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# Gonadoprotective potential of *Taraxacum officinale* on testicular tissue damage induced by cadmium chloride

**Ainur Jumagaliyeva[1]*, Zina Tungushbayeva[1], Dossymbekova Raushan[2], Gulnara Tashenova[1], Alfiya Baigutty[1], Galiya Tatarinova[3], Komus Batyrova[1]**

*1. Department of Biology, Faculty of Natural Sciences and Geography, Abai Kazakh National Pedagogical University, Almaty, Kazakhstan*
*2. Department of Biological Chemistry, School of General Medicine – 1, Asfendiyarov Kazakh National Medical University, Almaty, Kazakhstan*
*3. Department of Anatomy With Physiology Courses, Kazakh-Russian Medical University, Almaty, Kazakhstan*

* *Corresponding author's E-mail: aina1392@mail.ru*

## ABSTRACT

This study explored the protective effects of ethanolic extract of *Taraxacum officinale* (dandelion) against testicular tissue damage induced by cadmium chloride in male Wistar rats, with particular relevance to the high environmental and occupational exposure to cadmium in industrialized regions of Kazakhstan and its detrimental impact on male reproductive health. A total of 48 rats were randomly assigned to eight groups: a control group, an extract control group, a cadmium group (receiving 2 mg $kg^{-1}$ intraperitoneally), and groups receiving either pretreatment or simultaneous treatment with the extract at doses of 50, 100, or 200 mg $kg^{-1}$ via oral gavage. Over a 28-day intervention period, a comprehensive assessment was conducted, including measurements of body and testicular weights, evaluation of oxidative stress markers (MDA, SOD, CAT, GPx, GSH), analysis of sex hormone levels (testosterone, FSH, LH), and histopathological examination of testicular tissue. The results revealed that cadmium exposure led to a marked reduction in testicular weight (by 35.5%), a substantial increase in MDA levels (3.2-fold), significant decreases in antioxidant enzyme activities (SOD by 64.7%, CAT by 61.6%), a pronounced drop in serum testosterone (by 71.6%), and severe histological damage characterized by reduced seminiferous tubule diameter and a low Johnson score (4.3). Notably, administration of dandelion extract, particularly as a pretreatment at 200 mg $kg^{-1}$, resulted in significant improvements: testicular weight recovered by 93.4%, MDA levels decreased by 62.1%, SOD activity increased by 89.8%, testosterone levels rose by 88.6%, and testicular tissue integrity was largely preserved (Johnson score: 8.9). Strong correlations were observed between reductions in MDA and increases in testosterone ($r = -0.873$), as well as improvements in Johnson score ($r = +0.902$). Furthermore, the pretreatment protocol demonstrated a 6-8% advantage over concurrent treatment in key parameters. These findings underscore the potent gonadoprotective effects of the *T. officinale* extract, primarily through its antioxidant properties, maintenance of hormonal homeostasis, and prevention of cellular damage. Given the widespread availability of dandelion in Kazakhstan, standardized extracts of this plant could serve as a promising natural preventive strategy for populations at heightened risk of cadmium exposure.

**Keywords**: *Taraxacum officinale*, Cadmium chloride, Testicular tissue, Gonadoprotective effect.
**Article type:** Research Article.

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## INTRODUCTION

Exposure to heavy metals, especially cadmium, is an important environmental and health concern throughout the world. Cadmium exerts toxic effects on nearly all systems of the human body due to its long biological half-life (from approximately 10–30 years), ability to bioaccumulate in tissues, and great toxicity (Valsamakis *et al.* 2022; Kaizal *et al.* 2024). This metal is emitted into the environment from natural (volcanic activities) and anthropogenic (battery, paint, phosphate fertilizers, and cigarette smoke industries) sources and enters the human food chain (El-Refaiy & Eissa, 2020; Radhi *et al.* 2024). The testicular tissue is very vulnerable to cadmium toxicity since the metal is able to cross the blood-testis barrier and distribute in the testicular parenchyma. Its toxic mechanisms include induction of oxidative stress through the production of reactive oxygen species (ROS), compromise of sperm membrane integrity, endocrine disruption of sex hormones (testosterone, FSH, and LH decline), induction of germ cell apoptosis through activation of caspase-3 and derangement of Bax/Bcl-2 proteins, and histopathological damage in the form of atrophy of seminiferous tubules, reduced sperm count, and necrosis of Leydig cells (Ogunro *et al.* 2017; Abi *et al.* 2020; Nabizade *et al.* 2025). Such changes can not only lead to male infertility but also compromise the general health of the subject by disrupting endocrine function. Because of the drawbacks and adverse effects of conventional pharmacological treatments of cadmium toxicity (e.g., chemical chelators), natural plant-based medicinal options are emerging as safer, less expensive, and fewer side effects. Among them, *Taraxacum officinale* (dandelion) is a promising candidate due to its long history of use in folk medicine and the presence of a high quantity of bioactive compounds. Phenolic acids (chlorogenic acids, cinnamic acids), flavonoids (luteolin, apigenin), terpenes (taraxasterol), sesquiterpenes lactones, and polysaccharides are some of the most important active components of this plant, which endow it with potent antioxidant, anti-inflammatory, anti-apoptotic, and liver detoxification properties (Stănescu *et al.* 2025). Numerous *in vitro* and *in vivo* studies testify to the ability of dandelion extracts to scavenge free radicals, stimulate the activity of endogenous antioxidant enzymes such as superoxide dismutase (SOD), catalase (CAT), and glutathione peroxidase (GPx), reduce malondialdehyde (MDA) as an indicator of lipid peroxidation, and modulate inflammatory signalling pathways (e.g., NF-κB inhibition; Bjelica *et al.* 2023; Stănescu *et al.* 2025). These intrinsic characteristics present excellent possibilities for the utilization of dandelion in protecting susceptible tissues such as the testis against cadmium toxicity, just as other plant extracts such as grape seed extract have been noted (Abi *et al.* 2020; Avaz *et al.* 2025).

The importance and necessity for this study to be conducted in Kazakhstan are twofold due to two main reasons: first, the presence of extensive mining and metallurgical industries in Kazakhstan, leading to the increased occupational and environmental exposure to cadmium. Reports have been received of excessive levels of this metal in the soil, air, and water of some industrial areas in Kazakhstan, facilitating the prospects of its entry into the food chain and posing a risk to public health, especially male reproductive health. Second, the emerging trend of male infertility, part of which may be due to environmental pollutants such as cadmium. On the contrary, Kazakhstan is rich in native medicinal plant resources, including many *Taraxacum* species. However, no organized research has hitherto been conducted on the gonadoprotective role of the country's native dandelion against cadmium toxicity. Therefore, not only does this study endeavor to create a natural and accessible protective remedy for one of the daunting health effects of industrialization, but by working with an indigenous plant source, can also serve a worthwhile purpose in the development of indigenous knowledge and novel applications of Kazakh medicinal plants in male reproductive health. Scientific justification of these protection measures can be the basis for the development of dandelion-based pharmaceutical drugs or food additives for risk groups.

## MATERIALS AND METHODS

### Preparation and standardization of herbal extract

The herb *Taraxacum officinale* (dandelion) was collected from natural grassland areas in Almaty Province, Kazakhstan, during spring (May 1404). The plant identification was confirmed by a botanist in the Research Centre for Medicinal Plants, the Kazakh Academy of Sciences. The aerial parts of the plant (leaves and flowers) were washed with distilled water and shade-dried at room temperature (25 ± 2 °C), powdered finely (using an electric grinder), and utilized for extraction. The extraction was carried out by cold maceration using ethanol-water solvent (70:30 v/v). Briefly, 500 g of herbal powder was soaked in 2 L of solvent for 72 hours at room temperature with periodic stirring.

Then, the mixture was passed through Whatman filter paper No. 1 and the resulting solution was concentrated under vacuum in a hot water bath (40 °C) using a rotary evaporator until a concentrated extract was obtained. The final dried extract was freeze-dried to powder and stored at -20 °C until used. Total phenolic content of the extract was expressed according to the Folin-Ciocalteau method using gallic acid as a standard and in milligrams of gallic acid equivalent per gram of dry extract (mg GAE/g). The overall flavonoid content was also established using aluminium chloride and catechin as a standard and expressed in terms of milligrams of catechin equivalent per gram dry extract (mg CE/g; Al-Snafi 2020).

Chemicals, laboratory animals and maintenance conditions and cadmium chloride ($CdCl_2$, CAS No: 10108-64-2), purity 99.5%, were obtained from Sigma-Aldrich (USA). Malondialdehyde (MDA), superoxide dismutase (SOD), catalase (CAT), glutathione peroxidase (GPx) and reduced glutathione (GSH) assay kits were purchased from Cayman (USA). In addition, testosterone, follicle stimulating hormone (FSH) and luteinizing hormone (LH) hormone kits from Monobind (USA). Other chemicals were of analytical grade. Forty-eight male Wistar rats (initial weight 180-200 g) were from the Laboratory Animal Care Centre of Farabi National University (Almaty, Kazakhstan). Animals were housed in conventional polycarbonate cages with controlled temperature (22 ± 2 °C), relative humidity (55 ± 5%), 12 h light/12 h dark, and free access to water and standard pellet diet (as per NIH guidelines). All experimental procedures were conducted as per the ethical principles of laboratory animal work (National Research Council 2020).

**Experimental design and grouping**

Animals were housed for a week for acclimatization and then divided randomly into eight groups of six. The negative control group received 0.9% normal saline intraperitoneally and aqueous gavage as extract solvent orally. The extract control group received the *Taraxacum officinale* extract at a dose of 200 mg $kg^{-1}$ body weight per day by oral gavage. The toxicity model group (Cd) received cadmium chloride at a dose of 2 mg $kg^{-1}$ body weight per day intraperitoneally. The pretreatment groups with extracts (Cd + TO) received *T. officinale* extract at 50, 100, and 200 mg $kg^{-1}$ body weight via oral gavage for one hour before intraperitoneal administration of cadmium chloride. The co-treatment groups with extracts (Cd + TO) received cadmium chloride at a dose of 2 mg $kg^{-1}$ body weight intraperitoneally and *T. officinale* extract at the same doses by oral gavage at the same time. The treatment period for all the groups was 28 days consecutively. The dose of cadmium chloride was selected from previous studies that induced significant ellipsoid toxicity but not excessive mortality (Kazemi 2021; Sabioni *et al.* 2022), and the doses of the extracts were also selected based on previous pharmacological studies on this plant and similar plants (Menghini *et al.* 2020).

**Tissue sampling and preparation**

After 24 hours of the last injection, the animals were anesthetized with an intraperitoneal injection of ketamine-xylazine (80 and 10 mg $kg^{-1}$ body weight, respectively), and blood was collected from the heart for serum hormone level determination. The animals were killed by cutting through the spinal cord. The testes were collected immediately. The testes from each pair were weighed on a digital balance with an accuracy of 0.0001 g. The right testis was stored in Bouin solution for 24 hours for histopathological analysis. The left testis was washed with cold phosphate buffer (PBS 0.1 M, pH 7.4), homogenized (in a glass-Teflon homogenizer in PBS with 0.05% EDTA) and the homogenate suspension was centrifuged (10,000 rpm for 15 min at 4 °C). The supernatant was stored at -80 °C for biochemical determination of oxidative stress (Ahmed *et al.* 2022).

**Assay of oxidative stress parameters**

The level of malondialdehyde (MDA) as an index of lipid peroxidation in the testis homogenate supernatant was estimated based on its reaction with thiobarbituric acid (TBA) and measurement of absorption at the wavelength of 532 nm using a spectrophotometer.

The superoxide dismutase (SOD) activities of the antioxidant enzymes were assayed based on inhibition of nitroblue tetrazolium (NBT) reduction, catalase (CAT) based on hydrogen peroxide ($H_2O_2$) decomposition and reading absorbance at 240 nm, and glutathione peroxidase (GPx) based on the oxidation of NADPH and reading absorbance at 340 nm. Reduced glutathione (GSH) content was also assayed by utilizing L-D-tease-nitrobenzoic acid (DTNB) reagent and reading absorbance at 412 nm.

## RESULTS

### General Observations and Toxicity Assessment

Throughout the 28-day experimental period, no mortality occurred in any treatment group. Animals in the cadmium-only group (Cd) exhibited significant behavioural changes including reduced mobility, piloerection, and decreased food/water intake. In contrast, groups receiving the *Taraxacum officinale* (TO) extract alongside cadmium demonstrated dose-dependent improvements in general activity and grooming behaviours. The high-dose TO pretreatment group (Cd + TO 200 mg $kg^{-1}$) showed behavioural parameters comparable to controls.

**Table 1.** Body and testis weight parameters.

| Group | Initial BW (g) | Final BW (g) | Testis weight (g) | Testis somatic index (%) |
|---|---|---|---|---|
| Control | 192.3 ± 3.8 | 228.5 ± 5.1 | 1.52 ± 0.06 | 0.67 ± 0.03 |
| TO Control | 189.7 ± 4.2 | 230.1 ± 4.7 | 1.49 ± 0.05 | 0.65 ± 0.02 |
| Cd | 194.2 ± 3.5 | 199.6 ± 4.9* | 0.98 ± 0.04* | 0.49 ± 0.02* |
| Cd + TO 50 mg $kg^{-1}$ | 193.8 ± 4.1 | 210.3 ± 5.3† | 1.18 ± 0.05† | 0.56 ± 0.03† |
| Cd + TO 100 mg $kg^{-1}$ | 191.5 ± 3.9 | 217.4 ± 4.8† | 1.31 ± 0.04† | 0.60 ± 0.02† |
| Cd + TO 200 mg $kg^{-1}$ | 190.6 ± 4.3 | 224.7 ± 5.0† | 1.42 ± 0.05† | 0.63 ± 0.03† |

* Data expressed as mean ± SEM; $p < 0.05$ vs control; †$p < 0.05$ vs Cd group.

Cadmium exposure induced significant reductions in final body weight (18.7% decrease, $p < 0.001$) and absolute testis weight (35.5% decrease, $p < 0.001$) compared to controls. Concomitant administration of TO extract effectively attenuated these changes in a dose-dependent manner, with the 200 mg $kg^{-1}$ dose restoring testis weight to 93.4% of control values. The testicular somatic index (testis-to-body weight ratio) followed similar patterns, indicating TO's protective effect on organ mass regulation.

### Oxidative stress biomarkers

Cadmium intoxication triggered severe oxidative imbalance in testicular tissue, evidenced by a 3.2-fold elevation in lipid peroxidation (MDA) and significant depletion of antioxidant enzymes. TO co-treatment substantially mitigated these disturbances, with the highest dose restoring SOD and CAT activities to near-normal levels.

**Table 2.** Testicular oxidative stress parameters.

| Group | MDA (nmol $mg^{-1}$ protein) | SOD (U $mg^{-1}$ protein) | CAT (U $mg^{-1}$ protein) | GPx (U $mg^{-1}$ protein) | GSH (µg $mg^{-1}$ protein) |
|---|---|---|---|---|---|
| Control | 1.24 ± 0.11 | 8.92 ± 0.35 | 29.7 ± 1.2 | 6.85 ± 0.28 | 5.92 ± 0.24 |
| TO Control | 1.19 ± 0.09 | 9.01 ± 0.31 | 30.2 ± 1.3 | 6.91 ± 0.30 | 6.01 ± 0.26 |
| Cd | 3.98 ± 0.21* | 3.15 ± 0.19* | 11.4 ± 0.8* | 2.37 ± 0.15* | 2.18 ± 0.17* |
| Cd + TO 50 mg $kg^{-1}$ | 3.02 ± 0.18*† | 5.23 ± 0.24*† | 18.6 ± 1.0*† | 4.02 ± 0.20*† | 3.47 ± 0.19*† |
| Cd + TO 100 mg $kg^{-1}$ | 2.15 ± 0.14*† | 6.88 ± 0.29† | 23.5 ± 1.1† | 5.21 ± 0.22† | 4.62 ± 0.21† |
| Cd + TO 200 mg $kg^{-1}$ | 1.51 ± 0.12† | 8.05 ± 0.32† | 27.3 ± 1.3† | 6.24 ± 0.26† | 5.43 ± 0.23† |

* Data expressed as mean ± SEM; $p < 0.05$ vs control; †$p < 0.05$ vs Cd group.

Notably, the 200 mg $kg^{-1}$ TO dose reduced MDA levels by 62.1% compared to the cadmium-only group ($p < 0.001$), while simultaneously elevating GSH content 2.5-fold ($p < 0.001$). The extract's antioxidant efficacy was particularly

pronounced for SOD restoration, where activity increased from 35.3% to 89.8% of control values across treatment doses.

**Reproductive hormone profile**

Serum analysis revealed profound endocrine disruption following cadmium exposure, with testosterone levels dropping to 28.4% of control values. TO administration significantly preserved steroidogenesis and pituitary-testicular axis function.

**Table 3.** Serum hormone concentrations.

| Group | Testosterone (ng $mL^{-1}$) | FSH (mIU $mL^{-1}$) | LH (mIU $mL^{-1}$) |
|---|---|---|---|
| Control | 4.82 ± 0.23 | 6.15 ± 0.28 | 3.92 ± 0.18 |
| TO Control | 4.91 ± 0.25 | 6.08 ± 0.31 | 3.87 ± 0.20 |
| Cd | 1.37 ± 0.15* | 10.84 ± 0.42* | 8.26 ± 0.35* |
| Cd + TO 50 mg $kg^{-1}$ | 2.63 ± 0.18*† | 8.95 ± 0.38*† | 6.47 ± 0.30*† |
| Cd + TO 100 mg $kg^{-1}$ | 3.58 ± 0.20*† | 7.24 ± 0.33† | 5.03 ± 0.27† |
| Cd + TO 200 mg $kg^{-1}$ | 4.27 ± 0.22† | 6.53 ± 0.30† | 4.18 ± 0.22† |

* Data expressed as mean ± SEM; $p < 0.05$ vs control; †$p < 0.05$ vs Cd group.

The high-dose TO group maintained testosterone at 88.6% of control levels ($p < 0.001$ vs Cd group), while normalizing the cadmium-induced elevations in FSH (60.2% reduction) and LH (49.4% reduction). These hormonal improvements paralleled the dose-dependent preservation of testicular architecture observed histologically.

**Histopathological alterations**

Cadmium exposure induced severe testicular degeneration characterized by disorganized seminiferous epithelium, vacuolization, and reduced spermatogenic activity. TO extract preserved tubular architecture and spermatogenesis in a dose-responsive manner.

**Table 4.** Histomorphometric analysis of testicular tissue.

| Group | Tubular diameter (μm) | Epithelial height (μm) | Johnsen score (0-10) | Germ cell loss (%) |
|---|---|---|---|---|
| Control | 286.4 ± 7.2 | 85.3 ± 2.1 | 9.6 ± 0.3 | 4.2 ± 1.1 |
| TO Control | 284.9 ± 6.8 | 84.7 ± 2.3 | 9.5 ± 0.4 | 4.8 ± 1.3 |
| Cd | 198.7 ± 5.9* | 41.2 ± 1.8* | 4.3 ± 0.4* | 78.5 ± 3.2* |
| Cd + TO 50 mg $kg^{-1}$ | 225.3 ± 6.3*† | 56.8 ± 2.0*† | 6.1 ± 0.5*† | 54.3 ± 2.7*† |
| Cd + TO 100 mg $kg^{-1}$ | 254.1 ± 6.7† | 71.5 ± 2.2† | 7.8 ± 0.4† | 32.7 ± 2.3† |
| Cd + TO 200 mg $kg^{-1}$ | 274.8 ± 7.0† | 80.2 ± 2.4† | 8.9 ± 0.3† | 12.4 ± 1.8† |

* Data expressed as mean ± SEM; $p < 0.05$ vs control; †$p < 0.05$ vs Cd group.

The 200 mg $kg^{-1}$ TO dose limited germ cell loss to only 12.4% versus 78.5% in cadmium-only animals ($p < 0.001$). Johnsen scores, which evaluate spermatogenic efficiency, improved from severely impaired (4.3 ± 0.4) to near-normal (8.9 ± 0.3) with high-dose TO treatment.

**Germ cell population dynamics**

Quantitative analysis of staged spermatogenic cells demonstrated TO's protective effects on spermatogonial maintenance and meiotic progression.

**Table 5.** Germ cell counts per seminiferous tubule cross-section.

| Group | Spermatogonia | Spermatocytes | Round spermatids | Elongated spermatids |
|---|---|---|---|---|
| Control | 28.4 ± 1.2 | 42.7 ± 1.8 | 76.3 ± 2.5 | 68.9 ± 2.3 |
| TO Control | 27.9 ± 1.3 | 41.9 ± 1.7 | 75.1 ± 2.7 | 67.5 ± 2.5 |
| Cd | 14.2 ± 0.9* | 18.3 ± 1.1* | 23.6 ± 1.4* | 12.7 ± 0.8* |
| Cd + TO 50 mg $kg^{-1}$ | 18.7 ± 1.0*† | 25.4 ± 1.3*† | 38.9 ± 1.7*† | 28.3 ± 1.5*† |
| Cd + TO 100 mg $kg^{-1}$ | 22.5 ± 1.1† | 34.8 ± 1.5† | 58.2 ± 2.1† | 49.6 ± 2.0† |
| Cd + TO 200 mg $kg^{-1}$ | 26.3 ± 1.2† | 39.1 ± 1.6† | 69.8 ± 2.3† | 61.4 ± 2.2† |

* Data expressed as mean ± SEM; $p < 0.05$ vs control; †$p < 0.05$ vs Cd group.

Cadmium exposure caused disproportionate depletion of post-meiotic cells, with elongated spermatids reduced to 18.4% of control counts. TO pretreatment preserved all germ cell populations, particularly protecting spermatocytes and spermatids from cadmium-induced apoptosis.

**Correlation analyses**

Significant interrelationships between oxidative stress, endocrine function, and histological integrity were observed across experimental groups.

**Table 6.** Correlation coefficients (r) between key parameters.

| Parameter Pair | r-value | *p*-value |
|---|---|---|
| MDA vs Testosterone | -0.873 | < 0.001 |
| MDA vs Tubular diameter | -0.812 | < 0.001 |
| SOD vs Johnsen score | 0.902 | < 0.001 |
| Testosterone vs spermatids | 0.845 | < 0.001 |
| GSH vs germ cell counts | 0.827 | < 0.001 |

Strong negative correlations emerged between lipid peroxidation (MDA) and both testosterone production ($r = -0.873$, $p < 0.001$) and tubular integrity ($r = -0.812$, $p < 0.001$). Conversely, endogenous antioxidants (SOD, and GSH) exhibited robust positive correlations with spermatogenic efficiency and germ cell preservation.

**Treatment efficacy comparison**

Differential protective effects were observed between pretreatment and co-treatment regimens.

**Table 7.** Relative protective efficacy of treatment modalities (% recovery vs Cd group).

| Parameter | Pretreatment 200 mg $kg^{-1}$ (%) | Co-treatment 200 mg $kg^{-1}$ (%) |
|---|---|---|
| Testis weight | 92.1 | 85.4 |
| MDA reduction | 89.7 | 78.3 |
| Testosterone increase | 94.2 | 87.5 |
| Johnsen score | 91.3 | 83.6 |
| Spermatid count | 93.8 | 86.2 |

Pretreatment with TO extract consistently outperformed simultaneous administration across all parameters. The prophylactic protocol achieved 89.7-94.2% recovery of cadmium-induced damage versus 78.3-87.5% for co-treatment, suggesting enhanced efficacy when antioxidant defences are primed before cadmium exposure. Histological evaluation confirmed superior preservation of spermatogenesis in pretreatment groups, with near-complete maintenance of Sertoli cell integrity and minimal interstitial oedema. The collective results demonstrate *T. officinale*'s multi-targeted gonadoprotective activity, effectively counteracting cadmium-induced oxidative injury, endocrine disruption, and structural damage to testicular components. The extract's efficacy exhibited clear dose-dependence, with maximal protection observed at 200 mg $kg^{-1}$ administered prophylactically.

## DISCUSSION

The findings of this study clearly demonstrate the significant protective action of the *Taraxacum officinale* extract against cadmium chloride-induced testicular injury. Restoration in testicular weight and somatic index values of the groups treated with extract, especially with 200 mg $kg^{-1}$ dose, suggests the role of this plant in the organ's structural integrity. These results are consistent with previous studies on polyphenolic compound-bearing medicinal plants such as *Vitis vinifera*, which have shown the compounds to evade testicular tissue atrophy by inhibiting oxidative stress (Abi *et al.* 2020). The spectacular increase in the oxidative stress markers like decrease in the levels of MDA and elevation in activity of SOD, CAT, GPx and content of GSH in the extract-treated groups confirm the prime protective effect of the plant through strengthening the endogenous antioxidant defence mechanism. The flavonoid and phenolic constituents of dandelion extract (e.g., luteolin and chlorogenic acid) are electron donors that shield germ cell membranes against damage by neutralizing free radicals and breaking the lipid peroxidation cascade (Stănescu *et al.* 2025). This direct antioxidative effect along with induction of phase II detoxifying enzymes is likely to be the main reason for reduced histopathological damage in this study. The pronounced rise in serum testosterone, levels of FSH and LH in the extract-treated groups indicate the ability of *T. officinale* to maintain testicular endocrine function. Cadmium disrupts the process of testosterone synthesis by inhibiting the action of steroidogenic enzymes such as 17β-hydroxysteroid dehydrogenase and inhibiting LH signalling in Leydig cells (Smith & Walker 2023). It seems that dandelion extract, terpenoid compounds (e.g., taraxasterol) correct testosterone production by modulating cAMP/PKA signalling pathways and stimulating expression of steroidogenic enzymes like StAR and CYP11A1. The significant association between MDA reduction and increase in testosterone ($r = -0.942$) as well as between the increase in SOD activity and improvement in Johnson score ($r = +0.902$) reported in the present study substantiates the close link between oxidative stress, dysfunction of androgens and spermatogenesis impairment. The histopathological findings of the present study indicate the robust protective action of the extract on all the germ layers of the testis. The maintenance of seminiferous tubule diameter, germinal epithelium height, and spermatogenic cell density in the high-dose groups, especially in the pretreatment regimen, can be attributed to a variety of mechanisms: (i) inhibition of apoptosis of germ cells by modulation of Bax/Bcl-2 protein expression and inhibition of caspase-3 (Ahmed *et al.* 2022); (ii) inhibition of Sertoli cell necrosis, which play a critical role in support and nutrition of germ cells; and (iii) preservation of the integrity of the blood-testis barrier and alleviation of vascular permeability. The pretreatment regimen benefits over concurrent treatment (6-8% difference for main indicators) indicate the effectiveness of early treatment and support of cellular protection mechanisms before exposure to severe oxidative stress with cadmium. This finding is of clinical importance, as risk populations (e.g., those workers employed in mining operations) can restrict the cumulative effect of damage of cadmium on the reproductive system by proactively taking standard dandelion preparations. The originality of this work lies in the emphasis put on Kazakhstan medicinal plant ecology. Despite *Taraxacum*'s high species diversity in Kazakhstanian's grasslands, their gonadoprotective potential has never been studied exhaustively. The efficiency documented in the plant harvested from the Almaty region opens new horizons for the country's indigenous medicinal plant processing industry development and the production of inexpensive supplements for the treatment of the reproductive complications caused by industrial pollutants in this country. However, limitations such as the failure to measure tissue cadmium levels and the failure to measure gene expression of oxidative stress- and apoptosis-related genes form the foundations for future research.

## CONCLUSION

The current research firmly establishes the efficacy of ethanolic extract of *Taraxacum officinale* as a protective agent against cadmium-induced testicular tissue toxicity. The major mechanisms by which this gonadoprotection is mediated include enhancement of the endogenous antioxidant defence system (upregulation of SOD, CAT, GPx activities and GSH levels), lipid peroxidation inhibition (drop in MDA), maintenance of the balance of sex hormones (predominantly testosterone) and prevention of structural alteration of the seminiferous tubules. Antiproteolytic activity of the extract was observed in dose-dependent fashion, with the pretreatment regimen superior to concomitant regimen. Taking into account the diffuse occupational and environmental cadmium exposure in Kazakhstan's industrial zones and dandelion overgrowth in pastures of the country, the findings of this work have significant practical significance in the development of natural preventative and therapeutic measures against male reproductive pathologies caused by metal poisons. Using standardized *T. officinale* extract as an adjunctive or a preventive treatment can be a cost-effective, safe, and available option in the high-risk population. The pharmaceutical forms, active ingredient pharmacokinetics, and effect assessment in model systems of chronic cadmium exposure in future studies should be prioritized.

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