

ZIBELINE INTERNATIONAL™
PUBLISHING

ISSN: 2521-0858 (Print)

ISSN: 2521-0866 (Online)

CODEN: SHJCAS



REVIEW ARTICLE

ENDOCRINE-DISRUPTING ACARICIDES: A SILENT THREAT TO HEALTH AND THE ENVIRONMENT IN THE TROPICS

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ARTICLE DETAILS

Article History:

Received 17 June 2024

Revised 24 July 2025

Accepted 22 August 2025

Available online 02 September 2025

ABSTRACT

Acaricides with endocrine-disrupting effects represent an overlooked yet significant environmental and human health threat in tropical regions. These pesticides, including organophosphates, pyrethroids, and amitraz extensively used to control tick and mite infestations, pose considerable risks due to their potential to act as endocrine-disrupting chemicals (EDCs). They can interfere with endocrine function by binding to hormone receptors, disrupting hormone synthesis, and inhibiting key enzymatic pathways. The interference with endocrine function is associated with adverse outcomes in humans and wildlife, particularly aquatic ecosystems. The disruptions include reproductive and developmental abnormalities, immune suppression, population declines, and ecological imbalances. Chronic exposure is further associated with thyroid dysfunction and an increased risk of hormone-related cancers. In tropical environments, where acaricide application is intensive due to the high ectoparasite population, the risks are compounded by weak regulatory frameworks and inadequate environmental monitoring. This paper highlights the urgent need for the promotion of eco-friendly alternatives such as biopesticides, and the implementation of integrated pest management strategies. In conclusion, without timely and coordinated interventions, endocrine-disrupting acaricides will continue to pose an escalating threat to human health and biodiversity across tropical ecosystems.

KEYWORDS

Acaricides, Endocrine-disrupting Chemicals (EDCs), Endocrine-disrupting acaricides (EDAs), Environmental impact of acaricides, Organophosphates, Pyrethroids, Amitraz

1. INTRODUCTION

Acaricides are pesticides used in controlling ticks and mites, which transmit vector-borne diseases affecting livestock and humans. In tropical climates, the warm and humid conditions favour the life cycle of ticks and mites. As a result, the favourable climatic conditions in the tropics necessitate frequent use of acaricides to control tick-borne diseases (Deborah et al., 2022; Makwarela et al., 2025). Therefore, the favourable conditions for tick and mite reproduction in the tropics make acaricides like organophosphates, pyrethroids, and amitraz indispensable for pest management (Deborah et al., 2022; Wang et al., 2023). However, increasing dependence on these chemicals raises significant concerns about their potential as endocrine-disrupting chemicals (EDCs). EDCs are chemicals that mimic, block, or interfere with the normal hormones functioning in the body. As a result, they have been implicated in disrupting hormonal signalling pathways, leading to reproductive dysfunction, immune suppression, and an elevated risk of hormone-related cancers (Ahmad et al., 2024; Fagundes et al., 2024).

The extensive use of acaricides in tropical regions makes these areas particularly vulnerable to the harmful effects of endocrine-disrupting acaricides. The toxicity of these chemicals extends beyond human health, affecting wildlife populations and disrupting ecosystems. For instance, studies have shown that these chemicals can accumulate in water bodies, leading to endocrine-related reproductive issues in aquatic organisms and bioaccumulation in the food chain (Zaller and Zaller, 2020; Leskovac and Petrović, 2023). Despite mounting evidence of their adverse effects, regulatory frameworks in many tropical countries remain inadequate to

address their widespread adverse effects and continued use (Stadlinger et al., 2013; Lahr et al., 2016; Kosamu et al., 2020). The contributing factors for widespread uses include limited awareness of the risks, weak enforcement of pesticide regulations and a lack of viable alternatives (Deborah et al., 2022; Stadlinger et al., 2013; Mollong et al., 2025).

Regulatory gaps in many tropical countries highlight the urgent need for stronger policies to address the risks of acaricides with endocrine-disrupting effects. Weak legislation and outdated pesticide regulations in regions like Africa and Southeast Asia allow the continued use of hazardous chemicals leading to environmental contamination and public health concerns (Stadlinger et al., 2013; Lahr et al., 2016; Kosamu et al., 2020; Kumar and Reddy, 2024). Similarly, the current risk assessments often fail to capture the full complexity of the endocrine disruption effects of acaricides. For example, the most common laboratory tests for acaricide like other pesticide exposure are measurements of enzyme activity levels, which indicate exposure or poisoning pesticides (Garabrant et al., 2009; Wicaksono et al., 2023). Other methods measure acaricides and/or their metabolites in blood or urine. However, these types of risk assessment overlook endocrine disruption mechanisms like hormone receptor binding, which poses long-term threats to humans and animals (Kubickova et al., 2021). Moreover, some acaricides persist in the environment, contaminating water bodies, accumulating in food chains, and harming non-target organisms like aquatic species (Tudi et al., 2021). To mitigate these risks, adopting integrated pest management (IPM) strategies that reduce reliance on chemical acaricides is essential, alongside increased research into safer alternatives like biopesticides and plant-based compounds (Muniappan et al., 2024). This paper explores the

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Website:

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DOI:

10.26480/gws.02.2025.79.85

mechanisms of endocrine disruption of acaricides, their environmental threats, and the associated health risks. To address the existing knowledge gaps, a collaborative approach involving scientists, livestock stakeholders and policymakers is crucial to balance effective ticks and mites control with environmental and public health protection.

2. TYPES OF ACARICIDES COMMON IN TROPICAL COUNTRIES

2.1 Organophosphates

Organophosphates (OPs) are among the most extensively used acaricides in tropical countries for controlling ticks and mites infestations. Commonly used OPs include diazinon, chlorfenvinphos, coumaphos, and ethion. These are typically applied through dipping, where cattle are immersed in an acaricide solution for full-body coverage, though hand spraying and pour-on formulations are also employed, particularly in smallholder systems (Mulla et al., 2020). Their widespread use in tropical countries is mainly due to their low cost and availability, especially in rural and pastoral communities (Asamani et al., 2024). Organophosphates function by irreversibly inhibiting the enzyme acetylcholinesterase (AChE) activity, leading to the buildup of acetylcholine at nerve synapses (Araújo et al., 2023). The inhibition of AChE leads to overstimulation, paralysis, and death of ticks. However, the prolonged and often unsupervised use of OPs has led to resistance in tick populations (Githaka et al., 2022). Additionally, OPs pose considerable health risks to humans and animals due to their high toxicity (Mulla et al., 2020; Modak et al., 2024).

2.2 Carbamates

Synthetic carbamates, derived from carbamic acid, are used in tropical countries to control ticks and mites in livestock. Their mode of action is inhibiting acetylcholinesterase (AChE) reversibly, leading to nervous system overstimulation, paralysis, and death of parasites (Araújo et al., 2023). Common carbamates such as propoxur, carbaryl, and methomyl are commonly applied through spraying, dusting, or, less commonly, pour-on methods. They offer broad-spectrum efficacy and are often used in smallholder farms, where infrastructure limits access to plunge dips, and in integrated pest control programs for resistance management. Slow-release devices like ear tags and back rubbers are also used in high-infestation areas to offer extended protection. Despite their effectiveness, carbamates pose health and environmental risks due to their cholinesterase-inhibiting mechanism, which can harm humans and non-target organisms (Araújo et al., 2023).

Furthermore, the use of carbamates raises food safety concerns due to the potential accumulation of residues in meat and milk, prompting regulatory bodies to enforce strict withdrawal periods (Araújo et al., 2023). Carbamates remain valuable and safe and are preferred in many countries. However, their uses are constrained by cost, infrastructure, and resistance challenges (Araújo et al., 2023). When used responsibly and integrated with other control strategies, carbamates can contribute to sustainable ectoparasite management in tropical livestock systems.

2.3 Synthetic Pyrethroids

Synthetic pyrethroids (SPs) are a widely used class of acaricides in tropical livestock production, valued for their effectiveness against ticks and mites. They are derived as synthetic analogues of natural pyrethrins from *Chrysanthemum* flowers (Hodoşan et al., 2023). Their mode of action targets ligand-gated ion channels in arthropod nerve membranes, causing prolonged channel opening that leads to hyper-excitation, paralysis, and death. Common SPs include cypermethrin, deltamethrin, alphacypermethrin, and flumethrin, which are praised for their broad-spectrum activity, rapid knockdown effect, and relatively low mammalian toxicity (Hodoşan et al., 2023). Their mode of application methods ranges from sprays and pour-on to dips and collars, depending on the farming system. Pour-on formulations are especially popular in smallholder and pastoralist settings due to their ease of use and reduced stress on animals. However, widespread and improper use has led to significant resistance among tick species such as the *Rhipicephalus (Boophilus) microplus* (Githaka et al., 2022). Further concerns about SP uses are the potential for environmental threats due to runoff into aquatic ecosystems and their persistence in animal tissues, though to a lesser extent than organophosphates (Githaka et al., 2022).

2.4 Formamidine Acaricides

The main type of amidine group is Amitraz, which is widely used in tropical countries for controlling ticks and mites, particularly those resistant to other acaricide classes. Its popularity stems from its distinct mode of action and high efficacy against multi-resistant tick populations. Unlike organophosphates and synthetic pyrethroids, which target

cholinesterase enzymes or ligand-gated ion channels, Amitraz acts as an agonist at octopamine receptors in the nervous system of ticks and mites (Kita et al., 2017). Octopamine is a neurotransmitter unique to invertebrates that regulate several physiological processes such as locomotion, feeding, and reproduction. By overstimulating these receptors, Amitraz induces neurotoxicity, behavioural disruption, paralysis, detachment from the host, and eventual death (Guo, et al., 2021). This selectivity makes it especially effective against *Rhipicephalus (Boophilus) microplus*, a vector of bovine babesiosis and anaplasmosis. Despite its benefits, improper handling or failure to observe withdrawal periods can result in harmful residues in meat and milk, posing food safety risks.

2.5 Macrocytic Lactones

Macrocytic lactones (MLs), including ivermectin, doramectin, eprinomectin, and moxidectin, are powerful systemic acaricides. They are widely used in tropical livestock production to control both internal and external parasites. They work by binding to glutamate-gated chloride channels in parasites, causing an influx of chloride ions, leading to paralysis and death of the parasites (Lifschitz et al., 2024). Unlike contact acaricides, MLs are systemic, absorbed into the host's bloodstream and ingested by parasites during feeding, offering extended protection and reducing treatment frequency. They are commonly administered via injection, oral drench, or pour-on formulations. They are favoured for their broad-spectrum efficacy, prolonged residual activity, and ease of application, especially in extensive grazing systems. However, their widespread use has raised concerns over the emergence of resistance, particularly in the *Rhipicephalus (Boophilus) microplus*, compelled by overuse, under-dosing, and lack of acaricide rotation (Su et al., 2023). Environmental concerns also exist, as MLs are excreted unchanged in dung, where they can harm beneficial non-target organisms like dung beetles, disrupting ecological balance and environmental health (Su et al., 2023).

3. MECHANISMS OF ENDOCRINE DISRUPTION OF ACARICIDES

3.1 Hormone receptor modulation

Hormone receptor modulation is a key mechanism through which endocrine-disrupting acaricides (EDAs) interfere with hormonal regulation in humans and animals. Some acaricides, such as permethrin and cypermethrin, can bind directly to nuclear hormone receptors like estrogen (ERs) and androgen receptors (ARs) mimicking or blocking natural hormones and thereby disrupting hormonal balance and physiological functions (Warner et al., 2020). Acaricides may also activate the aryl hydrocarbon receptor (AhR), which interacts with other hormone pathways and alters gene expression via xenobiotic response elements (XREs), resulting in endocrine disruption. Additionally, activation of AhR can promote the degradation of hormone receptors, such as ER α , through the ubiquitin-proteasome pathway, diminishing normal estrogen signalling (Swedenborg et al., 2009). EDAs can further interfere by competing for essential co-activators and co-repressors required for receptor transcriptional activity, limiting hormonal responses (Kalyabina, et al., 2021).

3.2 Alteration of Hormone Synthesis and Metabolism

Acaricides, commonly used to control ticks and mites, have been recognized as endocrine-disrupting chemicals (EDCs) due to their ability to alter hormone synthesis and metabolism, posing significant health risks. One major mechanism involves the disruption of key enzymes in steroidogenesis, such as aromatase (CYP19), which converts androgens into estrogens. Inhibition of this enzyme can reduce estrogen production and lead to reproductive dysfunction (Bretveld et al., 2006). Organophosphates like chlorpyrifos also disrupt steroid hormone production by targeting enzymes critical for sex hormone biosynthesis (Hazarika et al., 2020). In contrast, some acaricides may induce enzymatic activity, such as increasing aromatase levels and disrupting the androgen-estrogen balance. Similarly, acaricides can affect thyroid hormone production by inhibiting thyroperoxidase, an enzyme essential for iodination processes during thyroid hormone synthesis (Bretveld et al., 2006). Beyond synthesis, acaricides influence hormone storage and release. For instance, some disrupt norepinephrine binding at alpha-2 adrenergic receptors, impeding the release of gonadotropin-releasing hormone (GnRH) and luteinizing hormone (LH), both essential for ovulation (Sharma et al., 2020). These disruptions collectively highlight the multifaceted impact of acaricides on endocrine function and underscore their potential role in reproductive and developmental disorders in humans and animals.

3.3 Neuroendocrine Disruption

Neuroendocrine disruption is a key mechanism through which acaricides can interfere with hormonal regulation in humans and animals. Organophosphate acaricides such as chlorpyrifos disrupt the hypothalamic-pituitary-gonadal (HPG) axis by inhibiting acetylcholinesterase (AChE), leading to excessive acetylcholine buildup at synapses. This alters hypothalamic signalling, suppressing gonadotropin release and results in impaired fertility, delayed development, and disrupted sexual maturation (Sharma et al., 2020). Chronic exposure has been linked to poor reproductive outcomes and the detection of chlorpyrifos in human breast milk and umbilical cord blood raises concern over fetal exposure during critical developmental stages (Engel et al., 2011). Some acaricides further impair the HPG axis by blocking gonadotropin-releasing hormone (GnRH) and disrupting neurotransmitter systems like norepinephrine, negatively impacting ovulation (Bretveld et al., 2006). Likewise, acaricides can disrupt the hypothalamic-pituitary-thyroid (HPT) axis. Compounds such as fipronil and carbamates inhibit thyroid peroxidase (TPO), reducing thyroid hormone synthesis and leading to hypothyroidism, developmental delays, and cognitive deficits (Forner-Piquer et al., 2024). Moreover, macrocyclic lactones like ivermectin impair thyroid regulation and steroidogenesis, particularly in aquatic ecosystems where they persist and accumulate, harming non-target species such as fish and amphibians by affecting reproduction and growth (Wang et al., 2019). These effects underline the neuroendocrine risks of acaricide exposure.

3.4 Epigenetic Modifications

Acaricides, widely used for controlling ticks and mites are capable of inducing epigenetic modifications that alter gene expression without changing the DNA sequence. These changes can disrupt hormonal regulation and lead to lasting physiological consequences. One primary mechanism involves DNA methylation, where exposure to acaricides like deltamethrin has been linked to altered methylation patterns in hormone-related genes, potentially causing transgenerational reproductive and developmental effects (Wang et al., 2023). Such disruptions may include hypomethylation and hypermethylation of gene promoter regions, leading to aberrant gene activity. For example, permethrin has been shown to induce hypomethylation in genes regulating reproduction, contributing to fertility issues and adult-onset diseases across generations (Thorson, 2020). These epigenetic alterations can be inherited trans generationally, meaning even unexposed descendants may experience endocrine-related disorders due to ancestral exposure. Studies, such as those on organophosphorus, demonstrate that such changes can affect reproductive behaviour and stress responses in multiple generations of animals, raising significant concerns about the long-term ecological and health risks posed by acaricide use (Govindarajan et al., 2019).

4. ENVIRONMENTAL RISKS OF ENDOCRINE-DISRUPTING ACARICIDES

4.1 Contamination of Aquatic Ecosystems

Acaricides contaminate aquatic ecosystems in tropical regions primarily through agricultural runoff, leaching, and improper disposal in livestock farming. Due to their low biodegradability, these chemicals persist in water bodies and sediments, leading to prolonged environmental exposure. Studies in East Africa, particularly in Tanzania and Kenya have detected residues of organophosphates in rivers and lakes, highlighting widespread contamination (Mwevura et al., 2021; Musa et al., 2011). Once present in aquatic systems, EDAs disrupt hormonal pathways in fish and amphibians, impairing vital biological functions. In fish, sublethal exposure to pyrethroids and organophosphates has been linked to altered gonadal development, hormonal imbalances, feminization, and reduced fertility effects that threaten population viability (Sumon et al., 2022). Amphibians similarly exhibit delayed metamorphosis, limb deformities, and reproductive impairments when exposed to low doses (Garcês et al., 2020). These disruptions not only affect individual organisms but also compromise aquatic biodiversity and destabilize aquatic ecosystems.

4.2 Bioaccumulation and Food Chain Contamination

Bioaccumulation of acaricides in aquatic and terrestrial food chains presents major ecological and public health concerns. Persistent compounds like amitraz and fipronil have been found in fish, meat, and dairy products, raising alarms over human exposure and food safety (Zaller and Zaller 2020; Leskovac and Petrović 2023). Similarly, pesticides can accumulate in predators, leading to potential bioaccumulation and biomagnification, especially at sublethal doses that can have cascading effects on biodiversity and ecosystem health (Tison et al., 2024). Furthermore, acaricide contamination affects soil ecosystems by disrupting beneficial microbial communities critical for nutrient cycling.

Organophosphates and pyrethroids can inhibit microbial enzymatic activity, compromising processes like nitrogen fixation and organic matter decomposition that are essential for soil fertility and agricultural productivity (Meena et al., 2020). Collectively, the bioaccumulative nature of acaricides not only endangers wildlife and undermines ecosystem health but also threatens food security and human well-being in tropical regions where such chemicals are widely applied.

4.3 Impact on Terrestrial Wildlife and Pollinators

Endocrine-disrupting acaricides (EDAs) affect terrestrial wildlife and pollinators, threatening ecological balance, food security, and agricultural sustainability. Bees and butterflies, essential pollinators, are particularly vulnerable to sublethal exposure from acaricides such as amitraz and fipronil, which impair vital behaviours such as foraging, navigation, and in-colony communication (Albero et al., 2023). These disruptions can weaken colonies, increase susceptibility to pathogens like *Nosema spp.*, and elevate the risk of colony collapse, ultimately diminishing pollination services crucial for global food crops (Albero et al., 2023). In addition, chronic acaricide exposure compromises pollinator immunity, further amplifying population declines. Terrestrial wildlife, including small mammals, amphibians, and reptiles, also suffer adverse effects from acaricide contaminated soil and water. These include hormonal imbalances, reproductive failures, and heightened vulnerability to disease (Dai et al., 2021). Amphibians are especially sensitive, with documented thyroid disruption, feminization, and delayed metamorphosis in species such as *Rana temporaria* (Ruthsatz et al., 2020). The resulting biodiversity loss weakens ecosystem resilience, disrupts natural pest control mechanisms, and may trigger cascading ecological instability, ultimately threatening the livelihoods of communities reliant on agriculture in the tropics.

5. HEALTH EFFECTS OF ENDOCRINE-DISRUPTING ACARICIDES

5.1 Reproductive health effects

Endocrine-disrupting acaricides (EDAs) pose significant reproductive health risks for both females and males by disrupting the hormonal regulation critical for reproductive function. In females, chronic exposure to commonly used acaricides such as organophosphates, pyrethroids, and amitraz can alter estrogen and progesterone signalling, leading to conditions like menstrual irregularities, anovulation, polycystic ovarian syndrome (PCOS), premature ovarian insufficiency, and early menopause (Marettova et al., 2017). Of particular concern is prenatal exposure, which has been linked to congenital anomalies such as neural tube defects, cleft palate, and urogenital malformations, likely resulting from disruptions in placental function and fetal hormone-mediated development (Tyagi et al., 2022). These findings highlight the vulnerability of pregnant women and developing fetuses to low dose EDA exposures during critical developmental windows, raising alarm over the long-term reproductive consequences for exposed populations.

In males, acaricides such as chlorpyrifos have been shown to impair Leydig and Sertoli cell function, leading to decreased testosterone production and disrupted spermatogenesis (da Costa et al., 2024). The resulting effects are poor semen quality, reduced sperm count and motility, and increased sperm abnormalities. These effects may persist long after exposure, suggesting enduring or even epigenetic damage to the hypothalamic-pituitary-gonadal (HPG) axis. Rodent studies further demonstrate that chronic low-dose exposure can cause testicular atrophy, oxidative stress, and germ cell DNA damage (Sule et al., 2022). These findings underscore the urgent need for stricter regulation, monitoring, and safer alternatives to acaricides with endocrine disruptive effects especially in tropical regions where their use is widespread.

5.2 Thyroid Dysfunction

Thyroid hormones, primarily thyroxine (T4) and triiodothyronine (T3) are vital for regulating metabolism, thermogenesis, neurodevelopment, and cardiovascular function under the tight control of the hypothalamic-pituitary-thyroid (HPT) axis. Acaricides, including organophosphates, pyrethroids, and phenylpyrazoles like fipronil can interfere with this axis at multiple levels (Sirikul and Sapbamrer, 2023). These compounds inhibit thyroid peroxidase, disrupt hormone transport by displacing T4 and T3 from proteins such as transthyretin and impair receptor binding. Such interference can lead to thyroid dysfunction, manifesting as either hypothyroidism characterized by fatigue, weight gain, and cold intolerance or hyperthyroidism, which presents with symptoms like weight loss, anxiety, and heat sensitivity. Both conditions are associated with neurocognitive disturbances, mood disorders, and metabolic imbalances, especially under chronic exposure scenarios (Stojković, 2022).

In pregnancy, thyroid hormone balance is essential for fetal development, particularly of the brain and skeleton. EDAs can cross the placental barrier, disrupting maternal thyroid function and impairing fetal neurodevelopment during critical periods when the fetus relies solely on maternal hormones. Thyroid disruption has been associated with adverse outcomes such as reduced IQ, attention deficits, and neurodevelopmental delays in children (Thompson et al., 2018; Wang et al., 2023). Some studies also reveal that induced maternal hypothyroidism can hinder hippocampal development and neurogenesis in offspring (Feng et al., 2025). In adults, chronic thyroid hormone disruption due to exposure to acaricides such as organophosphates and pyrethroids contributes also to hypothyroidism that may lead to cardiovascular complications, including hypertension and arrhythmias and neuropsychiatric disorders such as depression and anxiety (Khan et al., 2020; Sirikul and Sapbamrer, 2023).

5.3 Hormone-Related Cancers

Acaricides such as organophosphates and pyrethroids, are increasingly linked to hormone-sensitive cancers due to their ability to mimic or block natural sex hormones. Acting as xenoestrogens or anti-androgens, acaricides bind to hormone receptors altering gene expression and disrupting normal hormonal signaling (Fagundes et al., 2024). This interference promotes abnormal cell proliferation and neoplastic transformation. Long-term and low-dose exposure to these compounds has been associated with higher risks of breast, ovarian, endometrial, and prostate cancers, especially in populations with chronic occupational or environmental exposure (Alavanja et al., 2013; Ahmad et al., 2024). In women, acaricides -induced estrogenic activity can activate estrogen-responsive genetic elements, driving mammary and ovarian tumorigenesis (Fagundes et al., 2024). In men, interference with androgen pathways contributes to prostate hyperplasia and cancer, particularly among agricultural workers (Alavanja et al., 2013).

5.4 Neurodevelopmental and Neurological Effects

Acaricides, particularly organophosphates (e.g., chlorpyrifos, diazinon) and pyrethroids (e.g., permethrin, cypermethrin), have been increasingly associated with neurodevelopmental impairments in children. Prenatal and early-life exposure to these compounds has been linked to reduced IQ, language delays, memory deficits, attention-deficit/hyperactivity disorder (ADHD), and autism spectrum disorders (ASD) (Viel et al., 2015; Normann et al., 2025). Organophosphates exert neurotoxicity by inhibiting acetylcholinesterase (AChE), causing acetylcholine buildup at synapses and resulting in prolonged neuronal excitation and toxicity. Even exposure at low doses during critical developmental periods can impair synaptic plasticity and learning. Similarly, although pyrethroids are considered less acutely toxic, they can disrupt sodium channel kinetics and neurotransmitter balance in the developing brain, contributing to neurobehavioral deficits (Mohammadi et al., 2019).

Additionally, EDAs can interfere with the hypothalamic-pituitary-thyroid (HPT) axis, disrupting maternal thyroid hormone levels crucial for fetal neurodevelopment. Thyroid hormones play vital roles in the growth and development of the cerebral cortex, hippocampus, and cerebellum. Their disruption by EDCs has been linked with structural brain changes and long-term cognitive and behavioural disorders in offspring (Thompson et al., 2018). Epidemiological studies in agricultural communities have shown that children born to parents with occupational pesticide exposure are at increased risk of neurodevelopmental delays (Coleman et al., 2025). Supporting evidence from animal models further demonstrates that early-life pesticides exposure impairs spatial memory, alters locomotor activity, and induces anxiety-like behaviours (Nasuti et al., 2014). These findings underscore the neurotoxic potential of endocrine disrupting acaricides and highlight the need for stringent exposure regulations to protect vulnerable populations.

5.5 Immune system disruption

Endocrine-disrupting acaricides (EDAs), notably chlorpyrifos, fipronil, and permethrin are becoming more widely recognized for their immunotoxic effects. These compounds disrupt immune homeostasis by interfering with cytokine signalling, suppressing leukocyte activity, and impairing innate and adaptive immune responses (Corsini et al., 2013). A key mechanism involves the dysregulation of T-helper (Th) cell balance, particularly skewing towards a Th2-dominant profile, which promotes susceptibility to allergic conditions such as asthma and eczema (Corsini et al., 2013). EDAs also inhibit macrophage phagocytosis and natural killer (NK) cell cytotoxicity, weakening first-line defences against infections and malignancies. Furthermore, through endocrine-immune crosstalk, endocrine disruptors interfere with glucocorticoid and thyroid hormone signalling essential for lymphocyte maturation, inflammation control, and immune modulation (Izumi et al., 2024). Disruption of these pathways

may impair immune surveillance, increasing susceptibility to infections and tumorigenesis.

Long-term immune dysfunction is particularly concerning following early-life pesticide exposure. Epidemiological studies in agricultural communities in California and rural China reported increase in respiratory infections and allergic conditions among children whose parents had occupational exposure to pesticides (Roberts et al., 2012). Animal models support these findings, revealing that prenatal and neonatal exposure to endocrine disruptors leads to oxidative stress and DNA damage in lymphoid tissues like the thymus and spleen, impairing immune cell proliferation and differentiation (Corsini et al., 2013). These findings underscore the urgent need for biomonitoring programs, stricter pesticide regulations, and the promotion of safer, non-toxic alternatives for pest control.

6. REGULATORY AND POLICY CHALLENGES

Endocrine-disrupting acaricides (EDAs) pose significant health and environmental threats in tropical countries, yet their regulation is faced with several challenges. A core issue is the limited enforcement of existing pesticide laws, often due to inadequate funding, understaffed agencies, and weak institutional coordination. While countries like Tanzania have established entities such as the Tanzania Plant Health and Pesticides Authority (TPHPA) under Act No. 4 of 2020, and Kenya has operationalized the Pest Control Products Board (PCPB) under the Pest Control Products Act (Cap 346), enforcement remains inconsistent and fragmented (Stadlinger et al., 2013). In several Southeast Asian countries, including Laos and Cambodia, formal pesticide legislation is either outdated or lacking, leaving gaps in enforcement (FAO and WHO, 2021; Chanchao, 2023). Poor import regulation further enables the influx of banned or unregistered formulations, contributing to environmental and health hazards (Olisah et al., 2020).

Across tropical countries, pesticide regulation varies widely in structure and effectiveness. In Asia, for example, China's Institute for Control of Agrochemicals and India's Central Insecticides Board and Registration Committee regulate pesticide use and enforce maximum residue limits (MRLs), often in alignment with Codex Alimentarius standards. However, countries like Vietnam and Myanmar struggle with enforcement due to limited institutional resources (FAO and WHO, 2021). In Africa, while Ghana and Uganda have aligned national legislation with international conventions like the Rotterdam and Stockholm Conventions, enforcement capacity remains weak (Mensah et al., 2023). In Latin America, Brazil has developed robust pesticide legislation, yet political pressure from agribusiness lobbying sometimes undermines regulatory decisions (Kinniburgh, et al., 2023). Even in countries with formal regulatory bodies, issues such as limited laboratory capacity, lack of pesticide residue monitoring, and poor inter-agency coordination hinder effective implementation.

Monitoring endocrine-disrupting acaricides in food, water, and environmental samples in the tropics is generally inadequate. National surveillance systems are often underfunded, with laboratories lacking the infrastructure to detect trace concentrations of pesticides or to analyze endocrine-related endpoints. Most pesticide risk assessments still prioritize acute toxicity or carcinogenicity, rarely accounting for sub-lethal, chronic hormonal effects, such as those on reproduction or neurodevelopment (Shekhar et al., 2024). This is particularly problematic because endocrine disruption often occurs at low doses and can result in long-term, irreversible effects, especially in vulnerable populations like pregnant women, children, and immunocompromised individuals (Bouchard et al., 2011). Without hormone-specific bioassays, robust biomonitoring programs, or longitudinal exposure studies, the true scale of health risks associated with endocrine-disrupting acaricides remains largely unknown in many tropical countries.

Public awareness of the risks posed by endocrine disruption effects of acaricides is also low in many tropical regions. Farmers often lack knowledge on endocrine disruption and the long-term impacts of improper pesticides use (Wong et al., 2019). This knowledge gap contributes to unsafe practices such as over-application and poor handling, increasing occupational and environmental exposures (Alshalati, 2021). Furthermore, the limited availability of locally relevant research on acaricides with endocrine disruption effects exposure, persistence, and health outcomes restricts the development of context-specific interventions.

7. SUSTAINABLE ALTERNATIVES AND FUTURE DIRECTIONS

Addressing the environmental and health threats posed by endocrine-disrupting acaricides necessitates a shift toward sustainable alternatives.

Environmentally friendly pest control strategies such as biological agents, botanical compounds, and integrated pest management (IPM) offer viable solutions. Among biological alternatives, entomopathogenic fungi like *Beauveria bassiana* and *Metarhizium anisopliae* show strong acaricidal effects by infecting and killing ticks through enzymatic degradation of their exoskeletons (Rajput et al., 2024). Likewise, predatory mites such as *Amblyseius spp* provide natural pest suppression through selective predation (Mutuku et al., 2024). On the other hand, botanical acaricides also offer promise, with plant-derived compounds like neem oil and essential oils from lemongrass and eucalyptus have proven to disrupt pest nervous systems while degrading rapidly in the environment (Nwanade et al., 2020). However, broader adoption is hindered by limited production scalability, variable efficacy, and the need for standardization.

Integrated Pest Management (IPM) is a comprehensive strategy to reduce dependency on chemical acaricides by combining multiple pest control methods. IPM emphasizes long-term, ecologically sound practices such as biological control, use of pest-resistant breeds, and targeted acaricide use rather than blanket chemical applications (Ghosh et al., 2006). In tropical regions, where livestock and crop systems are heavily affected by tick infestations, IPM promotes sustainability by reducing pesticide load while maintaining control efficiency. For instance, rotational use of acaricides with biologics, pasture management, and seasonal application scheduling can all reduce environmental persistence and slow resistance development. Successful IPM implementation depends on farmer training, access to monitoring data, and institutional support factors, which are often lacking in resource-limited settings (Goulet et al., 2023). Ultimately, the adoption of IPM may contribute to safer ticks and mites control strategies and reinforcing a shift away from endocrine-disrupting chemicals toward more resilient, localized ticks and mites management systems.

8. CONCLUSION

The widespread use of acaricides with endocrine-disrupting effects in tropical regions presents significant and often overlooked threats to the environment and human health. Acaricides like organophosphates, pyrethroids, and amitraz, while effective in controlling ticks and mites, can disrupt hormonal pathways, leading to reproductive dysfunction, thyroid disorders, immune suppression, and an increased risk of hormone-related cancers. In aquatic ecosystems, their persistence contributes to ecological imbalances, affecting reproductive and developmental processes in aquatic animal species, and further threatening biodiversity. Despite mounting evidence of these harmful effects, inadequate regulatory frameworks and limited public awareness persist. In mitigating these risks, urgent action is required to strengthen regulations, enhance monitoring of acaricide residues, and endocrine-disrupting effects and raise awareness of their dangers. Promoting sustainable alternatives, such as biopesticides, integrated pest management (IPM), and formulation of safer acaricides, is crucial to reducing the harmful impacts of these chemicals. A collaborative, multidisciplinary approach involving governments, researchers, and livestock stakeholders is essential for sustainable solutions. By increasing research, fostering international cooperation, and ensuring stronger regulations, we can safeguard public health, protect biodiversity, and promote sustainable practices in tropical ecosystems for future generations.

CONFLICT OF INTEREST

The author declares no conflict of interest.

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