

Fertility Effects of Red Ginger Rhizome Extract (*Zingiber officinale* var. *rubrum*) on the Sperm Quality of Rats (*Rattus norvegicus* L.) Induced by Monosodium Glutamate

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Abstract

Modern lifestyle changes have led to increased consumption of processed foods containing monosodium glutamate (MSG), which, at excessive doses, may induce oxidative stress and impair male reproductive function. This study investigated the fertility-related effects of red ginger rhizome extract (*Zingiber officinale* var. *rubrum*) on sperm quality in MSG-induced rats (*Rattus norvegicus* L.). The experimental study employed a completely randomized design (CRD) consisting of four treatment groups with six replications: the control group received 1,600 mg MSG, while P1, P2, and P3 received red ginger extract at doses of 500, 750, and 1,000 mg/kg body weight (BW), respectively. MSG induction and extract administration were performed orally for 14 days, with the extract administered two hours after MSG exposure. On day 15, the rats were euthanized, and sperm quality parameters, including motility, viability, and morphology, were assessed. Data were analyzed using one-way analysis of variance (ANOVA) followed by a least significant difference (LSD) post hoc test at $\alpha = 0.05$. The results demonstrated that red ginger extract significantly improved sperm quality impaired by MSG induction, with the greatest improvement observed at 1,000 mg/kg BW (P3): motility reached 88.89%, viability 83.89%, and normal morphology 82.79%. These findings suggest that red ginger may exert protective antioxidant effects against MSG-induced reproductive damage. This study contributes to the exploration of red ginger as a potential herbal intervention for supporting male reproductive health.

INTRODUCTION

The rapid pace of modern life has fundamentally altered dietary habits, shifting consumption patterns from traditional home-cooked meals toward processed and fast foods that offer greater convenience. This transformation is particularly evident in urban populations, where time constraints and easy access to ready-to-eat products have become defining features of daily life. The food industry has responded to this demand by incorporating various additives to enhance flavor and extend shelf life, among which monosodium (Abdel-Aty et al., 2025) glutamate (Loi & Cynober, 2022) (MSG) is one of the most widely used flavor enhancers worldwide. MSG is commonly found in restaurant meals (Brewer & Sebby, 2021), packaged snacks, instant noodles, and other processed foods (Anyanwu & Orisakwe, 2020).

The safety of MSG consumption has been extensively evaluated by international health authorities. The Joint FAO/WHO Expert Committee on Food Additives (JECFA) has established an acceptable daily intake (ADI) of up to 30 mg/kg body weight per day, while the World Health Organization (WHO) recommends a broader range of 0–120 mg/kg body weight per day for human consumption (Laelago Ersedo et al., 2023). However, these

regulatory limits may not always reflect actual consumption patterns, particularly among populations with a high intake of processed foods. Studies have documented that daily MSG intake in some Asian populations may exceed recommended thresholds, raising concerns regarding the potential health effects of chronic or excessive exposure (Jamili et al., 2023).

Excessive MSG consumption has been associated with several adverse health effects, particularly those related to oxidative stress and excitotoxicity. Increased production of reactive oxygen species (ROS) can overwhelm endogenous antioxidant defenses and lead to cellular damage. This oxidative imbalance may be particularly detrimental to tissues with high metabolic activity, including reproductive organs (Abd-Elkareem et al., 2021). Testicular tissue is especially vulnerable to oxidative stress because normal spermatogenesis depends on the integrity of cellular membranes, mitochondrial function, hormonal regulation, and antioxidant defense mechanisms. MSG-induced oxidative damage may therefore disrupt spermatogenesis through lipid peroxidation, mitochondrial dysfunction, and altered cellular signaling pathways (Jamili et al., 2023).

The male reproductive system represents an important target of MSG-induced toxicity because spermatogenesis is a complex and highly regulated process. Previous studies have demonstrated that MSG exposure can reduce sperm count, motility, and viability while increasing morphological abnormalities. These effects have been associated with increased production of pro-inflammatory cytokines such as tumor necrosis factor- α (TNF- α), disruption of the blood–testis barrier, and impaired steroidogenesis resulting in reduced testosterone synthesis. Ogunmokunwa and Ibitoye (2025) reported that MSG-induced testicular dysfunction was associated with elevated oxidative stress markers and downregulation of steroidogenic enzymes, ultimately compromising reproductive function. These findings highlight the need to identify effective protective interventions against MSG-induced reproductive damage (Moradi et al., 2025).

In response to growing evidence of MSG-induced reproductive toxicity, increasing research attention has focused on natural compounds with antioxidant properties that may mitigate these adverse effects. Red ginger (*Zingiber officinale* var. *rubrum*) has emerged as a promising candidate because of its rich phytochemical (Roberts et al., 2016) composition and longstanding use as a medicinal plant (Famurewa et al., 2020). Red ginger contains bioactive compounds such as gingerols, shogaols, zingerone, gingerdiol, and flavonoids. These compounds have demonstrated antioxidant and anti-inflammatory activities through mechanisms including free-radical scavenging, enhancement of endogenous antioxidant enzyme activity, and modulation of inflammatory signaling pathways (Amalia & Triyannanto, 2023).

Scientific evidence supports the potential of ginger extracts to improve reproductive health parameters. A systematic review by Gholami-(Gholami-Ahangaran et al., 2021) concluded that ginger administration improved several semen quality parameters, including sperm count, viability, motility, morphology, and DNA integrity across different species. These effects have been attributed to ginger's antioxidant activity and its potential influence on reproductive hormones, including luteinizing hormone (LH), follicle-stimulating hormone (FSH), and testosterone. Clinical studies have also reported reduced sperm DNA fragmentation following ginger supplementation, providing further rationale for investigating the effects of red ginger on MSG-induced reproductive damage (Sumadi et al., 2019).

Previous studies have specifically examined the protective effects of red ginger against MSG-induced toxicity. Renaldi et al. (2024) demonstrated that red ginger extract maintained seminiferous tubule epithelial thickness and diameter in MSG-exposed rats. Sidharta et al. (2026) reported that red ginger extract preserved spermatogenic and Leydig cell populations, both of which are essential for spermatogenesis and testosterone production (Xue et al., 2022). Putri (2025) found that red ginger treatment tended to improve sperm motility in MSG-exposed rats. Furthermore, Aprilia et al. (2024) reported that ethanol extract of red ginger improved sperm motility, viability, and concentration in MSG-exposed mice. Collectively, these studies suggest that red ginger may exert protective effects by reducing oxidative stress, suppressing apoptotic pathways, and preserving testicular structure.

Despite these findings, several research gaps remain. First, many previous studies have used a single dose of red ginger extract without systematically assessing dose-dependent effects on multiple sperm quality parameters. Consequently, the most effective dose for protecting against MSG-induced reproductive damage remains unclear. Second, limited research has simultaneously evaluated motility, viability, and morphology within a single experimental design. Third, the dose–response relationship between red ginger extract and MSG-induced reproductive toxicity has not been comprehensively characterized across these major sperm quality endpoints. These gaps indicate the need for a more systematic evaluation of red ginger as a dose-dependent protective agent (Zhang et al., 2022).

The urgency of addressing these gaps is reinforced by the global burden of male infertility and the potential contribution of environmental and dietary factors to impaired reproductive health. Infertility affects a substantial proportion of couples worldwide, with male-related factors contributing to many cases. Increasing consumption of MSG-containing processed foods may represent an additional dietary concern, particularly where exposure is frequent or excessive. In this context, red ginger is of particular interest because it is widely cultivated and consumed in Indonesia and may offer an accessible source of antioxidant compounds with potential reproductive health benefits (Zolfaghari et al., 2025).

The novelty of this research lies in its simultaneous evaluation of the dose-dependent effects of red ginger extract on three major sperm quality parameters—motility, viability, and morphology—in an experimental model of MSG-induced reproductive toxicity. By using three doses of 500, 750, and 1,000 mg/kg body weight, the study seeks to characterize differences in treatment response across sperm quality endpoints and identify the dose associated with the greatest protective effect. This approach provides a more comprehensive assessment of red ginger’s potential role in protecting male reproductive function against MSG-induced damage.

Therefore, this study aims to determine the effects of red ginger rhizome extract on sperm quality in rats exposed to a toxic dose of MSG. Specifically, it evaluates sperm motility, viability, and normal morphology following administration of red ginger extract at three different doses. The findings are expected to contribute to the scientific understanding of the reproductive protective potential of red ginger and to provide a basis for further research in reproductive toxicology, herbal medicine, and the development of evidence-based phytotherapeutic approaches for supporting male reproductive health (Partyka & Nizański, 2021).

METHODS

This study employed an experimental design based on a completely randomized design (CRD) consisting of four treatment groups with six replications. The treatments included a control group (K) administered 1,600 mg MSG; P1, administered 500 mg/kg body weight (BW) red ginger extract plus 1,600 mg MSG; P2, administered 750 mg/kg BW red ginger extract plus 1,600 mg MSG; and P3, administered 1,000 mg/kg BW red ginger extract plus 1,600 mg MSG. The study population consisted of 30 healthy male rats (*Rattus norvegicus* L.) aged 2–3 months and weighing approximately 190–200 g. Rats meeting the inclusion criteria were selected using purposive sampling and acclimatized for 14 days under controlled laboratory conditions with a 12:12-hour light–dark cycle. They were provided commercial feed and drinking water ad libitum.

Red ginger rhizomes were washed, oven-dried at 70°C, ground into powder, and macerated in 96% ethanol for 48 hours. The filtrate was subsequently concentrated using a rotary evaporator at 45°C and 100 rpm until a semisolid extract was obtained. MSG and red ginger extract were administered orally for 14 consecutive days, with the extract administered two hours after MSG exposure. On day 15, the rats were anesthetized and euthanized, after which the cauda epididymis was collected and minced in 0.9% NaCl solution maintained at 32–34°C to obtain a homogeneous sperm suspension [citation:20]. Sperm quality parameters were subsequently examined using a light microscope connected to a computer.

Sperm motility was assessed using an improved Neubauer counting chamber at 400× magnification and classified as fast progressive, slow progressive, nonprogressive, or nonmotile [citation:21]. Sperm viability was evaluated by mixing 50 µL of sperm suspension with 25 µL of eosin–nigrosin stain and examining the resulting preparation microscopically [citation:21]. For morphological assessment, sperm smears were prepared on glass slides, fixed with 96% methanol for 5 minutes, and stained with 20% Giemsa solution for 30 minutes [citation:22]. A total of 100 spermatozoa per sample were examined at 1,000× magnification. Data were analyzed using IBM SPSS Statistics version 26. Normality and homogeneity were assessed before inferential analysis. One-way analysis of variance (ANOVA) was used to determine differences among treatment groups, followed by the least significant difference (LSD) post hoc test at a 95% confidence level ($\alpha = 0.05$). The study received ethical approval from the Faculty of Natural Sciences and Mathematics under Letter No. UN.29.17.5/SK/EC/2025.

RESULT AND DISCUSSION

The quality of spermatozoa is an indicator used to determine the fertility level of a male individual. Spermatozoa quality parameters include motility, viability and morphology of spermatozoa (Avianty et al., 2021).

Spermatozoa motility

Motility observations in this study were aimed at seeing the motility of normal and abnormal spermatozoa. The results of observations of spermatozoa motility can be seen in Table 1.

Table 1. Average percentage and standard deviation (SD) of sperm motility in rats between treatments

Treatment	Spermatozoa Motility (%)	
	Normal $\pm$ SD	Abnormal $\pm$ SD
K	34.48 $\pm$ 1.87a	65.52 $\pm$ 3.20a
P1	79.65 $\pm$ 1.47b	20.35 $\pm$ 1.94b
P2	85.05 $\pm$ 2.31c	14.95 $\pm$ 3.21c
P3	88.89 $\pm$ 3.72D	11.11 $\pm$ 3.65d

Source: Primary data from the research results, 2026.

Note: Numbers followed by different letters indicate a significant difference based on the least significant difference test at the 95% confidence level.

Based on Table 1, it shows that the red ginger rhizome extract in all treatments had a significant effect on spermatozoa motility compared to the control. The 1000 mg/kg extract dose treatment (P3) was the most effective in increasing spermatozoa motility, with actively and progressively moving sperm reaching a motility percentage of 88.89%. The K treatment (monosodium glutamate dose of 1600 mg) (Ogunmokunwa & Ibitoye, 2025) showed a low percentage of normal spermatozoa motility, namely 24.48%. The decrease in motility is caused by increased oxidative stress, which leads to damage to the plasma membrane and mitochondria of spermatozoa, thereby disrupting the production of energy (ATP) required for sperm movement (Wang, et al., 2025). Monosodium glutamate increases the formation of Reactive Oxygen Species (ROS) such as superoxide, hydrogen peroxide, and hydroxyl radicals, which can trigger lipid peroxidation reactions in spermatozoa membranes, thereby damaging membrane structure, reducing mitochondrial function, and negatively affecting sperm motility, viability, and morphology. Active compounds in red ginger such as gingerol, shogaol, and flavonoids act as antioxidants by donating hydrogen atoms to neutralize free radicals into more stable forms, as well as stopping lipid peroxidation chain reactions that cause damage (Ersedo et al. 2023).

Male rats induced with monosodium glutamate showed significantly higher testicular lipid peroxidation as a marker of reactive oxygen species (ROS) production (Ogunmokunwa and Ibitoye 2025). Lipid peroxidation is one of the main indicators of increased reactive oxygen species (ROS) production (Kayode et al., 2020). Monosodium glutamate can disrupt the balance between ROS production and the antioxidant defense system, thereby causing damage to cell membranes rich in unsaturated fatty acids, such as testicular cells. In the P1 treatment at a dose of 500 mg/kg body weight, there was an increase in normal spermatozoa motility of 79.65% and a decrease in abnormal motility of 20.35%. Active compounds in red ginger such as gingerol and flavonoids have antioxidant activity that can reduce free radical levels and protect the spermatozoa membrane structure from oxidative damage (Ahangaran et al. 2021). The increase in normal spermatozoa motility is increasingly evident in the P2 treatment, where normal motility increased to 85.05%, while in P3 it reached 88.89% (Diana Putri Amalia. M et al., 2022). The study by (Ogunmokunwa and Ibitoye 2025) reported that the administration of red ginger extract can significantly improve sperm motility through a mitochondrial protection mechanism and increased activity of endogenous antioxidant enzymes such as superoxide dismutase (SOD) and catalase (Luthfi & Noor, 2021).

Red ginger rhizome extract helps rat testes produce more hormones and antioxidant enzymes (Famurewa et al. 2020). The amino acid arginine in red ginger functions as a precursor molecule for NO (nitric oxide), which generates intercellular signals for metabolism. The way arginine affects sperm quality is by increasing nitric oxide production; arginine can protect the sperm plasma membrane from damage caused by lipid peroxidation (Famurewa et al. 2020). The amino acid arginine contained in red ginger increases NO synthesis, which prevents this lipid peroxidation in the sperm membrane. This can increase the availability of energy and the metabolic activity of sperm cells, which will promote spermatogenesis (Loggia & O’Flaherty, 2024). The red ginger rhizome extract in this study is thought to be able to increase antioxidant activity, including the effects of shogaol and gingerol in neutralizing free radicals. This antioxidant quality increases serum glutathione levels, sperm quantity and quality, and antioxidant enzyme levels, while simultaneously significantly reducing lipid peroxidation (Partyka 2021). The process of spermatozoa peroxidation will lead to modifications in the plasma membrane structure, which will disrupt membrane stability and function as well as reduce its fluidity. The decrease in sperm motility is caused by disruption of sperm cell metabolism due to damage to the mitochondrial plasma membrane (Jamili et al., 2023).

Spermatozoa viability

The results of the percentage of live spermatozoa and dead spermatozoa, which is the viability of spermatozoa, can be seen in Table 2.

Table 2. Average percentage and standard deviation (SD) of rat spermatozoa viability between treatments

Treatment	Spermatozoa Viability (%)	
	Life $\pm$ SD	Dead $\pm$ SD
K	45.76 $\pm$ 1.87d	54.24 $\pm$ 1.87a
P1	75.70 $\pm$ 3.32c	34.30 $\pm$ 3.54b
P2	77.29 $\pm$ 1.41b	22.71 $\pm$ 3.54c
P3	83.89 $\pm$ 1.47a	16.11 $\pm$ 2.92d

Source: Primary data from the research results, 2026.

Note: Numbers followed by different letters indicate a significant difference based on the least significant difference test at the 95% confidence level

Based on Table 2, it shows that treatment K (monosodium glutamate 1600 mg) exhibited a low percentage of live spermatozoa, namely 45.76%, and a high percentage of dead spermatozoa, namely 54.24%. The decrease in spermatozoa viability is closely related to increased oxidative stress, which causes damage to the sperm cell plasma membrane. This membrane damage results in disruption of ion balance and cell metabolism, causing spermatozoa to lose their ability to survive (L. Wang et al., 2020). In treatments P1, P2, and P3, there was an increase in the percentage of live spermatozoa compared to the control. The increase in spermatozoa viability was in line with the increasing dose of red ginger extract, particularly in P3 with a percentage of 83.89%. This effect is caused by the active compounds in red ginger such as gingerol, shogaol, and flavonoids, which have strong antioxidant activity so they are able to neutralize free radicals and suppress damage to the sperm cell membrane (Famurewa et al. 2020).

Research results by (Moradi et al. 2025) state that red ginger extract can increase the viability of spermatozoa in experimental animals experiencing oxidative stress. Antioxidants in red ginger play a role in protecting the phospholipid membrane of sperm cells from lipid peroxidation, thereby maintaining membrane integrity and extending the lifespan of spermatozoa (Ahangaran et al. 2021). High spermatozoa viability is very important because it is directly related to fertilization ability, living spermatozoa have a greater chance of reaching and fertilizing the ovum. The increase in spermatozoa viability in the P1, P2, and P3 treatments indicates that red ginger rhizome extract has the potential to improve sperm quality that has declined due to exposure to MSG.

Spermatozoa morphology

The average percentage of spermatozoa morphology is shown in Table 3.

Table 3. Average percentage of mouse spermatozoa morphology between treatments

Treatment	Spermatozoa morphology (%)	
	Normal $\pm$ SD	Abnormal $\pm$ SD
K+	51.41 $\pm$ 3.82d	48.59 $\pm$ 2.66a
K-	68.46 $\pm$ 1.94c	31.54 $\pm$ 1.87b
P1	76.48 $\pm$ 1.04b	23.57 $\pm$ 3.07c
P2	82.79 $\pm$ 3.26a	17.21 $\pm$ 3.71d

Source: Primary data from the research results, 2026.

Note: Numbers followed by different letters indicate a significant difference based on the least significant difference test at the 95% confidence level.

Based on Table 3, it shows that in the control treatment (K), the percentage of normal spermatozoa morphology was only 51.41%, while abnormal morphology reached 48.59%. In treatment P1, there was an increase in normal spermatozoa morphology to 68.46%, and P2 showed a higher increase, also at 68.46%. This increase is caused by the effect of compounds in red ginger extract in suppressing oxidative stress and protecting the integrity of spermatozoa membranes and organelles. The percentage of normal spermatozoa morphology in P3 had the highest value, namely 82.79%. These results indicate that the higher the dose in this treatment, the greater the effect on the cell protection mechanism against oxidative damage. Antioxidants play a role in suppressing oxidative stress in testicular and epididymal tissues, thereby protecting cell membranes and spermatozoa structures from damage.

The spermatozoa morphological abnormalities found in this study consist of primary and secondary abnormalities. Primary abnormalities occur during the spermatogenesis process in the testis, namely when sperm are formed in the seminiferous tubules due to disturbances. Secondary abnormalities occur after sperm leave the testis, especially during maturation in the epididymis, where normally formed sperm can develop morphological defects due to disruptions during this maturation stage (Aziz et al., 2025). Primary abnormalities include double heads, flattened heads, and small heads without an acrosome. Secondary abnormalities found include tails detached from the head, coiled tails, broken tail tips, and heads or midpieces that still contain cytoplasm (Jamili et al., 2023). Various forms of spermatozoa abnormalities in rats found in this study can be seen in the following figure.

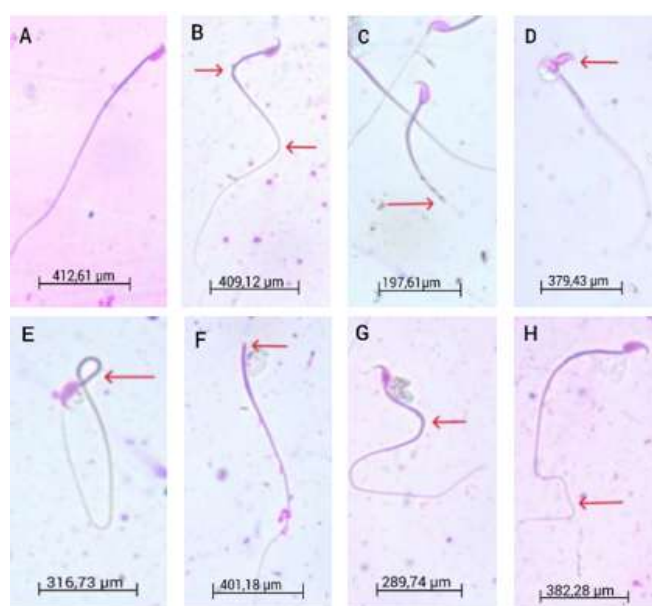


Figure 1. Various Forms of Normal and Abnormal Spermatozoa Morphology in Rats (*Rattus norvegicus* L.)

Source: Research documentation, 2026.

Figure. Various abnormal spermatozoa morphologies found in the study. A. Normal spermatozoa; B. Spermatozoa with a zigzag-shaped body; C. Spermatozoa without a tail; D. Spermatozoa with a double head; E. Coiled sperm body, wavy tail; F. Spermatozoa with detached head; G. Wavy spermatozoa; H. Spermatozoa with wavy tail.

Based on Figure above, the most commonly found spermatozoa morphological abnormalities in this study were spermatozoa with zigzag-shaped bodies, spermatozoa without tails, spermatozoa with double heads, spermatozoa with coiled bodies and wavy tails, spermatozoa with separated heads and bodies, wavy spermatozoa; and spermatozoa with wavy tails. Abnormalities according to (Jamili et al., 2023) are caused by disturbances in the sperm maturation process and the epididymis. In the epididymis, spermatozoa undergo a series of morphological and functional changes such as size, shape, midpiece ultrastructure, DNA, metabolic patterns, and plasma membrane properties. Primary spermatozoa abnormalities found are caused by decreased testosterone levels, which inhibit the formation of the α -tubulin protein as a basic component of microtubules and microfilaments that are important in the spermiogenesis process for moving the cytoplasm toward the rear toward the flagellum (Y. Wang et al., 2025). Compounds contained in monosodium glutamate will enter the bloodstream and travel to the testes and affect a decrease in the number of normal spermatozoa and an increase in the number of abnormal spermatozoa (Ogunmokunwa and Ibitoye 2025).

CONCLUSION

Based on the results of this study, it can be concluded that the administration of red ginger rhizome extract (*Zingiber officinale* var. *rubrum*) at doses of 500, 750, and 1,000 mg/kg body weight significantly improved sperm quality in rats (*Rattus norvegicus* L.) exposed to a toxic dose of monosodium glutamate (MSG; 1,600 mg/kg body weight). The extract increased the percentages of sperm motility, viability, and normal morphology across

all treatment groups compared with the control group. The greatest improvements were observed in the P3 group (1,000 mg/kg body weight), in which sperm motility reached 88.89%, viability reached 83.89%, and normal morphology reached 82.79%. These findings indicate a dose-dependent relationship between red ginger extract administration and improvements in sperm quality, with higher doses providing greater protection against MSG-induced reproductive damage. The bioactive compounds in red ginger, particularly gingerols, shogaols, flavonoids, and arginine, may contribute to these protective effects by reducing oxidative stress, limiting lipid peroxidation, preserving mitochondrial function, and maintaining spermatogenic cell integrity. The marked improvement in sperm quality at the highest dose indicates the potential of red ginger as a natural agent for supporting male reproductive health.

Future research should further investigate the mechanisms and therapeutic potential of red ginger. Hormonal analyses of testosterone, follicle-stimulating hormone (FSH), and luteinizing hormone (LH) could clarify the endocrine mechanisms underlying its effects on spermatogenesis. Histopathological examination of testicular tissue and assessment of apoptotic markers, including caspase-3, BAX, and BCL-2, as well as antioxidant enzymes such as superoxide dismutase (SOD), catalase (CAT), and glutathione peroxidase (GPx), could provide further insight into its cellular protective mechanisms. Longer-term studies covering a complete spermatogenic cycle are also recommended to evaluate sustained effects on sperm quality and fertility outcomes. In addition, phytochemical standardization and identification of the principal active compounds would support the development of consistent herbal preparations. Further preclinical studies followed by appropriately designed clinical trials are needed to establish safety, efficacy, and suitable dosages in humans. Overall, these findings provide a scientific basis for further investigation of red ginger rhizome as a potential natural intervention for improving sperm quality and supporting male reproductive health.

REFERENCES

- Abdel-Aty, D. M., Ibrahim, M. A., Mohamed, S. R., El-Khadragy, M. F., Abdel Moneim, A. E., Fathalla, A. S., & Soliman, D. (2025). Rutin and Moringa oleifera leaf extract prevent monosodium glutamate-induced testicular toxicity in adult male albino rats. *Frontiers in Veterinary Science*, 12. <https://doi.org/10.3389/fvets.2025.1566471>
- Abd-Elkareem, M., Abd El-Rahman, M. A. M., Khalil, N. S. A., & Amer, A. S. (2021). Antioxidant and cytoprotective effects of *Nigella sativa* L. seeds on the testis of monosodium glutamate challenged rats. *Scientific Reports*, 11(1). <https://doi.org/10.1038/s41598-021-92977-4>
- Amalia, D. N., & Triyannanto, E. (2023). Ready To Eat (RTE) Meatballs with Natural MSG Sources as Delicacy Potency in Indonesia. *Proceedings of the International Conference on Sustainable Environment, Agriculture and Tourism (ICOSEAT 2022)*, 26. https://doi.org/10.2991/978-94-6463-086-2_39
- Anyanwu, B. O., & Orisakwe, O. E. (2020). Current mechanistic perspectives on male reproductive toxicity induced by heavy metals. *Journal of Environmental Science and Health, Part C: Toxicology and Carcinogenesis*, 38(3). <https://doi.org/10.1080/26896583.2020.1782116>
- Avianty, E. S., Dewi, P. K., Setyawati, A. N., & Mochtar, A. A. (2021). The Effect Of Coffee On The Spermatozoa Motility Of Male Wistar Rats (*Rattus Norvegicus*) Exposed To

- Electric Cigarette Smoke. *Diponegoro Medical Journal (Jurnal Kedokteran Diponegoro)*, 10(3). <https://doi.org/10.14710/dmj.v10i3.29987>
- Aziz, E. K., Sherabia, N. I., Mansour, D. A., Nasr, M. A., Elhusseiny, E., Kishta, A. A., Elweza, A. E., Abdel-Bar, H. M., Korany, R. M., & Elshafey, B. A. (2025). Ginger oil microemulsion improves reproductive performance of male albino rats: sexual behavior, gross testicular measurements, spermatogenesis, and expression of sperm capacitation genes. *Beni-Suef University Journal of Basic and Applied Sciences*, 14(1). <https://doi.org/10.1186/s43088-025-00654-6>
- Brewer, P., & Sebby, A. G. (2021). The effect of online restaurant menus on consumers' purchase intentions during the COVID-19 pandemic. *International Journal of Hospitality Management*, 94. <https://doi.org/10.1016/j.ijhm.2020.102777>
- Diana Putri Amalia. M, Yetti, E., & Sumadi, T. (2022). Motions and Songs to Improve Basic Literacy through Animation Videos. *JPUD - Jurnal Pendidikan Usia Dini*, 16(2). <https://doi.org/10.21009/jpud.162.03>
- Famurewa, A. C., Ekeleme-Egedigwe, C. A., Onwe, C. S., Egedigwe, U. O., Okoro, C. O., Egedigwe, U. J., & Asogwa, N. T. (2020). Ginger juice prevents cisplatin-induced oxidative stress, endocrine imbalance and NO/iNOS/NF-κB signalling via modulating testicular redox-inflammatory mechanism in rats. *Andrologia*, 52(10). <https://doi.org/10.1111/and.13786>
- Gholami-Ahangaran, M., Karimi-Dehkordi, M., Akbari Javar, A., Haj Salehi, M., & Ostadpoor, M. (2021). A systematic review on the effect of Ginger (*Zingiber officinale*) on improvement of biological and fertility indices of sperm in laboratory animals, poultry and humans. In *Veterinary Medicine and Science* (Vol. 7, Number 5). <https://doi.org/10.1002/vms3.538>
- Jamili, Harlis, W. O., Ismail, S. S., & Armid, A. (2023). Antifertility Effect of Doses of *Avicennia lanata* Ridley Leaf Extract on the Spermatogenesis in Male Albino Mice (*Mus musculus* L.). *AIP Conference Proceedings*, 2704. <https://doi.org/10.1063/5.0138607>
- Kayode, O. T., Rotimi, D. E., Kayode, A. A. A., Olaolu, T. D., & Adeyemi, O. S. (2020). Monosodium glutamate (MSG)-Induced male reproductive dysfunction: A mini review. *Toxics*, 8(1). <https://doi.org/10.3390/toxics8010007>
- Laelago Erasedo, T., Teka, T. A., Fikreyesus Forsido, S., Dessalegn, E., Adebo, J. A., Tamiru, M., & Astatkie, T. (2023). Food flavor enhancement, preservation, and bio-functionality of ginger (*Zingiber officinale*): a review. In *International Journal of Food Properties* (Vol. 26, Number 1). <https://doi.org/10.1080/10942912.2023.2194576>
- Loggia, D., & O'Flaherty, C. (2024). Citrate Promotes Nitric Oxide Production during Human Sperm Capacitation. *Antioxidants*, 13(8). <https://doi.org/10.3390/antiox13080885>
- Loi, C., & Cynober, L. (2022). Glutamate: A Safe Nutrient, Not Just a Simple Additive. In *Annals of Nutrition and Metabolism* (Vol. 78, Number 3). <https://doi.org/10.1159/000522482>
- Luthfi, M. J., & Noor, M. M. (2021). A Simple Technique for Rapid Assessment of Rat (*Rattus norvegicus*) Sperm Motility. *Biology, Medicine, & Natural Product Chemistry*, 9(2). <https://doi.org/10.14421/biomedich.2020.92.105-107>
- Moradi, H. R., Khaksar, Z., Alipour, F., Fathollahi, S., Divar, M. R., & Rashidi, M. (2025). Protective Role of *Zingiber officinale* Extract on Acrylamide-Induced Toxicity in Rat Testes: Immunohistochemical, Histomorphological, Biochemical, and Sperm Analysis. *Andrologia*, 2025(1). <https://doi.org/10.1155/and/9324806>
- Ogunmokunwa, A. E., & Ibitoye, B. O. (2025). Monosodium glutamate (MSG) exposure induced oxidative stress and disrupted testicular hormonal regulation, exacerbating reproductive dysfunction in male WISTAR rats. *Endocrine and Metabolic Science*, 17. <https://doi.org/10.1016/j.endmts.2025.100226>

- Partyka, A., & Nizański, W. (2021). Supplementation of avian semen extenders with antioxidants to improve semen quality—is it an effective strategy? In *Antioxidants* (Vol. 10, Number 12). <https://doi.org/10.3390/antiox10121927>
- Roberts, A., Lynch, B., Rogerson, R., Renwick, A., Kern, H., Coffee, M., Cuellar-Kingston, N., Eapen, A., Crincoli, C., Pugh, G., Bhusari, S., Purkayastha, S., & Carakostas, M. (2016). Chemical-specific adjustment factors (inter-species toxicokinetics) to establish the ADI for steviol glycosides. *Regulatory Toxicology and Pharmacology*, 79. <https://doi.org/10.1016/j.yrtph.2016.05.017>
- Sumadi, T., Yetti, E., Yufiarti, Y., & Wuryani, W. (2019). Transformation of Tolerance Values (in Religion) in Early Childhood Education. *JPUD - Jurnal Pendidikan Usia Dini*, 13(2). <https://doi.org/10.21009/jpud.132.13>
- Wang, L., Yan, M., Wu, S., Mao, B., Wong, C. K. C., Ge, R., Sun, F., & Cheng, C. Y. (2020). Microtubule cytoskeleton and spermatogenesis-lesson from studies of toxicant models. In *Toxicological Sciences* (Vol. 177, Number 2). <https://doi.org/10.1093/toxsci/kfaa109>
- Wang, Y., Fu, X., & Li, H. (2025). Mechanisms of oxidative stress-induced sperm dysfunction. In *Frontiers in Endocrinology* (Vol. 16). <https://doi.org/10.3389/fendo.2025.1520835>
- Xue, W., Tang, Q., & Yang, L. (2022). The combination of ginger and zinc supplement could improve lead-induced reproductive dysfunction by inhibiting apoptosis mediated by oxidative damage and inflammation. *Andrologia*, 54(11). <https://doi.org/10.1111/and.14577>
- Zhang, S., Kou, X., Zhao, H., Mak, K. K., Balijepalli, M. K., & Pichika, M. R. (2022). Zingiber officinale var. rubrum: Red Ginger's Medicinal Uses. In *Molecules* (Vol. 27, Number 3). <https://doi.org/10.3390/molecules27030775>
- Zolfaghari, S., Soleimanzadeh, A., & Baqerkhani, M. (2025). The synergistic activity of fisetin on quercetin improves testicular recover in ischemia-reperfusion injury in rats. *Scientific Reports*, 15(1). <https://doi.org/10.1038/s41598-025-96413-9>