

Estrogenic disruption by pesticides exposure associated with breast cancer:a systematic review focusing on epigenetic mechanisms

Abstract:

Breast cancer (BC) has been highlighted worldwide in view of its high prevalence. There are several risk factors that can be associated with the occurrence of BC, such as reproductive aspects, genetic mutations and family history. In this sense, lifestyle and environmental conditions may also be relevant - factors that are related to environmental contamination by pesticides, which in Brazil stands out, given the high consumption rates, therefore, exposure of the population. Since some types of BC associate themselves to the positive regulation of ERs, being sensitive to certain pesticides, it is valid to assume the existence, thus, an epigenetic association between cases. Thus, through a systematic review of the literature of studies reporting pesticides that alter estrogenic expression and activity and establish a risk for BC, focusing on epigenetic mechanisms. Descriptors were used and inclusion and exclusion criteria were established, so that 195 articles were found, and 3 were selected by the criteria. It is evident the existence of a relationship between estrogenic regulation and activity according to mechanisms that interfere in the expression of associated control genes, and the set of these factors is determinant for the increased risk of developing BC. However, the epigenetic genetic mechanisms described, associated with BC, are not standardized, and further research in the area is necessary in order to delineate more clearly the epigenetic aspects that permeate the disease.

Keywords: pesticides; estrogen; breast cancer; epigenetic.

Introduction

According to the World Health Organization (WHO), by 2020 “there were 2.3 million women diagnosed with breast cancer (BC) worldwide, making it the most prevalent cancer in the world. BC occurs in all countries in women of any age after puberty, but with increasing rates in adulthood”.

Several risk factors are related to BC, including reproductive aspects, genetic mutations, and family history, for example. In addition, lifestyle and environmental and/or occupational conditions may be important in this context. The International Agency for Research on Cancer (IARC) has evaluated the carcinogenicity of numerous

substances that can possibly cause BC, however, there is still insufficient evidence data, so research in this field is encouraged (IARC, 2010; FENGA, 2016).

Environmental contamination by pesticides is a global concern, especially in Brazil, one of the largest consumers of pesticides (PANIS et al., 2022a). The uncontrolled use of pesticides can cause large-scale contamination and spread to various sources that will be consumed by the population, an example of this is the presence of pesticide residues classified as persistent organic pollutants in drinking water (EPA, 2021).

Consequences of this long-term exposure have an impact on human health, especially in cases of cancer (PANIS et al., 2022b). According to Ledda et al (2021), pesticide exposure may contribute to the risk of BC, especially in young women and those who had early menarche. This can be explained by the fact that some types of BC are associated with positivity for estrogen receptors (ERs) and the estrogenic activity presented by certain pesticides, such as organochlorines.

Several sources of excess estrogen have been related to the development of BC and knowing that cancer is not only a genetic disease but also an epigenetic one, that epigenetic mechanisms regulate different aspects of cancer biology and that endocrine disruptions of estrogen levels may be caused by modifications of the epigenome, it is understood that there is a relation between pesticides that disrupt this environment and the risk of developing BC (GARCIA-MARTINEZ et al 2021; HILL & HODSON, 2014). In this context, the emerging field of epigenetics may be a promising way to establish the pathophysiological basis of this relation.

Thus, the aim of this study was to conduct a systematic literature review of studies reporting pesticides altering estrogenic expression and activity, and establishing a risk to BC, with a focus on epigenetic mechanisms.

Method

Protocol

Review protocol the systematic review followed the *Preferred Reporting Items for Systematic Reviews and Meta-Analyses* (PRISMA) protocol, 2020.

Literature search

Science Direct and *PubMed* was used to perform the search (February 24th, 2023). The descriptors applied were “epigenetic”, “breast cancer”, “estrogen” and “pesticide”. Then, some filters were selected: English language, type of document

(article), no year restriction. The studies were pre-selected by reading their titles and abstracts and separated for further analysis and extraction of data.

Inclusion and exclusion criteria

Inclusion criteria: studies with complete data and statistical results that observed epigenetic effects caused by exposure to different pesticides and resulted in estrogenic disruption, increasing the risk of developing BC.

Exclusion criteria: review studies, meta-analyses, commentaries, studies that contained incomplete data and/or data outside the context of the study purpose.

Biases

The possible biases were analyzed according to the limitations of each study, such as sample size, statistics of the results and the parameters involved.

Results

In total, this search found 195 published works, of which 3 were selected according to the eligibility criteria, as detailed in figure 1. Three evaluators carried out the selection process of studies for review and those underwent a screening in two phases: initially, the studies were sorted by titles and abstracts and, if they were considered potentially relevant, these were moved to a later stage in which the full articles were selected for data extraction (presented in table 1).

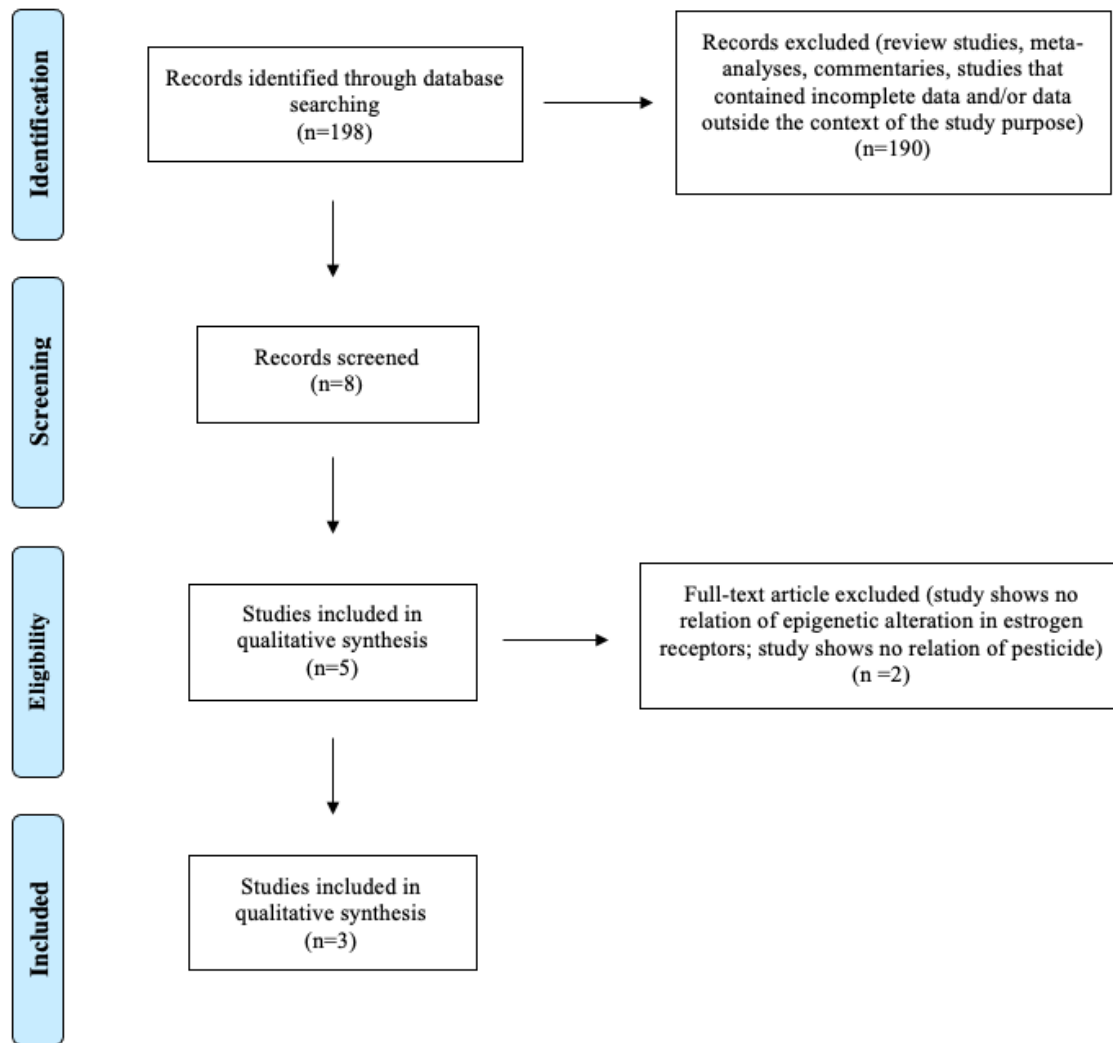


Figure 1 - Flowchart of the selection of studies adapted from PRISMA.

Table 1 - Data extracted from the selected studies

Authors	Aims	Results
Lorenz et al (2019)	Analysis of perinatal exposure to a glyphosate-based herbicide (GBH) on the expression of the ER α uterine gene in an animal model	<ul style="list-style-type: none"> GBH positively regulates the expression of total ERα mRNA, increasing the expression of the transcript variant of ERα-O
Ghosh et al (2018)	Analysis of the potential of α -Endosulfan in the modulation of multiple epigenetic enzymes in MCF-7 cells	<ul style="list-style-type: none"> α-Endosulfan significantly promotes the viability of MCF-7 cells Positively regulates the expression of DNMTs (DNA methyltransferases) Initially affects the global methylation status of DNA (subsequently recovered) Increases total intracellular activity of HDAC (histone deacetylase) Modulates expression and activity of arginine and lysine methylation enzymes (arginine methyltransferase 5 - PRMT5 and Enhancer of Zeste homologous 2 - EZH2) Increases the expression of histones H3 and H4, trimethylation of H3K27 (product of

		<p>EZH2) and dimethylation and H4R3 (product of PRMT5)</p> <ul style="list-style-type: none"> ▪ Increases the expression of five unidentified proteins whose arginine residues are dimethylated symmetrically (by increasing the level of PRMT5) ▪ Induces overexpression of the baseline level of the ERα receptor
Zou, Matsumura (2003)	Analysis of the impact of long-term in vitro exposure to α -HCH (α -hexachlorocyclohexano) in the transformation and metastatic potentials of MCF-7 cells	<ul style="list-style-type: none"> ▪ α-HCH increases the trend of transformation and invasion capacity ▪ Induces biochemical changes related to transformation in MCF-7 cells, such as a decline in ERα and P44/42 MAP kinase levels and a significant increase in the expression of c-ErbB2 and MMP-9 (matrix metalloproteinase 9) levels

Discussion and conclusion

This review is based on estrogen disruption by pesticide exposure associated with BC, focusing on epigenetic mechanisms. According to Hervouet et al (2013), estrogen signaling is mediated by ER α and ER β in hormone receptor positive BC, and during the last decade, epigenetic pathways have been related to tumorigenesis, such as modifications in gene expression regulation and chromosomal instability. In this study, the results of 3 studies are presented that showed that pesticide exposure affects estrogen regulation and activity, possibly constituting a risk for BC development.

In the study of Lorenz et al (2019) it was found that rats exposed to glyphosate-based herbicide (GBH) demonstrated higher levels of mRNA of the ER α -O variant than those of the control group, in the pre-implantation period, so that the results obtained are suggestive that specific activation of the promoter ER α -O in rats exposed to GBH may be related to the induction of ER α expression. In this sense, epigenetic mechanisms were investigated in order to elucidate which mechanisms would be associated with this induction of such that, since the DNA methylation status of the ER α -promoting regions and the corresponding ER α expression levels, when altered in addition to the normal changes that occur throughout development, may alter the expression of ER α pathologically. Therefore, the study demonstrated a decreased methylation state at the BstUI-site1 in the promoter ER α -O that correlates to higher levels of mRNA of ER α in rats exposed to GBH, suggesting that changes in the DNA methylation level of the promoter region of ER α is an epigenetic mechanism sensitive to environmental factors, especially in early life. In addition, the authors also identified a hypomethylated site in the group exposed to GBH, a potential binding site for transcription factors E2F-1 and

E47, which may also participate in the positive regulation of transcription of ER α in rats exposed to GBH. Also, findings related to histone changes with post-translational modifications in the GBH-induced ER α -O promoter could explain the increased expression of the ER α gene.

Furthermore, Ghosh et al (2018) investigated “the potential of α -Endosulfan in modulating multiple epigenetic enzymes in MCF-7 cells (breast cancer cell line), it was shown that α -Endosulfan at 1 and 10 μ M concentration significantly promoted the viability of MCF-7 cells, the expression of DNA methyltransferases was positively regulated, while the overall DNA methylation status was initially affected but later recovered. The total intracellular HDAC (histone deacetylase) activity was significantly increased (positive regulation of HDAC1), the expression and activity of arginine and lysine methylation enzymes, arginine protein methyltransferase 5 and Enhancer of Zeste homolog 2 were also modulated, in addition, increased expression of histones H3 and H4, trimethylated H3K27, the symmetric dimethylation of H4R3 and overexpression of the basal level of ER α were observed”.

In addition to the other effects observed, the two studies indicate that the different types of pesticides studied can interfere with the regulation of estrogen expression, reflecting on its activity, but in different aspects. In the review by Rossetti et al (2021), in relation to GBHs only, it was concluded that abnormal mammary gland growth after exposure to GBHs may occur, in part, due to aberrant DNA methylation and differences in the methylation pattern of histones. Furthermore, these changes may occur even after exposure has ceased, indicating that these effects may manifest themselves over the long term.

In contrast, Mesnage et al (2017) reports that GBHs activate ER α in breast cancer cells, but only at high concentrations, suggesting exposure would not result in ER activation at typical exposure levels. However, the study did not discuss epigenetic mechanisms and the clinical relevance justifies further investigation due also to the sum of different environmental estrogenic sources.

Finally, in the study by Zou and Matsumura (2003) “the impact of long-term *in vitro* exposure to β -HCH on cell transformation and metastatic potentials of MCF-7 cells was analyzed. Continuous exposure of MCF-7 cells to β -HCH at 100 nM and 1 μ M or to 17 β -estradiol at 1 nM for up to 13 months not only increased their transformation tendencies, but also promoted their invasion capacity. β -HCH induced transformation-related changes in MCF-7 cells, such as a decline in ER α and p44/42

MAP kinase levels and a significant increase in the expression of c-ErbB2 and MMP-9 levels. In contrast, long-term treatment with 17 β -estradiol resulted in negative regulation of ER α and p44/42 MAP kinase and positive regulation of MMP-9 only, but no changes in c-ErbB2. Such results indicate that these changes may be related to the phenotypic expression of transformed cells in BC and support the hypothesis that exposure to β -HCH is epigenetically related to progression of BC cells to an advanced stage of malignancy”.

The limitations of this review are related to the few studies available in the literature that aimed to establish a relation between these changes and epigenetic mechanisms, making clear the importance of conducting studies in this context with a design focused on the investigation of epigenetic changes involved in this process.

Perspectives

Few publications have described the epigenetic mechanisms involved in this context, however, the results of the studies analyzed and presented in this review demonstrate that there is a relationship between estrogenic regulation and activity according to mechanisms that interfere with the expression of associated control genes, and the set of these factors is crucial to the increased risk of developing BC. Thus, it is necessary that studies be carried out in a more directed way, so that it is possible to clarify and better characterize the epigenetic mechanistic associated with BC. Still, it is clear the need for further research in the area, in order to more clearly delineate the epigenetic aspects, since all studies included in this review approached the same theme from a different perspective.

References

^aPanis C, Kawassaki ACB, Crestani APJ et al. (2022). Evidence on human exposure to pesticides and the occurrence of health hazards in the Brazilian population: a systematic review. *Frontiers in public health*, 2210.

^bPanis C, Candiottto Lzp, Gaboardi SC et al. (2022). Widespread pesticide contamination of drinking water and impact on cancer risk in Brazil. *Environment International*, 107321.

EPA, 2021. Environmental Protection Agency of the United States. Persistent Organic Pollutants: A Global Issue, A Global Response. Available at: <https://www.epa.gov/international-cooperation/persistent-organic-pollutants-global-issue-global-response>.

Fenga C. (2016). Occupational exposure and risk of breast cancer. *Biomedical reports*, 4(3), 282–292.

Garcia-Martinez L, Zhang Y, Nakata, Y et al. (2021). Epigenetic mechanisms in breast cancer therapy and resistance. *Nature Communications*, 12:1786.

Ghosh K, Chatterjee B, Jayaprasad AG & Kanade, SR (2018). The persistent organochlorine pesticide endosulfan modulates multiple epigenetic regulators with oncogenic potential in MCF-7 cells. *The Science of the total environment*, 624, 1612–1622.

Hervouet E, Cartron PF, Jouvenot M & Delage-Mourroux R (2013). Epigenetic regulation of estrogen signaling in breast cancer. *Epigenetics*, 8(3), 237–245. <https://doi.org/10.4161/epi.23790>

Hill J & Hodsdon W (2014). In utero exposure and breast cancer development: an epigenetic perspective. *Journal of Environmental Pathology, Toxicology and Oncology*, 33(3).

International Agency for Research on Cancer. (2010). *Painting, firefighting, and shiftwork* (Vol. 98). IARC Press, International Agency for Research on Cancer.

Ledda C, Bracci M, Lovreglio P et al. (2021). Pesticide exposure and gender discrepancy in breast cancer. *Eur Rev Med Pharmacol Sci*, 25(7), 2898-2915.

Mesnage R, Phedonos A, Biserni M et al. (2017). Evaluation of estrogen receptor alpha activation by glyphosate-based herbicide constituents. *Food and chemical toxicology : an international journal published for the British Industrial Biological Research Association*, 108(Pt A), 30–42.

Rossetti MF, Canesini G, Lorenz V et al. (2021). Epigenetic Changes Associated With Exposure to Glyphosate-Based Herbicides in Mammals. *Frontiers in endocrinology*, 12, 671991. <https://doi.org/10.3389/fendo.2021.671991>

World Health Organization, 2022: Breast Cancer – Patient Version. Available at <https://www.who.int/news-room/fact-sheets/detail/breast-cancer>.