International Journal of Reproduction, Contraception, Obstetrics and Gynecology
Ezeagu DK et al. Int J Reprod Contracept Obstet Gynecol. 2025 Jul;14(7):2074-2082
www.ijrcog.org
pISSN 2320-1770 | eISSN 2320-1789

DOI: https://dx.doi.org/10.18203/2320-1770.ijrcog20251951

Original Research Article

Ripe banana peel extract: a natural protector of testicular health in experimental models

Darlington Kenechukwu Ezeagu*, Uzozie Chikere Ofoego

Department of Anatomy, Faculty of Basic Medical Sciences, Nnamdi Azikiwe University, Nnewi Campus, Anambra State, Nigeria

Received: 19 April 2025
Revised: 16 May 2025
Accepted: 17 May 2025

***Correspondence:**
Darlington Kenechukwu Ezeagu,
E-mail: dk.ezeagu@unizik.edu.ng

ABSTRACT

Background: Spermatogenesis is highly vulnerable to oxidative stress, which can be intensified by environmental toxins like paraquat (PQ), an herbicide known for its potent toxicity, particularly in inducing reactive oxygen species (ROS). Musa sapientum (banana), has garnered attention for its antioxidant properties, particularly in its peel, which contains bioactive compounds such as flavonoids and phenols. This study investigated the protective effects of the ethanolic extract of ripe banana peel on male reproductive health in Wistar rats exposed to paraquat-induced testicular dysfunction.
Methods: After acclimatization and toxicity tests, 25 rats were divided into 5 groups. Group A served as the control, receiving rat feed and distilled water. Group B received 20mg/kg of paraquat. Group C received 1000mg/kg of ethanolic banana peel extract. Groups D and E both received 20mg/kg of paraquat followed by 500mg/kg and 1000mg/kg of banana peel extract respectively for three weeks. Sperm quality and testicular histoarchitecture were assessed, with semen samples collected from the epididymis and testes processed for histological evaluation.
Results: Paraquat exposure significantly reduced sperm motility, count, and testicular weight, while increasing sperm abnormalities and histological damage. These effects were likely due to ROS-induced lipid peroxidation and DNA fragmentation. Treatment with banana peel extract significantly improved sperm motility, count, and testicular histoarchitecture, indicating its antioxidant properties.
Conclusions: This study suggests that banana peel extract has potent antioxidant effects and could alleviate paraquat-induced male infertility.

Keywords: Spermatogenesis, Paraquat, Oxidative stress, Banana peel extract, Reproductive function

INTRODUCTION

The increasing exposure to environmental chemicals and herbal products has raised concerns regarding their potential impact on reproductive health. Among these chemicals, paraquat, a widely used herbicide, has been implicated in severe cases of testicular injuries, often leading to infertility.[1,2] Paraquat is a dark green liquid herbicide employed in non-agricultural lands, side roads, orchards, and fallow lands to control annual grasses and broad-leaved weeds.[3] Its toxic effects stem from its redox cycling process, which generates superoxide anions, resulting in oxidative stress and cellular damage.[1,4] Studies have shown that paraquat exposure leads to a decrease in superoxide dismutase (SOD) activity and an increase in malondialdehyde (MDA) levels, markers of oxidative stress.[5] In the laboratories, paraquat is used to induce oxidative stress by generating superoxide anions.[6,7]

Oxidative stress, defined as the excessive production of reactive oxygen species (ROS), leads to structural and functional changes in nucleic acids, lipids, and proteins, contributing to inflammation, apoptosis, and cellular dysfunction.[8,9] Paraquat has been reported to cause severe vascular endothelial damage and disrupt blood clotting mechanisms when ingested.[10] Although it is rapidly excreted in the urine within 12–24 hours, its harmful effects on reproductive health, particularly the testes, remain significant.[11,12]

The testes are vital reproductive organs responsible for sperm and testosterone production.[13,14] They possess a self-renewing stem cell component, making them highly susceptible to environmental toxins with testicular dysfunction resulting in hormonal imbalances, sexual dysfunction, and infertility.[15,16] Given that male infertility accounts for 40-50% of infertility cases globally, there is an urgent need to explore potential protective interventions.[17,18]

Plant-based remedies, particularly those rich in phytochemicals, have gained attention for their therapeutic benefits against oxidative damage.[19] Banana (*Musa sapientum*) is a nutrient-packed fruit that thrives in tropical regions worldwide. It produces fruit within 9–12 months, with maturation occurring in 60–90 days.[20,21] However, banana peels are often discarded as waste, reflecting a lack of awareness of their nutritional potential. Laboratory studies have shown that banana peels are rich in antioxidants, phytochemicals, and essential nutrients.[22-24] They have diverse applications in skincare, hair care, and food enhancement, and show promise in animal feed, baking, pasta, and functional foods.[22,24-26] Banana peels offer antioxidant, antimicrobial, and nutritional benefits, with limited concerns regarding toxicity.[27,28] However, limited literature exists on the effects of ethanolic extract of ripe banana peel on oxidative stress-induced testicular damage. This study aims to investigate the protective and restorative effects of banana peel extract on testicular function in an experimental animal model, addressing a significant gap in reproductive toxicology research.

METHODS

Location and duration of the study

This study was carried at the Department of Anatomy, Faculty of Basic Medical Sciences, Nnamdi Azikiwe University, Nnewi, Anambra State. The ethical approval was obtained from the Ethical Committee of the Faculty of Basic Medical Sciences, Nnamdi Azikiwe University, Nnewi, Anambra State, Nigeria (NAU/CHS/NC/FBMS/1011), before commencing the research. The rats were allowed to acclimatize for two weeks, while the actual administration of test samples to the animals lasted for 35 days (5 Weeks). This research lasted from the 4th of September 2023 to the 24th of October, 2023.

Animal procurement and treatment

Thirty-eight (38) adults male wistar rats weighing between 120-150g were purchased from Best Farm Okofia Nnewi, Nnewi North Local Government Area of Anambra State. The animals were housed in well-ventilated stainless steel rat cages under room temperature (27-31^{0}C) throughout the course of the experiment. They were fed with standard rat diet and distilled water ad libitum and were adapted to the laboratory environment in the Department of Anatomy, within the period of acclimatization. The floors of the cage were sprinkled with saw dust obtained from a nearby sawmill and the cages cleaned every two days to prevent infections. The rats were weighed to access their growth and the guide for the care and use of laboratory animals followed the Guide for the Care and Use of Laboratory Animals.[29]

Procurement of ripe banana peels and preparation of its ethanolic extract

Ripe peels from naturally ripened bananas of the *Musa sapientum* species were obtained from a fruit vendor at Nkwo Nnewi Market, located in Nnewi North Local Government Area of Anambra State. The ripe banana peels were washed in running water to remove dirt and shed dried under ambient room temperature. The dried banana peels were grinded to powdered form and 250g of it soaked in 1000ml of 98% absolute ethanol for 48 hours with intermittent shaking, after which the mixture was sieved using porcelain cloth and further filtered using whatman filter paper into a clean glass beaker. The filtrate was concentrated using Digital Rotatory Evaporator (TT-S2 Techmel and Techmel USA) and was further dried using thermostat oven (DHG-9023A Pecmedicals USA) at 45^{0}C into a gelly-like substance and then stored in a refrigerator for further reconstitution and use.

Toxicity test for ethanolic extract of ripe banana peel

The median lethal dose (LD_{50}) of ethanolic extract of ripe banana peel (*Musa sapientum*) was carried out in the Department of Physiology, Faculty of Basic Medical Sciences, Nnamdi Azikiwe University, Nnewi Campus. In this study, 13 rats were used and received the extract via oral route, in two phases according to Lorke's method.[30] LD_{50} of ethanolic extract of ripe *Musa sapientum* peel was found to be above 5000mg/kg via oral route in adult male wistar rats.

Experimental design and protocol

After acclimatization and toxicity tests, 25 rats were weighed and divided into 5 groups of five rats each. Group A served as the control. The rats in this group were administered rat feeds and distilled water all through the duration of the experiment. Group B received 20mg/kg of paraquat only throughout the duration of the experiment. Group C received 1000mg/kg of ethanolic extract of Ripe Banana Peel (*Musa sapientum*) only throughout the

duration of the experiment. Group D received 20 mg/kg of paraquat for two weeks, followed by co-administration of 500 mg/kg of ethanolic extract of ripe banana peel for an additional three weeks. Group E received 20 mg/kg of paraquat for two weeks, followed by co-administration of 1000 mg/kg of ethanolic extract of ripe banana peel for another three weeks. Paraquat was administered twice a week (Mondays and Thursdays) while the banana peel extract was administered once daily, between the hours of 7am-9am. All administrations were done orally. Concentration of paraquat used in this experiment was determined after close evaluation of several scholarly workS.[2,31,32]

Termination of experiment and organ collection

The experiment lasted for 35 days (5 weeks). Twenty-four hours after the final extract administration, the rats were sacrificed via cervical dislocation. The right and left testes were promptly dissected, weighed, and the epididymis was removed for semen collection. Thereafter, the testes were fixed in freshly prepared Bouin's fluid for routine histological processing.

Evaluations of sperm count, sperm motility and sperm morphology

Sperm count evaluation

Sperm count analysis was conducted following the method outlined by the World Health Organization.[33] Semen was collected by excising the epididymis and diluted in sodium bicarbonate formalin solution at a 1:20 ratio using a graduated cylinder. The diluted sample was transferred to an Improved Neubauer ruled chamber using a Pasteur pipette and allowed to settle for 3–5 minutes. Observations were made under a 10× objective with the condenser iris adjusted for optimal contrast. Spermatozoa were counted in two large squares (2 sq mm), and the result was multiplied by 10^6.

Sperm motility

Sperm motility analysis was conducted following the method outlined by the World Health Organization.[33] A well-mixed drop of liquefied semen was placed on a slide, evenly spread, and covered with a coverslip. Observations were made using a 40× objective lens. A total of 100 spermatozoa were counted, with the motile and non-motile sperm recorded as a percentage.

Sperm morphology

Sperm morphology analysis was performed following the World Health Organization guidelines.[33] A thin smear of well-mixed, liquefied semen was prepared on a slide and fixed with 95% ethanol for 5-10 minutes before air-drying. The smear was washed with sodium bicarbonate formalin solution to remove mucus, rinsed with water, and stained with dilute (1 in 20) carbon fuchsin for 3 minutes. It was then counterstained with dilute (1 in 20) Loeffler's methylene blue for 2 minutes, washed, drained, and air-dried. Examination was conducted using a 40× objective, with a 100× objective used for confirmation of abnormalities. A total of 100 spermatozoa were assessed, and the percentage of normal and abnormal morphology was recorded. Morphological abnormalities included rudimentary tails, round heads, and detached heads.

Tissue processing and photomicrography

The fixed testis was processed at the Histopathological unit of Nnamdi Azikiwe University Teaching Hospital Nnewi using the standard H&E histological techniques which included fixation, dehydration, clearing, impregnation/infiltration, embedding, sectioning, mounting and H&E staining. The slides with the cover slips attached were finally viewed under light microscope.

Data analysis

Data obtained was analyzed using SPSS version 25 (IBM, USA, 2018). Relative testicular weights, Sperm morphology, motility, and count were analyzed using ANOVA followed by post Hoc LSD multiple comparison. Data was considered significance at $p \leq 0.05$.

RESULTS

Effect of administration of ethanolic extract of ripe banana peel (Musa sapientum) (EEMS) and paraquat (PQ) on relative testicular weight of wistar rats.

As shown in Table 1, only Group D (that received 20 mg/kg of PQ for 2-weeks and co-administration with 500 mg/kg of EEMS for 3-weeks) had a statistically lower relative testicular weight (p=0.03) compared to Group A. When compared to Group B (that received paraquat PQ only), Group D that received 20 mg/kg of paraquat for two weeks, followed by co-administration of 500 mg/kg of EEMS for an additional three weeks) showed statistically lower relative testicular weight with no statistical difference observed among the other experimental groups.

Effect of administration of ethanolic extract of ripe banana peel (Musa sapientum) and paraquat on sperm motility and total sperm count

As shown in Table 2, Group B had a statistically significant lower percentage of active motile sperm (p = 0.00) compared to Group A (Control). However, Groups C, D, and E exhibited a statistically significant higher percentage (p = 0.00 for each) of active sperm cells when compared to Group B.

The total sperm count results showed statistically significant lower percentages in Groups B and D (p=0.00 and p=0.01, respectively) when compared to Group A. However, Groups C, D, and E (p=0.00, p=0.00, p=0.00, respectively) showed statistically significant higher

percentages in total sperm count when compared to Group B

Data were analyzed using a paired t-test, and values were considered significant at $p \leq 0.05$. *Indicates significance, and # denotes no significance when compared to Group A. Similarly, a indicates significance, and b denotes no significance when compared to Group B. Abbreviations used: PQ (Paraquat), EEMS (Ethanolic Extract of *Musa sapientum*), and SEM (Standard Error of Mean).

Table 1: Effect of administration of ethanolic extract of ripe banana peel (*Musa sapientum*) and paraquat on the relative testicular weight of wistar rats.

Groups (n=5)	Relative testicular weight (g)
	Mean±Sem
Group A (control)	0.84±0.02b
Group B (20mg/kg of PQ)	0.63±0.12#
Group C (1000 mg/kg of EEMS)	0.60±0.08#b
Group D (20 mg/kg of paraquat for two weeks, followed by co-administration of 500 mg/kg of EEMS for an additional three weeks)	0.54±0.11**a
Group E (20 mg/kg of paraquat for two weeks, followed by co-administration of 1000 mg/kg of EEMS for another three weeks)	0.69±0.02#b
F-ratio	1.723

Data were analyzed using a paired t-test, and values were considered significant at $p \leq 0.05$. Asterisks (**) indicate statistical significance, while # denotes no significant difference when compared to Group A. Similarly, a represents significance, and b indicates no significant difference when compared to Group B. The abbreviations used include PQ (Paraquat), EEMS (Ethanolic Extract of Musa sapientum), and SEM (Standard Error of Mean).

Table 2: Effect of administration of ethanolic extract of ripe banana peel (*Musa sapientum*) and paraquat on sperm motility and total sperm count.

Groups (n=5)	Active motile sperm (%)	Non-motile sperm (%)	Total sperm count (x10^6/ml)
	Mean±sem	**Mean±sem**	**Mean±sem**
Group A (control)	86.67±3.33^{a}	13.33±3.33^{a}	67.00±2.64^{a}
Group B (20mg/kg of PQ)	55.00±2.88**	45.00±2.88**	27.30±1.95**
Group C (1000 mg/kg of EEMS)	92.67±1.45$^{\#a}$	7.33±1.45$^{\#a}$	70.33±2.40$^{\#a}$
Group D (20 mg/kg of paraquat for two weeks, followed by co-administration of 500 mg/kg of EEMS for an additional three weeks)	88.33±1.67$^{\#a}$	11.67±1.67$^{\#a}$	53.00±1.44^{**a}
Group E (20 mg/kg of paraquat for two weeks, followed by co-administration of 1000 mg/kg of EEMS for another three weeks)	88.33±2.03$^{\#a}$	11.67±2.03$^{\#a}$	63.25±1.45$^{\#a}$
F-ratio	41.510	41.510	69.345

Data were analyzed using a paired t-test, and values were considered significant at $p \leq 0.05$. * indicates significance, and # denotes no significance when compared to Group A. Similarly, a indicates significance, and b denotes no significance when compared to Group B. Abbreviations used: PQ (Paraquat), EEMS (Ethanolic Extract of Musa sapientum), and SEM (Standard Error of Mean).

Table 3: Effect of administration of ethanolic extract of ripe banana peel (*Musa sapientum*) and paraquat on sperm morphology.

Groups (n=5)	Normal sperm cells (%)	Abnormal sperm cells (%)
	Mean±sem	**Mean±sem**
Group A (control)	92.67±3.33^{a}	7.33±3.33^{a}
Group B (20mg/kg of PQ)	45.00±2.88**	55.00±2.88**
Group C (1000 mg/kg of EEMS)	90.33±1.45$^{\#a}$	9.67±1.45$^{\#a}$
Group D (20 mg/kg of paraquat for two weeks, followed by co-administration of 500 mg/kg of EEMS for an additional three weeks)	89.33±2.33$^{\#a}$	10.67±2.33$^{\#a}$

Continued.

Groups (n=5)	Normal sperm cells (%)	Abnormal sperm cells (%)
Group E (20 mg/kg of paraquat for two weeks, followed by co-administration of 1000 mg/kg of EEMS for another three weeks)	90.00±2.88$^{\#a}$	10.00±2.88$^{\#a}$
F-ratio	76.31	76.31

Data were analyzed using a paired t-test, and values were considered significant at $p \leq 0.05$. *indicates significance, and # denotes no significance when compared to Group A. Similarly, a indicates significance, and b denotes no significance when compared to Group B. Abbreviations used: PQ (Paraquat), EEMS (Ethanolic Extract of Musa sapientum), and SEM (Standard Error of Mean).

Histopathological findings

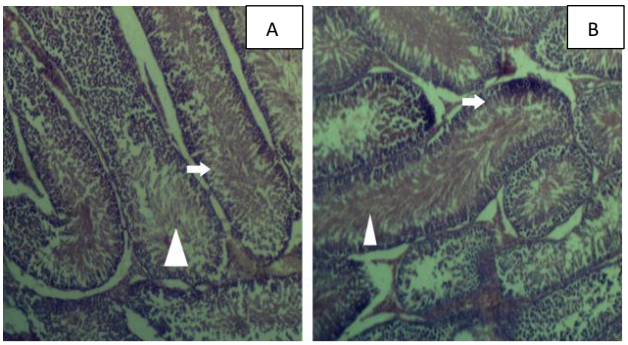

Figure 1 (A and B): Photomicrograph of sections of testis from Group A (which received only feed and water). The connective tissues (arrow) are shown with normal architecture. The seminiferous tubules (arrowhead) display active and normal spermatogonia and spermatids (stained with H&E, ×100 magnification).

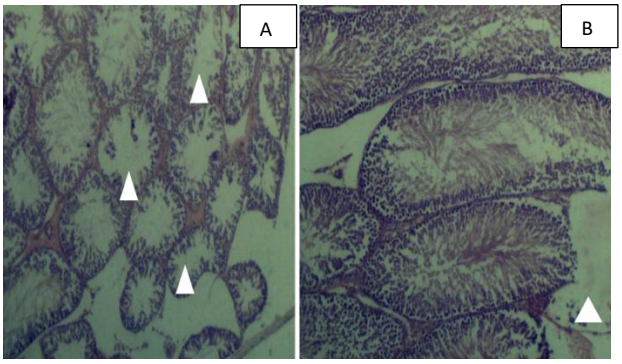

Figure 2 (A and B): Photomicrograph of sections of testis from Group B (which received 20 mg/kg of paraquat only), showing reduced level of spermatogenesis. The seminiferous tubules (arrowhead) exhibit reduced spermatogonia and spermatids, with moderate spermatogenic arrest (stained with H&E, ×100 magnification).

Effect of administration of ethanolic extract of ripe banana peel (Musa sapientum) and paraquat on sperm morphology

As shown in Table 3, Group B exhibited a statistically significant lower percentage of normal sperm cells (p=0.00) when compared to Group A. However, Groups C, D, and E showed non-statistically significant lower percentages (p=0.49, p=0.33, p=0.44, respectively) compared to Group A. Additionally, Groups C, D, and E demonstrated a statistically significant higher percentage of normal sperm cells (p=0.01, p=0.00, p=0.01, respectively) when compared to Group B.

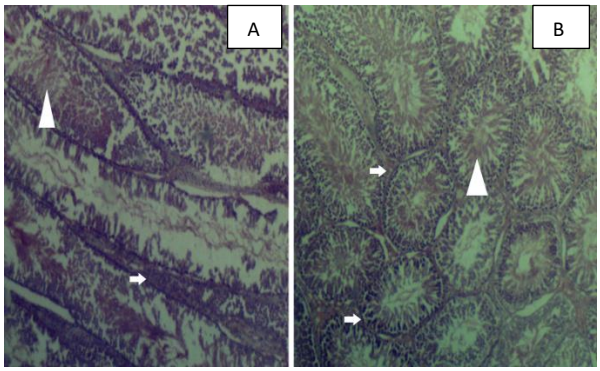

Figure 3 (A and B): Photomicrograph of sections of the testis from Group C (which received 1000 mg/kg of ethanolic extract of ripe banana peel (*Musa sapientum*))c, showing connective tissue (arrow) with normal architecture. The seminiferous tubules (arrowhead) display active and normal spermatogonia and spermatids (stained with H&E, ×100 magnification).

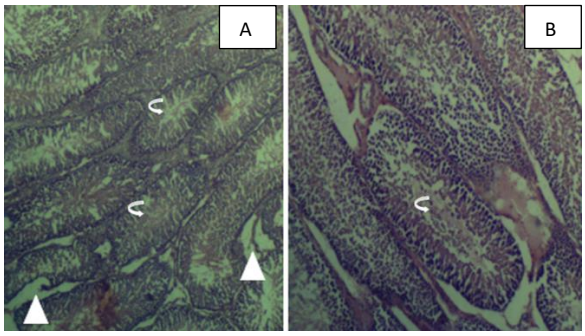

Figure 4 (A and B): Photomicrograph of sections of testis from Group D (20 mg/kg of paraquat for two weeks, followed by co-administration of 500 mg/kg of ethanolic extract of ripe banana peel for an additional three weeks), showing mild necrosis (arrowhead) and increased active and normal spermatogonia and spermatids (curved arrows) in the seminiferous tubules (stained with H&E, ×100 magnification).

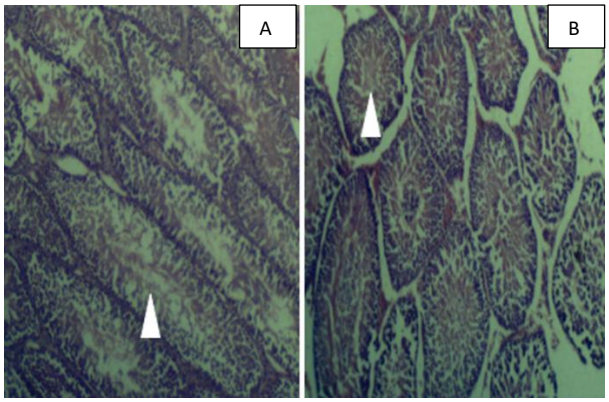

Figure 5 (A and B): Photomicrograph of sections of testis from Group E (which received 20 mg/kg of paraquat for two weeks, followed by co-administration of 1000 mg/kg of ethanolic extract of ripe banana peel for another three weeks), showing normal morphology of the testes, with the arrowhead indicating an increased level of spermatids and spermatogonia in the seminiferous tubules (stained with H&E, ×100 magnification).

DISCUSSION

Spermatogenesis, the complex process by which male germ cells develop into mature spermatozoa, occurs within the seminiferous tubules of the testes. These germ cells progress in an orderly manner from spermatogonia at the base of the tubule to spermatids, which subsequently undergo morphological transformation into spermatozoa through spermiogenesis.[34] The integrity of this process is critical for male fertility and can be disrupted by various environmental and chemical factors. In recent years, medicinal plants have garnered significant attention in the management of male infertility. This interest is largely due to the presence of secondary metabolites in plants, which are known to mitigate oxidative stress a key contributor to male infertility.[2,35]

The present study examined the protective effects of the ethanolic extract of ripe *Musa sapientum* (banana) peel on the male reproductive function of Wistar rats following paraquat-induced testicular dysfunction. Organ toxicity studies provide vital insights into how toxic substances such as paraquat (PQ) alter the physiological and structural integrity of organs. Paraquat, a widely used herbicide, is known for its potent toxic effects, particularly due to its role in enhancing lipid peroxidation and reactive oxygen species (ROS) generation.[36,37] These effects have been reported to severely impact testicular function.[1,2] In the laboratories, paraquat is usually used to induce production of ROS.[1,2,38]

One of the findings in this study was the observation of a non-significant decrease in relative testicular weight in the paraquat-treated group (Group B) compared to the control group. This marginal decrease may be associated with oxidative stress-induced alterations in testicular tissue. Oxidative damage might have led to reduced spermatogenesis and sperm density observed in this study, potentially resulting in testicular weight loss. This finding is somewhat inconsistent with several previous studies. For instance, Chen et al, and Li et al, reported significantly reduced testicular weights following paraquat exposure.[31,39] Similarly, Yang et al, and Ijaz et al, also documented marked decreases in relative testicular weights due to paraquat toxicity.[1,38] In contrast, studies by Ofoego et al, found no significant changes in testicular weight, aligning more closely with our findings.[40,41] Dewi et al, also reported a non-significant increase in testicular weight post-paraquat exposure, supporting the observed trend in this study.[42] Interestingly, treatment with ripe banana peel extract resulted in varying outcomes. Rats in Group D exhibited significantly lower relative testicular weights, possibly due to the loss of sperm bundles resulting from prior paraquat toxicity. On the other hand, Group E, which received both paraquat and banana peel extract, demonstrated a significant improvement in testicular weight compared to Group B, indicating improved spermatogenesis and tissue recovery following treatment.

Sperm motility is a crucial parameter in assessing male fertility. The paraquat-treated group (Group B) exhibited a significantly lower percentage of active sperm cells, accompanied by a notable increase in non-motile sperm. These alterations are likely attributable to ROS-induced lipid peroxidation and DNA fragmentation within the sperm membrane, consequences of paraquat toxicity.[2] These findings are consistent with the reports by Chen et al, and Ijaz et al, who observed similar reductions in sperm motility and vitality following paraquat exposure in experimental models.[31,38]

Furthermore, the paraquat-treated group also showed a significant decline in total sperm count relative to the control. This reduction may be linked to the herbicide's ability to disrupt germ cell differentiation and maturation through oxidative mechanisms that impair mitochondrial function, DNA synthesis, and trigger tissue necrosis.[43] The continuous influx and generation of reactive oxygen species (ROS) from both endogenous and exogenous sources can lead to oxidative damage of cellular components, thereby impairing numerous cellular functions, with the most susceptible biological targets of oxidative stress including proteins, enzymes, lipid membranes, and DNA.[36] These propagation reactions occur repeatedly, resulting in the peroxidation of multiple unsaturated lipids within the membrane, damage to specific amino acid residues, and alterations in protein tertiary structures. Oxidative stress can also cause indirect damage such as lipid peroxidation, protein degradation, and fragmentation.[36] The consequences of protein damage include loss of enzymatic activity and disruption of normal cellular functions.[37] These observations corroborate previous findings by Ofoego et al, Dewi et al, and Ijaz et al, reinforcing the detrimental reproductive effects of paraquat.[40-42,44]

Conversely, the administration of ripe banana peel extract was associated with significant improvements in sperm parameters. Groups C, D, and E demonstrated increased active sperm motility and total sperm count, along with reduced percentages of non-motile sperm, compared to the paraquat-only group. These improvements are likely due to the high concentration of antioxidants in banana peel, including flavonoids, phenols, saponins, and terpenoids.[27,45] These compounds are known to neutralize free radicals, enhance cellular function, and protect reproductive tissues.[46-48] Zulkifli et al, similarly reported improved sperm motility and count following banana peel extract treatment in rats fed a high-fat diet.[49] However, it is worth noting that Dike and Etsede observed a decline in sperm count with calcium carbide-ripened bananas, emphasizing the importance of natural ripening methods.[50]

Sperm morphology, another essential indicator of fertility, was also significantly affected by paraquat. Group B rats showed lower percentages of normal sperm cells and higher incidences of abnormal forms, likely due to DNA fragmentation and possible oxidative stress induced alteration to the sperm morphology. These findings echo the results of Chen et al, and Ofoego et al, all of whom reported paraquat-induced morphological abnormalities.[31,40,41] However, treatment with banana peel extract markedly improved sperm morphology in this study, as evidenced by higher percentages of normal sperm and fewer abnormal forms in the treated groups. The improvements observed may be attributed not only to the phytochemicals present in ripe banana peels but also to the presence of essential trace elements in banana peel, such as zinc, iron, calcium, potassium, and vitamins like vitamin C.[23,24] These micronutrients play key roles in testicular development, sperm maturation, and overall reproductive function.[51-53] The enhancement in sperm morphology in this study aligns with the findings of Zulkifli et al, who demonstrated similar effects in high-fat diet rats treated with banana peel extract.[49]

Histological evaluation further supported our pathophysiological findings. Testes from paraquat-treated rats (Group B) showed evidence of spermatogenic arrest, disrupted seminiferous tubules, and reduced germ cell layers. This arrest likely resulted from ROS-mediated DNA damage and interference with the hypothalamic-pituitary-gonadal axis, as suggested by Ofoego et al, and Shibeshil et al.[2,54] In contrast, rats treated with banana peel extract showed significant improvements in testicular architecture, with restored seminiferous tubules and germinal epithelium, suggesting tissue regeneration and protective effects conferred by the extract. In addition to several phytochemicals, banana peels contain Quercetin (a type of flavonoid) a plant pigment with powerful antioxidant and anti-inflammatory properties. Quercetin compounds contribute to the antioxidant effects of banana peel, providing protection against oxidative stress, inflammation, and tissue damage.[55]

Limitations of the study

This research was conducted under a strict budget due to the prevailing economic hardship in the country. This constrained the scope of the study.

CONCLUSION

This study demonstrated that oral exposure to paraquat (an herbicide extensively used by our local farmers) resulted in a reduction in testicular weight, sperm quality, and spermatogenic arrest in the testes of male Wistar rats. Histological analysis also showed significant alterations in testicular architecture. However, treatment with ethanolic extract of ripe *Musa sapientum* (banana) peel improved testicular weight, sperm parameters, and the histological features of the testes. These findings suggest that ripe *Musa sapientum* peel extract has potential protective effects against male fertility impairments induced by paraquat toxicity in experimental animals.

ACKNOWLEDGEMENTS

We are grateful to the technologists of the Departments of Anatomy and Human Physiology, Faculty of Basic Medical Sciences, Nnamdi Azikiwe University, Nnewi Campus, Anambra State, Nigeria, who helped in both animal handling as well as sacrificing of the experimental animals.

Funding: No funding sources
Conflict of interest: None declared
Ethical approval: The study was approved by the Ethics Committee of Faculty of Basic Medical Sciences, Nnamdi Azikiwe University, Anambra State, Nigeria (NAU/CHS/NC/FBMS/1011)

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Cite this article as: Ezeagu DK, Ofoego UC. Ripe banana peel extract: a natural protector of testicular health in experimental models. Int J Reprod Contracept Obstet Gynecol 2025;14:2074-82.