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Ameliorative effects of C*urcuma longa* (turmeric) rhizoid ethanolic extract on cadmium chloride-induced reproductive toxicity in male albino rats

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Abstract

Cadmium exposure is a significant environmental toxicant associated with male reproductive dysfunction through oxidative damage and impairment of sperm quality. This study evaluated the ameliorative effects of *Curcuma longa* Rhizoid ethanolic extract on cadmium chloride–induced reproductive toxicity in male albino rats. Twenty adult male albino rats weighing 150–200 g were randomly assigned into five groups of four animals each. Group 1 served as the normal control, while Group 2 served as the cadmium-treated control. Groups 2–5 received 30% of the LD_{50} of cadmium chloride every other day for 17 days. Thereafter, Groups 3, 4, and 5 were administered 100, 200, and 300 mg/kg body weight of *Curcuma longa* Rhizoid ethanolic extract daily for another 17 days. At the end of the 34-day experiment, animals were sacrificed, and the testes and epididymis were excised. Semen samples collected from the cauda epididymis in warm physiological saline were analyzed. Sperm concentration was determined using a haemocytometer, motility was assessed microscopically by estimating the percentage of actively moving sperm cells, while morphology was evaluated using stained smears to identify structural abnormalities. Cadmium exposure significantly impaired sperm functional parameters, whereas treatment with the extract resulted in improved sperm concentration, enhanced morphological integrity, and partial restoration of motility indices. These findings indicate that Curcuma longa Rhizoid ethanolic extract exhibits ameliorative potential against cadmium-induced reproductive toxicity.

Keywords: *Curcuma longa*; Cadmium chloride; Reproductive toxicity; Sperm parameters; Albino rats; Oxidative stress

1. Introduction

Environmental contamination by heavy metals has become a major global health concern due to rapid industrialization, urban expansion, and agricultural activities. Heavy metals are persistent environmental pollutants capable of accumulating in biological systems and producing long-term toxicological effects. Among these contaminants, cadmium is recognized as one of the most hazardous metals because of its long biological half-life, bioaccumulative nature, and high toxicity even at low exposure levels.

Cadmium exposure occurs mainly through contaminated food and water, industrial emissions, cigarette smoke, and occupational exposure. After absorption into the body, cadmium accumulates in organs such as the liver, kidneys, and reproductive tissues, where it interferes with cellular metabolism and induces structural and functional damage. Unlike essential trace elements, cadmium has no physiological benefit and exerts deleterious biological effects through multiple mechanisms.

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The male reproductive system is particularly susceptible to cadmium toxicity. Experimental studies have demonstrated that cadmium chloride disrupts spermatogenesis, alters hormonal regulation, and damages seminiferous tubules, resulting in reduced sperm concentration, decreased motility, and abnormal sperm morphology. These alterations may ultimately impair fertility and reproductive efficiency.

Oxidative stress represents a major mechanism of cadmium-induced reproductive toxicity. Cadmium indirectly promotes the generation of reactive oxygen species (ROS), leading to lipid peroxidation, protein oxidation, DNA damage, and apoptosis of germ cells. Spermatozoa are especially vulnerable to oxidative damage because of the high polyunsaturated fatty acid content of their membranes and limited endogenous antioxidant defenses.

Natural antioxidants derived from medicinal plants have gained increasing scientific interest as protective agents against toxicant-induced tissue damage. *Curcuma longa*, a perennial herb belonging to the Zingiberaceae family, is widely known for its medicinal and nutritional value. The plant contains biologically active compounds such as curcumin, flavonoids, phenolic compounds, and essential oils with potent antioxidant and anti-inflammatory properties.

Bioactive constituents of *Curcuma longa* have been reported to neutralize free radicals, enhance antioxidant enzyme activities, and stabilize cellular membranes against oxidative injury. These properties suggest that *Curcuma longa* may mitigate reproductive damage induced by heavy metal exposure.

Although several studies have documented the pharmacological benefits of *Curcuma longa*, limited information exists regarding the ameliorative effects of *Curcuma longa* rhizoid extract on semen quality following cadmium chloride exposure. Therefore, this study was designed to evaluate the protective effects of *Curcuma longa* rhizoid ethanolic extract on sperm concentration, motility, and morphology in male albino rats exposed to cadmium chloride.

2. Materials and Methods

2.1. Study Location

The experiment was conducted at the Biochemistry Laboratory, Department of Chemical Sciences, Akwa Ibom State Polytechnic, Ikot Osurua, Ikot Ekpene, Akwa Ibom State, Nigeria.

2.2. Collection and Identification of Plant Material

Fresh *Curcuma longa* rhizoids were purchased from a local market in Ikot Ekpene, Akwa Ibom State, Nigeria. The plant material was identified using standard botanical characteristics prior to experimental use.

2.3. Preparation of Curcuma longa Rhizoid Ethanolic Extract

The *Curcuma longa* rhizoids were washed thoroughly with distilled water to remove debris and contaminants. The samples were sundried to remove moisture and subsequently ground into fine powder using a laboratory grinder.

Approximately 350 g of powdered *Curcuma longa* rhizoid was soaked in 70% ethanol for 72 hours with intermittent agitation to enhance extraction efficiency. The mixture was filtered using Whatman No. 1 filter paper, and the filtrate was concentrated in a water bath at 45 °C. The concentrated extract was stored at 4 °C in a refrigerator until required for administration.

2.4. Experimental Animals

Twenty adult male albino rats weighing between 150–200 g were obtained from the animal house of the Biochemistry Unit, Department of Chemical Sciences, Akwa Ibom State Polytechnic. The animals were acclimatized for two weeks under standard laboratory conditions with free access to feed and water.

3. Experimental Design

The animals were randomly divided into five groups of four rats each:

- Group 1: Positive control (normal feed and water)
- Group 2: Negative control (cadmium chloride only)
- Group 3: Cadmium chloride + 100 mg/kg body weight *Curcuma longa* rhizoid extract
- Group 4: Cadmium chloride + 200 mg/kg body weight extract

- Group 5: Cadmium chloride + 300 mg/kg body weight extract

Groups 2–5 received cadmium chloride every other day for 17 days. Thereafter, Groups 3–5 received daily oral administration of Curcuma longa rhizoid extract for another 17 days, giving a total experimental duration of 34 days.

3.1. LD_{50} Determination and Dose Calculation

The median lethal dose (LD_{50}) of cadmium chloride used for dose determination was 88.0 mg/kg body weight in rats as reported by the Agency for Toxic Substances and Disease Registry (ATSDR, 2018). Thirty percent of the LD_{50} equivalent to 26.4 mg/kg body weight was calculated using the mean body weight of animals and dissolved in distilled water prior to administration.

3.2. Organ Collection and Preparation of Epididymal Sperm Suspension

At the end of the experimental period, animals were sacrificed under mild anesthesia. The testes and epididymides were carefully excised through a lower abdominal incision. The cauda epididymis was transferred into warm physiological saline (0.9% NaCl at 37 °C), and a small incision was made to allow spermatozoa to diffuse into the medium, producing epididymal sperm suspension for semen evaluation.

3.3. Semen Analysis

Semen samples were collected from the cauda epididymis into warm physiological saline to obtain sperm suspension. Sperm concentration was determined using a Neubauer hemocytometer following dilution, while motility was evaluated microscopically by estimating the percentage of motile sperm cells on fresh preparations. Morphological assessment was carried out using eosin–nigrosin staining to identify structural abnormalities, with at least 200 sperm cells examined per sample according to standardized procedures described by the World Health Organization (2021).

3.4. Statistical Analysis

Data were expressed as mean ± standard deviation (Mean ± SD). Statistical differences among groups were analyzed using one-way analysis of variance (ANOVA), and significance was accepted at $p < 0.05$.

4. Results

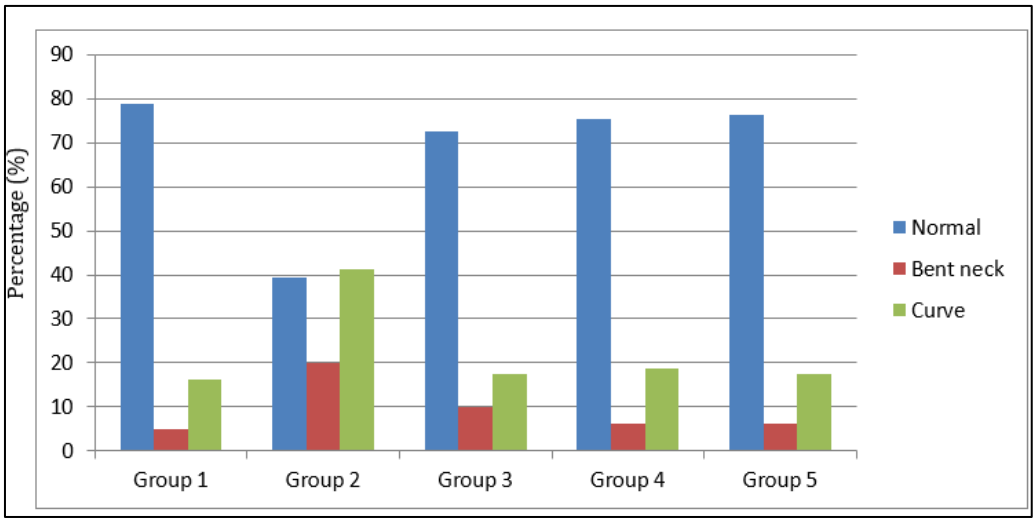

Figure 1 The Result of *Curcum longa* (Turmeric) rhizoid extract of semen morphology of male albino wistar rats exposed to Cadmium chloride

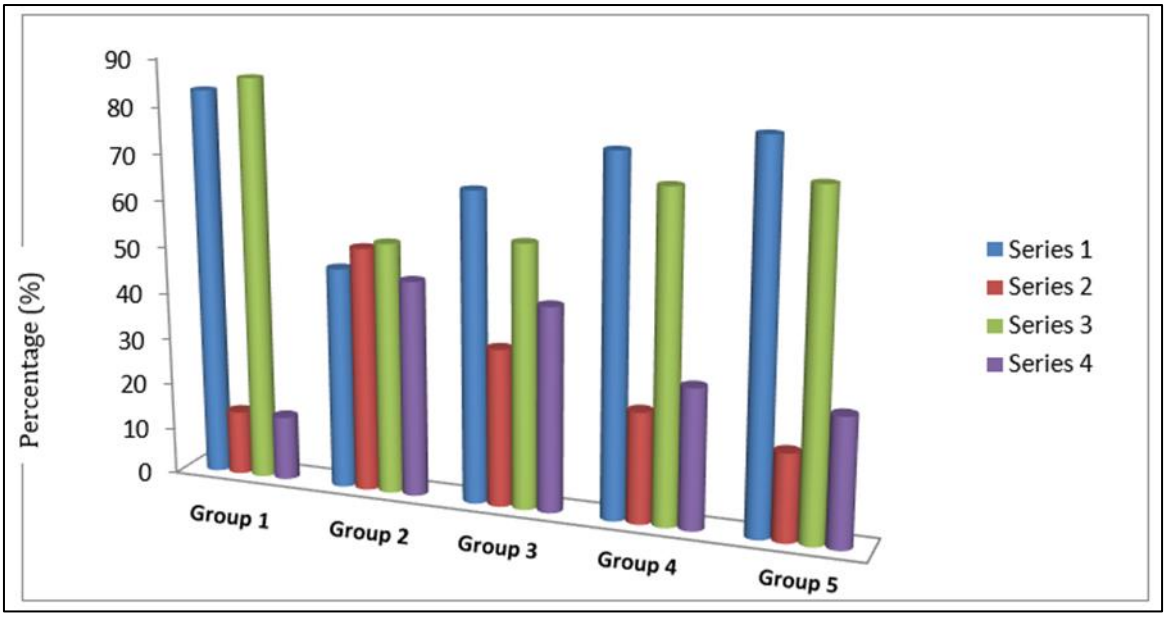

Figure 2 The Result of Curcum longa (Turmeric) rhizoid extract of semen motility of male albino wistar rats exposed to Cadmium chloride

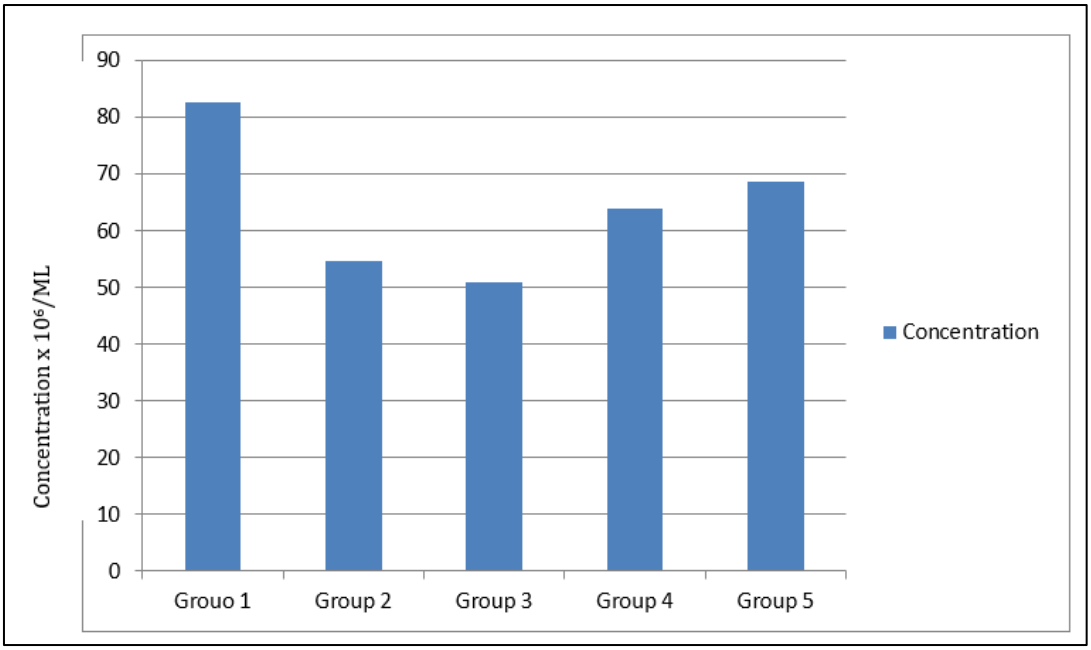

Figure 3 The Result of the effect of *Curcuma longa* rhizoid extract on the semen concentration of male albino rats exposed to Cadmium chloride

5. Discussion

Cadmium chloride exposure is a well-established cause of reproductive toxicity due to its capacity to induce oxidative stress, disrupt endocrine signaling, and produce structural damage within reproductive tissues. The present study investigated the ameliorative potential of *Curcuma longa* rhizoid ethanolic extract on semen characteristics of male albino rats exposed to cadmium chloride, using sperm motility, concentration, and morphology as indices of reproductive competence. The findings demonstrate that cadmium exposure negatively altered semen quality, whereas

administration of *Curcuma longa* rhizoid extract produced observable improvements, suggesting biochemical and histological recovery mechanisms.

Sperm motility is a critical determinant of fertilization capacity because it depends on mitochondrial energy production, membrane integrity, and intracellular ionic balance. In this study, motile and non-motile sperm cells showed a non-significant decrease in treatment groups compared with the normal control but improved relative to cadmium-exposed animals. Active sperm cells increased slightly following treatment, while sluggish sperm cells declined compared with the cadmium control group. These findings indicate that cadmium impaired functional sperm activity, whereas *Curcuma longa* rhizoid extract supported partial restoration of sperm function.

Cadmium toxicity promotes excessive generation of reactive oxygen species (ROS), which disrupt mitochondrial oxidative phosphorylation and reduce adenosine triphosphate (ATP) production required for sperm motility. Spermatozoa possess membranes rich in polyunsaturated fatty acids that are highly susceptible to lipid peroxidation, making them particularly vulnerable to oxidative damage (Aitken & Roman, 2008). Oxidative injury alters membrane fluidity and damages axonemal proteins necessary for flagellar motion. Furthermore, cadmium interferes with calcium signaling and enzymatic pathways involved in sperm energy metabolism, ultimately impairing progressive movement (Thompson & Bannigan, 2008; Genchi *et al*., 2020).

The modest improvement in motility observed following treatment may be attributed to antioxidant constituents of *Curcuma longa*. Curcuminoids scavenge reactive oxygen species and enhance endogenous antioxidant enzymes such as superoxide dismutase and catalase, thereby restoring redox homeostasis (Hewlings & Kalman, 2017). Preservation of mitochondrial integrity promotes ATP synthesis required for sperm movement, while inhibition of lipid peroxidation stabilizes sperm plasma membranes (Menon & Sudheer, 2007). The incomplete restoration of motility relative to the normal control may indicate that functional recovery requires longer therapeutic exposure compared with structural repair.

Sperm concentration analysis revealed a significant reduction in the cadmium-treated group compared with the normal control, confirming suppression of spermatogenesis. Cadmium disrupts the blood–testis barrier and induces apoptosis of germinal epithelial cells through oxidative stress mechanisms (Renu *et al.,* 2021). Sertoli cells, which provide nutritional and structural support to developing germ cells, are particularly sensitive to heavy metal toxicity, resulting in decreased sperm production. Additionally, Cadmium inhibits steroidogenic enzymes and reduces testosterone synthesis, thereby impairing spermatogenic progression (Siemiątkowska *et al*., 2011).

Treatment groups demonstrated a non-significant increase in sperm concentration relative to cadmium-exposed animals, indicating gradual recovery of spermatogenic activity. The improvement observed following administration of *Curcuma longa* rhizoid ethanolic extract may be attributed to its potent antioxidant and anti-inflammatory properties, which likely reduced cadmium-induced oxidative stress, limited germ cell apoptosis, enhanced cellular detoxification through possible metal-chelating activity, and supported restoration of steroidogenic function, thereby promoting recovery of spermatogenesis and improving sperm concentration. *Curcumin* activates cytoprotective signaling pathways such as nuclear factor erythroid-2–related factor 2 (Nrf2), leading to increased expression of antioxidant defense genes that protect testicular tissues from oxidative injury (Gupta *et al.,* 2013).

Morphological evaluation revealed significant improvement in normal sperm cells alongside reductions in bent neck and curved sperm abnormalities in treatment groups compared with cadmium-treated animals. Abnormal sperm morphology reflects disruption of spermiogenesis caused by oxidative DNA damage and cytoskeletal instability. Reactive oxygen species generated by cadmium exposure induce chromatin fragmentation and protein oxidation, leading to defective sperm structures that reduce fertilization potential (Agarwal *et al.,* 2014). Improvement in morphology following treatment suggests stabilization of cellular membranes and protection of developing germ cells. Curcuminoids inhibit lipid peroxidation and preserve membrane architecture, preventing structural deformation during sperm maturation (Priyadarsini, 2014). Anti-inflammatory effects further reduce cytokine-mediated tissue injury within seminiferous tubules, allowing normal differentiation of spermatids into mature spermatozoa (Hatcher *et al*., 2008).

The reproductive improvements observed in this study may also be explained through systemic protective effects involving other organs affected by heavy metal toxicity. Cadmium accumulates in detoxification organs such as the kidney, where it induces oxidative stress and structural degeneration. Renal dysfunction disrupts metabolic homeostasis and may indirectly impair reproductive physiology through accumulation of toxic metabolites and altered electrolyte balance. Histopathological investigations have demonstrated tubular degeneration, epithelial necrosis, and inflammatory infiltration in kidneys following heavy metal exposure. Udo *et al.* (2024) reported significant

histopathological alterations in kidneys of Wistar rats exposed to heavy metals, indicating systemic oxidative injury capable of contributing to reproductive dysfunction. Restoration of antioxidant balance following administration of *Curcuma longa* rhizoid extract may therefore improve both renal and reproductive functions simultaneously.

Biochemically, the ameliorative effects observed can be attributed to multiple interconnected mechanisms. Antioxidant activity reduces reactive oxygen species and prevents lipid peroxidation, anti-inflammatory actions suppress nuclear factor-kappa B signaling pathways, and potential metal-chelating properties reduce cadmium accumulation within tissues. Enhancement of endogenous antioxidant enzyme activity strengthens cellular defense systems, preserving seminiferous tubular architecture and improving sperm quality. These coordinated biochemical actions explain the simultaneous improvement observed in sperm concentration, morphology, and motility.

The results of this study support the concept that oxidative stress represents the central mechanism linking cadmium exposure to reproductive dysfunction. Intervention with phytochemical antioxidants such as *Curcuma longa* rhizoid extract offers a multi-target protective strategy capable of restoring cellular homeostasis. Natural plant-derived compounds have gained considerable attention as therapeutic agents due to their safety profile and broad biochemical activities (Hewlings & Kalman, 2017; Gupta *et al.,* 2013).

6. Conclusion

Cadmium chloride exposure induced reproductive toxicity characterized by decreased sperm concentration, impaired motility, and increased morphological abnormalities in male albino rats. These alterations were associated with oxidative stress–mediated cellular damage and disruption of spermatogenic processes. Administration of *Curcuma longa* rhizoid ethanolic extract produced ameliorative effects evidenced by improved sperm concentration, enhanced morphological integrity, and partial restoration of motility parameters. The protective action of the extract is attributed to antioxidant, anti-inflammatory, and cytoprotective mechanisms that mitigate cadmium-induced biochemical and histopathological damage. Integration of histopathological evidence further suggests that reproductive recovery may be linked to systemic organ protection, including restoration of kidney structure affected by heavy metal toxicity as demonstrated by Udo *et al.* (2024). Collectively, these findings indicate that *Curcuma longa* rhizoid ethanolic extract possesses significant therapeutic potential as a natural protective agent against heavy metal–induced reproductive dysfunction.

Compliance with ethical standards

Ethical approval for this study was obtained from the Biochemistry Unit, Department of Chemical Sciences, Akwa Ibom State Polytechnic, Ikot Osurua, Akwa Ibom State, Nigeria. All laboratory animals were handled in accordance with institutional and internationally accepted guidelines for the care and use of experimental animals. Experimental procedures were conducted to minimize pain, stress, and discomfort. The number of animals used was kept to the minimum required to achieve reliable scientific results.

Disclosure of conflict of interest

There was no conflict of interest.

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