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Perspective

Invisible Risks: The Toxicological Footprint of Triadimenol in Poultry and Public Health

Pedro Alvarez*

Department of Clinical Nutrition, Universidad de Barcelona, Barcelona, Spain

DESCRIPTION

Triadimenol, a systemic triazole fungicide widely used in agricultural settings, particularly for cereals and ornamental crops, has attracted increasing toxicological scrutiny due to its persistence in the environment and its potential transfer through the food chain. Of growing concern is its indirect exposure in non-target species such as broiler chickens through contaminated feed or residues in crops, ultimately impacting both animal health and human food safety. Although regulatory thresholds such as Maximum Residue Limits (MRLs) are in place, the complexity of triadimenol's metabolism, its endocrine-disrupting potential and cumulative exposure scenarios highlight the need for a more precautionary and integrative toxicological risk assessment framework.

From a human health perspective, triadimenol's primary toxicological concerns stem from its endocrine-modulating properties, hepatic metabolism and developmental and reproductive effects observed in animal models. Triadimenol inhibits sterol biosynthesis in fungi, a mechanism analogous to cholesterol metabolism in vertebrates. Studies in rodents have demonstrated that repeated exposure can lead to hepatomegaly, altered lipid metabolism and changes in hormonal profiles. While such effects are dose-dependent and often observed at higher concentrations than typical dietary exposure, the lack of long-term epidemiological data in humans raises important ethical and precautionary questions. In particular, vulnerable populations such as children, pregnant women and immunocompromised individuals may experience disproportionate effects from low-level chronic exposure.

In the context of broiler health, triadimenol exposure is particularly concerning when poultry are raised in environments where treated grains or feed ingredients carry residual fungicide. Chickens, being highly sensitive to disruptions in hepatic and renal function, can exhibit subtle physiological stress even at low doses of xenobiotics. Although acute toxicity may be rare, subclinical effects—such as oxidative stress, enzyme modulation and immune suppression—can impair growth, reduce feed efficiency and compromise resistance to infections. Additionally, the biotransformation of triadimenol in avian species may lead to the formation of active metabolites that persist in edible tissues, posing a downstream risk to human consumers.

The bioaccumulation potential of triadimenol and its metabolites in broiler tissues, particularly in the liver and adipose deposits, presents a tangible risk to food safety. While current monitoring practices focus on residues in muscle and liver, the possibility of untested metabolite retention or synergistic interactions with other agricultural chemicals remains underexplored. Furthermore, the increasing global demand for poultry and the intensification of broiler farming necessitate more rigorous surveillance of chemical inputs—not only for compliance with residue limits but also for broader public health implications.

One critical ethical concern is the adequacy and transparency of regulatory toxicology frameworks. Many current assessments rely heavily on NOAEL (No-Observed-Adverse-Effect Level) and safety factor models derived from short-term animal studies, which may not adequately capture chronic low-dose exposure, multi-pesticide interactions, or real-world dietary variability. Risk assessment protocols often fail to integrate cumulative effects across multiple sources—food, water and occupational exposure—leading to an underestimation of total human intake. Additionally, inter-species variability in metabolism and detoxification capacity makes it difficult to extrapolate animal data to human risk with high precision.

Another limitation is the narrow focus on single-compound toxicology, which ignores the increasingly recognized concept of the "cocktail effect"—where multiple chemicals, each at individually "safe" levels, may produce harmful synergistic or additive effects. This is particularly pertinent in intensive agricultural systems where broilers may be exposed to combinations of pesticides, antibiotics and feed additives, which may together influence gut microbiota, immune function, or metabolic pathways in unforeseen ways.

A shift toward integrated Toxicological Risk Assessment (iTRA) frameworks that encompass the following:

Correspondence to: Pedro Alvarez, Department of Clinical Nutrition, Universidad de Barcelona, Barcelona, Spain, E-mail: palvarez@ub.es

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- Evaluation of triadimenol should include not only acute and chronic dietary exposure but also inhalational and dermal routes for farmers and workers. For broilers, dietary exposure through feed, bedding and water sources must be quantified.
- Modern tools like metabolomics, transcriptomics and targeted biomarker panels can reveal early signs of organ stress, oxidative imbalance, or immunotoxicity—long before clinical symptoms appear in exposed animals or humans.
- New computational models and in vitro assays can simulate real-world scenarios where triadimenol is present alongside other common residues, offering a more realistic view of toxicity thresholds.
- Regulatory bodies should mandate differential risk assessments for sensitive populations and life stages (e.g., prenatal, neonatal, elderly), which may require stricter MRLs and exposure limits.
- There is a need for clearer, more public-friendly risk labels and advisories. Consumers and producers alike must be informed not only of MRL compliance but also of emerging data on sub-threshold and long-term health risks.

In conclusion, while triadimenol continues to play a valuable role in crop protection, the growing awareness of its toxicological footprint in both humans and animals calls for a more comprehensive approach. Regulatory frameworks must evolve to include cumulative exposure data, animal welfare indicators and advanced biomonitoring tools. Ethical food production and public health policies must prioritize transparency, scientific innovation and precaution in the face of chemical exposures with known endocrine, hepatic and reproductive risks. As scientific knowledge advances, so too must our standards for safety, not only to protect the end consumer but also to ensure the sustainability and integrity of our food systems.