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Agrochemical Exposure and Male Reproductive Health: Linking DNA Fragmentation with Hormonal Disruption

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Abstract

Chronic exposure to agrochemicals represents a significant occupational hazard in agricultural communities and may adversely affect male reproductive health through mechanisms such as oxidative stress and endocrine disruption. This study aimed to evaluate the impact of agrochemical exposure on infertility prevalence, sperm DNA fragmentation, and key reproductive hormone levels among farmers in Dhamtari district, Chhattisgarh. A total of 100 male farmers were recruited, including 70 individuals with regular agrochemical exposure (exposed group) and 30 without such exposure (control group). Comprehensive semen analysis, sperm DNA fragmentation assays, and serum hormonal profiling—including testosterone, luteinizing hormone (LH), and follicle-stimulating hormone (FSH)—were conducted. Infertility was defined according to WHO criteria. Statistical analyses were performed using independent t-tests and Chi-square tests. The prevalence of infertility was significantly higher in the exposed group (45.7%) compared to the control group (13.3%) ($\chi^2 = 10.92$, $p < 0.01$). Exposed farmers exhibited markedly elevated sperm DNA fragmentation levels (38.2 ± 6.5%) relative to controls (21.4 ± 5.1%) ($p < 0.001$). Serum testosterone levels were significantly reduced in the exposed group (4.1 ± 0.7 ng/mL) compared to controls (5.6 ± 0.8 ng/mL, $p < 0.001$), whereas LH and FSH levels were significantly increased ($p < 0.001$). Chi-square analysis further confirmed significant associations between agrochemical exposure and increased DNA fragmentation, reduced testosterone levels, and altered gonadotropin profiles. In conclusion, chronic agrochemical exposure is strongly associated with increased risk of infertility, elevated sperm DNA damage, and hormonal imbalance among male farmers. These findings underscore the need for targeted occupational health strategies and the adoption of safer agricultural practices to mitigate reproductive health risks.

Keywords: Hormones, agrochemicals, infertility, DNA fragmentation index, , farmers, pesticides.

1. Introduction

Agriculture remains a primary occupation in many developing regions, including India, where the extensive use of agrochemicals such as pesticides, herbicides, and fertilizers has become integral to enhancing crop productivity. However, chronic exposure to these chemicals poses significant health risks to farmers, particularly due to inadequate protective measures and prolonged occupational contact. Increasing evidence suggests that agrochemical exposure may adversely affect male reproductive health, leading to reduced fertility potential (Sharma et al., 2020; Gupta & Singh, 2019).

Male infertility is a growing global health concern, contributing to nearly 40–50% of infertility cases worldwide. Among various contributing factors, environmental and occupational exposures have gained considerable attention. Agrochemicals are known to act as endocrine-disrupting compounds (EDCs), interfering with hormonal regulation and impairing spermatogenesis (Diamanti-Kandarakis et al., 2009). These substances can alter the hypothalamic–pituitary–gonadal (HPG) axis, resulting in imbalances in key reproductive hormones such as testosterone, luteinizing hormone (LH), and follicle-stimulating hormone (FSH) (Rattan et al., 2017).

One of the critical mechanisms underlying agrochemical-induced reproductive toxicity is oxidative stress, which leads to cellular and molecular damage. Sperm cells are particularly vulnerable to oxidative stress due to their limited antioxidant defense systems. This can result in sperm DNA fragmentation, a key biomarker associated with impaired fertility, poor embryo development, and adverse reproductive outcomes (Aitken & Baker, 2006; Agarwal et al., 2003). Elevated levels of sperm DNA fragmentation have been strongly linked with environmental toxicant exposure, including pesticides (Meeker et al., 2004).

Despite growing global evidence, there is limited region-specific data from central India, particularly in agricultural districts such as Dhamtari in Chhattisgarh, where agrochemical use is widespread. Understanding the association between occupational exposure and reproductive health parameters is crucial for developing targeted interventions. Therefore, the present study aims to assess the impact of agrochemical exposure on sperm DNA fragmentation, hormonal alterations, and infertility prevalence among male farmers in this region.

2. Materials and Methods

2.1 Study Design and Population

A cross-sectional study was conducted among 100 male farmers from the Dhamtari district of Chhattisgarh, India. Participants were categorized into two groups: an exposed group (n = 70), comprising individuals with at least five years of direct occupational exposure to agrochemicals during farming activities, and a non-exposed (control) group (n = 30), consisting of farmers with no reported history of agrochemical exposure. This study design is consistent with previous investigations assessing occupational exposure and reproductive health outcomes (Perry, 2008).

2.2 Inclusion and Exclusion Criteria

Inclusion criteria comprised males aged 21–50 years, married, and actively attempting conception. Exclusion criteria included individuals with known reproductive disorders such as varicocele or cryptorchidism, chronic systemic illnesses, or a recent history of febrile episodes that could affect semen quality. These criteria were adopted to minimize confounding factors influencing male fertility (WHO, 2010).

2.3 Semen Sample Collection and Analysis

Semen samples were collected by masturbation following a period of 2–5 days of sexual abstinence. Samples were allowed to liquefy at 37 °C prior to analysis. Basic semen parameters, including volume, concentration, motility, and morphology, were assessed according to standard guidelines before conducting DNA fragmentation testing (WHO, 2010).

2.4 DNA Fragmentation Analysis (SCD Test)

Sperm DNA fragmentation was evaluated using the sperm chromatin dispersion (SCD) method with the QwikCheck™ DFI kit. A minimum of 200 spermatozoa per sample were analyzed under a microscope.

Spermatozoa exhibiting large or medium halos were classified as non-fragmented, whereas those with small or no halos, or showing nuclear degeneration, were categorized as fragmented. DNA fragmentation index (DFI) was interpreted as follows: <15% indicating excellent fertility potential, 15–30% indicating fair to good fertility, and >30% indicating poor fertility potential (Fernández et al., 2003).

2.5 Hormonal Assessment

Venous blood samples were collected for the estimation of serum testosterone, luteinizing hormone (LH), and follicle-stimulating hormone (FSH) levels using electrochemiluminescence immunoassay techniques. Reference ranges were considered as follows: testosterone (249–1080 ng/dL), LH (1.5–9.30 mIU/mL), and FSH (1.4–18.11 mIU/mL). Hormonal evaluation was performed following established clinical endocrinology protocols (Bhasin et al., 2018).

2.6 Statistical Analysis

Categorical variables were analyzed using the Chi-square test to determine associations between agrochemical exposure and infertility status, DNA fragmentation index, and hormonal alterations. Continuous variables were expressed as mean ± standard deviation and compared using independent t-tests. A p-value of <0.05 was considered statistically significant. Statistical analyses were performed using SPSS software (version XX), following standard biostatistical approaches (Field, 2013).

3. Results

3.1 Agrochemical Usage and Fertility

A statistically significant difference in infertility rates was observed between agrochemical-exposed and non-exposed groups (Table 1). The prevalence of infertility was markedly lower in the non-exposed group, with only 13.3% (4 out of 30) individuals affected, compared to 45.7% (32 out of 70) in the exposed group. This represents more than a threefold increase in infertility among farmers with agrochemical exposure, highlighting a strong association between occupational exposure and impaired reproductive outcomes.

Table 1. Agrochemical exposure and infertility rate

Group	Infertile (n)	Fertile (n)	Total (n)	Infertility Rate (%)
Non-exposed	4	26	30	13.3%
Exposed	32	38	70	45.7%

3.2 Sperm DNA Fragmentation and Hormonal analysis

Mean sperm DNA fragmentation was significantly higher in the agrochemical-exposed group (38.2 ± 6.5%) compared to the non-exposed group (21.4 ± 5.1%; $p < 0.001$) (Table 2). In addition, serum testosterone levels were markedly reduced in exposed farmers (4.1 ± 0.7 ng/mL) relative to non-exposed individuals (5.6 ± 0.8 ng/mL; $p < 0.001$). Conversely, serum luteinizing hormone (LH) and follicle-stimulating hormone (FSH) levels were significantly elevated in the exposed group ($p < 0.001$ for both). These findings collectively indicate a disruption of the hypothalamic–pituitary–gonadal axis associated with chronic agrochemical exposure.

Table 2. Sperm DNA fragmentation and hormonal profile

Parameter	Non-exposed (n=30)	Exposed (n=70)	p-value
DNA Fragmentation (%)	21.4 ± 5.1	38.2 ± 6.5	<0.001
Testosterone (ng/mL)	5.6 ± 0.8	4.1 ± 0.7	<0.001
LH (mIU/mL)	4.8 ± 0.9	6.2 ± 1.0	<0.001
FSH (mIU/mL)	5.0 ± 0.8	6.5 ± 0.9	<0.001

3.3 Chi- square analysis

Chi-square analysis revealed statistically significant associations between agrochemical exposure and all assessed reproductive health parameters (Table 3). Infertility showed a strong association with exposure status ($\chi^2 = 10.92$, $p = 0.0009$). A significantly higher prevalence of elevated sperm DNA fragmentation (>30%) was observed among exposed farmers ($\chi^2 = 15.37$, $p = 0.00008$). Furthermore, reduced testosterone levels and abnormal concentrations of luteinizing hormone (LH) and follicle-stimulating hormone (FSH) were all significantly associated with agrochemical exposure ($p < 0.05$ for each), reinforcing the link between occupational exposure and endocrine as well as reproductive dysfunction.

Table 3. Chi-square analysis of categorical reproductive health outcomes

Parameter	Exposed (n=70)	Non-exposed (n=30)	χ^2 Value	p-value	Significance
Infertility rate (%)	32 (45.7%)	4 (13.3%)	10.92	0.0009	p<0.01
High DNA fragmentation (%)	42 (60%)	6 (20%)	15.37	0.00008	p<0.001
Low testosterone (%)	29 (41.4%)	4 (13.3%)	8.21	0.0042	p<0.01
Low LH (%)	25 (35.7%)	3 (10%)	6.48	0.0109	p<0.05
Low FSH (%)	27 (38.6%)	4 (13.3%)	7.12	0.0076	p<0.01

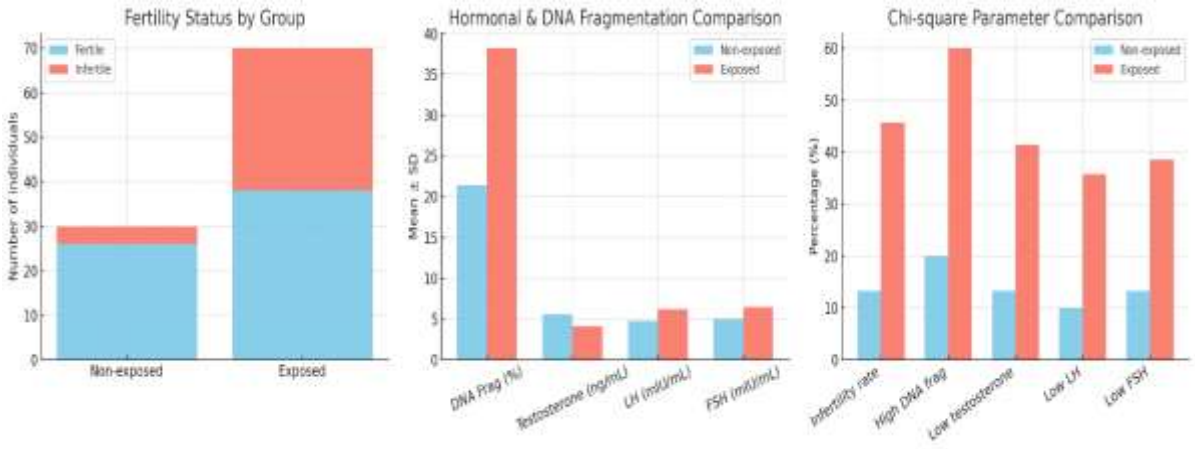

Figure 1. Comparative analysis of agrochemical exposure effects on male reproductive parameters: (A) Fertility status distribution between exposed and non-exposed groups. (B) Mean sperm DNA fragmentation and hormone levels (Testosterone, LH, FSH) in both groups.

Discussion:

The present study demonstrates a significant association between chronic agrochemical exposure and impaired male reproductive health among farmers. The markedly higher infertility prevalence observed in the exposed group (45.7%) compared to the non-exposed group (13.3%) corroborates earlier epidemiological findings linking pesticide exposure with reduced fertility, impaired spermatogenesis, and delayed conception (Oliva et al., 2001; Sallmén et al., 2006). These findings highlight the substantial reproductive risks associated with occupational exposure in agricultural settings. The observed increase in sperm DNA fragmentation among exposed individuals suggests that oxidative stress and genotoxicity are key mechanisms underlying agrochemical-induced reproductive toxicity. Spermatozoa are particularly susceptible to oxidative damage due to their limited antioxidant defense capacity, leading to compromised chromatin integrity and reduced fertilization potential (Aitken & De Iuliis, 2010). Previous studies have reported that exposure to commonly used pesticides, including organophosphates and carbamates, is associated with elevated reactive oxygen species (ROS) production and increased DNA damage in sperm cells (Meeker et al., 2004; Pant et al., 2014).

Hormonal analysis in the present study revealed significantly reduced testosterone levels in exposed farmers, indicating possible Leydig cell dysfunction or disruption of the hypothalamic–pituitary–gonadal (HPG) axis. Concurrently, elevated levels of luteinizing hormone (LH) and follicle-stimulating hormone (FSH) were observed, suggesting a compensatory pituitary response to impaired testicular function. This endocrine profile is consistent with patterns reported in other studies of pesticide-exposed populations, where hormonal imbalance contributes to subfertility and reproductive dysfunction (Rattan et al., 2017; Perry, 2008). The statistical significance of associations observed through Chi-square analysis further strengthens the evidence linking agrochemical exposure with infertility, increased sperm DNA fragmentation, and hormonal dysregulation. These findings underscore the multifactorial nature of pesticide-induced male infertility, involving direct gonadotoxic effects, endocrine disruption, and oxidative DNA damage. Such integrated mechanisms may collectively compromise male reproductive capacity over prolonged exposure periods. Given the occupational nature of agrochemical exposure, the findings of this study emphasize the urgent need for preventive and regulatory interventions. The adoption of personal protective equipment (PPE), implementation of safer handling and storage practices, and the promotion of less toxic or bio-based alternatives could significantly reduce exposure risks. Furthermore, routine reproductive health screening and awareness programs in high-risk agricultural communities may facilitate early detection and management of fertility-related issues.

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