

# Protective Role of Saffron (*Crocus sativus*) against Lead-Induced Toxicity in Poultry and Farm Animals: A Review

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**Annotation:** Pollution with heavy metals (Pb) is harmful to human and animal health, animal productivity and food safety. Abstract Background Exposure of birds and livestock to environmental lead significantly modifies the anaerobic biochemical pathways, induces oxidative stress and causes organ specific damage, all of which affects growth, reproduction and economic loss. But, the negative effects of these additives made researchers find natural feed additives with potent antioxidant activity as a potential alternative. Background: Saffron (*Crocus sativus*) is one of the richest sources of bioactive food compound bioactive ingredients (e.g., crocin, crocetin, safranal and picrocrocin) that is effective in lead toxicity. It exerts antioxidant activity through augmenting antioxidant enzyme activity, reducing lipid peroxidation, and maintaining parameters of hematology delivery, immune response and reproductive performance, as indicated by the data from saffron supplementation. Furthermore, its inclusion in animal feeds has the potential to reduce chemical and drugs use and produce sustainable animals' production of better quality products. In this review, we do not indicate that our hypothesis driven-integrative literature survey is devoid of further focused research on saffron supplementation but depict its nutraceutical prospects based on the putative ameliorative actions (glaring indications of potential if not well-defined actual; dose-dependent, high GrAS dosage toxicity and possible-to-establish concentration gradient toxicokinetics yet to be standardised aided by multinational field trial case studies) against heavy metal toxicity in poultry and farm animals.

**Keywords:** Lead toxicity; Poultry; Livestock; Antioxidant defense; Nutraceuticals; Sustainable.

## Introduction

Heavy metals contamination of the environment is recognized as a worldwide problem in every livestock and poultry production and systems. Lead is of particular interest amongst these metals due to its ubiquitous nature, persistence in the environment and its bioaccumulation potential in the food chain. The lead exposure of poultry and livestock, almost always associated with water (through contaminated water, feed, soil or industrial effluent), impairs disease resistance in animals (Aljohani et al., 2023; Mukherjee et al., 2022) and adversely affects the food safety of human consumers.

Due to its toxic nature, lead inflicts myriad physiological and biochemical alterations, such as hepatotoxicity, nephrotoxicity, hematological dysfunction, neurotoxicity, and reproductive diseases. Pb interferes with enzymes, induces oxidative stress by excess of reactive oxygen species (ROS), and consumption of antioxidant defenses, resulting in lipid peroxidation and cellular injury on a molecular level (Merck Vet Man, 2025; Oke et al., 2024).

This progresses to not only harm animal welfare and production profit, but also burden poultry and livestock farmers with tremendous economic losses. Tensor records on conventional remedy for this poisonous heavy metallic assets remained largely accretional due to polygenic influence possessions of conventional therapeutic machineries; for this reason, the additive & nutraceutical utilization of herbal feed had been given extra focal point for the management of this heavy metallic toxicity. As redox balance, response and resilience of the animal can be modulated (Ebrahimi et al., 2023), plant metabolites, especially antioxidants, have been pointed out as excellent regulatory candidates for compensation.

Nutraceutical potential of saffron (*Crocus sativus* L.) for use in animal feed Elsevier Ltd With well-known free radical scavenging, anti-inflammatory, and cytoprotective properties, this prized spice is rich in bioactive compounds like crocin, crocetin, safranal and picrocrocin (Bostan et al., 2017; Golden et al., 2023). Research Papers on the Scientific Value of Saffron The positive effect of saffron on antioxidant status and oxidative damage and on productive and reproductive performance of poultry has been documented in many experimental works under stressful or dietary inducible toxic conditions (Vakili et al., 2022; Mhamad & Palani, 2025). Besides its role as protectant, saffron is also expected to help in long-term financial treatment (Palani, 2025a; Palani, 2025b), therefore, it likely plays a role in much sustainable animal production systems.

Hence, the objective of this manuscript is to summarize the recent findings pertaining to the protecting effects of saffron (*Crocus sativus*) against lead-induced physiological and biochemical disturbances, in poultry and farm animal species. Particularly, molecular pathways, summary of experimental data and potential for saffron to be considered as a nutraceutical for sustainable livestock production will be outlined.

## Lead Toxicity in Farm Animals

### Sources of Lead Contamination

Thus, Pb is one of the most widespread heavy metal in environment, having natural and anthropic source. Farm animals are primarily at risk of exposure due to drinking contaminated water, grazing on contaminated feed, atmospheric deposition and soil ingestion. Industrial activities such as smelting and mining, fossil fuel combustion, and lead-based pesticides and paint applications in regions with lax environmental regulations further compound this issue (Aljohani et al., 2023; Mukherjee et al., 2022). In grazing animals, exposure occurs mainly

through ingestion of contaminated forage and soil whilst in poultry, industrial effluent contaminated water and feed grains can lead to lead entry respectively.

### Absorption and Bio-distribution

Intestinal absorption of lead is 33% higher administered orally than parenterally and highly factors affecting lead absorption are age, nutritional status and composition of the work environment. Pb accumulation is age dependent (neonates absorb Pb more readily than adults) (Egwyunenga et al.), and Pb absorption will also be affected by exposure levels of Pb. The preexisting lead in blood would be taken up by the erythrocyte, and here it can stay, stored in the erythrocyte (when temporarily stored or distributed to the soft tissue) or stored or stay in the bone (second depot – here lead can easily also re-enter the circulation (Merck Veterinary Manual, 2025). For instance, lead (with a slowly excreting depreciation rate in bone [its half-life], also an issue due to bioaccumulation health trajectories for animals of concerned animal species) [Mukherjee et al., 2022].

### Physiological Effects

Lead poisoning is characterized by multi organ involvement. According to the study, Pb is known to weaken detoxification processes in liver and goes on causing degenerate of hepatocellular and inhibiting the enzymes activity (11). It injures the kidney by causing nephropathy, tubular degenerative changes and impaired filtration. CNS: Lead action as neurotransmitters in the CNS results in neurobehavioral impairment, decreased reflexes, and in severe cases encephalopathy (Aljohani et al. It has been suggested that Pb disrupts the reproductive system in terms of sperm quality [5], ovarian function, fertility, and hormone level [6] (Palani et al., 2025; Ameen & Shekhani). Overall, these effects contribute to both low animal welfare and productivity.

### Biochemical Alterations

Biochemically, lead causes oxidative stress. Lead (Pb) enhances oxidative stress (OS) through the augmentation of reactive oxygen species (ROS) as well as suppression of the endogenous antioxidant defensive mechanisms such as activities of antioxidant enzymes e.g., superoxide dismutase (SOD), catalase (CAT) and glutathione peroxidase. A report states it has blocked levels of CAT, SOD, and GPx. This imbalance leads to lipid peroxidation, oxidative protein damage and DNA degradation (Oke et al., 2024). It is a potent enzyme inhibitor, as it binds strongly to sulfhydryl groups, displacing calcium, zinc and iron which are intimately involved in several enzymatic processes, causing alteration of heme biosynthesis and consequently deficiency of hemoglobin synthesis. Ebrahimi et al. Sci. 2023, 5 When arrays reveal widespread impact of environmental toxicants, Pb-intoxicated animals showed low levels of thyroid hormone and gonadal hormone.

### Evidence from Poultry and Ruminants

Results: Pb exposure in poultry and broilers causes a reduction in growth and feed efficiency, reduction in egg production and carcass quality with elevation of markers of oxidative damage (Aljohani et al. Prolonged chronic grazing of ruminants in contaminated pastures leads to systemic accumulation of Pb which has been shown to produce hepatic and testicular lesions, oxidative stress pollution, and reproductive dysfunction (Palani et al, 2025). Mukherjee et al. Since 20th ground science (2022) have defined that lead poisonous trace effect depend upon dose, factor and species of exposed However, the overall end is decrease in manufacturing and fitness which are an big financial loss to the farmers.

### Chemical Composition of Saffron

Saffron (*Crocus sativus* L.) is an economically significant medicinal and spice plant, and the dried stigmas of *Crocus sativus* flowers were utilized as saffron. Saffron contains a diverse range of carotenoids, including crocins, lycopene, and carotene, as well as different flavonoids,

including quercetin, kaempferol, and myricetin, as well as terpenoids and phenolic compounds, which are responsible for the unique pharmacological and therapeutic potential of saffron (Bostan et al., 2017). These compounds together may explain the uniqueness of saffron as a potential nutraceutical in the human and animal body. However, the unique color, taste and smell of saffron stem from the four main bioactive compounds, namely crocin (a carotenoid), crocetin (a carotenoid), safranal (a terpenoid) and picrocrocin (a monoterpenoid).

### **Main Biocomponents**

**Crocin:** A water-soluble carotenoid that gives saffron its deep red color. It possesses high antioxidant activity by removing free radicals and preventing lipid peroxidation. Crocin is also said to be protective in the case of nerves and the heart (Mhamad & Palani, 2025).

A dicarboxylic form of carotenoid Crocin-A carotenodiphenol derived from hydrolysis of crocin. Due to its low polarity, Crocetin crosses biological membranes quite easily, thus increasing its bioavailability. In addition, it has been shown saffron exerts anti-inflammatory, anticancer properties and hepatoprotective role (Abedi et al., 2023).

Saffron Extract or Fresh Saffron Antonin Bostan Abstract Extracts from fresh saffron are potentially effective antioxidant (Bostan et al 2017), anticonvulsive and antidepressant Monoterpene Aldehydes- Safranal responsible for saffron characteristic flavor Mechanism(s) of Action are under investigation The protective effects on the CNS (central nervous system) Abstract AbstractMonnosub11,17,18,19,20 and Dosunmu 32 have identified various of these properties from saffron extract or fresh saffron, but, seem to actively be under study and dosing continues to e under elucidation 24, 25, 26, 277-28.

**Picrocrocin:** A bitter glycoside precursor of safranal, responsible for the bitter taste of saffron. Although information regarding picrocrocin is limited, it may play a part in stimulating digestion and participation in some antioxidant defences as well.

### **Pharmacological Properties**

Saffron and its major components have been well detailed in terms of their pharmacological effects. These include: **Antioxidant:** Its activity quenches the free radicals and protects cellular damage caused by oxidative stress (Abedi et al., 2023). **Anti-Inflammatory—**Reducing expression of pro-inflammatory mediators like TNF- $\alpha$ , IL-6, and nuclear factor kappa B – NF- $\kappa$ B— to reduce low-grade chronic inflammation. **Neuroprotective effect:** Both crocin and safranal are capable of neuroprotective effects against excitotoxicity, neurodegeneration and cognition-promoting potential (Bostan et al., 2017). **Hepatoprotective & Reno protective** Saffron appears to play a protective role in liver and kidney animal studies, due to the ability of saffron to protect against chemical-induced toxicity, including heavy metals (Mhamad, Palani & Al-Zubaidy, 2025).

### **Traditional and Contemporary Uses**

Saffron is the dried flower stigma of *Crocus sativus* that has been reported to possess medicinal properties in Persian, Indian and Mediterranean folk medicine to treat depression, asthma, and digestive system disorders. Saffron extracts had also used for livestock agriculture to increase feed intake and to increase their activity in livestock farming (Mhamad & Palani, 2025). Recent pharmacological studies have broadened the applications for this space, thus saffron is used as a remedy of diseases linked to oxidative stress, also enhances reproductive performance and provides defence against lead toxicity in both avian and mammalian species. In some poultry species, saffron supplementation is beneficial in terms of antioxidant status, egg quality and immune function under stress conditions (Vakili et al., 2022; Ebrahimi et al.

## Natural Protective Mechanisms of Saffron against Lead Intoxication

### Increasing Activity of Antioxidant Enzymes

The most important protective mechanism of saffron against lead-induced oxidative damage is its ability to induce host biochemical antioxidant defense mechanism. When superoxide dismutase, catalase and glutathione peroxidase — nature's stops on oxygen wear — wear down in the presence of lead, other enzymes have to do double time. Importantly, crocin and crocetin, which are well-known carotenoid derivatives of saffron, have been known to increase the expression of these enzymes, thereby regulating the redox potential and reactive oxygen species in the cells.

### Reducing Levels of Lipid Peroxidation

Lead induces lipid peroxidation that spoils cellmem-branes and free malondialdehyde are also released as a marker of oxidative stress. Addition of saffron brings down MDA considerably — amurs to indicating saffron is capable of adequately 4 absorbing lipid per oxidation, thereby stabilizing lipid bi layers. But it is crocin that is more crucial to this specific antioxidant benefit, as in drops, it eliminate totally free radicals by stranding in lipid oxidation chain reaction.

### Hepatic and Renal Protection

Basically, lead spoilage affects the liver and the kidneys. Conditions in Pb-treated animals are classical for liver hygiene and kidney pathology. In most cases, liver cell degeneration and massive renal tubule necrosis are revealed, signals that the systemic dysfunction can be felt. On the other side, crocin of saffron protects liver and kidney tissue from oxidative destruction and maintains organ standard histology. As a consequence, saffron supplements may have a rooting as natural organotropics.

### Improvement of Hematological and Immunological Parameters

In conclusion, saffron realises protection against lead possibly due to elevation in red blood cell count, haemoglobin content and better Feb-23. Sauce equalization causes rings of penetration of protection against Pb in rats and pigs, increasing hyperemia and immunity. They add up to an ideal exit — especially considering that while alternatives (alongside its use) have tested to be very questionable. The single drawback is that the herbs become unable to counteract protracted falling blood lead levels Long term Pb exposure leads to cumulative lassitude eventually.

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### Reproductive Health and Correct Operating

Also, chronic lead exposure in males can lead to sperm quality issues and testicular damage, while in females it results in ovulatory and hormonal dysfunction [26]. Saffron has antioxidation and anti-inflammatory effects that preserve the reproductive organ microenvironment and prevent germ cell apoptosis. Optiemal hop in early-stage saffron foresees on improved fertility in later generations by optimal vigor and disease resistency Saffron research analyzes the significance of saffron consumption associated with the productive capacity and profitability of the farm in animals of the different phases of exposure to different forms of lead.

## Effects on Productive Performance

Some studies have shown growth promoting effects of Saffron on poultry and ruminants. Is the enhancement of body-weight gain, suppresses the feed conversion ratio, and improves the quality of egg production in poultry (Vakili et al. 2024; Ebrahimi et al. 2023). With this knowledge, it was found that saffron by-products very significantly improved rumen fermentation, and nutrient digestibility and milk yield in ruminants (Bostan et al. 2017). Oxidative stress can be reduced by these antioxidant properties of saffron for better metabolic efficiency.

## Effect on Protein Quality of Meat and Animal Products

Saffron was also able to decrease muscle lipid peroxidation, improving the shelf-life and stability of broilers (as shown by Vakili et al. (5). 2024).– In addition, can contribute to better water holding<sup>2</sup> and safety of food by decreasing the presence of microorganism<sup>3</sup>; (Oke et al., 2024) The antioxidant-rich Saffron also indirectly promotes the quality of milk in dairy animals by increasing its antioxidant content, but also by reducing somatic cell counts and by promoting udder health (Abedi et al. 2023).

## Effect on Blood Count and Damage to Organs

Improvement in hematology indices (increased hemoglobin levels and leukocyte counts) in lead-exposed animals that received dietary saffron supplementation. (Mhamad & Palani, 2025). Aljohani et al. 2023). The superiority of immune function response to stress especially signifying enhanced disease resistance under stress in saffron supplemented poultry (trial on ebrahimi et al. 2023). Comparison Between Poultry and Ruminants It has been shown to possess anti-oxidant properties, enhance production parameters such as growth and egg quality in poultry species (Vakili et al. 2022). For example, traits of interest for ruminants are milk yield, reproductive efficiency, rumen health and improved fertility Performance (Palani, Ameen and Shekhani, 2025). Increases productivity, generalizes product quality and contextual-independent reaction to evolve toward environmental stressors by the advantages of saffron enrichment.

## Future Perspectives and Practical Applications

### Saffron Addition in the Diet

Recent global-scale research findings have indicated that saffron and its byproducts (petals, floral residues) as phytogetic feed additives for animal diets supplementation could be an attractive proposition in the enhancement of antioxidant status and performance. The authors concluded that adding 80 ppm saffron petal extract to the diet can be regarded as a natural feed additive for enhancing the antioxidant status and lowering lipid peroxidation in laying hens. These results support potential practical application of the saffron petal in the dairy goat feeding plan to receive more healthy and high quality products, as supplemented with saffron petal up to 3% of total diet enhanced antioxidant activity in milk and blood. Safflower meal was used in poultry after being dried and dress in its petals and it improved broiler growth efficiency and carcass yield up to 2 g/kg and strengthened the rational use of this crop on the poultry farm. This positive effects could be attributed to the three active bio-ingredients of saffron; crocin, crocetin and safranal with potential anti-oxidant and anti-inflammatory properties.

### Practical Guidance for Initial Trials:

Poultry: Saffron extract 50–100 ppm or 1–2 g/kg dried petals. 1–3% of dry matter saffron petals (or standard preparation) in diet of ruminants. These doses are based on current experimental works and will need to be optimized individually by dose–response trials. The Challenges and Barriers: Cost, Availability, and Standardized Dosage. The biggest challenges being cost and availability. For a commercial scale, the dry stigma are harvested manually (15–30 kg/ha and never more than 50 kg/ha) and directly sold as spices for human consumption (not applicable for animal fed at a large scale, except at research lab scale, due to their cost). Thus, the valorization

of by-products, petals, and tepals is a research pursuit since they are low-value and abundant sources, while also being endowed with bioactive antioxidant compounds.

### **Standardization and Dose:**

Experimental design is highly variable, source of saffron (aqueous/ethanolic extracts, dried petals or standardized crocin preparations) and concentrations of active compounds are frequently not reported. Future applications will require standardised production with the same amount of crocin or crocetin to produce the maximum impact and to guarantee safety.

### **Interactions with Other Feed Additives:**

Promising results from phytogetic feed additive studies in poultry and ruminants may point to saffron replacing or being used in conjunction with other conventional natural supplements (organic acids, essential oil); however, further dose–response studies and tests for interaction need to be conducted for combinations of additives [8].

### **Sustainability and Supply Chain Opportunities**

The saffron cultivation process generates enormous quantities (~350 flowers fresh weight/1 kg dry stigmas) of floral waste rich in petals and other floral plant material. The use of these latter as feed additives can present waste minimization, potential economic gains for saffron producers, and high-quality sources of antioxidants for animal production based on new data from circular economy studies and life-cycle assessment (LCA) [11]. In addition, appealing aspects of the inclusion of residual saffron in ruminant feeding belong to an extensive context associated with the production of bio-based feed that promotes both reductions in environmental footprint while meeting supply for high producing animal classes [14].

### **Future Research Directions**

There is promising literature to date on these issues, but between now and October 2023, we need bigger & better studies in the following: Commercial farm-based long term field trials Product quality and return studies. These participations in the cost-effectiveness analyses of standardized intra-oral extracts against the respective valid reduced price dried petals with a cost–benefitor cost perkg milk, eggandkg live weight gain per treatment. The high-dose administration of crocin in safe dosage forms within established safety limits. Broader range of stress models: the ability of saffron to confer protection against a range of environmental stresses (heavy metals, mycotoxins, pathogens) must to be assessed in order to evaluate the relevance of these results to actual production systems.

### **Executive Recommendations**

Minimum: 50 Phillips, 100 ppm extract in poultry (or 1 2 g/kg dried petals in broilers; inclusion at 3% in ruminants. Lesson 1: Aim for way with cost & sustainability on by-products(use of petals/tepal). Other phytogetic additive combinations should be tested on a dose–response basis progressively.

### **Conclusion**

The bioactive crocin and its metabolites in saffron (*Crocus sativus* L.) have an anti-melancholic action in broilers or farm animals poisoned with lead. Saffron may help support antioxidase system, reduce oxidative stress, regulate the balance of free and abundant fatty acids in animals and restore homeostasis in the biological functions of all organs, including gut mesenteric lymph nodes. May lead to enhanced growth, enhanced reproductive success and improved resistance. Therefore, these benefits provide saffron to such a feed additive as a safe, natural, sustainable solution to the major problem of heavy metal toxicity in livestock and provides the possibility of sustainable production in the long run.

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