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Research Article

Review on the Impact of Pesticides on the Production of Safety and High-Quality Honey in Ethiopia

Tegegn Teshome*

Ethiopian Agricultural Authority Department of Milk and Honey Health Safety Quality Regulatory, Addis Ababa, Ethiopia

Abstract

Honey is a highly valued natural product, prized not only for its unique taste but also for its nutritional, medicinal and economic significance. Rich in vitamins, minerals, antioxidants, and bioactive compounds, honey has been used for centuries as a dietary supplement, therapeutic agent, and natural sweetener. In Ethiopia, which is recognized as the largest honey producer in Africa and one of the leading suppliers globally, apiculture plays a critical role in supporting rural livelihoods. Beekeeping contributes significantly to household incomes, enhances food security through pollination of crops and generates substantial export revenue, making it an important component of the national economy. However, the quality and safety of honey are increasingly threatened by the accumulation of residues from pesticides, veterinary drugs and environmental contaminants. Such residues can alter honey's physicochemical and enzymatic properties, reducing its nutritional and organoleptic quality and may pose serious health risks to consumers, including neurotoxicity and endocrine disruption. Addressing these challenges requires a multifaceted approach that includes the implementation of integrated pest management (IPM), routine monitoring of chemical residues and systematic training programs for farmers and beekeepers on safe practices. Furthermore, promoting organic and bee-friendly farming systems can help protect pollinators, maintain ecological balance and ensure the production of high-quality honey. Sustainable apiculture in Ethiopia depends on coordinated national policies, investment in research and extension services and active engagement of stakeholders across the honey value chain. By prioritizing pollinator protection, food safety and quality control measures, Ethiopia can secure the long-term viability of its honey sector while continuing to meet both domestic and international demand for safe, nutritious and high-quality honey.

Keywords

Honey Quality, Pesticide Residues, Honeybee Health, Food Safety, Integrated Pest Management (IPM)

1. Introduction

Honey is a natural, nutrient-dense food produced primarily by the western honeybee (Apis mellifera) and other bee species. It contains sugars (mainly fructose and glucose), amino acids, vitamins, minerals, organic acids and numerous bioactive compounds that contribute to its nutritional, medicinal and antimicrobial properties [2]. Beyond its dietary importance, honey plays a crucial role in traditional medicine and serves as a vital income source for rural and smallholder farmers [8].

In Ethiopia, beekeeping is an ancient practice deeply inte-

*Corresponding author: tegegnteshome12@gamil.com (Tegegn Teshome)

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grated into rural livelihoods. The country is Africa's leading honey producer and ranks among the top ten globally, contributing significantly to household income, food security and export earnings [9]. However, the quality and safety of honey are closely tied to the health of honeybee colonies and the integrity of their foraging environment. The expansion of modern agriculture and the increased use of chemical pesticides including insecticides, herbicides, and fungicides have created growing threats to bee health [11].

While pesticides are vital for crop protection, their residues can contaminate nectar and pollen, harm bees directly and compromise honey quality. These contaminants affect bee survival and behaviour, reduce honey yield and pose challenges to Ethiopia's honey export potential, especially with the rising international demand for residue-free honey [7].

2. Pesticides and Honeybee Health

Honeybees are among the most vulnerable non-target organisms affected by pesticide exposure. Bees encounter pesticides through several pathways, including direct contact during spraying, ingestion of contaminated nectar or water and drift from nearby treated fields [6].

Pesticides exert both *acute* and *chronic* effects:

1) *Acute toxicity:* Insecticides such as neonicotinoids (e.g., imidacloprid, thiamethoxam) and organophosphates (e.g., chlorpyrifos, malathion) can kill bees within hours by disrupting their nervous systems [12].
2) *Sub-lethal effects:* Chronic exposure impairs learning, orientation and communication (e.g., waggle dance), reduces foraging efficiency and weakens the immune system, predisposing bees to pathogens like Nosema and Varroa mites [5].
3) *Colony Collapse Disorder (CCD):* Pesticides are major contributors to CCD a condition where worker bees vanish, leaving behind the queen and brood [14].
4) In Ethiopia, indiscriminate pesticide application especially during crop flowering has led to significant bee mortality and colony weakening, reducing honey yield and altering its moisture balance [1].

3. Pesticide Residues in Honey

When bees forage on pesticide treated plants, residues accumulate in honey, wax and pollen. The most common pesticide classes detected in honey include neonicotinoids, organophosphates, pyrethroids and fungicides [4].

Residues raise multiple concerns:

1) *Food safety risks:* Chronic exposure can lead to neurotoxicity, endocrine disruption, and immune suppression in humans
2) *Trade limitations:* Export markets, particularly the European Union, enforce strict Maximum Residue Limits (MRLs). Exceeding these thresholds can lead to the rejection of Ethiopian honey exports
3) *Altered honey chemistry:* Pesticides may change sugar ratios, inhibit key enzymes (invertase, diastase) and reduce antioxidant activity [15].

Recent studies in Ethiopia (e.g., Oromia, Amhara, and SNNP regions) have detected residues of organophosphates and pyrethroids in honey samples near farmlands, underscoring the urgent need for residue monitoring and enforcement of pesticide regulation [14].

4. Impact on Honey Quality Parameters

Pesticides affect honey quality both indirectly through bee health and directly through chemical contamination:

1) *Moisture Content:* Weak colonies process nectar inefficiently, leading to honey with high moisture and increased fermentation risk [3].
2) *Enzymatic Activity:* Pesticide exposure reduces enzymes such as diastase, invertase, and glucose oxidase key freshness indicators).
3) *Microbial Quality:* Compromised bee immunity and hygiene can lead to microbial contamination
4) *Organoleptic Properties:* Residues may cause off-flavours, discoloration, or unpleasant odours, lowering market value

5. Risk to Public Health

Honey contaminated with pesticide residues represents a growing public health concern, particularly in developing countries such as Ethiopia, where regulatory monitoring systems are still developing. Since honey is consumed widely by all age groups including children, pregnant women and the elderly and is frequently used in traditional medicine for its perceived therapeutic properties, any level of contamination poses potential health risks. The health effects depend on the type, concentration and persistence of the pesticide residues present in the honey. The main categories of health risks include *neurotoxicity, endocrine disruption, carcinogenicity and allergic or immunotoxic reactions* [13].

5.1. Neurotoxicity

Several classes of pesticides, particularly *organophosphates*, *carbamates* and *neonicotinoids*, are known neurotoxic agents that interfere with the normal function of the nervous system.

1) *Mechanism of Action:* Organophosphates and carbamates inhibit the enzyme *acetylcholinesterase (AChE)*, which is essential for breaking down the neurotransmitter acetylcholine at nerve synapses. This inhibition causes overstimulation of nerve cells, leading to symptoms such as headache, dizziness, muscle tremors, con-

fusion, and in severe cases, respiratory paralysis or death.
2) *Chronic Effects:* Prolonged exposure, even to low doses, may result in memory impairment, reduced cognitive performance, developmental neurotoxicity in children, and long-term neurological disorders.
3) *Neonicotinoids*, although less acutely toxic to humans, act on *nicotinic acetylcholine receptors* and may affect human brain development and cognitive function when exposure occurs during early life stages.

5.2. Endocrine Disruption

Some pesticides act as *endocrine-disrupting chemicals (EDCs)* by mimicking or blocking the natural action of hormones in the body.
1) *Fungicides* such as *vinclozolin* and *triazoles*, and *herbicides* such as *atrazine* and *glyphosate*, are known to interfere with hormonal signaling pathways.
2) *Health Consequences:* Exposure to such residues can lead to reproductive and developmental abnormalities, altered thyroid function, metabolic disorders, and increased susceptibility to hormone-related cancers (e.g., breast, ovarian, and prostate cancer).
3) *Vulnerable Populations:* Infants, pregnant women, and adolescents are particularly at risk due to their developing endocrine systems [10].

5.3. Carcinogenic and Mutagenic Effects

Long-term consumption of honey contaminated with certain pesticide residues, even at levels below acute toxicity thresholds, may increase the risk of *cancer* and *genetic mutations*.
1) *Carcinogenic Pesticides:* Some organochlorine pesticides (such as *DDT*, *lindane*, and *dieldrin*) are classified as probable or possible human carcinogens by the International Agency for Research on Cancer (IARC).
2) *Mechanisms:* These compounds can induce oxidative stress, DNA damage, and disruption of cellular signaling pathways, which can lead to tumor formation over time.
3) *Bioaccumulation:* Because some pesticides are fat-soluble, they can accumulate in human tissues and magnify through the food chain, increasing chronic exposure risks.

5.4. Allergic, Immunotoxic, and Other Systemic Effects

Even at trace levels, pesticide residues may provoke *allergic reactions* or *immunotoxic effects* in sensitive individuals.
1) *Allergic Reactions:* Symptoms can include skin irritation, respiratory distress, and hypersensitivity reactions due to immune system over activation.
2) *Immune Suppression:* Certain pesticides weaken immune responses, making individuals more susceptible to infections and reducing the efficacy of vaccines.
3) *Metabolic and Hepatotoxic Effects:* Chronic exposure may impair liver and kidney function due to the body's continuous effort to metabolize and excrete toxic compounds.

5.5. Broader Public Health Implications

The widespread use of pesticides in agriculture and their transfer into honey also have *broader societal and economic consequences*:
1) *Public Health Burden:* Increased healthcare costs due to pesticide-related illnesses.
2) *Food Safety Concerns:* Contaminated honey can undermine consumer trust, reduce export competitiveness, and affect the reputation of Ethiopian honey in international markets.
3) *Regulatory Challenges:* Weak enforcement of *Maximum Residue Limits (MRLs)* and insufficient laboratory capacity make it difficult to ensure compliance with international food safety standards.

6. Strategies to Mitigate Pesticide Impact

To ensure the production of safe, residue-free and high-quality honey in Ethiopia, a combination of regulatory, technical and community-based approaches is essential. The following multi-sectorial strategies can be implemented to minimize the adverse effects of pesticides on bees and honey quality:

6.1. Integrated Pest Management (IPM)

Integrated Pest Management (IPM) is a sustainable approach that combines biological, cultural, mechanical and chemical methods to manage pests while minimizing harm to pollinators and the environment.

Biological Control: Use of natural enemies such as predators, parasitoids, or microbial agents (e.g., Bacillus thuringiensis) to control pest populations.

Cultural Practices: Crop rotation, intercropping and adjusting planting times to break pest life cycles and reduce pesticide dependence.

Use of Resistant Varieties: Promoting pest-resistant crop species to reduce pesticide application.

Selective Use of Chemicals: When chemical control is necessary, choosing pesticides with lower toxicity to bees and applying them in a targeted manner.

6.2. Bee-Friendly Pesticide Application Practices

To protect pollinators, special precautions must be taken

during pesticide use:

Timing of Application: Avoid spraying during flowering periods or when bees are actively foraging; instead, apply pesticides during late evening or early morning hours.

Application Methods: Use precision application technologies (e.g., low-drift nozzles) to reduce off-target contamination.

Product Selection: Prefer formulations with lower toxicity, such as wettable powders or granules, rather than dusts or emulsifiable concentrates that are more hazardous to bees.

Label Compliance: Farmers should strictly adhere to pesticide label instructions regarding dosage, timing, and preharvest intervals.

6.3. Residue Monitoring and Regulation Enforcement

Routine monitoring of pesticide residues in honey, beeswax and hive products is essential to ensure compliance with national and international *Maximum Residue Limits (MRLs)*.

1) *Testing Programs:* Establish regional laboratories to perform periodic sampling and analysis of honey products.
2) *Data Sharing:* Develop a centralized database for residue monitoring to support traceability and risk assessment.
3) *Policy Implementation:* Enforce penalties for misuse of banned or restricted pesticides and encourage registration of safer alternatives.

6.4. Buffer Zones and Forage Management

Creating safe zones and managing bee forage sources can significantly reduce exposure to pesticides.

1) *Buffer Zones:* Establish pesticide-free buffer areas (e.g., 3–5 km radius) around apiaries to minimize drift.
2) *Bee-Friendly Flora:* Promote the planting of diverse flowering plants, shrubs, and trees that provide uncontaminated nectar and pollen sources.
3) *Habitat Restoration:* Encourage agroforestry systems and natural vegetation corridors to sustain pollinator health.

6.5. Awareness Creation and Capacity Building

Educating farmers, pesticide applicators and beekeepers on the ecological importance of bees and the dangers of pesticide misuse is vital.

1) *Training Programs:* Conduct joint training sessions for farmers and beekeepers on safe pesticide handling, IPM, and pollinator protection.
2) *Information Dissemination:* Use local media, agricultural extension services, and cooperatives to spread awareness on best practices.
3) *Community Cooperation:* Foster collaboration between crop producers and beekeepers to synchronize spraying schedules and minimize risks.

6.6. Promotion of Organic and Sustainable Beekeeping

Encouraging organic beekeeping not only protects bees but also enhances the marketability and export potential of Ethiopian honey.

1) *Certification Schemes:* Support beekeepers in obtaining organic or fair-trade certification through government or cooperative initiatives.
2) *Incentives and Support:* Provide financial or technical assistance for organic inputs, hive management, and marketing.
3) *Environmental Sustainability:* Promote the use of natural pest repellents, botanical extracts, and mechanical controls instead of synthetic chemicals.

7. Discussion

Pesticide exposure has become a major challenge to honey production and quality in Ethiopia. The widespread use of synthetic chemicals, particularly neonicotinoids and organophosphates, endangers bee health, weakens colonies and contaminates honey. While acute exposure can lead to massive bee deaths, long-term exposure disrupts their ability to forage, navigate and resist disease ultimately lowering honey yield and quality.

Residues of pesticides such as organophosphates and pyrethroids found in Ethiopian honey raise serious concerns for both food safety and international trade. Contaminated honey not only poses health risks to consumers but also threatens export opportunities, as it may fail to meet strict international residue standards. These chemicals can also alter the natural taste, aroma and enzyme content of honey, reducing its overall quality and market value.

Beyond environmental and health impacts, pesticide misuse directly affects the livelihoods of smallholder beekeepers who rely on honey for income, nutrition and rural development. Protecting bees from harmful pesticide exposure is therefore essential to ensure sustainable honey production, safeguard rural livelihoods and maintain Ethiopia's reputation for pure, high quality honey.

8. Conclusion

Pesticides pose a critical threat to the production of safe, high-quality honey in Ethiopia. Their effects on bee survival, honey composition and human health undermine both local livelihoods and export competitiveness. Sustainable solutions require integrating bee protection into pest management sys-

tems, strengthening monitoring and enforcement and promoting environmentally friendly and organic practices. Coordinated action among farmers, beekeepers, researchers and policymakers is essential to safeguard Ethiopia's apiculture and ensure a resilient, residue-free honey industry.

9. Recommendations

1) *Encourage Integrated Pest Management (IPM):* Promote sustainable farming practices that minimize chemical use by combining biological control, crop rotation, and resistant crop varieties.
2) *Timing of Pesticide Application:* Avoid spraying pesticides during flowering or when bees are actively foraging to reduce exposure and protect pollinators.
3) *Pesticide-Free Zones and Forage:* Establish buffer areas around apiaries and plant bee-friendly flowers to provide safe foraging habitats.
4) *Capacity Building and Training:* Educate farmers and beekeepers on safe pesticide use, bee protection, and sustainable apiculture practices.
5) *Promote Organic and Sustainable Beekeeping:* Support certification schemes and environmentally friendly methods to enhance honey quality, market access, and long-term sustainability.

Abbreviations

IPM	Integrated Pest Management
MRL	Maximum Residue Limit
CCD	Colony Collapse Disorder
FAO	Food and Agriculture Organization
EFSA	European Food Safety Authority
SNNP	Southern Nations, Nationalities and Peoples

Author Contributions

Tegegn Teshome is the sole author. The author read and approved the final manuscript.

Conflicts of Interest

The author declares no conflicts of interest.

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