodies such as universities implemented all the published papers between 2012 and 2022.

Akkar area

Akkar governorate, bordered by Syria in the north of Lebanon, constitutes the second largest agriculture area after Bekaa plain. It is considered an impoverished region due to government neglect, high illiteracy rates, and lack of basic infrastructure. The crops mainly grown in Akkar are cereals, vegetables, olives, fruits, and tobacco. Due to the heavy agriculture activities in this area, many cross-sectional studies were implemented to assess the groundwater for pesticide residues. In 2011 a cross-sectional study was done in 8 villages in Akkar. It revealed alarming high groundwater residue of specific searched insecticides and fungicides (Trifluralin, Penconazol, Dimethoate, Cyhalothrin); However, this water is the only source for drinking, daily use, and agriculture irrigation in this area [61]. In 2013 Osmani et al. assessed the levels of 28 organochlorine pesticides in the groundwater at ten sites in Akkar. However, Lebanon agreed on the content of the Stockholm Convention in May 2001 and banned Organochlorine from any use in agricultural or public health. Osmani et al. detected 16 out of the 28 searched organochlorines, all exceeding the accepted level set by the European Commission legislation, which mainly confirms the recent use of these toxic and prohibited pesticides in this area [27]. To continue Akkar water monitoring, in 2016, Chbib et al. assessed water wells in Akkar. Thirty-three pesticides from three classes (Organochlorine, Organophosphate, and carbamates) were explored in fifteen samples from underground water. Chbib et al. results were shocking by finding a very high level of OCs (58.9 ug/ L) which confirmed a recent use despite the ban, especially since its concentration was higher than the result found by Osmani et al. in 2012 in the same area. Organophosphate was also very high (44.6 ug/ L), and the Carbamates level was 5.6 ug/L [26]. The levels detected by Chaza et al. were alarming and the highest among all tests done before in the Akkar area. The last groundwater quality assessment in Akkar was published in Nov 2022. The author did two sampling campaigns, one during 2017 and the other during 2019- 2020. They compared the evolution of 20 organochlorines and eight organophosphate pesticides in eight wells in many villages in Akkar. The results were concurrent with the findings of Chbib et al.; pesticide values increased over three years, and higher pesticide concentrations were detected nearby vegetables and fruit crops. However, farmers revealed the use of plant protection products every 15 days instead of every 35 days as recommended and mixing the pesticide solution at 100 times more than the advisable concentration [21].

Kadisha or Abu Ali river

More water assessment was implemented on the Kadisha river, which is known as the Abu Ali river in the north of Lebanon. Jabali et al. did six sampling campaigns during 2015- 2017 from the river and 14 wells around its basin. A total of 30 samples were extracted at different times of the year.

Methomyl, Alpha Endosulfan, Methamidofos, and Ethion were the most detected pesticide from the organophosphate family, and all levels exceeded the accepted value set by the EU [24]. Superior levels were also detected in the surface and groundwater of this river from the organochlorine category, which has been banned in Lebanon since 1982 [22] such as the metabolite of DDT insecticide (DDD), HCB fungicide, and Alachlor herbicide. Cypronil (chlorantraniliprole fungicide) and Chlorpropham (carbamates herbicide) also exceeded the tolerable levels for water [24].

Bekaa plain, Litani, Hasbani, and Wazzani rivers

The mass of agriculture activities in the country is carried out in the Bekaa plain, south of Lebanon [62]. The Litani river is the primary surface water resource in Lebanon's south. The river length is approximately 174 Km; it extends from the Bekka valley to the Mediterranean Sea in the south of Lebanon [63]. In 2012 Youssef et al. assessed the occurrence of 67 compounds from different classes of pesticides in the surface water of Litani (the longest river in Lebanon) and Hasbani river during the four seasons, Wazzani river during the spring and the summer season in addition to the assessment of 3 wells in an urban area in Lebanon south, one spring and one lake. Among the 67 searched pesticides, only 25 types were detected, including banned Organochlorine DDE (DDT metabolite) above 0.1ug/L. Pirimiphos-methyl (organophosphate) was documented to be threefold the accepted level (0.3 ug/L). Higher levels of all detected pesticides were recorded during the fall, indicating the heavy use during summer and the dilution effect during winter [64]. In 2013 a water quality assessment study was implemented on the Hasbani river (south of Lebanon). Heavy metals, microbial pollution (sewage), and synthetic pesticides were detected. Among the detected pesticides, Diazinon (organophosphate) levels were high, and banned organochlorines such as DDE and Hexachlorobenzene were distinguished. Propoxur from the carbamates family was found in accepted levels set by the environmental protection agency (EPA) [23].

Ibrahim river, Qaraoun lake, and Hasbani river water assessment

Aisha et al. assessment results in 2014 were very similar to all the previous studies; Ibrahim river (Jbeil- Keserwan district-north of Lebanon), Hasbani river, and Qaraoun lake (south of Lebanon) were mostly polluted by Diazinon and Chlorpyrifos (organophosphate), DDT metabolites and Fenpropathrin (pyrethroid), with the Ibrahim river being the less polluted [65].

Nationwide comprehensive assessment

Samples of water were taken in 2011, 2012, and 2013 by Kouzayha et al., A nationwide assessment of 67 types of pesticides in surface water, groundwater, rainwater, and drinking water in many agricultural and residential areas across Lebanon from north to south. They revealed the existence of 28 pesticides, most of them were within the tolerance limit except for Diazinon and chlorpyrifos (organophosphate insecticides) with values very close to the high maximum range in groundwater and surface water, Hexachlorobenzene and Teradifon (Organochlorine), although banned, were found in the groundwater within the high acceptable range for surface water. However, most of the detected pesticide levels were acceptable; they were of great concern since they have been very toxic, persistent, and banned in Lebanon since 1992 [25].

Global review included lebanon

A global review of the assessment of drinking water for 31 countries, including Lebanon, was done by El- Nahhal et al., who

relied on one or two studies from each country. A comparison was made between the levels of Organochlorine, organophosphate, carbamate, pyrethroid, and other classes of detected pesticides between these countries. They classified pesticides level in drinking water according to the type of pesticide (herbicide, insecticide, and fungicide). Lebanon ranked fourth after Spain, Japan, and Brazil regarding the diversity of the detected pesticides. Moreover, it was categorized second after Egypt for its high water residue Hazard Index for insecticides. Fifteen organochlorine pesticides were detected in Lebanon drinking water with levels that range from 0.02 and 12.8 ug/ L. Five organochlorines exceeded the Acute Reference dose (ARfD). Seven organophosphate levels were between 0.07- 4.5 ug/L, and seven herbicide levels fell between 0.26- 1.73 ug/L [66].

Biological monitoring of pesticides residue in lebanon

Biomonitoring is an essential tool to assess human vulnerability to pesticides [67]; it could help determine health impacts and chemical traces in occupational settings and the general population. Biological and environmental monitoring could be complementary and practical tools for scientists and policymakers to make decisions in controlling, reevaluating, and banning some substances [68]. In Lebanon, after detecting high levels of Plant Protection Products (PPT) in many environmental matrices, three small-scale studies were done to assess the biological levels of Organochlorine pesticides. Two studies assessed human serum, and one assessed Organochlorine in the maternal and cord serum among Lebanese pregnant women.

In 2018, Helou et al. implemented a biomonitoring study; 98 women answered a structured questionnaire about diet style, habits, and demographics. Venous blood samples were drawn from 98 pregnant women at three hospitals in Beirut (the capital of Lebanon), and arterial umbilical cord blood was also checked for 49 women after delivery (147 women). This study measured the serum level of 4 OCPs. The Hexachlorobenzene (HCB), ß- hexachlorocyclohexane (ß- HCH), dichlorodiphenyltrichloroethane (DDT), and dichlorodiphenyldichloroethylene (DDE). Polychlorinated biphenyls (PCBs) were also part of this study, although we will not list PCB's results because it is not included in our review. The searched OCPs were detected in all blood samples (umbilical cord and venous blood). Red meat and cold cut consumption were associated with higher OCP levels, and no association was identified between OCP levels and age, weight, smoking, primiparous or multiparous, pesticide use at home, or living nearby landfills. Cord serum levels were higher than maternal serum. Delivery length and OCP cord serum level were positively associated [32].

Another cross-sectional study was conducted at a university in Beirut between 2013 and 2015. Students and staff members were randomly selected to participate in this study; the total was 314 participants (133 men and 181 women). The participants answered a set of questions (demographics, diet, habits), and a venous blood test was performed to search for some organochlorines' occurrence and levels. The investigated organochlorines were the Hexachlorobenzene (HCB), ß- Hexachlorocyclohexanes (ß- HCH), p,p'- Dichlorodiphenyltrichloroethane (DDT), and its metabolite p,p' Dichlorodiphenyldichloroethylene (DDE). The detected levels of OCPs were acceptable compared to similar studies in many countries; the perceived values did not expose this population to any health hazard. No positive association was marked with particular food consumption, habits, or personal characteristics (age, weight) [30].

Environmental biomonitoring studies

In 2016, Al Alam et al. emphasized the importance of using honey as effective environmental biomonitoring. According to their study, honey samples from the heavily agricultural area were highly polluted with pesticides compared to an area with low agricultural activity. This study collected honey samples from Akkar, Byblos, and the cedars. Pesticide concentration levels were the highest from the samples taken from Akkar, followed by Byblos, and the cedars area was the least polluted [69].

In 2019, Baroudi et al. highlighted the importance of using insects for pollution biomonitoring. They tested the snails in three locations, and the pesticide level was higher for the snails very close to the pesticide spraying [70].

The biomonitoring studies in Lebanon are mainly aimed at creating an effective and affordable technique to monitor the environment continuously.

Farmer's knowledge and practice studies

The lack of knowledge about pesticide toxicity and the safe handling technique among agriculture workers will lead to a higher risk of incidental toxicity and environmental pollution [71]. In Lebanon, a community-based intervention was done in 2019 in two small agricultural areas. Thirty-seven agriculture workers participated and answered questions to assess their knowledge about plant protection products' function, safety measures, best practices, and attitudes. Afterward, educational sessions were implemented to increase their knowledge and awareness about the subject. Post-tests were done using the same baseline questions. The statistical results confirmed that the educational sessions effectively increased farmers' knowledge and awareness [20].

In 2016, a Knowledge, Attitude, and Practice study was implemented in two agriculture areas in Lebanon. The study aimed to understand the agricultural farmers' level of knowledge and perception of pesticide perception, risks, and benefits. One hundred and four agricultural farmers were interviewed face-to-face using a structured questionnaire. The study findings revealed that 59.6% of farmers do not know the pesticides according to their name or main ingredient; instead, 97.1% recognize them according to their target pests. Banned pesticides were known by almost half of the respondents. Thirty-six percent declared preparing the pesticide mixture without wearing appropriate personal protective equipment. Forty-five percent of the farmers rely on the manufacturer's label to prepare the pesticide mixture. Around 87% of farmers declared respecting the recommended dosage on the container label. More than half of the participants agreed on pesticide exposure's possible health and environmental effects. Eighty-six percent of farmers were willing to use biopesticide if effective, available, and affordable [72].

Discussion

In Lebanon, most published papers were implemented by academic bodies and funded by the private sector. The Lebanese government's case is very similar to all the developing countries; no specific budget has been assigned to support scientific research [13,73]. The country's public debt has been increasing since the end of the civil war in 1999 [74], and Lebanon's status has become more critical since the economic crisis in 2019 [42]. All the scientific published reports in Lebanon confirmed

that the banned Organochlorine still existed, and high MRL of many legal and illegal pesticides are detected in water resources and many food products. Hence, the assessment studies done on food were limited to the fruits and vegetable category, and dairy, meat, poultry, and fish pesticide assessment were not included in any published paper. Water assessment studies revealed the pollution of Lebanon's water resources by sewage, heavy metals, and synthetic pesticides. The continuous assessment of wells water in the Akkar area (north of Lebanon) confirmed that pesticide values increased over time, and the responsible authorities have taken no action. Efficient removal of pesticides from water resources should be considered in Lebanon, primarily when the polluted groundwater is meant for drinking. Most used pesticides in Lebanon belong to the Organophosphates class [49,37], known for its acute occupational toxicity [75] and endocrine disruptors activity; the MRL alone is not reliable in predicting their harmful effects since many factors such as comorbidities, habits, lifestyle could change their sequel [51].

Moreover, the biomonitoring research studies were limited to the organochlorine human serum, breast milk, and umbilical cord blood in women after delivery. Although the detected values were acceptable, we cannot bet alone on these studies since they are small-scale and did not address women living nearby or working in agricultural activities. Air pollution by Pesticides was not studied in Lebanon; air quality research is fundamental, especially because pesticides can travel from one area to another and persist for a long time in the environment [76]. A recent comparative cross-sectional study that assessed the existence of organochlorine pesticides in the air in 5 countries, including Lebanon, revealed that OCP contamination was the highest in Kartaba Lebanon (Keserwan- Jbeil governorates); OCP air levels in this area indicate an increasing potential cancer risk for children [77].

Lebanon urgently needs to plan and implement a large-scale comprehensive study to assess the extent of pesticide pollution in the country. The current published studies could be the starting point in estimating the magnitude of this issue. Hence, more in-depth research, health assessment, and testing of every food category are vital so that researchers can predict the entire pesticide exposure through dietary intake. The use of many pesticides on the same harvest might contribute to what is known as the " Cocktail Effect"; nowadays, researchers are emphasizing the necessity to consider and study the synergetic result of some pesticides when mixed [78]. Imported food, especially wheat for bread and flour-based products, should be tested before entering Lebanon. Agriculture farmers should undergo regular physical examinations to prevent, detect and treat health issues related to pesticide misuse. Educational sessions, workshops, and vocational training should be conducted locally in every governorate. Big farm holders must be responsible for the health of their workers, and high-risk plant protection products should be avoided or used under the direct supervision of a certified pesticide applicator or an agricultural engineer.

All the implemented studies pointed out and criticized the responsible authorities' failure to enforce the law and stop the illegal import of halted pesticides into the country. Lebanon was involved in many international agreements to protect the environment, such as the Stockholm Convention; moreover, the Lebanese government always signs but still needs to ratify the agreements. Till now, banned agrochemicals are smuggled into the country by any means without the capability of the special authorities to stop them [13,22]. Therefore, the responsible authorities in Lebanon must be dedicated to correcting pesticide policy loopholes, putting more control on the borders, and imposing a sanction on the smugglers.

Conclusion

Research findings in Lebanon between 2012 and 2022 revealed a high level of prohibited plant protection products in surface and groundwater, food products, breast milk, and human serum. Most of the criticism was directed toward the country's system, which cannot force the law and stop the halted pesticide smuggling. Wider-scale comprehensive studies should be implemented by the ministry of public health, the ministry of environment, and the ministry of agriculture. The findings must be transparent to suggest solutions and urge all stakeholders to take responsibility. Completing epidemiological studies is crucial, especially among the vulnerable population, such as agriculture farmers, people living nearby heavy agriculture areas, and children. Media can also play an integral role in raising community awareness. Moreover, agriculture farmers should undergo specific training regarding the best handling technique and the necessity to adhere to the safety measures to protect their and the consumer's health. Smuggling phased-out pesticides should end, and the ministry of agriculture should encourage organic farming, exempt taxes on biopesticide imports, and support the raw material cost to encourage local natural pesticide industries and promote the registration of eco-friendly plant protection products.

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