Journal of Elementology ISSN 1644-2296

Czarny-Działak M., Chmielewski J., Gietka M., Gworek B., Łuszczki J.J. 2022. *Occupational exposure to pesticides – a challenge for environmental health specialists and occupational medicine practitioners.* J. Elem., 27(3): 579-595. DOI: 10.5601/jelem.2022.27.2.2228

RECEIVED: 2 December 2021
ACCEPTED: 1 July 2022

ORIGINAL PAPER

OCCUPATIONAL EXPOSURE TO PESTICIDES – A CHALLENGE FOR ENVIRONMENTAL HEALTH SPECIALISTS AND OCCUPATIONAL MEDICINE PRACTITIONERS*

Małgorzata Czarny-Działak[1], Jarosław Chmielewski[1], Mariusz Gietka[3], Barbara Gworek[4], Jarogniew J. Łuszczki[5]

[1] Institute of Health Sciences, Collegium Medicum The Jan Kochanowski University in Kielce, Poland
[2] College of Rehabilitation in Warsaw, Poland
[3] PHN S.A. in Warsaw, Poland
[4] Department of Environmental Chemistry and Risk Assessment National Research Institute, Warsaw, Poland
[5] Institute of Rural Medicine in Lublin, Poland

Abstract

Pesticides, in general, are chemical substances (synthetic or natural) used in agriculture to control harmful or undesirable organisms in order to protect crops. Health effects may affect people directly exposed to pesticides, including spray workers, residents of areas requiring chemical protection, and people eating food contaminated with pesticide residues. The aim of the study: the aim of the study is to demonstrate possible adverse health effects associated with exposure to pesticides, as well as to systematize knowledge and supplement it with the latest search results. Study methods: Epidemiological studies on the relationship between pesticide exposure and risk of adverse health effects were reviewed. The paper uses biblimetrics considering the years 2011-2021, and covering pesticide use and its health effects. A literature review was conducted by searching PubMed, Google Scholar database. The criterion of selecting entries aligned with the set subject matter was applied to carry out analyses of bibliographic data. Results: There is a constant interest in environmental pollution by pesticides and their impact on health, regardless of the route of entry (inhalation, ingestion or dermal). Scientific reports show the negative impact of pesticides on health resulting in cancer, miscarriages, early births, effects on the foetus causing developmental delays and poisoning due to their residues in food. Conclusions: It is necessary to apply pesticides as recommended and to monitor surface and groundwater and food. In order to minimize the health effects of exposure to pesticides, it is reasonable to

Jarosław Chmielewski, Ph.D., College of Rehabilitation in Warsaw, 01-234 Warsaw, St. Kasprzaka 49, e-mail: j.chmielewski@ios.gov.pl

* Source of financing: This work was supported under the program of the Minister of Education and Science under the name Regional Initiative of Excellence in 2019-2022 project number: 024/RID/2018/19, financing amount: 11.999.000,00 PLN.

conduct health and environmental education among farmers and professional users. For occupational exposure to pesticides, the use of personal protective equipment is unconditional.

Keywords: pesticides, human health, environmental health, occupational exposure, organic pollutants.

INTRODUCTION

According to the adopted regulations within the European Union (EU) including, inter alia, Directive 2009/128/EC establishing a framework for Community action to achieve the sustainable use of pesticides (Text with European Environment Agency (EEA) relevance), "pesticide" means: a plant protection product as defined in Regulation (EC) No. 1107/2009 (*Regulation (EC) No. 1107/2009*); a biocidal product as defined in Directive 98/8/EC of the European Parliament and of the Council of 16 February 1998 (*Directive 98/8/EC*) concerning the placing on the market of biocidal products (*Directive 2009/128/EC*). Pesticides are a group of products altogether containing more than 1000 active substances used to control and prevent the appearance of organisms considered harmful. Pesticides are used in agriculture, horticulture as well as in recreational areas, e.g. parks and gardens. Biocides play a similar role, albeit used in other areas such as disinfection for sanitary and personal hygiene purposes or for the protection of materials. The term includes, but is not limited to: herbicides, fungicides, insecticides, acaricides, nematicides, molluscicides, rodenticides, growth regulators, repellents, rodenticides, and biocides (MacFarlane et al. 2013, Chmielewski et al. 2016, Rajmohan et al. 2020, Bąk-Badowska et al. 2021).

Due to the toxicity of pesticides, the chemical composition of the active ingredients and their effects on target organisms, there are several classification systems for pesticides. The International Health Organization (WHO) recommended classification of pesticides is shown in Table 1, while Table 2 shows revised Globally Harmonized System (GHS) classification of pesticide, and Table 3 shows Pesticide classification by target pests (Akashe et al. 2018). Table 4 shows the classification based on chemical structure (Rajmohan et al. 2020).

Table 1

WHO classifications of pesticides (modified after Akashe et al. 2018)

WHO class	Toxicity level	Example
Ia	extremely hazardous	parathion, dieldrin, phorate
Ib	highly hazardous	aldrin, dichlorvos
II	moderately hazardous	DDT, chlordane
III	slightly hazardous	malathion
U	unlikely to present acute hazard	carbetamide, cycloprothrin

Table 2

GHS classification of pesticides (modified after Akashe et al. 2018)

GHS category	Classification criteria	
	oral	dermal
	hazard statement	hazard statement
1	fatal if swallowed	fatal in contact with skin
2	fatal if swallowed	fatal in contact with skin
3	toxic if swallowed	toxic in contact with skin
4	harmful if swallowed	harmful in contact with skin
5	may be harmful	may be harmful

Table 3

Classification of selected pesticides by target pests (modified after Akashe et al. 2018)

Type of pesticides	Target pests/function	Example
Acaricides	substances that are used to kill mites and ticks or to disrupt their growth or development	DDT, dicofol, chlorpyrifos, permethrin, etc.
Algicides	substances that used to kill or inhibit algae	copper sulphate, diuron, oxyfluorfen, etc.
Antifeedants	chemicals which prevent an insect or other pest from feeding	chlordimeform, azadirachtin, etc.
Bird repellents	chemicals which repel the birds	diazinon, methiocarb, etc.
Chemosterillants	chemicals that renders an insect infertile and thus prevent it from reproducing	diflubenzuron
Desiccants	act on plants by drying their tissues	boric acid
Fungicides	chemicals which are used to prevent, cure eradicate the fungi	cymoxanil, thiabendazole, Bordeaux mixture
Herbicides	substances that are used to kill the plants, or to inhibit their growth or development	alachlor, paraquat, 2,4-D
Insecticides	a pesticide that is used to kill insects or to disrupt their growth or development	azadirachtin, DDT, chlorpyrifos, malathion, etc.
Lampricides	target larvae of lampreys which are jawless fish like vertebrates	nitrophenol
Molluscicides	substances used to kill slugs and snails	metaldehyde, thiadicarb, etc.
Ovicides	inhibit the growth of eggs of insects and mites	benzoxazin
Rodenticides	substances used to kill rats and related animals	strychnine, warfarin, zinc phosphide, etc.
Silvicides	acts against woody vegetation	tebuthiuron

Table 4

Pesticides classification: based on chemical structure with examples
(modified after Rajmohan et al. 2020)

Type of pesticide	Abbreviation and other names	Chemical formula
Organochlorines	methoxychlor/methoxcide/dimethoxy-DDT methoxy-DDT	$C_{16}H_{15}Cl_3O_2$
	DDT	$C_{14}H_9Cl_5$
	lindane	$C_6H_6Cl_6$
	endosulfan/benzoepin/endocel/parrysulfan	$C_9H_6Cl_6O_3S$
	aldrin/HHDN octalene	$C_{12}H_8Cl_6$
	chlordane/octachloro-4,7-methanohydroindane	$C_{10}H_6Cl_8$
Organophosphorous	parathion/E605	$C_{10}H_{14}NO_5PS$
	malathion/carbofos/maldison/mercaptothion	$C_{10}H_{19}O_6PS_2$
	diazinon/basudin/diazide/spectracide	$C_{12}H_{21}N_2O_3PS$
Inorganic	benomyl	$C_{14}H_{18}N_4O_3$

The importance of the issue of pesticide uses in the context of reducing the risks and impacts of pesticide use on human health and the environment is evidenced by the fact that within the framework of the European Green Deal, and within the Farm to Fork and Biodiversity strategies, the European Commission has committed itself to take action to reduce the use of chemical pesticides and their risks by 50% by the end of 2030. In order to do so, the Commission will reconsider the Sustainable Use of Pesticides Directive, strengthen the provisions on Integrated Pest Management (IPM) and advocate wider use of substitute means of crop protection against pests and diseases (*Report* 2020).

Studies show that a significant proportion of pesticides is misapplied and does not reach the intended destination, with the remaining amount contaminating soil, air, and water (Erhunmwunse et al. 2012, Chudy 2021).

This makes pesticides likely to have adverse health effects on people who are directly exposed to them, as well as on residents of the areas where they are applied, or on people who consume water and food contaminated with their residues (Kalliora et al. 2018, Chmielewski et al. 2020, 2021).

It should be made clear that the negative effects of pesticide exposure are not limited to the environment but also affect human health. The effects of pesticide exposure, as with other chemicals, depend on the dose, routes of exposure, route of ingestion, type of effect, and persistence in the body, as well as the health status of the individual (Chmielewski et al. 2016, 2020).

The globalization process has had a significant impact on the development of agriculture and trade in agricultural and food products in the world.

The United States of America (USA), the common countries of the European Union (EU), Brazil and China are among the largest agricultural producers and exporters of agricultural products and, consequently, among the largest users of agricultural pesticides in the world. Each of these countries has its own regulations regarding the rules and use of pesticides. For this reason, it is an important task for both the environment and public health to continuously monitor the contamination of the environment and agricultural products. This is because pesticides used for plant pest and disease control as well as protection can have far-reaching and serious health effects on both wildlife and humans (Donley 2019).

The purpose of this article is to summarize the basic knowledge about the adverse health effects of pesticide exposure.

HEALTH EFFECTS OF EXPOSURE TO PESTICIDES

Recently, numerous epidemiological studies have been published addressing exposure to pesticides (including pest control agents) and the potential for various health disorders. To date, adverse health effects associated with pesticide use have been identified. These include various cancers, diabetes, neurodegenerative diseases such as Parkinson's disease, Alzheimer's disease, and amyotrophic lateral sclerosis (ALS), birth defects and reproductive disorders, genetic damage, epigenetic changes, endocrine system disorders, oxidative stress (Erhunmwunse et al. 2012, Mostafalou, Abdollahi 2013, Chmielewski et al. 2016, Searles-Nielsen et al. 2017, Kalliora et al. 2018, Chmielewski et al. 2021).

Examples of adverse health effects associated with pesticide exposure can be found in Table 5.

In Poland, 450 and 440 persons were medically treated for poisoning by plant protection products (PPPs) in 2016-2017, of which 295 and 236 required hospitalizations, respectively (NIK 2020).

According to the data in the reports on incidence of infectious diseases, infections, and poisonings of the National Institute of Public Health PZH - PIB (NIZP PZH-PIB), 126 reports of (acute) pesticide poisoning were reported in Poland between 2012 and 2020 (NIZP PZH -PIB 2021). The data on acute pesticide poisonings are presented in Table 6.

As shown by the Office for Registration of Medicinal Products, Medical Devices and Biocidal Products (URPLWMIPB), 2,112 cases of poisoning with biocidal products were reported in Poland between 2012 and 2020 (URPLW -MIPB 2021). The data on poisonings with biocidal products are presented in Table 7.

Table 5

Health effects of exposure to selected agricultural pesticides
(modified after Erhunmwunse et al. 2012)

Active substances	Type of pesticide	Health effects
Hydrazine	herbicides	mutagenic
Ethylene dibromide	fumigant nematocide	mutagenic
Chlorophenols	fumigant	carcinogenic
Methoxychlor	broad-insecticide	carcinogenic potential in liver and testes
Molinate	herbicide	impairment of the reproductive performance
Heptachlor and heptachlor epoxide	broad-spectrum insecticide	kidney tumour
Fenopropane	herbicide	degeneration and necrosis of hepatocytes and fibroblastic proliferation
Chorotoluron	post-emergence herbicide	cholinesterase inhibitor
Pentachloronitrobenzene	molluscicides	teratogenicity or fetal toxicity
Captan	it is foliage fungicide with protective action	teratogenicity or fetal toxicity
Chlorophenoxy	herbicide	carcinogenic
Dibromochloropropane	nematocide	sterility in male
Organotin	acaricide and protective fungicides	effect on the immune system
Isoproturon	systemic herbicide	marked enzyme induction and liver enlargement

Table 6

Reports of acute pesticide poisonings from 2012 to 2020 (NIZP PZH-PIB 2021)

Year									
Number of poisonings per year	2012	2013	2014	2015	2016	2017	2018	2019	2020
	30	16	4	14	17	10	14	19	2
Poisonings in total	**126**								

own elaboration

Table 7

Reports of biocidal product poisonings from 2012 to 2020 (URPLWMIPB 2021)

Year									
Number of poisonings per year	2012	2013	2014	2015	2016	2017	2018	2019	2020
	203	229	312	281	238	275	227	195	152
Poisonings in total	**2.112**								

own elaboration

MATERIAL AND METHODS

The volume of scientific content related to the presentation of the health effects of pesticide exposure from PubMed, an online English-language database from the National Library of Medicine, National Institutes of Health, Bethesda, MD, USA (http://www.ncbi.nlm.nih.gov/PubMed), containing articles in the fields of medicine and biology, was analysed. Literature published between 2011 and 2021 was reviewed. A period of analysis was selected t meet the editors' requirement that manuscripts contain primarily indexed literature from the last 10 years prior to publication. Advanced search options based on keywords or keyword combinations (Step 1, Table 8) and a specific time period (Step 2, Table 9) were used. This search retrieved

Table 8

Step one of keyword-based literature trend analysis

Key words	pesticides, pesticide exposure, occupational exposure to pesticides, health effects of pesticide exposure

Table 9

Stage two of the literature trend analysis with a fixed time frame

Time interval (years)	2011, 2012, 2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020, 2021

a total of 134,349 articles by keyword. The articles were in English. The search found 6,890 articles dealing with the health effects of pesticide exposure. After analysing the titles and abstracts of the 2020-2021 articles with respect to disease risk from environmental pesticide exposure, 34 potentially relevant articles addressing the topic at hand were selected by evaluating the full text of each article. This was done to show the current state of knowledge based on the characteristics of the studies and the results of each study.

Documents such as opinions, conference reports, letters to the editor, book chapters, and conference and training notes were excluded from the analysis.

RESULTS AND DISCUSSION

The conducted analysis revealed that in the PubMed scientific database there are 134, 349 publications (as of 28/10/2021) on health problems resulting from environmental exposure to pesticides in the period 2011-2021. Table 10 provides a quantitative listing of the problems raised in publications according to the key to search terms in the analysed period from 2011

Table 10

Publications related to the use of pesticides 2011-2021

Year of publication	Number of publications based on keyword search				
	pesticides	pesticide exposure	occupational exposure to pesticides	health effects of pesticide exposure	total
2011	7.848	1.636	247	390	10.121
2012	8.417	1.778	238	442	10.875
2013	8.622	1.837	228	443	11.130
2014	8.871	1.979	301	528	11.679
2015	9.044	2.023	286	604	11.957
2016	9.270	2.131	289	646	12.336
2017	9.476	2.298	309	757	12.840
2018	9.882	2.363	311	767	13.323
2019	10.110	2.465	339	777	13.691
2020	10.768	2.640	321	829	14.558
2021	8.609	2.247	276	707	11.839
Total results	100.917	23.397	3.145	6.890	134.349

Source: developed by the authors

to 2021. In the analysed period, out of 134,349 (100% of publications) of all publications, 75.11% dealt with pesticides, 17.41% – with pesticide exposure, 2.34% – with pesticide exposure in the workplace, and 5.12% of all publications dealt with the health effects of pesticide exposure.

It can be noted that during the analysed period, the number of publications on widely discussed topics related to the use of pesticides has been steadily increasing, owing to the scientific activities of many authors from all over the world. The exception is 2021, when the total number of publications decreased by almost 12% compared to 2020. This is related to the circumstances of the prevailing pandemic COVID-19. Since 2011, there has been an increasing interest among researchers in the topic of occupational exposure to pesticides and the health effects of pesticide exposure, although it accounts for only 7.47% of all publications.

Human pesticide health impacts

Increasing public awareness through continuous education (both health, environmental and consumer education) has led to the inhabitants of EU Member States no longer perceiving the use of pesticides only as a source of danger to the environment, but above all as a threat to their own health. Despite legislation aimed at limiting the use of pesticides in agricultural crops, their complete elimination seems unrealistic. This is mainly due to the growing demand for food, which goes hand in hand with the need for their

use, and the fact that switching from the current method of crop protection to the use of biopesticides in the global market for pesticides involves a costly registration process and more difficult and cumbersome application. For economic reasons, organic food represents only a small part of the supply to consumers. Therefore, the presence of pesticide residues in the environment and in food should be of interest to institutions dealing with environmental health and public health issues due to potential health effects (Valcke et al. 2017, Kalliora et al. 2018, Kerr, Bullard 2020, Piwowar 2021).

Due to their biological and toxic properties, pesticides occupy a special place among environmental pollutants. This is because pesticides, by the nature of their use, are primarily aimed at protecting crops from pests and thus do not distinguish between pests and other life forms. Pesticide use is also associated with various costs, such as monitoring the environment for contamination of soil, drinking water, or food; treating symptoms of poisoning in pesticide users or occupational illnesses in farmers; and affecting non-target organisms such as bees and other beneficial insects, fish, and birds (Chmielewski et al. 2016, Valcke et al. 2017, Chmielewski et al. 2020, 2020*a*, 2020*b*, 2020*c*, Bąk-Badowska et al. 2021, Chmielewski et al. 2021).

The use of pesticides in crop protection has been a source of environmental and health concern for many years, both among physicians and public health officials. In response to this concern about pesticide use, numerous exposure and health risk assessments of pesticide exposures and residues in water and food are being conducted worldwide. The health effects of pesticide exposure depend on the duration of exposure, the concentration of the pesticide, and the rate of development of toxic symptoms (Erhunmwunse et al. 2012, Mostafalou, Abdollahi 2013, Chmielewski et al. 2016, Valcke et al. 2017, Chmielewski et al. 2020, 2021).

A systematic literature search conducted by Boedeker et al. covering the period 2006-2018 was supplemented with mortality data from WHO that included annual national acute pesticide poisoning (UAPP) data. Based on their analysis, the researchers estimated that there are about 385 million cases of UAPP worldwide each year, including about 11,000 deaths. Using their data, they found that about 44% of the world's approximately 860 million farmers are poisoned by pesticides each year. Table 11 shows the annual number of deaths due to acute pesticide poisoning worldwide (Boedeker et al. 2020).

Studies show that exposure to organophosphorus pesticides (OPPs) can lead to constant muscle contraction, resulting in neuromuscular complications and impaired cardiovascular function, neuroendocrine and immunological function, and other disorders (Jorjandi et al. 2020).

Previous studies show that one of the most important effects of organochlorine pesticides (OCPs) and OPPs on the body is an imbalance in the oxidant/antioxidant system (Abolhassani et al. 2019, Mortazavi et al. 2019).

Table 11

Estimated worldwide annual fatal UAPP by region (modified after Boedeker et al. 2020)

Region	Subregion	Estimated fatalities in subregion
Africa	east	81
	middle-southern	67
	northern	154
	western	0
America	caribbean	8
	central	296
	north	6
	south	229
Asia	central	4
	eastern	338
	south-eastern	159
	southern	9.401
	western	39
Europe	eastern	75
	northern	1
	southern	14
	western	7
Oceania	AUS, NZ, Mel-Mic-Polynesia	3
All	All	10.881

As shown in case-control studies, exposure to OCPs and OPPs can cause colon and bladder cancer (Ramirez et al. 2016, Abolhassani et al. 2019, Mortazavi et al. 2019).

Studies on agricultural workers show that numerous pesticides act individually or in combination as endocrine disruptors, neurodevelopmental toxins, immunotoxicants, and carcinogens (Bonner et al. 2017, Chmielewski et al. 2016, 2021, Petrakis et al. 2017), while negative health effects such as rheumatoid arthritis (RA) (Meyer et al. 2017), incidence of central nervous system (CNS) diseases (Piel et al. 2017); liver cancer (Saad-Hussein et al. 2019); epilepsy (Requena et al. 2018); thyroid dysfunction (Bernieri et al. 2019); birth defects (Kalliora et al. 2018); diabetes (Park et al. 2019); deoxyribonucleic acid (DNA) developmental disorders (Paul et al. 2018); sleep disorders (Baumert et al. 2018, Li et al. 2019); risk for depression and other mental disorders (Koh et al. 2017, Lyu et al. 2018); or reproductive disorders in males and females (Chmielewski et al. 2020*d*). Table 12 shows the reproductive disorders occurring due to pesticide exposure in men and women (Chmielewski et al. 2020*d*).

Table 12

Reproductive dysfunction due to pesticide exposure
(modified after Chmielewski et al. 2020*d*)

Pesticide/exposure	Observed health effects
Male reproductive system	
Dibromochloropropan (DBCP)	decrease in sperm concentration and infertility
	atrophy of the seminiferous epithelium
	reduction in sperm count
	testicular dysfunction
Repeated exposure to pesticides among farmers, horticulturists, and agri-food workers	adverse reproductive effects
	reduction in sperm count and decrease in testosterone levels
Female reproductive system	
Repeated exposure to pesticides in female horticultural workers	higher miscarriage rate
Exposure to pesticides in the first trimester of pregnancy	low birth weight of the new-born baby
Pesticide exposure in pregnant women working in greenhouses	spontaneous abortion

Studies also report adverse health effects in children due to pesticide exposure, as follows: increased incidence of childhood cancers, including cancers of the hematopoietic system; predisposition to the development of lymphocytic leukaemia and brain tumors in new-borns; increased risk of brain tumours, Hodgkin's lymphoma and non-Hodgkin's lymphoma, and kidney cancer in their children (Pascale, Laborde 2020).

Table 13 shows selected health effects in children due to pesticide exposure of their parents and themselves.

SUMMARY AND CONCLUSIONS

The global use of pesticides to protect and increase crop yields in agriculture without adequate preventive measures such as education, workplace risk assessment, provision of personal protective equipment (PPE) and environmental monitoring poses significant health risks to workers (Gesesew et al. 2016, Ghafari et al. 2017, Chmielewski et al. 2020).

It is estimated that nearly 220,000 people worldwide die each year as a result of pesticide exposure (Ngowi et al. 2016). Globally, there are about 385 million cases of UAPP each year, including about 11,000 deaths (Boedeker et al. 2020), which is a major public health problem. According to

Table 13

Health effects in children caused by exposure to pesticides

Author	Methodological design	Main findings
Von Ehrenstein et al. (2019)	population based case-control study	Increased risk for autism spectrum disorders in offspring after prenatal exposure to environmental pesticides within 2000 m of the mother's home during pregnancy. Exposure of the infant therefore may influence the increase of the risk for autism spectrum disorders if concomitant intellectual disabilities are present.
Coste et al. (2020)	prospective cohort study	Increased risk of solid tumours other than central nervous system (CNS) cancers in children whose parents were vulnerable to pesticides at their professions.
Addissie et al. (2020)	retrospective case-control study	Exposure to pesticides may be a predisposing factor for pregnancy affected by holoprosencephaly (HPE).
Kartini et al. (2019)	case-control study	Exposure to pesticides may be a determinant condition for growth disorders in children living in agricultural areas.
Wang et al. (2017)	longitudinal birth cohort study	Prenatal exposure to organophosphorus pesticides (OPP) may affect neurological development in children at 24 months of age, particularly in boys. The prenatal period may be a predisposing factor for exposure to OPPs.
Ueker et al. (2016)	hospital-based case-control study	Father exposure to pesticides may be associated with a higher rate of fetal malformations.
Spinder et al. (2017)	case-malformed control study	Occupational exposure of the mother to pesticides is a threat to the offspring to whom the oral clefts may occur.
Yu et al. (2016)	case-control study	Exposure to OPPs may adversely affect neurological development in children, particularly the development of attention-deficit/hyperactivity disorder (ADHD).
Costa et al. (2021)	literature review	Parental exposure to pesticides can cause congenital malformations in children, including: reproductive system, nervous system, musculoskeletal system, cross-sectional limb malformations, gastrointestinal system, and other malformations such as fetal growth restriction, cleft palate, and congenital heart defects.

Ngowi et al, this condition is due to the lack of adequate knowledge of people working with pesticides and awareness of the existing health risks. These authors point out the need for workplace safety education and health education that highlight the negative effects of pesticides (Ngowi et al. 2016). The inadequate awareness of the health risks associated with pesticide use was also confirmed in a study by Gesesew et al. which also found that 42% of the farmers in the study had never used PPE to protect themselves from pesticide exposure (Gesesew et al. 2016). A study conducted by Ghafari et al.

found that 68% of workers in the study did not use PPE when applying pesticides (Ghafari et al. 2017). The failure of workers to consistently use PPE during occupational activities involving pesticides was highlighted by Piel et al. who stated that this is a result of lack of training and awareness of the importance of PPE in disease prevention (Piel et al. 2017).

To ensure safe and hygienic working conditions, workers exposed to pesticides should be provided with adequate working conditions through measures aimed at minimizing adverse health effects. These include: assessment of exposure to chemical agents in the work process, provision of PPE, adequate training, and medical care, including occupational health examinations (Chmielewski et al. 2015, 2015*a*, 2016, 2020).

To minimize the health effects of pesticide exposure, the use of PPE by workers is strongly recommended.

It is recommended to continue research on occupational health of workers in crop production (agriculture and horticulture), to set research priorities based on epidemiological results and to clarify the health status of workers through cohort studies.

Educational and preventive measures should be taken to promote the health and safety of workers exposed to pesticides.

Preventive measures should result from an assessment of the health risk of exposure to pesticides.

Declaration of competing interests: The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work in this article.

REFERENCES

Abolhassani M., Asadikaram G., Paydar P., Fallah H., Aghaee-Afshar M., Moazed V., Moradi A. 2019. *Organochlorine and organophosphorous pesticides may induce colorectal cancer; A case-control study*. Ecotox. Environ. Safe., 178: 168-177. DOI: 10.1016/j.ecoenv.2019.04.030

Addissie Y.A., Kruszka P., Troia A., Wong Z.C., Everson J.L., Kozel B.A., Muenke M. 2020. *Prenatal exposure to pesticides and risk for holoprosencephaly: a case-control study*. Environ. Health-UK, 19(1): 65 DOI: 10.1186/s12940-020-00611-z

Akashe M.M., Pawade U.V., Nikam A.V. 2018. *Classification of pesticides: a review*. Int J Res Ayurveda Pharm, 9(4): 144-150. DOI: 10.7897/2277-4343.094131

Baumert B.O., Carnes M.U., Hoppin J.A., Jackson C.L., Sandler D.P., Freeman L.B., London S.J. 2018. *Sleep apnea and pesticide exposure in a study of US farmers*. Sleep Health, 4(1): 20-26. DOI: 10.1016/j.sleh.2017.08.006

Bąk-Badowska J., Żeber-Dzikowska I., Gworek B., Szajner J., Wójtowicz B., Suwara I., Chmielewski J. 2021. *Pesticides as the source of the environment risk for pollinating insects. Ecological education*. Przem. Chem., 100(3): 268-274. (in Polish) DOI: 10.15199/ /62.2021.3.9

Bernieri T., Rodrigues D., Barbosa I.R., Ardenghi P.G., Basso da Silva L. 2018. *Occupational exposure to pesticides and thyroid function in Brazilian soybean farmers*. Chemosphere, DOI: 10.1016/j.chemosphere.2018.11.124

Boedeker W., Watts M., Clausing P., Marquez E. 2020. *The global distribution of acute unintentional pesticide poisoning: estimations based on a systematic review*. BMC Public Health, 20(1): 1875. DOI: 10.1186/s12889-020-09939-0

Bonner M.R., Beane Freeman L.E., Hoppin J.A., Koutros S., Sandler D.P., Lynch C.F., Hines C.J., Thomas K., Blair A., Alavanja M.C.R. 2017. *Occupational exposure to pesticides and the incidence of lung cancer in the Agricultural Health Study*. Environ. Health Perspect., 125: 544-551. DOI: 10.1289/EHP456

Chmielewski J., Galińska E.M., Anusz K., Nagas T., Trela M., Zagórski J. 2015. *Personal protection measures in veterinary practice*. Życie Wet, 90(05): 277-280. (in Polish) https://www.vetpol.org.pl/dmdocuments/ZW-05-2015-01.pdf

Chmielewski J., JACKOWSKA N., Wojciechowska M., Anusz K., Szpringer M., Jagusztyn I., Trela M., Zagórski J., Nagas T. 2015*a*. *Occupational exposure to chemicals in veterinary practice*. Życie Wet, 90(11): 711-715. (in Polish) https://vetpol.org.pl/dmdocuments/ZW-11-2015-01.pdf

Chmielewski J., Gorczyca D., Dawid U., Żyfka-Zagrodzińska E. 2016. *Occupational health risks associated with the use of pesticides*. Przem. Chem., 95(3): 370-373. (in Polish) DOI: 10.15199/62.2016.3.7

Chmielewski J., Nowak-Starz G., Gworek G., Król H., Szpringer M., Wójcik T., Dziewisz E., Kowalska A., Czarny-Działak M. 2020. *Chemical substances occuring in the work environment as an etiological factor of occupational diseases*. Przem. Chem., 99(5): 718-726. (in Polish) DOI: 10.15199/62.2020.5.9

Chmielewski J., Nowak-Starz G., Rutkowski A., Bartyzel M., Czarny-Działak M., Gworek B., Król H., Łuszczki J.J., Szpringer M. 2020*a*. *Occupational exposure to carcinogens and mutagens in the work environment*. Przem. Chem., 99(3): 397-405. (in Polish) DOI: 10.15199/62.2020.3.8

Chmielewski J., Żeber-Dzikowska I., Kosecka J., Wójtowicz B., Działak M., Osuch M., Gworek B., Chmielowiec B., Czarny-Działak M. 2020*b*. *Exposure to chemicals as an etiological agent of occupational skin diseases and related health education*. Przem. Chem., 99(8): 1254-1260. (in Polish) DOI: 10.15199/62.2020.8.28

Chmielewski J., Kosowska E., Bąk-Badowska J., Żeber-Dzikowska I., Gonczaryk A., Nowak-Starz G., Czarny-Działak M., Gworek B., Szpringer M. 2020*c*. *Polychlorinated dibenzodioxins and dibenzofurans as an environmental health threat*. Przem. Chem., 99(1): 135-144. (in Polish) DOI: 10.15199/62.2020.1.21

Chmielewski J., Szpringer M., Łuszczki J.J., Czarny-Działak M., Dutkiewicz E., Zięba E., Gworeka B., Dziechciaż M., Nowak-Starz G. 2020*d*. *Occupational and environmental exposure to substances and chemical mixtures that are toxic to human reproduction*. Przem. Chem., 99(6): 865-874. (in Polish) DOI: 10.15199/62.2020.6.7

Chmielewski J., Łuszczki J., Czarny-Działak M., Dutkiewicz E., Król H., Gworek B., Nowak-Starz G. 2021. *Environmental exposition to xenoestrogens and related health effects*. J. Elem., 26(3): 717-730. DOI: 10.5601/jelem.2021.26.2.2157

Chudy A.B. 2021. *Agricultural pesticide residues: an emerging environmental and health threat to life in Ebonyi State, Nigeria*. J Environ Sci Toxicol Food Technol, 15(6): 01-04. DOI: 10.9790/2402-1506010104

Costa N.Z., Dalla Nora C.R., Souto L.H.D., Carlotto F.D., Afonso R.S., Riquinho D.L. 2021. *Exposure to toxic agrochemicals and development of congenital malformations: a scoping review*. Texto Contexto Enfer., 30: e20200372. DOI: 10.1590/1980-265X-TCE-2020-0372

Coste A., Bailey H.D., Kartal-Kaess M., Renella R., Berthet A., Spycher B.D. 2020. *Parental occupational exposure to pesticides and risk of childhood cancer in Switzerland: a census-based cohort study*. BMC Cancer., 20(1): 819. DOI: 10.1186/s12885-020-07319-w

Directive 98/8/EC of the European Parliament and of the Council concerning the placing of biocidal products on the market. https://www.fao.org/faolex/results/details/en/c/LEX-FAOC019011

Directive 2009/128/EC of the European Parliament and of the Council of 21 October 2009 establishing a framework for Community action to achieve the sustainable use of pesticides (Text with EEA relevance). https://www.fao.org/faolex/results/details/en/c/LEX-FAOC113943/

Donley N. 2019. *The USA lags behind other agricultural nations in banning harmful pesticides*. Environ. Health, 18: 44. DOI: 10.1186/s12940-019-0488-0

Erhunmwunse N.O., Dirisu A., Olomukoro J.O. 2012. *Implicatons of pesticide usage in Nigeria*. Tropical Freshwater Biol, 21(1): 15-25. DOI: 10.4314/tfb.v21i1.2

Gesesew H.A., Woldemichael K., Massa D., Mwanri L. 2016. *Farmers knowledge, attitudes, practices and health problems associated with pesticide use in rural irrigation villages, Southwest Ethiopia*. PLoS One, 11(9): e0162527. DOI: 10.1371/journal.pone.0162527

Ghafari M., Cheraghi Z., Doosti-Irani A. 2017. *Occupational risk factors among Iranian farmworkers: a review of the available evidence*. Epidemiol Health, 39: e2017027. DOI: 10.4178/epih.e2017027

Jorjandi M.A., Asadikaram G., Abolhassani M., Fallah H., Abdollahdokht D., Salimi F., Pournamdari M. 2020. *Pesticide exposure and related health problems among family members of farmworkers in southeast Iran*. A case-control study. Environ. Pollut., 267: 115424. DOI: 10.1016/j.envpol.2020.115424

Kalliora C., Mamoulakis C., Vasilopoulos E., Stamatiades G.A., Kalafati L., Barouni R., Tsatsakis A. 2018. *Association of pesticide exposure with human congenital abnormalities*. Toxicol. Appl. Pharm., 346: 58-75. DOI: 10.1016/j.taap.2018.03.025

Kartini A., Subagio H.W., Hadisaputro S., Kartasurya M.I., Suhartono S., Budiyono B. 2019. *Pesticide exposure and stunting among children in agricultural areas*. Int. J. Occup. Environ. Med., 10(1):17-29. DOI: 10.15171/ijoem.2019.1428

Kerr A., Bullard G. 2020. *Biocontrol of crown gall by Rhizobium rhizogenes: challenges in biopesticide commercialisation*. Agronomy, 10(8): 1126. DOI: 10.3390/agronomy10081126

Koh S.B., Kim T. H., Min S., Lee K., Kang D.R., Choi J.R. 2017. *Exposure to pesticide as a risk factor for depression: A population-based longitudinal study in Korea*. Neurotoxicology, 62: 181-185. DOI: 10.1016/j.neuro.2017.07.005

Li J., Hao Y., Tian D., He S., Sun X., Yang H. 2019. *Relationship between cumulative exposure to pesticides and sleep disorders among greenhouse vegetable farmers*. BMC Public Health, 19(1): 373. DOI: 10.1186/s12889-019-6712-6

Lyu C.P., Pei J.R., Beseler L.C., Li Y.L., Li J.H., Ming R.E.N., Ren S.P. 2018. *Case control study of impulsivity, aggression, pesticide exposure and suicide attempts using pesticides among farmers*. Biomed. Environ. Sci., 31(3): 242-246. DOI: 10.3967/bes2018.031

MacFarlane E., Carey R., Keegel T., El-Zaemay S., Fritschi L. 2013. *Dermal exposure associated with occupational end use of pesticides and the role of protective measures*. Safety Health Work, 4(3): 136-141. DOI: 10.1016/j.shaw.2013.07.004

Meyer A., Sandle, D.P., Beane Freeman L.E., Hofmann J.N., Parks C.G. 2017. *Pesticide exposure and risk of rheumatoid arthritis among licensed male pesticide applicators in the agricultural health study*. Environ. Health Persp., 125(7): 077010. DOI: 10.1289/EHP1013

Mortazavi N., Asadikaram G., Ebadzadeh M., Kamalati A., Pakmanesh H., Dadgar R., Abolhassani M. 2019. *Organochlorine and organophosphorus pesticides and bladder cancer: A case-control study*. J. Cell. Biochem, DOI: 10.1002/jcb.28746

Mostafalou S., Abdollahi M. 2013. *Pesticides and human chronic diseases: Evidences, mechanisms, and perspectives*. Toxicol. Appl. Pharm., 268(2): 157-177. DOI: 10.1016/j.taap.2013.01.025

Ngowi A., Mrema E., Kishinhi S. 2016. *Pesticide health and safety challenges facing informal sector workers: A case of small-scale agricultural workers in Tanzania*. New Solutions: J Environ Occupational Health Policy, 26(2): 220-240. DOI: 10.1177/1048291116650262

NIK 2020. *Safety system for the marketing of plant protection products*. https://www.nik.gov.pl/
/kontrole/wyniki-kontroli-nik/kontrole,20175.html

NIZP PZH – PIB 2021. Narodowy Instytutu Zdrowia Publicznego PZH – PIB.

http://wwwold.pzh.gov.pl/oldpage/epimeld/index_p.html#01

Park S., Kim S.K., Kim J.Y., Lee K., Choi J.R., Chang S.J., Koh S.B. 2018. *Exposure to pesticides and the prevalence of diabetes in a rural population in Korea*. Neurotoxicology. DOI: 10.1016/j.neuro.2018.10.007

Pascale A., Laborde A. 2020. *Impact of pesticide exposure in childhood*. Rev. Environ. Health, 35(3): 221-227. DOI: 10.1515/reveh-2020-0011

Paul K.C., Chuang Y.H., Cockburn M., Bronstein J.M., Horvath S., Ritz B. 2018. *Organophosphate pesticide exposure and differential genome-wide DNA methylation*. Sci. Total Environ., 645: 1135-1143. DOI: 10.1016/j.scitotenv.2018.07.143

Petrakis D., Vassilopoulou L., Mamoulakis C., Psycharakis C., Anifantaki A., Sifakis S., Tsatsakis A. 2017. *Endocrine disruptors leading to obesity and related diseases*. Int. J. Env. Res. Pub. He., 14(10): 1282. DOI: 10.3390/ijerph14101282

Piel C., Pouchieu C., Tual S., Migault L., Lemarchand C., Carles C., Boulanger M., Gruber A., Rondeau V., Marcotullio E., Lebailly P., Baldi I. 2017. *Central nervous system tumors and agricultural exposures in the prospective cohort AGRICAN*. Int. J. Cancer., 141(9): 1771-1782. DOI: 10.1002/ijc.30879

Piwowar A. 2021. *The use of pesticides in Polish agriculture after integrated pest management (IPM) implementation*. Environ. Sci Pollut Res., 28: 26628-26642. DOI: 10.1007/s11356-
-020-12283-w

Rajmohan K.S., Chandrasekaran R., Varjani S. 2020. *A review on occurrence of pesticides in environment and current technologies for their remediation and management*. Ind J. Microbiol., 60(2): 125-138. DOI: 10.1007/s12088-019-00841-x

Ramirez D., Gupta A., Canter D., Harrow B., Dobbs R.W., Kucherov V., Lotan Y. 2016. *Microscopic haematuria at time of diagnosis is associated with lower disease stage in patients with newly diagnosed bladder cancer*. BJU Int, 117(5): 783-786. DOI: 10.1111/bju.13345

Regulation (EC) No. 1107/2009 of the European Parliament and of the Council concerning the placing of plant protection products on the market and repealing Council Directives 79/117/EEC and 91/414/EEC. https://www.fao.org/faolex/results/details/en/c/LEX-FAOC
103352/

Requena M., Parrón T., Navarro A., García J., Ventura M.I., Hernández A.F., Alarcón R. 2018. *Association between environmental exposure to pesticides and epilepsy*. Neurotoxicology, 68: 13-18. DOI: 10.1016/j.neuro.2018.07.002

Report 2020. *Report from the Commission to the European Parliament and the Council. On the experience gained by Member States on the implementation of national targets established in their National Action Plans and on progress in the implementation of Directive 2009/128/EC on the sustainable use of pesticides*. https://ec.europa.eu/food/system/
/files/2020-05/pesticides_sud_report-act_2020_en.pdf

Saad-Hussein A., Beshir S., Tah, M.M., Shahy E.M., Shaheen W., Abdel-Shafy E.A., Thabet E. 2019. *Early prediction of liver carcinogenicity due to occupational exposure to pesticides*. Mutat. Res-Gen. Tox. En., 838: 46-53. DOI: 10.1016/j.mrgentox.2018.12.004

Searles Nielsen S., Hu S.C., Checkoway H., Negret, M., Palmández P., Bordianu T., Simpson C.D. 2017. *Parkinsonism signs and symptoms in agricultural pesticide handlers in Washington State*. J. Agromed, 22(3): 215-221. DOI: 10.1080/1059924x.2017.1317684

Spinder N., Bergman J.E.H., Boezen H.M., Vermeulen R.C.H., Kromhout H., de Walle H.E.K. 2017. *Maternal occupational exposure and oral clefts in offspring*. Environ. Health, 16(1): 83. DOI: 10.1186/s12940-017-0294-5

Ueker M.E., Silva V.M., Moi G.P., Pignati W.A., Mattos I.E., Silva A.M.C. 2016. Parenteral exposure to pesticides and occurence of congenital malformations: hospital-based case-control study. BMC Pediatr., 16(1): 125. DOI: 10.1186/s12887-016-0667-x

URPLWMIPB. 2021. Urząd Rejestracji Produktów Leczniczych, Wyrobów Medycznych i Produktów Biobójczych http://www.urpl.gov.pl/sites/default/files/pictures/Informacja%20graficzna%20do%20Raportu.pdf

Valcke M., Bourgault M.H., Rochette L., Normandin L., Samuel O., Belleville D., Phaneuf D. 2017. *Human health risk assessment on the consumption of fruits and vegetables containing residual pesticides: A cancer and non-cancer risk/benefit perspective*. Environ. Int., 108: 63-74. DOI: 10.1016/j.envint.2017.07.023

von Ehrenstein O.S., Ling C., Cui X., Cockburn M., Park A.S., Yu F., Wu J., Ritz B. 2019. *Prenatal and infant exposure to ambient pesticides and autism spectrum disorder in children: population based case-control study*. BMJ., 364: l962. DOI: 10.1136/bmj.l962

Wang Y., Zhang Y., Ji L., Hu Y., Zhang J., Wang C., Ding G., Chen L., Kamijima M., Ueyama J., Gao Y., Tian Y. 2017. *Prenatal and postnatal exposure to organophosphate pesticides and childhood neurodevelopment in Shandong*, *China*. Environ Int., 108: 119-126. DOI: 10.1016/j.envint.2017.08.010

Yu C.J., Du J.C., Chiou H.C., Chung M.Y., Yang W., Chen Y.S., Chen M.L. 2016. *Increased risk of attention-deficit/hyperactivity disorder associated with exposure to organophosphate pesticide in Taiwanese children*. Andrology, 4(4): 695-705. DOI: 10.1111/andr.12183