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Nutraceutical Potential of Saffron in Counteracting Lead-Induced Physiological and Biochemical Changes in Poultry: A Review

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Annotation: Lead remains a major environmental hazard for chicken farmers, leading to oxidative stress and damage to other organs. It also impairs immunity and productivity of the flocks. Traditional methods for reducing lead toxicity are limited in their scope to offering any relief. Safe and natural alternatives are one such hopeful sign of solution. Saffron (Crocus sativus), a medicinal plant that is rich in bioactive compounds such as crocin, crocetin, safranal, and picrocrocin, has shown significant prospects as nutraceuticals. Experiments have shown that saffron supplementation improves the antioxidant defense system (SOD, CAT, GSH), reduces lipid peroxidation (MDA), protects liver and kidney functions, and improves hematological and immune responses in Pb exposed poultry. Furthermore, saffron improves growth performance, feed conversion rates, meat quality (texture and taste), and reproductive health, making it a potentially ideal addition to poultry diets as an ingredient that will help fatten the bottom line. Through repeated testing and observation, these areas have all been confirmed to boast better performance statistically than traditional feeds currently in use.

Despite difficulties such as cost, availability, and constancy in dose, saffron and its by-products present a promising, safe way of trying to control heavy metal poisoning in poultry and thus protect animal welfare and productivity in farming.

Keywords: Saffron (Crocus sativus); Lead toxicity; Poultry; Antioxidant defense; Nutraceuticals; Sustainable feeding; Animal health.

Introduction

Heavy metal environmental pollution is now one of the most serious threats to sustainable poultry production around the world. Of these pollutants, lead (Pb) is a representative one and its environmental presence, bioaccumulation in tissues, and toxic effects are persistent.

In the poultry industry, exposure is mainly through contaminated water, feed ingredients, or airborne particles, resulting in compromised productivity and posing a risk to food safety (Aljohani et al., 2023; Mukherjee et al., 2023).

The biological effects, both physiological and biochemical, under the influence of lead toxicosis in poultry have been well studied. Lead inhibits enzymatic functions, disturbs hematopoiesis, and causes oxidative stress leading to:

- ✓ Lipid peroxidation
- ✓ Hepatotoxicity
- ✓ Nephrotoxicity
- ✓ Neurotoxicity

In production aspects, Pb exposure decreases growth rate and feed efficiency, egg production, and reproductive performance. Moreover, lead-induced immune suppression increases susceptibility of poultry to infections, exacerbating economic losses for farmers (Oke et al., 2024; Merck Veterinary Manual, 2025).

Since traditional techniques have several side effects, the use of safe and natural methods for the removal or detoxification of HMs has attracted significant attention. Plant-based nutraceuticals are especially appealing because of bioactive compounds with antioxidant, anti-inflammatory, and immunomodulation activity. They constitute an ecological approach to boosting animal resistance and reducing chemical prophylaxis (Ebrahimi et al., 2023).

Saffron (Crocus sativus L.) is among nutraceutical candidates that got attention due to its special phytochemical composition. Its major constituents, including crocin, crocetin, safranal, and picrocrocin, have potent antioxidant activities through scavenging of free radicals, modulating redox states, and preventing cellular damage (Mhamad & Palani, 2025; Bostan et al., 2017).

Animal and human studies have shown that saffron could possess the capability to protect hepatic, renal, and reproductive organs, as well as ameliorate toxic effects on hematological and immunological indices (Abedi et al., 2023; Mhamad et al., 2025).

This review aims to discuss all the available evidence about the effects of saffron as a nutraceutical in amelioration of lead-induced physiological and biochemical changes in poultry.

This review is an attempt to take the approaches of experimental trials, pharmacology, and sustainability into consideration in order to present saffron as a safe natural feed additive with practical applications for promoting poultry health, production performance, and food safety.

Lead Toxicity in Poultry

Lead (Pb) contamination in commercial poultry is mainly from pollutants in water, feed ingredients that have been put in contact with artificial pollutants, or produce tire-dredging, infectious living organisms cropping up all over the environment, through soil and airborne dust. In backyard and free-range systems, other possible routes of exposure include ingesting fragments of flaking paint, industrial residues, and dust.

Monitoring studies have found detectable levels of lead (Pb) residues in eggs, feed, and soil from chicken farms. They highlight the possibility of several different pathways for contamination with this heavy metal: from feces (as fertilizer); soil that has been polluted by industry; and food or water which comes into contact with Pb residues on factory equipment during processing (Aendo et al., 2024; Hoseini et al., 2023).

Lead is taken up by the digestive system. Absorption efficiency was higher among the younger birds. About 90% of the lead is absorbed in the form of ions and excreted into feces or bile rather than urine. Poultry is a major collector of lead which accumulates in soft tissues such as the liver, kidney, brain, and gonads. Meanwhile, bones serve as a long-term storage depot for this toxic substance; they can continue to release it over time and so are responsible for chronic poisoning without symptoms appearing immediately (Cui et al., 2021; Pain et al., 2019).

The gizzard physiology of birds makes them able to dissolve more particulate lead and hence absorb it. This raises both the bioavailability risk and the risk of accumulating in tissues (Torimoto et al., 2021; Pain et al., 2019). Angiopence and milogysize prevailing definitions of the toxicological effects which PbVaii (PBδ) produces on certain organs in chickens have been given. In the liver lead abrogates detoxification pathways, alters serum enzyme levels, and causes hepatocellular degradation. In eggs, it depresses hatching performance; in chicks, it causes soft bones and defective beaks. In chick kidneys, it produces granular degeneration (nephrosis). The blood system is affected via, for example, inhibition by lead of enzymes such as ALAD, leading to anemia and impaired hematopoiesis. In the nervous system, lead disrupts animal chemical transmitters; mitochondria are poisoned; apoptosis results in neurobehavioral problems. Recent cellular studies with chickens finally confirmed that Pb exposure leads to cell proliferation impairment and cell death using ROS/mitochondria as a method of apoptosis (Liu et al., 2025; Merck Veterinary Manual, 2023).

At a biochemical level, lead inflicts its poisoning upon multiple targets. In contrast to the divalent ions, it substitutes for metal cations such as calcium, zinc, and iron. It also complexes with sulfhydryl groups of important enzymes. This results in oxidative stress—increase of ROS, lipid peroxidation, decreased activity by key antioxidant enzymes including SOD, CAT, and GPx. For example, pylethroids reduce NO production rate as well as synthesis of NOX by stimulating iNOS; inhibiting nNOS while leaving COX-2 unaffected. Hormonal disequilibrium has been found in Pb-exposed poultry. Significantly, the levels of central hormones such as thyroxine and gonadotrophins change, which affects growth performance: egg laying frequency declines with lay stops altogether for a while till both sides are back in balance again; immunity is weakened. (Aljohani et al., 2023; Oke et al., 2024; Generalova et al., 2025)

Possibly, the eggs of a variety of commercial breeds are not particularly contaminated with lead under certain conditions; but chronic exposure—especially to heavy metals—still constitutes a tremendous risk for animal performance and safety of the consumer. Tissue samples from experimental chickens exposed over 2 years (758 birds in two groups) provide clear evidence that lead is harmful to health. It produces lesions in the liver, kidney, and blood; results in a reduction of reproductive efficiency. Yields tested within these same two groups showed lower than normal fertility after one month when they had been incubated at 16°C instead of 24°C (Aendo et al., 2024; Mukherjee et al., 2022).

Saffron and Its Bioactive Compounds

Saffron (Crocus sativus L.) is a precious medicinal and functional plant of Asia, the Middle East, and Europe with a wide range of therapeutic values. Its effectiveness is due to a specific profile of biologically active compounds, namely crocin, crocetin, safranal, and picrocrocin, that determine its color, taste, and smell as well as its pharmacological properties (Mhamad et al., 2025).

Crocin is a water-soluble carotenoid glycoside and the most abundant component of saffron, with potent antioxidant effects. It has been reported that it scavenges reactive oxygen species (ROS), suppresses lipid peroxidation, and benefits the health of neurons and reproductive organs.

Crocetin, the aglycone of crocin, exerts anti-inflammatory and hepatoprotective activity by inhibiting inflammatory cytokines and ameliorating mitochondrial function.

Safranal, regarded as a volatile active constituent in saffron and being responsible for the characteristic aroma, acts as a neuroprotective and antidepressant agent, which is probably related to the GABAergic system and serotonergic neurotransmission.

Picrocrocin, which is responsible for bitterness, has been proved to be related to metabolic regulations and gastroprotective effects (Bostan et al., 2017; Anaeigoudari et al., 2023).

Pharmacologically, saffron exhibits a broad range of physiological effects. It has been reported to recover strong antioxidant activities and act against free radicals, thus increasing the action of endogenous antioxidants, SOD, CAT, and GPx. It shows anti-inflammatory activity by reducing different pro-inflammatory mediators such as TNF-α and IL-1β via NF-κB pathways. Furthermore, saffron has hepatoprotective and renoprotective properties in preserving the structure and function of the liver and kidneys under toxicosis, including heavy metal exposure like lead (Palani et al., 2025; Abedi et al., 2023).

Saffron has traditionally been used in folk medicine to cure digestive, cardiovascular, and sexual diseases. Historically, saffron has been used in the traditional systems of medicines for treating a number of ailments. Saffron has been used in Persian and Ayurvedic medicine as a treatment for fertility problems, mood disorders, and as an energizing tonic.

An evidence-based review of the traditional uses shows that modern experimental and clinical trials support a significant number, with positive effects of oxadiazaphosphinines being noticed in conditions caused by oxidative stress, neurodegenerative ailments, liver dysfunction, and sexual problems (Mhamad & Palani, 2025; Vakili et al., 2022).

Altogether, these exclusive contents of saffron and its multi-functional pharmacological effects suggest a valuable nutraceutical candidate for offsetting heavy metal toxicity as well as improving poultry health and productivity in a holistic way.

Biological Mechanisms of Saffron in Counteracting Lead Toxicity

Saffron (Crocus sativus L.) protects against lead (Pb)-induced damage predominantly by the active compounds in it—crocin, crocetin, safranal, and picrocrocin—a particular bioactive molecule that can act across multiple biochemical or physiological channels at once.

One of the most extensively studied methods erases the results of free radicals generated in redox linkage. When exposed to lead, one's body produces reactive oxygen species (ROS) that break down its own cells and cut the activity of antioxidant enzymes in them. Saffron supplements can restore glutathione (GSH)'s reduced form, active superoxide dismutase (SOD), or effective catalase (CAT), thus replacing antioxidants free to roam the cell and prevent injury (Mhamad & Palani, 2025; Abedi et al., 2023).

Meanwhile, saffron significantly lowers levels of malondialdehyde (MDA): an indicator of lipid peroxidation. By eliminating free radicals, and protecting and stabilizing cell membranes, it serves to avoid damage to lipids, proteins, DNA, etc., reducing cell death and degenerative changes within a single tissue (Oke et al., 2024; Anaeigoudari et al., 2023).

Apart from this, saffron also protects vital organs such as the liver and kidneys, which are the main targets of Pb accumulation. Studies show that saffron not only decreases Pb-induced hepatocellular necrosis but also normalizes serum liver enzyme levels and stops renal tubular injury in Pb-exposed animals. All this action is associated with regulation on detoxification pathways and inhibition of oxidative stress-induced apoptosis (Bostan et al., 2017; Aljohani et al., 2023).

Moreover, saffron improves hematological indices and alleviates Pb-induced anemia. In poultry and mammalian experiments, we could see increased red blood cell count and hemoglobin concentration, and heightened leucocyte activity after adding saffron to their diet. Saffron protects hematopoietic tissues against oxidative stress and helps restore normal blood functions and oxygen transport (Mhamad, Palani, & Al-Zubaidy, 2025; Liu et al., 2025).

Finally, it has both immunomodulatory and anti-inflammatory effects. When administered to animals, saffron significantly reduces such inflammatory mediators as TNF-α and IL-1β whilst increasing the proliferation rate of lymphocytes and antibody responses. These effects serve to safeguard the immune system, enabling both animals and birds to ward off infection better (Vakili et al., 2022; Palani, Ameen, & Shekhani, 2025).

In light of these findings, we assert that saffron has a number of targeted mechanisms for preventing lead poisoning—boosting various antioxidant systems, suppressing situations where free radicals are out of control, toughening up vital organs that should serve organisms well but are more exposed, raising values for someone's building materials, and last but not least, also the target of hematological indices and immune system function.

Experimental and Applied Evidence

Recently, researchers have published a new study about saffron or saffron anthocyanins overcoming lead-mediated adverse effects (Mhamad & Palani, 2025; Abedi et al., 2023). For example, with improved dietary supplements, adding saffron and its active ingredients can enhance birds' antioxidant status, reduce oxidative damage of body tissues, save them from lead exposure stress, etc.

Laboratory experiments demonstrate that in such cases, there is also increased productivity (Mhamad & Palani, 2025; Abedi et al., 2023); and finally, on zeolite hookup, dietary saffron supplementation increases broiler body weight gain, feed intake efficiency, and feed conversion rate in experimental lead-laden feed trials.

These beneficial effects are closely related to decreased malondialdehyde (MDA) levels in brain cortex homogenates and increased activities of tissue antioxidant enzymes such as superoxide dismutase (SOD) and catalase (CAT). Moreover, as reflected by normalized serum enzyme activity values and improved pathological pictures relative to Pb-exposed controls (Oke et al., 2024; Aljohani et al., 2023), liver and kidney function authorizations throughout dietary supplementation with saffron are significantly better for birds.

In contrast, field experiments stress that conditions ranging from individual environments, the amount of lead encountered concurrently in feed and drinking water through one's exposure to saffron dose form will all bring about variable effects.

In commercial farms, practical experience supports the introduction of saffron by-products (petals and extracts) into poultry diets to help birds counter environmental stressors. However, verification at an industrial scale remains somewhat lacking, and standardized protocols for the dosage and formulations are still needed (Marrone et al., 2024).

In addition, other publications are targeted at food quality characteristics due to birds being able to easily fly several hundred kilometers within TTL—unlike meats from cattle grown in Europe. By animal feeding saffron experiments, broilers improved meat spoilage resistance (lower TBARS values produced in 7 days definitely benefit the consumer), while enhanced water retention capacity also results in a far better shelf-life after curing compared to controls later undergoing transport stimulation such as gassing treatment for fruit or vegetable.

Consequently, saffron also shows active differentials in some physiological indicators such as reproductive function and immunity. In models of poultry, birds on saffron supplied by their diet had restored fertility indices and hatchability after being compromised by lead. Also seen are signs for improvements at the level of animals in blood cells: much higher hemoglobin (Hb) values with red cell counts (literature sources: Mhamad, Palani, & Al-Zubaidy, 2025; Liu et al., 2025).

These results suggest that saffron can be used as both a protective agent against lead-induced damage and also an innovative feed additive serving to boost productivity and health in poultry.

Butterflies? Around one in four, however, was already dead—including a female. Evidently, both bench and field studies are now revealing that saffron greatly counters lead poisoning effects on chickens. The way in which such recovery bet on a deer farm differs from routine tends to spread faster than ever before.

Future work needs to focus on how practical applications of saffron can be maximized in commercial poultry systems, including dose standardization and cost-benefit analysis and full integration with other phytogenic feed additives.

Future Perspectives and Applications

The expanding literature of the protective effects of saffron on lead-induced toxicity supports its possibility as a feed-based nutraceutical in the poultry industry.

The addition of saffron or its derivatives (petals, extracts, and standardized compounds) in the poultry diet could possibly be a prophylactic measure for enhancing oxidative stability, protecting the vital organs, immune system potential, and reproductive enjoyment.

This is in line with the current worldwide need for safer, natural feed additives which minimize reliance on synthetic drugs and enhance sustainable animal production systems (Mhamad & Palani, 2025; Abedi et al., 2023).

Despite their potential advantages, there are some concerns. The high price of a stigma of saffron, its limited supply, and the fluctuation in the concentration of active compounds are important barriers to wider implementation.

But, emerging evidence showed that the valorization of saffron by-products like petals and tepals—removed during spice processing and considered as waste material—might represent a cheaper and sustainable source for new antioxidant agents but also for bioactive ones (Marrone et al., 2024).

A further problem is that there are no standardized dose regimens. The current works varied for formulation (extracts vs. powders), concentrations, and length of administration, thus hampering the establishment of common feeding standards. This indicates the need for dose–response trials and formulation standardization prior to the use of saffron in commercial feed programs (Anaeigoudari et al., 2023; Sheikh et al., 2023).

Further studies must be conducted in large field scale trials on the farms under commercial farm conditions to confirm what was found in the laboratory trial and the long-term effect of saffron supplementation on poultry production, product quality including economic aspects. Incorporating supplementation with saffron into the broader context of animal production economics will be critical for evaluating how cost-effective this practice is relative to existing conventional feed additives. Mixing saffron with other phytogenics might improve its efficacy and may be used to bring down the cost per unit of production (Oke et al., 2024; Palani, 2025a, b).

In summary, saffron stands as a promising natural and safe dietary approach to alleviate heavy metal stress and improve poultry performance. However, challenges of cost, availability, and standardization and conducting on-farm economic evaluations will decide its future in commercial poultry nutrition.

Conclusion

Saffron (Crocus sativus) has been reported to have potential protective effects against lead-induced toxicity in birds due mainly to its antioxidant, anti-inflammatory, and organ-protective features. Saffron protects bird health and production subjected to HM exposure by enhancing the enzymatic defense, lowering oxidative stress, and improving hematological and immune statuses.

Saffron's bioactive profile and efficacy demonstrated its potential as a safe and effective nutraceutical feed additive. Adding saffron, in particular from the standpoint of its cheap derivative, to poultry diets has been recognized as one potential tool to augment animal welfare and product quality, and implement sustainable feeding practices within contemporary poultry systems.

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