

**STRUCTURAL AND FUNCTIONAL CHANGES IN LYMPHOID ORGANS
AND PERIPHERAL BLOOD UNDER THE INFLUENCE OF HERBICIDES**

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Abstract: Herbicides are widely used in modern agriculture to control weeds and improve crop productivity. However, their excessive, prolonged, or improper use may cause adverse effects on living organisms, particularly on the immune and hematopoietic systems. Lymphoid organs, including the spleen, thymus, and lymph nodes, play a crucial role in immune defense, while peripheral blood reflects the functional state of the hematopoietic and immune systems. Exposure to herbicides may lead to morphological changes in lymphoid tissues, alterations in lymphocyte populations, disturbances in leukocyte counts, and changes in erythrocyte and platelet parameters. These effects may impair immune responses and disrupt the normal physiological balance of the organism. This article focuses on the structural and functional alterations in lymphoid organs and peripheral blood associated with herbicide exposure. Understanding these changes is important for evaluating the potential toxicological effects of herbicides and their implications for human and animal health.

Keywords: herbicides, lymphoid organs, peripheral blood, immune system, hematopoietic system, lymphocytes, leukocytes, hematotoxicity, immunotoxicity, morphological changes.

INTRODUCTION

The widespread use of herbicides in modern agriculture has become an important component of crop protection and weed management. These chemical compounds help improve agricultural productivity by controlling unwanted vegetation and reducing crop losses. However, their intensive and improper application has raised concerns

regarding their potential toxic effects on living organisms and the environment. Depending on their chemical composition, concentration, exposure duration, and route of entry into the body, herbicides may produce various biological effects, including disturbances in cellular metabolism, immune responses, and hematopoietic processes. The immune system plays a fundamental role in maintaining physiological homeostasis and protecting the organism against infectious agents and other harmful factors. Lymphoid organs, particularly the thymus, spleen, and lymph nodes, are essential components of this system. They are involved in lymphocyte development, differentiation, proliferation, and immune response regulation. Exposure to toxic chemical substances may alter the structural organization of these organs, affect lymphoid cell populations, and interfere with their normal functional activity. Such changes may reduce the effectiveness of immune defense and increase the organism's susceptibility to various pathological conditions.

Peripheral blood is another important indicator of the physiological condition of the organism and its response to toxic exposure. Changes in erythrocyte and leukocyte counts, hemoglobin concentration, platelet levels, and leukocyte distribution may reflect disturbances in hematopoiesis, inflammation, or immune regulation. Certain herbicides and their metabolites may influence these parameters through different mechanisms, including oxidative stress, cellular membrane damage, and alterations in metabolic processes. Nevertheless, the nature and severity of these effects depend on the specific herbicide, its dose, exposure duration, and the biological characteristics of the exposed organism. The study of structural and functional changes in lymphoid organs and peripheral blood is therefore important for understanding the potential immunotoxic and hematotoxic effects of herbicides. A comprehensive assessment of these changes can provide valuable information about the biological consequences of herbicide exposure and support the development of appropriate preventive measures. The aim of this article is to examine the potential structural and functional changes in lymphoid organs and peripheral blood under the influence of herbicides, with particular attention to alterations in lymphoid tissue morphology, immune cell populations, and

hematological

parameters.

MATERIALS AND METHODS

This article is based on a review and analysis of scientific literature concerning the toxicological effects of herbicides on lymphoid organs and peripheral blood. Relevant scientific publications were examined to identify the potential morphological, hematological, and immunological alterations associated with herbicide exposure. The literature review focused on studies investigating the effects of herbicides on the spleen, thymus, and lymph nodes, as well as changes in peripheral blood parameters. Particular attention was given to alterations in lymphocyte populations, total leukocyte counts, erythrocyte counts, hemoglobin concentration, and platelet levels. Studies examining oxidative stress, cellular damage, inflammatory responses, and immunotoxic mechanisms were also considered.

Scientific information was analyzed using a comparative approach to identify similarities and differences in the reported biological effects of various herbicides. The findings were interpreted in relation to the chemical composition of the herbicides, exposure concentration, duration of exposure, and experimental conditions. Where available, morphological observations of lymphoid tissues were considered alongside hematological and immunological indicators to provide a more comprehensive understanding of potential toxic effects. The methodological approach emphasized the relationship between structural alterations in lymphoid organs and functional changes in the immune and hematopoietic systems. Particular consideration was given to the limitations of existing evidence, including differences in study design, experimental models, exposure conditions, and the specific herbicides investigated. As this article is designed as a literature-based review, no new animal experiments, clinical examinations, or laboratory measurements were conducted. Therefore, the discussion of biological effects is based on previously published scientific evidence rather than newly generated experimental data.

RESULTS

The analysis of scientific literature indicates that exposure to certain herbicides may be associated with structural and functional alterations in lymphoid organs and changes in peripheral blood parameters. The severity and nature of these effects depend on the chemical composition of the herbicide, exposure concentration, duration, and biological characteristics of the exposed organism. The available evidence suggests that the immune and hematopoietic systems may be important targets of herbicide-induced toxicity. **Structural Changes in Lymphoid Organs** .The spleen, thymus, and lymph nodes are essential components of the immune system. According to experimental studies, exposure to certain herbicides may induce morphological alterations in lymphoid tissues. These changes can include disturbances in tissue architecture, alterations in lymphocyte distribution, and signs of cellular degeneration. Such findings suggest that exposure to some herbicides may interfere with the normal structural organization of immune organs. The spleen is particularly important because it filters peripheral blood, removes damaged blood cells, and participates in immune responses. Experimental research on paraquat, a toxic herbicide, has demonstrated oxidative stress-related injury and cellular changes in splenic tissue. These findings indicate that oxidative damage may contribute to herbicide-associated alterations in lymphoid organs. However, these effects should not be generalized to all herbicides. Different active substances may produce different biological responses, and the extent of tissue damage depends on the exposure conditions.

Changes in Peripheral Blood Parameters Peripheral blood parameters are important indicators of the body's response to potentially toxic substances. The scientific literature identifies erythrocyte count, hemoglobin concentration, total leukocyte count, leukocyte distribution, and platelet count as relevant indicators for evaluating possible hematological effects. Exposure to certain herbicides may be associated with alterations in these parameters. Changes in leukocyte counts or lymphocyte populations may indicate disturbances in immune regulation, whereas changes in erythrocyte and hemoglobin levels may reflect effects on oxygen transport or hematopoietic processes. Platelet alterations may also be relevant when assessing

possible effects on blood cell production and hemostasis. Nevertheless, the direction and magnitude of these changes are not uniform across all herbicides. Some studies report cellular injury or immune modulation, while the available evidence does not establish a consistent pattern of hematological changes for every herbicide or exposure condition. Therefore, these parameters should be interpreted in relation to the specific chemical compound, dose, duration of exposure, and other relevant factors.

Functional Alterations in the Immune System. The structural integrity of lymphoid organs is closely related to their physiological function. Changes in lymphocyte populations, immune cell maturation, and cellular activity may influence the organism's ability to respond to infectious agents and other immune challenges. Research on pesticide-associated immunotoxicity, including the effects of herbicides, has identified histopathological changes in immune tissues, alterations in immunocompetent cell populations, and potential disturbances in immune function. These findings support the importance of evaluating both morphological and functional indicators when investigating the biological effects of chemical exposure. Oxidative stress is one potential mechanism underlying these effects. An imbalance between the production of reactive oxygen species and the body's antioxidant defenses may damage cellular structures and contribute to inflammatory responses or programmed cell death. Experimental findings involving paraquat provide evidence that oxidative mechanisms may participate in herbicide-induced splenic injury.

Summary of the Main Findings. The literature analysis highlights three major areas of potential herbicide-associated effects:

1. Lymphoid organs: possible morphological alterations and disturbances in the structural organization of immune tissues.
2. Peripheral blood: potential changes in hematological parameters, including erythrocyte, leukocyte, lymphocyte, hemoglobin, and platelet indicators.
3. Immune function: possible alterations in immune cell populations and cellular processes associated with immune regulation. Overall, the available scientific evidence

indicates that certain herbicides may affect the structural integrity of lymphoid organs and the functional state of the immune and hematopoietic systems. However, the effects vary according to the active substance and exposure conditions. Further standardized experimental and clinical research is needed to clarify the mechanisms involved and determine the relevance of these findings to human health.

DISCUSSION

The findings of the reviewed scientific literature indicate that certain herbicides may adversely affect the immune and hematopoietic systems by inducing structural changes in lymphoid organs and functional disturbances in peripheral blood. These effects are associated with several biological mechanisms, including oxidative stress, mitochondrial dysfunction, inflammatory responses, and apoptosis. However, the severity of these alterations varies depending on the chemical properties of the herbicide, the dose, the duration of exposure, and the biological characteristics of the organism.

One of the most important mechanisms underlying herbicide-induced toxicity is oxidative stress. Sengupta et al. (2017) demonstrated that paraquat exposure in mice induced oxidative damage in splenic tissue, increased the production of reactive oxygen species, reduced antioxidant defense activity, and promoted apoptosis and inflammatory responses. The study also reported increased expression of pro-inflammatory markers, including TNF- α and IL-6. These findings suggest that oxidative stress may play a central role in the disruption of lymphoid tissue integrity and immune regulation. The spleen is particularly important in this context because it filters peripheral blood, removes damaged erythrocytes, and participates in immune responses through the activity of lymphocytes and macrophages. Oxidative damage to splenic cells may therefore affect both the structural organization of the organ and its immunological functions. Nevertheless, the findings obtained with paraquat should not automatically be generalized to all herbicides, as different compounds may act through distinct toxicological pathways. Changes in peripheral blood and immune cells represent another important aspect of herbicide-associated toxicity. A study published

in 2022 investigated paraquat-induced oxidative stress, DNA damage, and cytotoxicity in peripheral lymphocytes in rats. The researchers observed oxidative damage and DNA alterations in lymphocytes, indicating that paraquat can affect immune cells directly. These findings support the importance of examining cellular integrity alongside conventional hematological parameters when evaluating the potential toxic effects of herbicides.

The possible relationship between lymphoid tissue alterations and peripheral blood changes deserves particular attention. Lymphoid organs provide the environment necessary for the development, maturation, and activation of immune cells, whereas peripheral blood reflects changes in circulating cell populations. Consequently, disturbances in lymphoid tissue structure may occur alongside alterations in immune cell function. However, a direct causal relationship between specific histological changes and particular blood parameters cannot be established without appropriately designed experimental studies. Inflammation and apoptosis may further contribute to herbicide-induced cellular injury. Excessive production of reactive oxygen species can damage cellular membranes, proteins, and nucleic acids, while mitochondrial dysfunction may activate pathways leading to programmed cell death. Inflammatory mediators may amplify tissue injury and interfere with normal cellular functions. A review by Chen et al. (2021) similarly highlighted oxidative stress, cytotoxicity, and inflammatory responses as important mechanisms involved in paraquat toxicity. Despite these findings, several limitations must be considered when interpreting the available evidence. First, much of the mechanistic research has been conducted using experimental animals or isolated cells, and the results may not directly reflect the effects of environmental or occupational exposure in humans. Second, differences in herbicide formulations, exposure concentrations, treatment duration, and experimental methods complicate comparisons between studies. Third, evidence concerning paraquat cannot be considered representative of all herbicides because their chemical structures and biological mechanisms differ.

Further research should therefore investigate a wider range of herbicides using

standardized experimental protocols. Combined assessment of lymphoid organ histology, complete blood count, lymphocyte subpopulations, oxidative stress markers, and inflammatory mediators could provide a more comprehensive understanding of their potential biological effects. Longitudinal studies and well-designed epidemiological investigations would also help clarify the relevance of experimental findings to human health. Overall, the available literature supports the hypothesis that certain herbicides may affect lymphoid organs and peripheral blood through interconnected oxidative, inflammatory, and cytotoxic mechanisms. However, the extent of these effects and their clinical significance depend on the specific compound and exposure conditions. Further investigations are necessary to establish reliable exposure–response relationships and to determine the long-term implications for immune and hematopoietic health.

CONCLUSION

The analysis of scientific literature indicates that exposure to certain herbicides may cause structural and functional disturbances in lymphoid organs and peripheral blood. The spleen, thymus, and lymph nodes are important components of the immune system, and their structural integrity is essential for maintaining normal immune responses. Experimental studies have demonstrated that certain herbicides, particularly paraquat, may induce oxidative stress, inflammatory reactions, cellular damage, and apoptosis in immune tissues. Changes in peripheral lymphocytes and other hematological indicators may provide important information about the potential effects of herbicides on immune and hematopoietic functions. Oxidative stress appears to be one of the major mechanisms involved in herbicide-induced cellular injury. However, the nature and severity of these effects depend on the chemical composition of the herbicide, exposure concentration, duration, and biological characteristics of the organism. It is important to emphasize that the effects observed with one herbicide cannot be generalized to all herbicidal compounds. Further experimental and epidemiological studies are required to clarify the mechanisms of toxicity, establish dose–response relationships, and assess the long-term implications of herbicide

exposure for human and animal health. Comprehensive evaluation of lymphoid tissue morphology, peripheral blood parameters, and immunological indicators may contribute to improved toxicological assessment and the development of effective preventive measures.

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