



Carcinogenic pesticides and insecticides: a critical review of cancer risks and mechanisms

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ABSTRACT

Insecticides and pesticides are extensively used across the world to protect crops from pests and increase agricultural output. Still, there is mounting evidence that some of these chemicals may be carcinogenic to humans. Epidemiological research has linked increased risks of cancer, including non-Hodgkin lymphoma, leukaemia, prostate, breast, and lung cancers. The occupational and environmental exposure to certain pesticide classes, such as carbamates, organochlorines, organophosphates, and herbicides like glyphosate, can cause various types of cancer. Experimental studies have further demonstrated various carcinogenicity pathways, including genotoxicity, oxidative stress, endocrine disruption, and epigenetic modifications. Certain pesticides have been categorized as actual or potential human carcinogens by regulatory agencies, such as the International Agency for Research on Cancer (IARC), highlighting the need to reevaluate their safety. However, there are still unanswered questions about cumulative exposures, synergistic effects, and long-term dangers in susceptible groups. In addition to highlighting mechanistic insights from toxicological studies, this review summarises the most recent data on the carcinogenic risk of commonly used herbicides and insecticides and suggests important areas that need further investigation. Regulatory policy, public health protection, and the creation of safer agricultural methods all depend on a better knowledge of the cancer risks associated with pesticides.

Keywords: Carcinogenic pesticides, Insecticides, Cancer risk.

INTRODUCTION

Modern agriculture has benefited greatly from the widespread use of insecticides and pesticides, which increase crop production and provide pest protection. But their possible health risks, especially their carcinogenic effects, have raised severe worries across the world (Alavanja *et al.*, 2013). Pesticide exposure is strongly linked to malignancies such as non-Hodgkin lymphoma, leukaemia, prostate, breast, and lung cancers. Pesticide exposure is strongly linked to malignancies such as non-Hodgkin lymphoma, leukaemia, prostate, breast, and lung cancers (Koutros *et al.*, 2020). Among the most vulnerable groups are farmers, agricultural labourers, and those who live close to agricultural areas because of ongoing environmental and occupational exposures. (WHO, 2020).

The processes by which pesticides cause cancer have been clarified by experimental research. These include oxidative stress, endocrine disruption, genotoxicity, and epigenetic changes, all of which have the potential to cause or accelerate the development of cancer (Mostafalou & Abdollahi, 2017). Herbicides, including glyphosate, carbamates, organochlorines, and organophosphates, are among the major pesticide types linked to carcinogenicity. The International Agency for Research on Cancer (IARC) and other regulatory agencies have identified several pesticides as likely or suspected human carcinogens, highlighting the need to review their safety regulations (IARC, 2018).

Despite the strong data, significant knowledge gaps remain. Further research is necessary to comprehend the long-term risks to vulnerable populations, the cumulative and synergistic effects of combined pesticide exposure, and the persistence of pesticide residues in ecosystems (Mostafalou & Abdollahi, 2017). In addition to protecting public health and regulating policy, a better knowledge of these dangers is crucial for directing the shift to safer farming methods (WHO, 2020). The purpose of this review is to summarise the available data about the carcinogenic risk of pesticides and insecticides, point out molecular pathways, and determine research priorities for next investigations.

CLASSIFICATION OF CANCER-CAUSING PESTICIDE:

Many of the chemical classes that pesticides are a part of have been linked to possible human cancer. Some pesticides and herbicides have been categorized as potential, likely, or known human carcinogens by regulatory bodies, including the World Health Organization (WHO) and the International Agency for Research on Cancer (IARC, 2018). Herbicides based on glyphosate, carbamates, organochlorines, and organophosphates are the most pertinent classes.

Organochlorines: Pesticides that include organochlorines, including aldrin and dichlorodiphenyltrichloroethane (DDT), are persistent organic pollutants that bioaccumulate in human tissues and the environment. Lymphoma, liver cancer, and breast cancer have all been related to prolonged exposure (Beard *et al.*, 2013). Given this environmental stability, residues continue to exist even after being banned in many nations. DDT is still produced and used under strict government regulation for public health purposes, especially in

vector-borne disease management programs like malaria control, even though it is prohibited for use in agriculture in India (Government of India, 2011; NVBDCP, MoHFW, n.d.). The Stockholm Convention's exclusions for disease vector control allow India to continue using DDT (Stockholm Convention Secretariat, 2001). However, despite legal limitations, worries about environmental persistence, dangers to human health, and cases of unlawful distribution still exist (Down To Earth, 2018; New Indian Express, 2024).

Organophosphates: In agriculture, organophosphate pesticides, such as diazinon and malathion, are frequently utilised. Associations between leukaemia and non-Hodgkin lymphoma are suggested by epidemiological research. Malathion and diazinon have been categorized by the IARC as likely carcinogenic to humans (Group 2A) (IARC, 2017, 2018).

Carbamates: Studies on animals have shown that carbamate insecticides, such as carbaryl, can be genotoxic and affect hormones (Mostafalou & Abdollahi, 2017). Human data is less clear, although they are still being studied for carcinogenicity, especially in relation to occupational exposure.

Glyphosate: The most used herbicide in the world, glyphosate, has been the subject of heated scientific discussion. Based on adequate evidence in animals and little evidence in people, especially for non-Hodgkin lymphoma, the IARC categorized glyphosate as probably carcinogenic to humans (IARC, 2018). Regulatory discrepancies are highlighted by the fact that other organizations, including the US EPA, have not recognized any obvious carcinogenic danger (Koutros *et al.*, 2020).

Mechanisms of Carcinogenicity:

Insecticides and pesticides cause cancer via a variety of biological mechanisms. Molecular biology research and experimental toxicology have shown several ways in which these substances might cause or worsen cancer.

Genotoxicity: In direct contact with DNA, pesticides can cause chromosomal abnormalities, strand breakage, and mutations. In animal and human lymphocyte experiments, for instance, it has been demonstrated that organophosphate pesticides like

malathion and diazinon harm DNA (IARC, 2018). DDT and other persistent organochlorines have also been connected to mutagenic activity in lab animals (Mostafalou & Abdollahi, 2017).

Oxidative Stress: Reactive oxygen species (ROS) are produced in excess by a number of pesticides, upsetting the redox balance of cells. Lipids, proteins, and nucleic acids may all be harmed by this oxidative stress, which can then set off signalling pathways that cause cancer. It has been demonstrated that glyphosate and carbamates induce oxidative stress in cells that are exposed (Guyton *et al.*, 2015).

Endocrine Disruption: As endocrine-disrupting chemicals (EDCs), certain pesticides imitate or inhibit hormone signalling. DDT and other organochlorines have estrogenic properties, which may be a factor in breast and reproductive malignancies (Diamanti-Kandarakis *et al.*, 2009). When it comes to vulnerable groups like children and expectant mothers, endocrine disruption is especially troubling.

Epigenetic Modifications: According to new research, pesticides may modify gene expression through processes including DNA methylation, histone modification, and microRNA control without altering the DNA sequence. These epigenetic modifications can activate oncogenes or silence tumour-suppressor genes, which contribute to the development and spread of cancer (Hou *et al.*, 2012).

Immunotoxicity and Chronic Inflammation: The immune system's capacity to identify and eradicate cancer cells can be compromised by long-term pesticide exposure. Furthermore, a tumour-promoting microenvironment may be created by inflammatory reactions triggered by chemical residues (Mostafalou & Abdollahi, 2017).

CONCLUSION

According to recent research, several widely used pesticides and insecticides have significant cancer hazards. Exposures are linked to cancers such as non-Hodgkin lymphoma, leukaemia, and hormone-related malignancies, particularly among agricultural workers and surrounding communities, according to epidemiological and experimental research. Mechanistic evidence demonstrating that pesticides can cause oxidative stress, endocrine disruption, DNA

damage, and other cancer-promoting pathways supports these conclusions. However, there are still significant unknowns about long-term low-dose effects, dangers to vulnerable populations, and cumulative and mixed exposures. Reducing the incidence of pesticide-related cancer requires strengthening regulations, enhancing monitoring systems, and encouraging safer agricultural alternatives. To clarify unsolved dangers and direct evidence-based public health protections, further study is required.

Conflict of interest

The authors declare no competing interests.

Data Availability Statement: Not applicable.

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