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RESEARCH

Protective effects of commercial artichoke (*Cynara scolymus L.*) leaf powder against aflatoxin B1-induced reproductive toxicity in male rats

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Abstract

Aflatoxin B_1 (AFB_1) is an unavoidable environmental pollutant frequently found in feed and foodstuffs and is considered the most toxic of all aflatoxins, known to impair testicular function. This study investigated the potential protective effect of artichoke leaves powder (ArLP) against the reproductive toxicity induced by AFB_1 in male rats. In a 42-day experiment, rats received either sterile water, 4% DMSO, ArLP (100 mg/kg/body weight), AFB_1 (72 µg/kg/body weight), or a combination of ArLP and AFB_1 via oral gavage. AFB_1 exposure led to increased oxidative stress, abnormal sperm parameters, hormonal disturbances, elevated prostate specific antigen (PSA) levels and histopathological damage in the testes. Co-administration of ArLP with AFB_1 significantly mitigated these adverse effects, with most parameters approaching values observed in the control groups. These findings suggest that oral administration of ArLP exerts a protective effect against AFB_1-induced reproductive toxicity in male rats and support its potential use in mitigating toxin-related reproductive damage.

Keywords Natural product · Prostate-specific hormone · Follicle-stimulating hormone · Luteinizing hormone · Antioxidant

Introduction

The ubiquitous presence of pollutants in the environment has been an increasing global concern (Pleadin et al. 2019). Mycotoxins, which are secondary metabolites produced by fungi, are among the most hazardous contaminants and, in some cases, exhibit greater toxicity than certain pesticides (Tarhane et al. 2023; Skrzydlewski et al. 2022; Ülger et al. 2020). These substances may be found in a variety of very important agricultural and food products depending on their physico-chemical characterization. They may be synthesized on the field, during harvest as well as during storage (Martín et al. 2022). Among these contaminats, aflatoxins produced by *Aspergillus* spp. deserve more attention because they are widely distributed in nature and represent big threats to food safety and human health (Jaćević et al. 2023). Aflatoxin B_1 (AFB_1) is deemed the most toxic of these compounds and its metabolites have a variety of adverse biological activities, including toxicity, teratogenicity, mutagenicity, and carcinogenicity (Tang et al. 2025; Cao et al. 2022; Pickova et al. 2021). Unavoidable exposure to AFB_1 is associated with an increased incidence of negative health consequences, including reproductive disorders and dysfunction (Wang et al. 2025; Fasihi-Ramandi et al. 2023). Early alterations of reproductive toxicity are manifested by inhibition of gonadal sex determination gene and steroidogenesis, and disturbed gametogenesis, leading later to dysfunctions in sperm production (Hassan et al. 2022; Marcu et al. 2023). Such disrupted structures and functions of reproductive organs are evidenced by decreased fertility. In humans, it has been reported that about 30% of infertility reasons is caused by male factor, with 2% of these exhibiting suboptimal sperm parameters (Barratt et al. 2017). Nowadays, naturally derived products that counteract the adverse effects of variable toxicities are in the forefront line, particularly that the nature has been the source of life-changing and saving medications for centuries. In the present study, an approach to minimize reproductive

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toxicity caused by AFB_1 was investigated in which diets were supplemented with an entirely natural, plant-based product, artichocke leaves powder (ArLP). This therapeutic alternative, if effective, would be eco-friendly, cost-effective and with minimal side effects.

Natural products have been widely employed as a rich source of compounds for drug discovery and development with high molecular diversity, novel biofunctionality, and minimal adverse effects (El-Ashram et al. 2021; Amr et al. 2022; Naeem et al. 2022; Bakr et al. 2023; Abbas et al. 2024; Ali et al. 2024; Omar et al. 2024; Alqurashy et al. 2025a, 2025b; Zaied et al. 2025, Matar et al. 2025). Among these, artichoke (*Cynara scolymus*) is one of the potent herbal remedies as extracts obtained either from the whole plant or from different parts of artichoke mainly leaves, fruits, and roots. ArLP contains a wide range of bioactive compounds, including polyphenols and phenolic acids (Fig. S1), which were previously identified by reversed-phase HPLC in the same experimental series using the same batch of animals, dosing regimens, and ArLP extract. This identification aimed to evaluate the protective effects of artichoke against AFB1-induced neurotoxicity and hepatotoxicity (Ibrahim et al. 2022; Nasef et al. 2022), thereby highlighting its nutritional and pharmaceutical value. Moreover, the potential healh benefits of these leaves include, but is not limited to, anti-inflammatory, antioxidant, antibacterial, anticarcinogenic, hepatoprotective, choleretic, diuretic, and hypocholesterolemic activities (Awad et al. 2020; Salekzamani et al. 2019). Nevertheless, studies relating to the significance of ArLP potential in preventing and/or reducing reproductive toxicity still need to be explored.

In the current study, we aim to evaluate the potential protective effects of ArLP against AFB1-induced reproductive toxicity in male rats, an area that remains underexplored. For this purpose, adult male rats were orally administered ArLP (100 mg/kg body weight) and/or AFB_1 (72 µg/kg body weight) for 42 consecutive days. We assessed a range of parameters related to male reproductive health, including biochemical markers, semen characteristics, reproductive hormones, and total prostate-specific antigen (PSA). In addition, oxidative stress markers and antioxidant enzyme activities were evaluated in testicular tissue, and histopathological examination was conducted to investigate tissue-level alterations.

Materials and methods

Chemicals

Aspergillus flavus's AFB_1 powder ($C_{17}H_{12}O_6$) with 99.7% purity and 312.27 molecular weight (CAS Number 1162–65-8) was obtained from Sigma-Aldrich, France. Commercial capsules of artichoke leaf extract (Super Artichoke, capsules) were purchased from Western Pharmaceutical Industries, Cairo, Egypt. Other chemicals, solvents, and reagents of analytical grade were used throughout the whole study.

Animals

Adult twenty-five male albino rats (185 ± 8 g) were purchased from the Medical Research Institute (Center of Medical Technology), Alexandria University, Egypt. The rats were randomly divided into five groups (5 rats/group) and housed in clean cages. For a 1-week acclimatization period, and throughout the entire treatment duration, animals had free access to clean tap water and a standard chow diet (composed of 7% simple sugars, 3% fat, 50% polysaccharide, and 15% protein (w/w); energy content: 3.5 kcal/g) supplied by a local manufacturer (Tanta feed Company, Egypt). The animals were maintained under standard housing conditions: temperature of 25 ± 3 °C, relative humidity of 50–70%, and a 12-h light/dark cycle.

Experimental design

The experimental animal study was conducted for 42 consecutive days, during which five animals per group were orally administered different treatments as follows: the control group received 1 mL/kg body weight (BW) of sterile water; the DMSO group received 1 mL/kg BW of 4% dimethyl sulfoxide (DMSO); the AFB_1 group was administered AFB_1 at a dose of 72 µg/kg BW, corresponding to 1/100 of the LD_{50} (7.2 mg/kg BW); the ArLP group received 100 mg/kg BW of ArLP dissolved in 4% DMSO; and the final group (ArLP + AFB_1 group) received both AFB_1 and ArLP. AFB_1 and ArLP were administered separately by oral gavage, each prepared in its respective vehicle. To avoid any potential pre-administration interaction, the two compounds were given at different time points on the same day, and doses were adjusted every second day according to the animal's current body weight to ensure accurate and consistent dosing and minimize variability due to changes in weight during the course of treatment. All animals were then euthanized under general anesthesia using isoflurane (2 mL/kg BW) by inhalation, followed by cardiac puncture for blood collection. Blood plasma was isolated following centrifugation at 3000 rpm for 20 min. After removal of the reproductive sex organs (testes and epididymis) from the adhering fat and connective tissues, they were weighted, and the measure was recorded. Right testis from each animal was minced and homogenized (10%, w/v), separately, in ice-cold sucrose buffer (0.25 M) in a Potter–Elvehjem type homogenizer (Thomas Scientific, USA). The homogenates were centrifuged at 8000 rpm for 20 min at 4 °C, then the supernatants were collected for the determination of tested parameters.

Animal ethics

All experimental procedures were approved by the Research Ethics Committee (Approval number: 10–230410-1–01) and conducted according to animal care and use guidelines stipulated by Alexandria University, Egypt, and strictly followed all the procedures and techniques used to minimize any suffering during the experiments. This study is reported in accordance with ARRIVE guidelines and all experiments were performed in accordance with these relevant guidelines and regulations.

Biochemical analyses

Testes free radicals and antioxidant enzymes assays

The levels of thiobarbituric acid reactive substances (TBARS, Ref. code MD25 29), and the activities of key antioxidant enzymes, superoxide dismutase (SOD, Ref. code SD25 21), glutathione S-transferase (GST, Ref. code GT25 19), and glutathione peroxidase (GPx, Ref. code GP25 24), were determined using commercially available kits from BioDiagnostic Company (Egypt) according to the manufacturer's instructions. The standardized published methods of glutathione level (GSH; Jollow et al. 1974), xanthine oxidase (XO) activity (Litwack et al. 1953), and the level of nitric oxide (NO, Montgomery and Dymock 1961) were applied.

Reproductive hormones

Enzyme-linked immunosorbent assay (ELISA) kits were used for the quantitative determination of concentrations in rat plasma of testosterone (DRG International Co., USA), follicle-stimulating hormone (FSH; Biocode-Hycel Co., Rue E. Solvay 101, 4000 Liège, Belgium), and luteinizing hormone (LH; Elabscience Biotechnology Co., Ltd). The assays were done strictly according to the procedure given along with the kits.

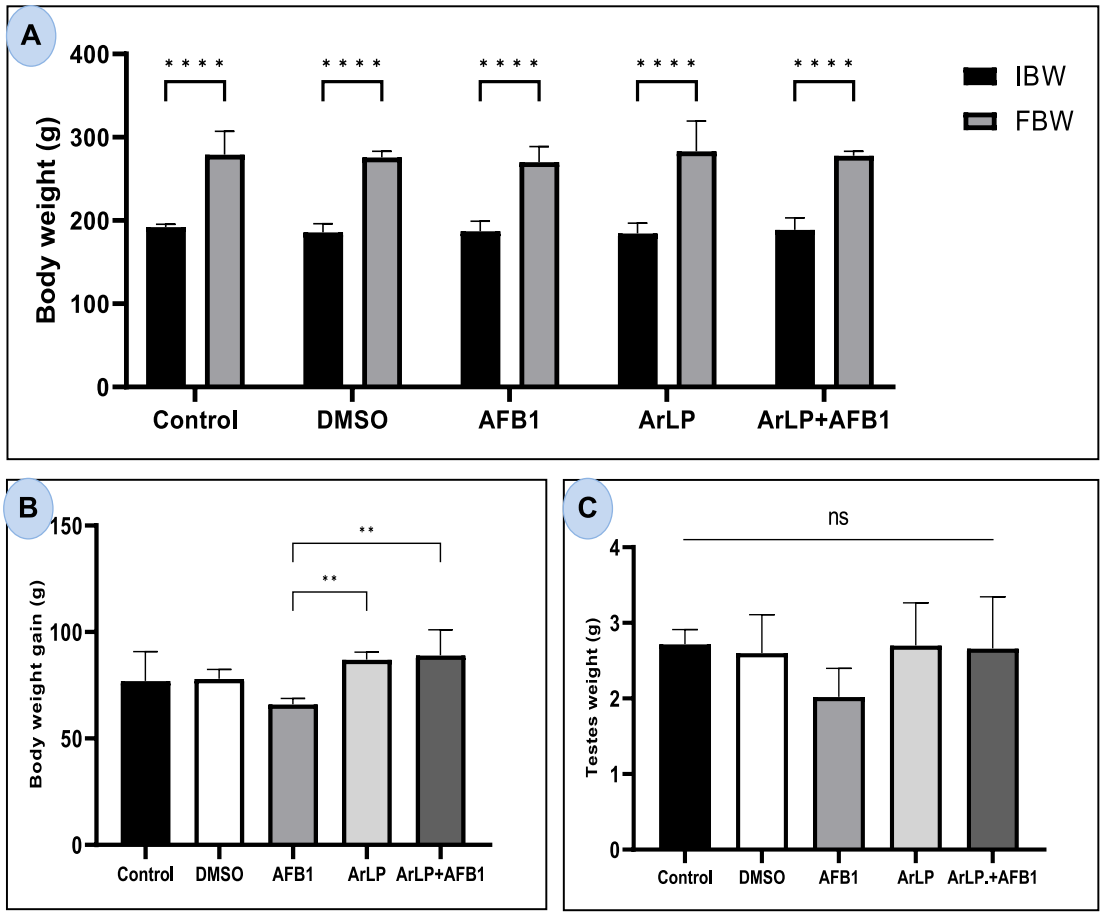
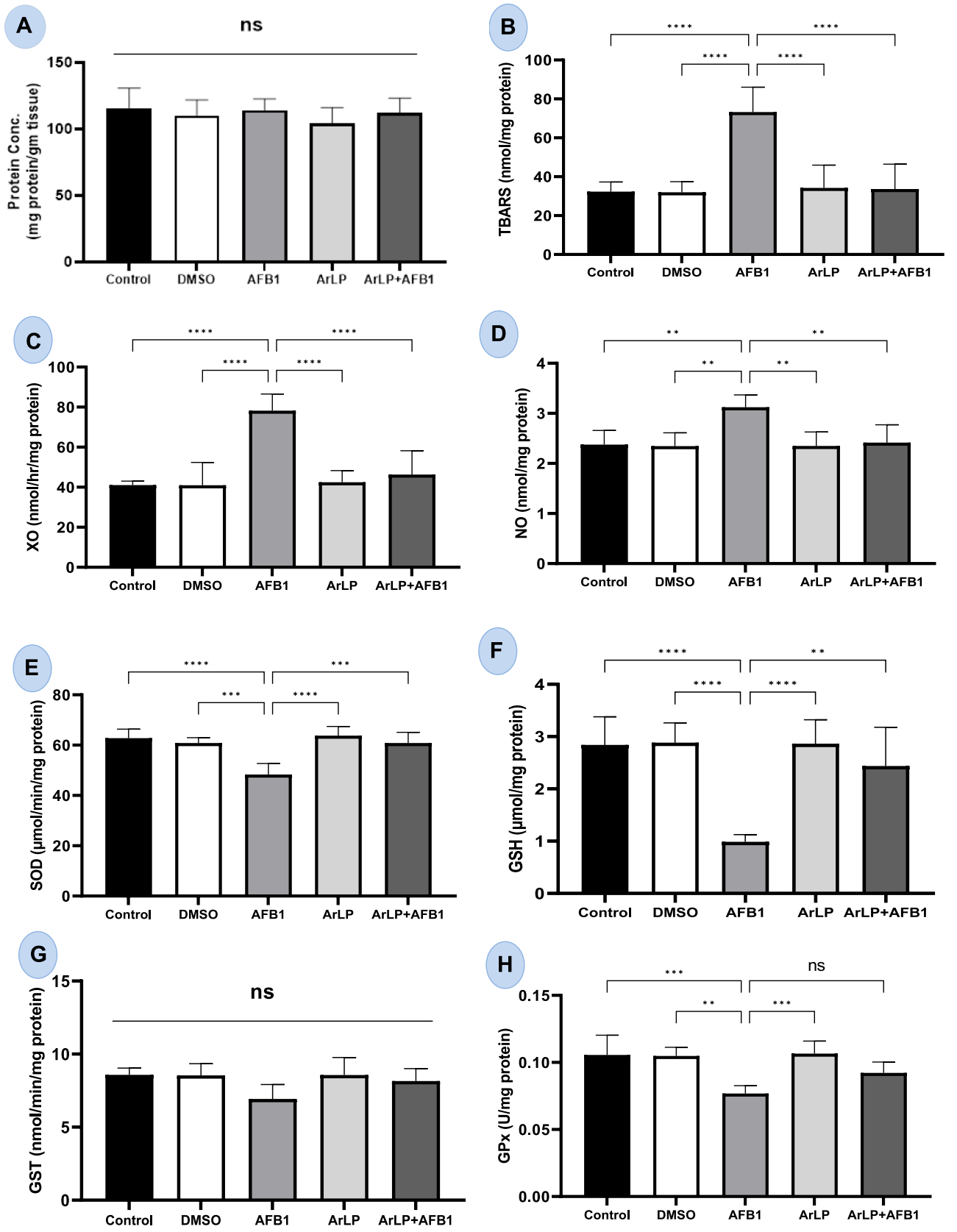


Fig. 1 Body and testicular weights of control male rats and those treated with DMSO, ArLP, AFB1, or ArLP+AFB1 for 42 consecutive days. **A** Changes in body weight, showing initial body weight (IBW) is and final body weight (FBW),**B** body weight gain, and**C** testicular weight. Data are presented as mean ± SE ($n = 5$). Statistical analysis was performed using one-way ANOVA followed by LSD post hoc test. Significant differences are indicated as*$p < 0.05$,**$p < 0.01$,***$p < 0.001$,****$p < 0.0001$


A
ns
Protein Conc. (mg protein/gm tissue)
150
100
50
0
Control
DMSO
AFB1
ArLP
ArLP+AFB1
B
TBARS (nmol/mg protein)
100
80
60
40
20
0
****
****
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****
Control
DMSO
AFB1
ArLP
ArLP+AFB1
C
XO (nmol/hr/mg protein)
100
80
60
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20
0
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Control
DMSO
AFB1
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ArLP+AFB1
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NO (nmol/mg protein)
4
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SOD (µmol/min/mg protein)
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GST (nmol/min/mg protein)
15
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DMSO
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Control
DMSO
AFB1
ArLP
ArLP+AFB1

◂**Fig. 2** Assessment of antioxidant and oxidative stress markers in control male rats and those treated with DMSO, ArLP, AFB1, or ArLP+AFB1 for 42 consecutive days. **A** Protein content, **B** thiobarbituric acid reactive substances (TBARS),**C** xanthine oxidase (XO) activity,**D** nitric oxide (NO) concentration, **E** superoxide dismutase (SOD) activity, **F** reduced glutathione (GSH) concentration, **G** glutathione S-transferase (GST) activity, and **H** glutathione peroxidase (GPx) concentration.Data are presented as mean ± SE ($n = 5$). Statistical analysis was performed using one-way ANOVA followed by LSD post hoc test. Significant differences are indicated as*$p < 0.05$,**$p < 0.01$,***$p < 0.001$,****$p < 0.0001$

Total prostate-specific antigen

Prostate-specific antigen (PSA) was determined by an ELISA kit (Prechek Bio, Inc., USA). The assay system utilizes a goat anti-PSA antibody directed against intact PSA for solid phase immobilization (on the microtiter wells). Total PSA was measured with an immunocolorimetric assay using a microtiter plate reader with the optical density at 450 nm according to the manufacturer's recommendations.

Semen characteristics

Epididymis was prepared to evaluate sperm count, sperm motility and sperm morphology. A Computer Assisted Semen Analysis (CASA System; Germany) with Olympus microscope (Olympus, Tokyo, Japan) was used according to the method of Adamkovicova et al. (2016). A total of 200 spermatozoa from each rat were examined and individually scored normal or abnormal, according to the strict sperm morphology criteria by Wang et al. (2016).

Histopathological examination

The testes were assessed histologically using hematoxylin and eosin (H&E) stained sections where the tissues were immediately fixed in 10% formalin after collection and processed by cutting pieces in tissue cassettes with an automated tissue processor. They were then embedded in paraffin and sectioned with microtome at 4–6 µm thickness. The sections were then stained with hematoxylin and counterstained with eosin for histological examination. Images were taken on an Olympus XC30 microscope (Germany) with a digital Olympus UC30 camera (Germany). Representative pictures from each treatment group were taken at 20 × and 40 × magnification.

Statistical analysis

All biochemical measurements were performed on five biological replicates per group, with each sample analyzed once without technical replication. Distribution of the data and homogeneity of variance was checked for all the parameters before analysis. The least significant difference test (ANOVA, LSD post hoc test, $p < 0.05$) was performed separately for each parameter. Body and reproductive sex organs mass and all biochemical parameters were expressed as the mean ± SE in the figures. Significant difference was *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$, ****$p < 0.0001$. Statistical analysis was performed using GraphPad Prism 9.

Results

ArLP mitigates AFB1-induced impairment in body weight gain

We investigated the effects of ArLP on body and testicular weight as well as body weight gain. As demonstrated in Fig. 1A, each treatment group exhibited a significant increase between initial and final body weights over the course of the experiment, consistent with normal growth and food intake. However, no statistically significant differences were observed in either initial or final body weights when comparing across experimental groups. Regarding body weight gain, no significant differences were found among the control, DMSO, and ArLP groups, indicating that ArLP administration did not affect normal weight progression under the experimental conditions. However, there was a significant difference between AFB_1 group and $ArLP + AFB_1$ group (Fig. 1B). This significant increase in body weight gain of $ArLP + AFB_1$ group compared with AFB_1 group is attributed to ArLP administration. ArLP incorporation with AFB_1 compensated for the observed decrease in body weight gain induced by AFB_1 in AFB_1-treated rats. Moreover, Fig. 1C shows that there was no significant difference between testicular weight among all groups. Hence, ArLP has no negative effect on body or sex organ weights. Furthermore, it reversed the decrease in body weight gain induced by AFB_1 via improving food consumption.

ArLP normalizes oxidative stress markers and antioxidant defenses disrupted by AFB_1

Total protein content in testicular tissue showed slight variations across experimental groups (Fig. 2A); however, these differences were not statistically significant. This indicates that under the present experimental conditions, neither AFB1 exposure nor ArLP treatment had a substantial effect on overall protein concentration, suggesting preserved tissue integrity at the general protein level.

We then examined the effects of ArLP, AFB_1, and their combination on oxidative stress markers and antioxidant enzymes in testicular tissue. In the present study, the concentration of TBARS, a marker of lipid peroxidation, was

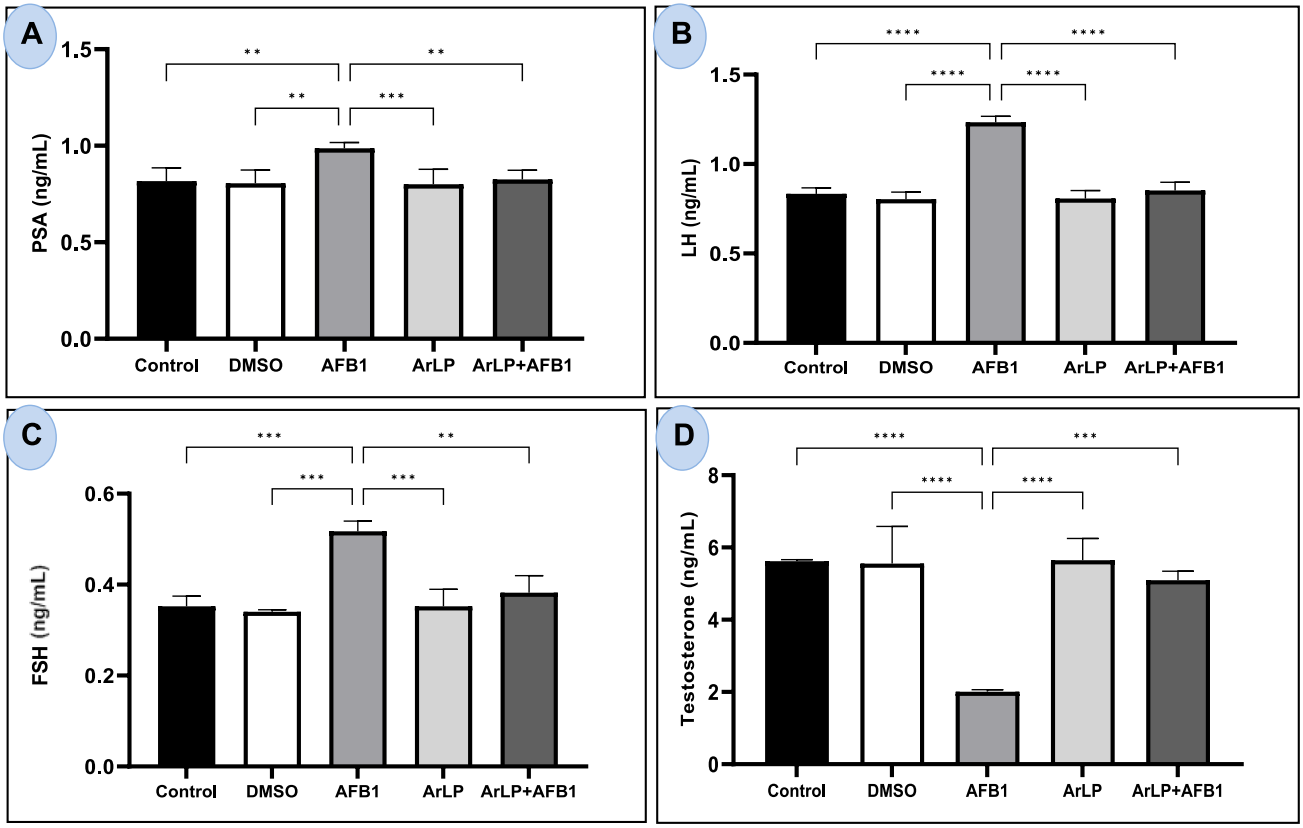


Fig. 3 Analysis of male sex hormone and prostate specific antigen (PSA) levels in control rats and those treated with DMSO, ArLP, AFB1, or ArLP+AFB1 for 42 consecutive days. **A** PSA concentration,**B** luteinizing hormone (LH),**C** follicle-stimulating hormone (FSH), and**D** testosterone concentration. Data are presented as mean ± SE ($n = 5$). Statistical analysis was performed using one-way ANOVA followed by LSD post hoc test. Significant differences are indicated as*$p < 0.05$,**$p < 0.01$,***$p < 0.001$,****$p < 0.0001$

used to assess oxidative stress in rat testes. TBARS levels were significantly increased in the AFB_1-treated group compared to all other groups, while co-administration of ArLP with AFB_1 significantly reduced TBARS concentrations (Fig. 2B). Similarly, XO activity (Fig. 2C) and NO concentration (Fig. 2D) were significantly elevated in the AFB_1 group and significantly decreased in the ArLP + AFB_1 group.

To assess antioxidant defense, the activity or concentration of key antioxidant markers, SOD, GSH, GST, and GPx, was evaluated in testicular tissue (Fig. 2E–H). ArLP administration alone did not significantly alter the levels of SOD, GSH, GST, or GPx compared with the control and DMSO groups. In contrast, AFB_1 treatment led to a significant reduction in SOD activity, GSH, concentration, and GPx concentration.

Co-treatment with ArLP and AFB_1 significantly increased SOD activity, GSH, and GPx concentrations compared to AFB_1 group. GST levels showed a slight, but non-significant increase following ArLP or ArLP + AFB1 treatment.

ArLP reverses AFB1-induced alterations in prostate-specific antigen and male sex hormone levels

To assess the effect of ArLP on male reproductive markers, PSA and sex hormone levels (LH, FSH, and testosterone) were measured.

As shown in Fig. 3A, PSA concentrations did not differ significantly between the control, DMSO, and ArLP groups. However, PSA levels were significantly elevated in the AFB_1-treated group compared to all other groups. Co-administration of ArLP with AFB_1 significantly reduced PSA levels compared to AFB_1 alone. Similar patterns were observed for LH and FSH. AFB_1 treatment led to a significant increase in both LH (Fig. 3B) and FSH (Fig. 3C) levels, while ArLP + AFB1 treatment significantly reduced their concentrations compared to the AFB_1 group.

Testosterone levels (Fig. 3D) remained unchanged in the control, DMSO, and ArLP groups. In contrast, AFB_1 administration significantly decreased testosterone concentration compared to all other groups. Co-treatment with ArLP

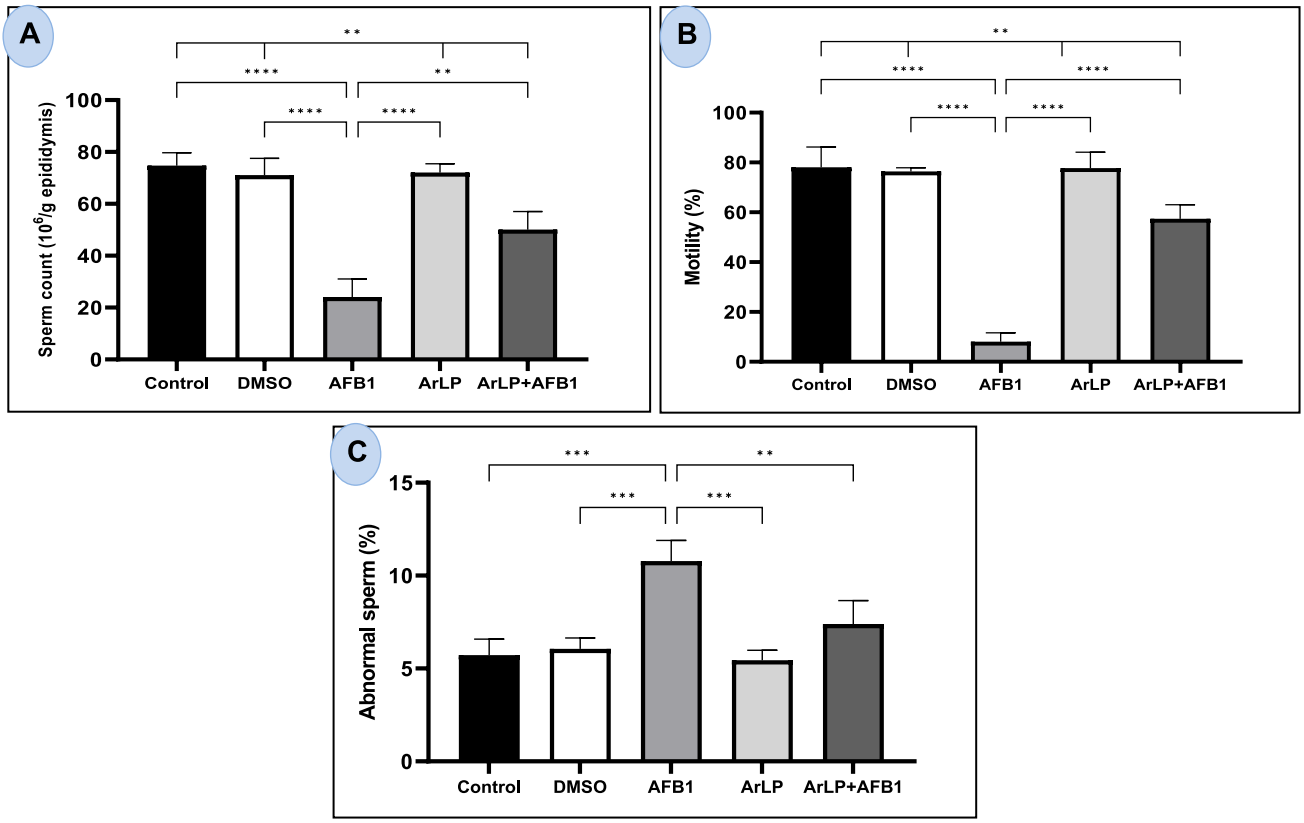


Fig. 4 Semen analysis of control male rats and those treated with DMSO, ArLP, AFB1, or ArLP+AFB1 for 42 consecutive days. **A** Sperm count,**B** sperm motility (%), and**C** abnormal sperm (%). Data are presented as mean ± SE ($n = 5$). Statistical analysis was performed using one-way ANOVA followed by LSD post hoc test.Significant differences are indicated as $*p < 0.05$,$**p < 0.01$,$***p < 0.001$,$****p < 0.0001$

significantly restored testosterone levels compared to AFB_1 treatment alone.

ArLP partially ameliorates AFB1-induced impairments in semen quality

Semen characteristics, including sperm count, motility, and abnormal morphology, were assessed to evaluate the impact of ArLP, AFB1, and their combination on male reproductive function.

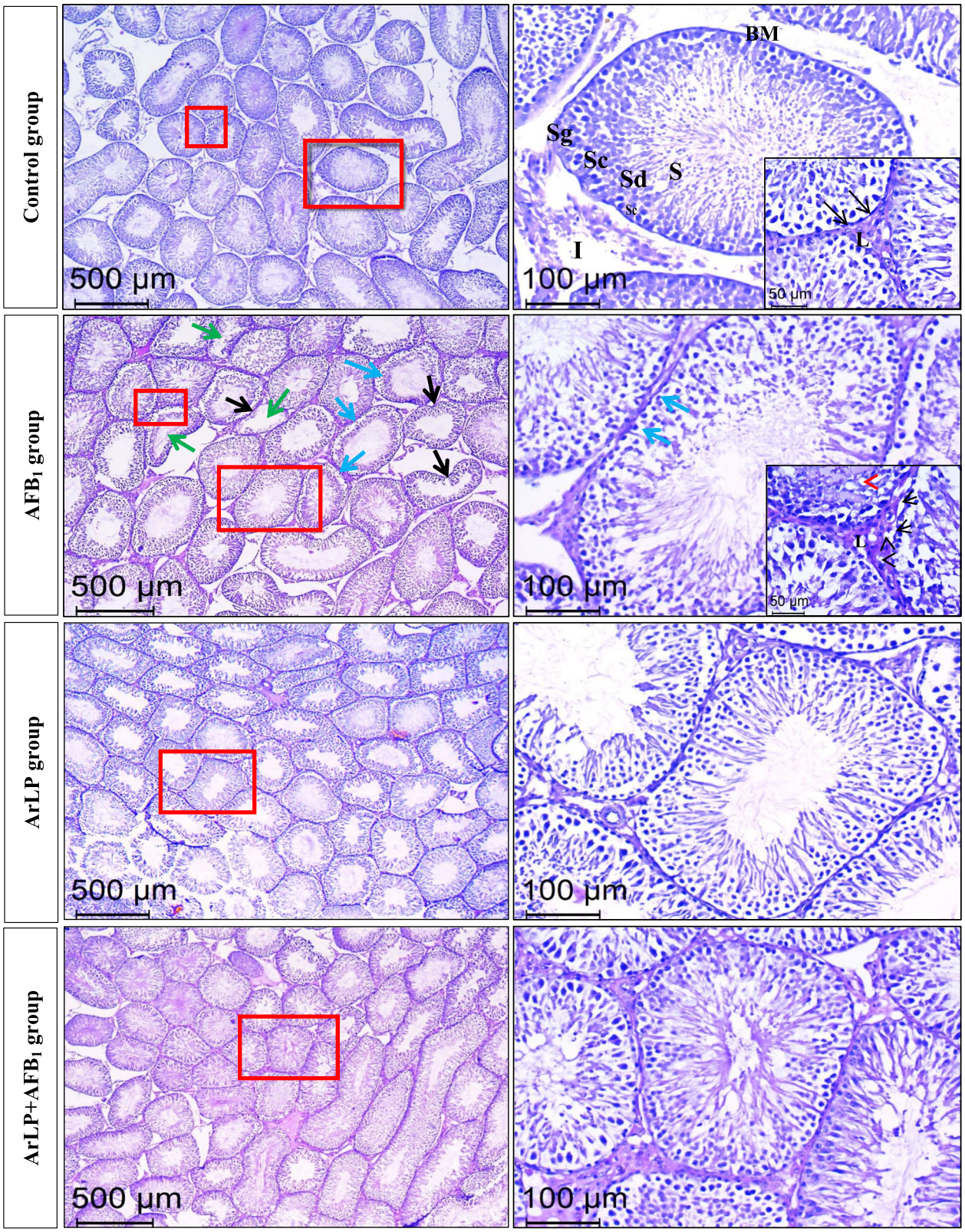
Sperm count in the ArLP group did not differ significantly from that of the control and DMSO groups (Fig. 4A). AFB_1 treatment significantly reduced sperm count compared to all other groups. Co-administration of ArLP with AFB_1 resulted in a significant increase in sperm count compared to the AFB_1 group, though levels remained significantly lower than those of the control, DMSO, and ArLP groups.

As shown in Fig. 4B, AFB_1 significantly reduced sperm motility compared to all other groups. The combination of ArLP and AFB_1 significantly increased sperm motility relative to the AFB_1-only group. However, motility levels in the ArLP + AFB_1 group remained significantly lower than in the control, DMSO, and ArLP groups.

Abnormal sperm percentage was significantly elevated in the AFB_1-treated group compared to all other groups (Fig. 4C). No significant difference in abnormal sperm percentage was observed among the control, DMSO, and ArLP groups. Co-treatment with ArLP significantly reduced the percentage of abnormal sperm compared to the AFB_1 group, with values not significantly different from the control group.

ArLP protects testicular tissue from AFB1-induced structural alterations

ArLP remarkably improved semen characteristics; subsequently its effect on testicular tissue structure was examined. As illustrated in Fig. 5, the control group had normal architecture of seminiferous tubules showing normal basement membrane with different stages of spermatogenesis. This involved normal spermatogonia, primary and secondary spermatocytes, spermatids, and finally sperms. Besides, Leydig cells were well seen in the interstitial space. In ArLP group, no obvious histological damage was observed in



both the seminiferous tubules and Leydig cells where they appeared normal as the control group. On the contrary, AFB_1 administration affected the structure of the seminiferous tubules which became partially deformed or atrophied. The images revealed irregular and buckled basement membrane with mild testicular degeneration manifested by reduced

◂**Fig. 5** Representative images of H&E stained testicular tissue sections of rats from different experimental groups showing (i) in the control group, magnification of delineated squares revealed a regular basement membrane (BM, black arrows) with different stage of spermatogenesis: spermatogonia (Sg), primary and secondary spermatocytes (Sc); spermatids (Sd) and finally sperms (S). Leydig cells (L) are well seen in the interstitial space (I), (ii) in the AFB_1 group, partially deformed or atrophied tubules (green arrows), irregular and buckled basement membrane (BM, black arrows), and reduced numbers of spermatogenic cells (blue arrows) were obvious. Magnification of delineated squares revealed vacuoles within both the tubules (red arrowhead) and the interstitial space (black arrowheads) among Leydig cells (L), (iii) in the ArLP group, magnification of delineated square shows no obvious histological damage on the seminiferous tubules as well as the interstitial spaces that display normal Leydig cells, and (iv) in the ArLP+AFB_1 group, magnification of delineated square clarifies the impact of ArLP co-supplementation in alleviating the harmful effect of AFB_1 on the seminiferous tubules manifested by the increase in the density of the different spermatogenic cells

numbers of spermatogenic cells. Other alterations observed were the presence of vacuoles within the tubules as well as in the interstitial space among Leydig cells. Moreover, increased luminal diameter which is one of the pathological features was clearly observed in AFB_1 group. Combining ArLP with AFB_1 counteracted the harmful effect of AFB_1 administration on testicular tissue. This was evident by increasing the density of spermatogenic cells, decreasing the testicular lumen, and increasing the sperm filled lumens and the presence of normal Leydig cells compared with AFB_1 group. Altogether, artichoke prevented testicular tissue deformities induced by AFB_1 toxicity.

Discussion

Artichoke is well known for its nutritional benefits and medicinal properties. It exhibits various therapeutic advantages including hypoglycemic (Jalili et al. 2020), hepatoprotective (Nasef et al. 2022), anti-atherosclerotic and cholesterol lowering effects (Romain et al. 2018). Artichoke medicinal products are mainly composed of dried leaves. Therefore, we investigated the effects of ArLP against induced toxicity on male reproductive system by AFB_1 which is known for imposing reproductive toxic consequences (Owumi et al. 2022).

The beneficial components of ArLP, including polyphenols, phenolic acids, flavonols, flavonones, bioflavonids, and phenolic aldehydes, play an important role in health promotion as manifested by body weight gain. As expected, AFB_1 caused a decrease in rats body weight, since weight loss is an indicator of a drop in animal's health status. These findings are consistent with the data shown by other studies that used AFB_1 orally (Subramaniam et al. 2022) or intraperitoneally (Deng et al. 2020; Ruggeberg et al. 2020). Upon ArLP administration, there was a significant increase in body weight gain of ArLP+AFB_1 group compared with AFB_1 group which clearly shows the positive effect of ArLP incorporation. The same effect of ArLP was reported in CCl4-intoxicated rats where ArLP significantly increased the body weight gain (Al-Ahdab 2014). In addition, no significant difference in testicular weight was observed among all groups.

Furthermore, we investigated the effect of ArLP administration on antioxidant enzymes of testicular tissue due to their eminent role in protecting male reproductive system and testicular function (Barati et al. 2020; Mannucci et al. 2022). It was shown that AFB_1 can induce oxidative stress and significantly impair the testicular antioxidant defense system causing germ cell apoptosis and spermatogenesis obstruction in both rats and mice (Yasin et al. 2018). The negative impact of AFB_1 on the antioxidant system was evident even across species (Ben Taheur et al. 2022; Gao et al. 2022; Lin et al. 2022). One of the mechanisms responsible for AFB_1 destructive action is oxidative stress related PI3K/AKT/mTOR signaling pathway in testicular tissue (Huang et al. 2019). In our study, AFB_1 caused a significant decrease in SOD, GSH, GST, and GPx levels and combining ArLP with AFB1 led to significant elevation in their concentration in the testicular tissue. Similar results were reported by others in rats (Yilmaz et al. 2017) and in mice (Choudhary and Verma 2005) intoxicated with AFB_1. On the other hand, ArLP showed the same improvement in antioxidant enzymes levels in other tissues such as brain (Ibrahim et al. 2022) and liver (Nasef et al. 2022). Moreover, this robust elevation in antioxidants activity induced by artichoke was also reported in vitro (Miláčková et al. 2017) and even in humans (Panahi et al. 2018). A meta-analysis study provided convincing evidence for the increase in artichoke induced antioxidant activity in animals (Salekzamani et al. 2019). Our study also revealed that artichoke protected rats' testicular tissue from the increase in TBARS and NO levels in addition to XO activity which was induced by AFB_1. These data are consistent with the findings from Baldissera et al. (2018) and Owumi et al. (2023) who demonstrated that AFB_1 induced oxidative toxicity in rats via inducing NO level and XO activity.

Another aspect that we investigated is artichoke's effect on PSA and male sex hormones. Prostate gland performs vital functions for supporting male fertility. Prostatic diseases or an unhealthy prostate can negatively affect normal male reproductive function (Verze et al. 2016). PSA is a well-known marker used for early detection of prostate cancer (Höti et al. 2023). Its high level is also detected in infertile men (Boeri et al. 2021). In our study, AFB_1 induced a significant increase in PSA levels and ArLP administration along with AFB_1 significantly decreased this elevated PSA to normal level. LH, FSH, and testosterone were also measured due to their immense importance for normal male

reproductive function. LH induces testosterone release by the Leydig cells of the testes, and it initiates and maintains human spermatogenesis during puberty (Oduwole et al. 2021). On the other hand, FSH regulates the proliferation and maturation of germ cells (Oduwole et al. 2021). Testosterone is another vital hormone for the health status of male reproductive system. It is responsible for male morphological changes such as sex differentiation in addition to male physiological processes such as spermatogenesis and fertility (Grande et al. 2022). Herein, AFB_1 led to a significant increase in LH and FSH levels in addition to a decrease in testosterone level when administered alone. However, ArLP administration along with AFB_1 reversed AFB_1-induced disturbance in the three male sex hormones. This was evident by the decrease in LH and FSH elevated levels as well as the increase in testosterone suppressed level and their return to normal levels. High LH and FSH levels are associated with low level of testosterone and testicular damage, respectively. The same pattern of hormonal changes was evident even in Wistar rat's offspring which were exposed to AFB_1 prenatally (Rotimi et al. 2021). This was also shown in humans who were exposed to AFB_1 such as miller flour workers (Beshir et al. 2020). Although Owumi et al. (2022) group reported that there was a decrease in testosterone level as our study, they showed that LH has decreased after AFB_1 administration. This may be attributed to the difference in AFB1 dose administered and the duration of exposure.

Semen quality is another crucial determinant of male fertility. Hence, we examined the semen quality after AFB_1 intoxication including sperm count, motility, and abnormality. AFB_1 significantly decreased sperm count, almost diminished sperm motility and doubled the level of abnormal sperm. Our results indicate that while ArLP alone had no impact on sperm quality, its co-administration with AFB_1 effectively attenuated AFB_1-induced impairments in semen parameters. Data from other studies supported our findings where AFB_1 negatively affected sperm viability (Komsky-Elbaz et al. 2018). Furthermore, the changes seen in our study such as decreased sperm count and deteriorated quality of sperm have been reported in AFB_1-treated mice and rats (Asadpour et al. 2020; Supriya et al. 2014). Faisal et al. (2008) demonstrated that AFB_1 induced sperm mitochondrial pathology which led to sperm abnormality. It also caused significant changes in sperm proteomic profile and decreased its fertilization competence. As for artichoke, the study conducted by Mohammed et al.'s (2020) group was consistent with our findings. They showed that it successfully alleviated the reduction in sperm quality induced by nandrolone decanoate.

Furthermore, the alterations in testicular tissue induced by AFB_1 administration were investigated as well. AFB_1 administration led to partially deformed or atrophied seminiferous tubules, reduced numbers of spermatogenic cells, and increased the vacuoles within the tubules as well as increased luminal diameter. Combining ArLP with AFB_1 counteracted the harmful effects of AFB_1 administration and restored rats normal testicular tissue. Similar deleterious changes on testicular tissue were reported by others in AFB_1 intoxicated rats, including but not limited to, reduced differentiation and spermiogenesis ratios, germ cells dissociation, deformed seminiferous tubules with edematous connective tissue and tubular depletion (Yasin et al. 2018; Asadpour et al. 2020). In addition, studies displaying similar protective effect of artichoke on testicular tissue were reported (Mohammed et al. 2020). Therefore, our study suggests that ArLP exerts a protective effect against AFB_1-induced toxicity in the male reproductive system when administered concurrently.

Conclusion

AFB_1 is an unavoidable environmental pollutant frequently found in feed and foodstuffs. It is the most toxic among all aflatoxins and has been shown to severely impair testicular development and function. Collectively, our data demonstrate that AFB_1 adversely affects multiple parameters of male reproductive health, including oxidative stress markers, antioxidant enzyme activity, PSA levels, sex hormone concentrations, semen quality, and testicular histoarchitecture. Co-administration of ArLP effectively attenuated these AFB_1-induced alterations and helped restore the measured parameters toward normal values. These findings support the potential role of ArLP as a protective agent against AFB_1-induced reproductive toxicity and highlight the need for further mechanistic and dose-optimization studies in preclinical models.

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Declarations

Consent to participate Not applicable.

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References

Abbas RZ, Raketsky V, Munir F, Mustafin B, Aubakirov M (2024) Botanicals in ameliorating mycotoxicosis in poultry. Int J Vet Sci 13(6):878–888. https://doi.org/10.47278/journal.ijvs/2024.232

Adamkovicova M, Toman R, Martiniakova M, Omelka R, Babosova R, Krajcovicova V, Grosskopf B, Massanyi P (2016) Sperm motility and morphology changes in rats exposed to cadmium and diazinon. Reprod Biol Endocrinol 14(1):42. https://doi.org/10.1186/s12958-016-0177-6

Al-Ahdab MA (2014) Protective effect of artichoke (Cynara scolymus L.) leaves and pulp extracts against carbon tetrachloride-induced acute hepatotoxicity in rats. World Appl Sci J 32(6):1004–1014. https://doi.org/10.5829/idosi.wasj.2014.32.06.14539

Ali E, Helmy MW, Radwan EH, Abdul Aziz KK, El-Wahed AAA, El-Samad LM, El Wakil A (2024) Evaluation of the cytotoxic activity of chemically characterized propolis originating from different geographic regions and vitamin D co-supplementation against human ovarian cancer cells. J Ovarian Res 17(1):181. https://doi.org/10.1186/s13048-024-01500-6

Alqurashy NN, Yousef MI, Hussein AA, Kamel MA, El Wakil A (2025a) Monascus red pigment influence on hydroxyapatite nanoparticles-mediated renal toxicity in rats. Sci Rep 15(1):2715. https://doi.org/10.1038/s41598-024-84959-z

Alqurashy NN, Yousef MI, El Tabakh MAM, Hussein AA, Kamel MA, El Wakil A (2025b) Protective role of Monascus red pigment against hydroxyapatite nanoparticle-induced liver injury in rats via modulation of metabolic regulators. Biochem Biophys Res Commun 775:152179. https://doi.org/10.1016/j.bbrc.2025.152179

Amr A, Abd El-Wahed A, El-Seedi HR, Khalifa SAM, Augustyniak M, El-Samad LM, Abdel Karim AE, El Wakil A (2022) UPLC-MS/MS analysis of naturally derived Apis mellifera products and their promising effects against cadmium-induced adverse effects in female rats. Nutrients 15(1):119. https://doi.org/10.3390/nu15010119

Asadpour R, Aliyoldashi MH, Saberivand A, Hamidian G, Hejazi M (2020) Ameliorative effect of selenium nanoparticles on the structure and function of testis and in vitro embryo development in Aflatoxin B1-exposed male mice. Andrologia 52(11):e13824. https://doi.org/10.1111/and.13824

Awad OME, El-Sohaimy SA, Ghareeb DA, Aboulenein AM, Saleh SR, El-Aziz NMA (2020) Phytochemical analysis and toxicity assessment of artichoke by-product extract. Pak J Biol Sci 23(1):81–91. https://doi.org/10.3923/pjbs.2020.81.91

Bakr BA, Sadek IA, El-Samad LM, El Wakil A (2023) Switchable hepatic organelles aberrations in DEN-induced mice under the influence of chemically characterized silk sericin. Tissue Cell 82:102101. https://doi.org/10.1016/j.tice.2023.102101

Baldissera MD, Souza CF, Doleski PH, Zeppenfeld CC, Descovi S, Da Silva AS, Baldisserotto B (2018) Xanthine oxidase activity exerts pro-oxidative and pro-inflammatory effects in serum of silver catfish fed with a diet contaminated with aflatoxin B_1. J Fish Dis 41(7):1153–1158. https://doi.org/10.1111/jfd.12812

Barati E, Nikzad H, Karimian M (2020) Oxidative stress and male infertility: current knowledge of pathophysiology and role of antioxidant therapy in disease management. Cell Mol Life Sci 77(1):93–113. https://doi.org/10.1007/s00018-019-03253-8

Barratt CLR, Björndahl L, De Jonge CJ, Lamb DJ, Osorio Martini F, McLachlan R, Oates RD, Van Der Poel S, St John B, Sigman M et al (2017) The diagnosis of male infertility: an analysis of the evidence to support the development of global WHO guidance—challenges and future research opportunities. Hum Reprod Update 23:660–680. https://doi.org/10.1093/humupd/dmx021

Ben Taheur F, Mansour C, Mechri S, Laaouar H, Safta Skhiri S, Bouricha M, Jaouadi B, Mzoughi R, Zouari N (2022) Protective effects of dietary Kefir against aflatoxin B1-induced hepatotoxicity in Nile tilapia fish, Oreochromis Niloticus. Food Sci Nutr 10(7):2300–2311. https://doi.org/10.1002/fsn3.2838

Beshir S, Shaheen W, Saad-Hussein A, Saeed Y (2020) Aflatoxin b1 as an endocrine disruptor among miller flour workers. South East Eur J Public Health 14. https://doi.org/10.4119/seejph-3441

Boeri L, Capogrosso P, Cazzaniga W, Ventimiglia E, Pozzi E, Belladelli F, Schifano N, Candela L, Alfano M, Pederzoli F, Abbate C, Montanari E, Valsecchi L, Papaleo E, Viganò P, Rovere-Querini P, Montorsi F, Salonia A (2021) Infertile men have higher prostate-specific antigen values than fertile individuals of comparable age. Eur Urol 79(2):234–240. https://doi.org/10.1016/J.EURURO.2020.08.001

Cao W, Yu P, Yang K, Cao D (2022) Aflatoxin B1: metabolism, toxicology, and its involvement in oxidative stress and cancer development. Toxicol Mech Methods 32(6):395–419. https://doi.org/10.1080/15376516.2021.2021339

Choudhary A, Verma RJ (2005) Ameliorative effects of black tea extract on aflatoxin-induced lipid peroxidation in the liver of mice. Food Chem Toxicol 43(1):99–104. https://doi.org/10.1016/j.fct.2004.08.016

Deng ZJ, Zhao JF, Huang F, Sun GL, Gao W, Lu L, Xiao Q (2020) Protective effect of procyanidin B2 on acute liver injury induced by aflatoxin B_1 in rats. Biomed Environ Sci 33(4):238–247. https://doi.org/10.3967/bes2020.033

El-Ashram S, El-Samad LM, Basha AA, El Wakil A (2021) Naturally-derived targeted therapy for wound healing: beyond classical strategies. Pharmacol Res 170:105749. https://doi.org/10.1016/j.phrs.2021.105749

Faisal K, Periasamy VS, Sahabudeen S, Radha A, Anandhi R, Akbarsha MA (2008) Spermatotoxic effect of aflatoxin B1 in rat: extrusion of outer dense fibres and associated axonemal microtubule doublets of sperm flagellum. Reproduction 135(3):303–310. https://doi.org/10.1530/REP-07-0367

Fasihi-Ramandi M, Bayat G, Kachuei R, Golmohammadi R (2023) Effects of aflatoxin B1 exposure on sperm in rodents: a systematic review and meta-analysis. Int J Environ Res Public Health 33(12):1629–1639. https://doi.org/10.1080/09603123.2022.2113766

Gao X, Jiang L, Xu J, Liu W, Li S, Huang W, Zhao H, Yang Z, Yu X, Wei Z (2022) Aflatoxin B1-activated heterophil extracellular traps result in the immunotoxicity to liver and kidney in chickens. Dev Comp Immunol 128:104325. https://doi.org/10.1016/j.dci.2021.104325

Grande G, Barrachina F, Soler-Ventura A, Jodar M, Mancini F, Marana R, Chiloiro S, Pontecorvi A, Oliva R, Milardi D (2022) The role of testosterone in spermatogenesis: lessons from proteome profiling of human spermatozoa in testosterone deficiency. Front

Endocrinol 13:852661. https://doi.org/10.3389/fendo.2022.852661
Hassan E, Magdy S, Attaallah A, Gaber E, Mansour O, Gomaa RA, Odessy H, Augustyniak M, El-Samad LM, El Wakil A (2022) Silk sericin alleviates aberrant photoperiod-induced alterations in testicular and adrenal steroidogenesis in adult mice. Reprod Biol Endocrinol 20(1):158. https://doi.org/10.1186/s12958-022-01032-y
Höti N, Lih TS, Dong M, Zhang Z, Mangold L, Partin AW, Sokoll LJ, Kay Li Q, Zhang H (2023) Urinary PSA and serum PSA for aggressive prostate cancer detection. Cancers 15(3). https://doi.org/10.3390/CANCERS15030960/S1
Huang W, Cao Z, Zhang J, Ji Q, Li Y (2019) Aflatoxin B_1 promotes autophagy associated with oxidative stress-related PI3K/AKT/mTOR signaling pathway in mice testis. Environ Pollut 255(Pt 2):113317. https://doi.org/10.1016/j.envpol.2019.113317
Ibrahim EA, Yousef MI, Ghareeb DA, Augustyniak M, Giesy JP, Aboul-Soud MAM, El Wakil A (2022) Artichoke leaf extract-mediated neuroprotection against effects of aflatoxin in male rats. Biomed Res Int 2022:4421828. https://doi.org/10.1155/2022/4421828
Jaćević V, Dumanović J, Alomar SY, Resanović R, Milovanović Z, Nepovimova E, Wu Q, Franca TCC, Wu W, Kuča K (2023) Research update on aflatoxins toxicity, metabolism, distribution, and detection: a concise overview. Toxicology 492:153549. https://doi.org/10.1016/j.tox.2023.153549
Jalili C, Moradi S, Babaei A, Boozari B, Asbaghi O, Lazaridi AV, Hojjati Kermani MA, Miraghajani M (2020) Effects of Cynara scolymus L. on glycemic indices: a systematic review and meta-analysis of randomized clinical trials. Complement Ther Med 52:102496. https://doi.org/10.1016/j.ctim.2020.102496
Jollow DJ, Mitchell JR, Zampaglione N, Gillette JR (1974) Bromobenzene-induced liver necrosis. Protective role of glutathione and evidence for 3,4-bromobenzene oxide as the hepatotoxic metabolite. Pharmacology 11(3):151–169. https://doi.org/10.1159/000136485
Komsky-Elbaz A, Saktsier M, Roth Z (2018) Aflatoxin B1 impairs sperm quality and fertilization competence. Toxicology 393:42–50. https://doi.org/10.1016/j.tox.2017.11.007
Lin LX, Cao QQ, Zhang CD, Xu TT, Yue K, Li Q, Liu F, Wang X, Dong HJ, Huang SC, Jian FC (2022) Aflatoxin B1 causes oxidative stress and apoptosis in sheep testes associated with disrupting rumen microbiota. Ecotoxicol Environ Saf 232:113225. https://doi.org/10.1016/j.ecoenv.2022.113225
Litwack G, Bothwell JW, Williams JN Jr., Elvehjem CA (1953) A colorimetric assay for xanthine oxidase in rat liver homogenates. J Biol Chem 200(1):303–310
Mannucci A, Argento FR, Fini E, Coccia ME, Taddei N, Becatti M, Fiorillo C (2022) The impact of oxidative stress in male infertility. Front Mol Biosci 8:799294. https://doi.org/10.3389/fmolb.2021.799294
Marcu D, Keyser S, Petrik L, Fuhrimann S, Maree L (2023) Contaminants of emerging concern (CECs) and male reproductive health: challenging the future with a double-edged sword. Toxics 11(4):330. https://doi.org/10.3390/toxics11040330
Martín I, Gálvez L, Guasch L, Palmero D (2022) Fungal pathogens and seed storage in the dry state. Plants 11(22):3167. https://doi.org/10.3390/plants11223167
Matar S, Gomaa RA, El Wakil A, Essawy A (2025) Human placental extract rescues hippocampal damage associated with cognitive impairment in diabetic male rats through antioxidative, anti-inflammatory, and neuromodulatory activities. Metab Brain Dis 40(6):225. https://doi.org/10.1007/s11011-025-01646-2
Miláčková I, Kapustová K, Mučaji P, Hošek J (2017) Artichoke leaf extract inhibits AKR1B1 and reduces NF-κB activity in human leukemic cells. Phytother Res 31(3):488–496. https://doi.org/10.1002/ptr.5774
Mohammed ET, Radi AM, Aleya L, Abdel-Daim MM (2020) *Cynara scolymus* leaves extract alleviates nandrolone decanoate-induced alterations in testicular function and sperm quality in albino rats. Environ Sci Pollut Res Int 27(5):5009–5017. https://doi.org/10.1007/s11356-019-07302-4
Montgomery HAC, Dymock JF (1961) Determination of nitrite in water. Analyst 86(102):414
Naeem A, Hu P, Yang M, Zhang J, Liu Y, Zhu W, Zheng Q (2022) Natural products as anticancer agents: current status and future perspectives. Molecules 27(23):8367. https://doi.org/10.3390/molecules27238367
Nasef MA, Yousef MI, Ghareeb DA, Augustyniak M, Aboul-Soud MAM, El Wakil A (2022) Hepatoprotective effects of a chemically-characterized extract from artichoke (Cynara scolymus L.) against AFB_1-induced toxicity in rats. Drug Chem Toxicol. https://doi.org/10.1080/01480545.2022.2129672
Oduwole OO, Huhtaniemi IT, Misrahi M (2021) The roles of luteinizing hormone, follicle-stimulating hormone and testosterone in spermatogenesis and folliculogenesis revisited. Int J Mol Sci 22(23):12735. https://doi.org/10.3390/ijms222312735
Omar EM, El-Sayed NS, Elnozahy FY, Hassan E, Amr A, Augustyniak M, El-Samad LM, El Wakil A (2024) Reversal effects of royal jelly and propolis against cadmium-induced hepatorenal toxicity in rats. Biol Trace Elem Res 202(4):1612–1627. https://doi.org/10.1007/s12011-023-03775-0
Owumi SE, Irozuru CE, Arunsi UO, Faleke HO, Oyelere AK (2022) Caffeic acid mitigates aflatoxin B1-mediated toxicity in the male rat reproductive system by modulating inflammatory and apoptotic responses, testicular function, and the redox-regulatory systems. J Food Biochem 46(5):e14090. https://doi.org/10.1111/jfbc.14090
Owumi SE, Ajakaiye B, Akinwunmi AO, Nwozo SO, Oyelere AK (2023) The hydrophobic extract of Sorghum bicolor (L. Moench) enriched in apigenin-protected rats against aflatoxin B1-associated hepatorenal derangement. Molecules. https://doi.org/10.3390/MOLECULES28073013
Panahi Y, Kianpour P, Mohtashami R, Atkin SL, Butler AE, Jafari R, Badeli R, Sahebkar A (2018) Efficacy of artichoke leaf extract in non-alcoholic fatty liver disease: a pilot double-blind randomized controlled trial. Phytother Res 32(7):1382–1387. https://doi.org/10.1002/ptr.6073
Pickova D, Ostry V, Toman J, Malir F (2021) Aflatoxins: history, significant milestones, recent data on their toxicity and ways to mitigation. Toxins 13(6):399. https://doi.org/10.3390/toxins13060399
Pleadin J, Frece J, Markov K (2019) Mycotoxins in food and feed. Adv Food Nutr Res 89:297–345. https://doi.org/10.1016/bs.afnr.2019.02.007
Romain C, Piemontese A, Battista S, Bernini F, Ossoli A, Strazzella A, Gaillet S, Rouanet JM, Cases J, Zanotti I (2018) Anti-atherosclerotic effect of a polyphenol-rich ingredient, Oleactiv®, in a hypercholesterolemia-induced golden syrian hamster model. Nutrients 10(10):1511. https://doi.org/10.3390/nu10101511
Rotimi OA, Onuzulu CD, Dewald AL, Ehlinger J, Adelani IB, Olasehinde OE, Rotimi SO, Goodrich JM (2021) Early life exposure to aflatoxin B1 in rats: alterations in lipids, hormones, and DNA methylation among the offspring. Int J Environ Res Public Health 18(2):589. https://doi.org/10.3390/ijerph18020589
Ruggeberg KG, O'Sullivan P, Kovacs TJ, Dawson K, Capponi VJ, Chan PP, Golobish TD, Gruda MC (2020) Hemoadsorption improves survival of rats exposed to an acutely lethal dose of aflatoxin B_1. Sci Rep 10(1):799. https://doi.org/10.1038/s41598-020-57727-y
Salekzamani S, Ebrahimi-Mameghani M, Rezazadeh K (2019) The antioxidant activity of artichoke (Cynara scolymus): a systematic

review and meta-analysis of animal studies. Phytother Res 33(1):55–71. https://doi.org/10.1002/ptr.6213

Skrzydlewski P, Twarużek M, Grajewski J (2022) Cytotoxicity of mycotoxins and their combinations on different cell lines: a review. Toxins 14(4):244. https://doi.org/10.3390/toxins14040244

Subramaniam S, Sabran MR, Stanslas J, Kirby BP (2022) Effect of aflatoxin B1 exposure on the progression of depressive-like behavior in rats. Front Nutr 9:1032810. https://doi.org/10.3389/fnut.2022.1032810

Supriya C, Girish BP, Reddy PS (2014) Aflatoxin B1-induced reproductive toxicity in male rats: possible mechanism of action. Int J Toxicol 33(3):155–161. https://doi.org/10.1177/1091581814530764

Tang K, Tian J, Xu Y, Shang G, Peng X, Yue P, Wang Y, Chen S, Hu Z (2025) Aflatoxin B1 exposure suppresses the migration of dendritic cells by reshaping the cytoskeleton. Int J Mol Sci 26(4):1725. https://doi.org/10.3390/ijms26041725

Tarhane S, Dursun I, Mor B, Kanici A, Kızıltepe Ş, Filazi İ, Güven A (2023) Determination of the mycotoxin activity of filamentous fungi isolated from the intestinal region of adult honey bees by the PCR and UHPLCOrbitrap-HRMS methods. Kafkas Univ Vet Fak Derg 29(5):473–481. https://doi.org/10.9775/kvfd.2023.29447

Ülger TG, Uçar A, Çakıroğlu FP, Yilmaz S (2020) Genotoxic effects of mycotoxins. Toxicon 185:104–113. https://doi.org/10.1016/j.toxicon.2020.07.004

Verze P, Cai T, Lorenzetti S (2016) The role of the prostate in male fertility, health and disease. Nat Rev Urol 13(7):379–386. https://doi.org/10.1038/nrurol.2016.89

Wang YX, Sun Y, Feng W, Wang P, Yang P, Li J, Huang Z, Chen YJ, Liu C, Sun L, Yue J, Gu LJ, Zeng Q, Lu WQ (2016) Association of urinary metal levels with human semen quality: a cross-sectional study in China. Environ Int 91:51–59. https://doi.org/10.1016/j.envint.2016.02.019

Wang T, Cui R, Yu HF, Yang D, Zhang S, Nie Y, Teng CB (2025) The impact of aflatoxin B1 on animal health: metabolic processes, detection methods, and preventive measures. Toxicon 255:108262. https://doi.org/10.1016/j.toxicon.2025.108262

Yasin M, Mazdak R, Mino I (2018) Aflatoxin B1 impairs spermatogenesis: an experimental study for crosslink between oxidative stress and mitochondria-dependent apoptosis. Environ Toxicol 33(11):1204–1213. https://doi.org/10.1002/tox.22627

Yılmaz S, Kaya E, Comakli S (2017) Vitamin E (α tocopherol) attenuates toxicity and oxidative stress induced by aflatoxin in rats. Adv Clin Exp Med 26(6):907–917. https://doi.org/10.17219/acem/66347

Zaied H, Ashmawy MI, Abdel Karim AE, Ghareeb DA, El Wakil A (2025) Berberine-loaded albumin nanoparticles alleviate liver damage in rats by modulating mitochondrial biogenesis and mitochondria-endoplasmic reticulum interactions. Biochem Biophys Res Commun 754:151555. https://doi.org/10.1016/j.bbrc.2025.151555