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THE PROTECTIVE ROLE OF *Moringa oleifera* IN REPRODUCTIVE TRAITS OF CADMIUM CHLORIDE EXPOSED JAPANESE QUAILS

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ABSTRACT

This study evaluates the impact of cadmium chloride ($CdCl_2$) exposure on breeding Productivity and the potential mitigating role of *Moringa oleifera* as an antioxidant agent in Japanese quail (*Coturnix japonica*). The experimental design followed a completely randomized design (CRD) with 400 day-old Japanese quail, divided into eight treatment groups: NC (negative control), PC (positive control fed with *Moringa oleifera*), T1 (Cd 25 mg/kg), T2 (Cd 50 mg/kg), T3 (Cd 75 mg/kg), T4 (Cd 25 mg/kg + Moringa), T5 (Cd 50 mg/kg + Moringa), and T6 (Cd 75 mg/kg + Moringa). Production and breeding productivity were assessed through body weight, hen-housed egg production (HHEP), hen-day egg production (HDEP), egg weight, egg mass, fertility, hatchability, and key egg quality parameters from the month of November 2023 to April 2024 at 24th week. Results indicated that Cd exposure significantly impaired breeding productivity and egg quality ($p \leq 0.01$), with the highest Cd level (75 mg/kg) causing the most severe declines. Conversely, groups supplemented with *Moringa oleifera* demonstrated significant improvements ($p \leq 0.01$) in body weight, egg production, egg mass, fertility, and hatchability, highlighting Moringa's protective antioxidant effects. ANOVA analysis confirmed significant differences among groups, reinforcing the effectiveness of *Moringa oleifera* supplementation at 7 g/kg feed in counteracting cadmium toxicity in quail. These findings suggest Moringa as a viable dietary intervention for improving poultry health under heavy metal contamination.

Keywords: Cadmium chloride, *Moringa oleifera*, productive performance, egg quality, Japanese quail.

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INTRODUCTION

Environmental pollution, particularly with heavy metals such as cadmium (Cd), poses a severe danger to the health and productivity of livestock. Cadmium chloride ($CdCl_2$) is a pervasive environmental contaminant that has been extensively documented for its deleterious effects on biological systems, inducing oxidative stress, disrupting metabolic processes, and impairing reproductive performance in avian species (Ketta *et al*.,2021). The escalating concern over Cd toxicity underscores the urgent need for effective nutritional strategies to mitigate its harmful impacts on poultry health and productivity.

Moringa oleifera, commonly referred to as the "drumstick tree," is renowned for its exceptional nutritional profile and myriad medicinal properties. Rich in vitamins, minerals, and potent antioxidants, *Moringa oleifera* has been traditionally used in various cultures for its health-promoting benefits (Anwar *et al*., 2007). Its potential as a natural remedy for counteracting oxidative stress and enhancing overall health makes it an intriguing candidate for improving poultry resilience against environmental stressors such as Cd.

Recent studies have highlighted the beneficial effects of *Moringa oleifera* supplementation in poultry diets, demonstrating improvements in immune function, growth performance, and reduction of oxidative stress markers (Verma *et al*., 2009). However, there is a paucity of research specifically examining its efficacy in ameliorating the reproductive and production impairments induced by Cd exposure in poultry.

The need for this study arises from the limited research on the mitigation of Cd-induced reproductive impairments in poultry through natural dietary supplements. By exploring the potential of *Moringa oleifera*, this research aims to evaluate its effectiveness in counteracting heavy metal toxicity and promoting reproductive success in poultry. This research study aims to bridge the gap by examining the protective effects of *Moringa oleifera* leaves powder on the reproductive performance and overall productivity of Japanese quail exposed to $CdCl_2$ It is hypothesized that the dietary incorporation of *Moringa oleifera due to its rich antioxidant properties,* will mitigate the negative effects of Cd, thereby enhancing reproductive health and productivity.

MATERIALS AND METHODS

Experimental Design: This study was conducted in accordance with the guidelines for experimental animals at the Veterinary Teaching Hospital (VTH) of the Cholistan University of Veterinary and Animal Sciences (CUVAS), Bahawalpur, with ethical approval (ORIC-320, Dated 26-07-2024). A total of 400 one-day-old Japanese quail were randomly allocated to eight treatment groups, each consisting of 10 birds with five replicates per group. The treatments included a negative control group (NC) with standard poultry feed, a positive control group (PC) with feed supplemented with *Moringa oleifera* leaves powder, and groups T1, T2, and T3 with standard feed containing 25 mg, 50 mg, and 75 mg of $CdCl_2$, respectively. Additionally, groups T4, T5, and T6 received standard feed containing the same $CdCl_2$ concentrations along with *Moringa oleifera* leaves powder.

The poultry feed was prepared to meet the nutritional requirements of Japanese quail (Rafieian *et al*., 2021). The *Moringa oleifera* leaves powder was added at a concentration of 7 g/kg. Cadmium chloride was mixed into the feed at the specified concentrations for each treatment group, ensuring homogenous mixing through mechanical processes (Ahmed *et al*., 2019). Chicks were brooded in a temperature-controlled environment with continuous access to feed and water, and the temperature was gradually reduced from 37°C to 24°C over six weeks. Mortality was monitored daily, and any dead chicks were promptly removed.

Parameters evaluated

Production performance: Body weight was measured weekly using an electronic balance (KERN & SOHN GmbH, Model ABJ 220-4NM, Germany) with an accuracy of 0.01 g, recording individual weights to monitor growth performance throughout the study. Hen-housed egg production (HHEP) and hen-day egg production (HDEP) were calculated as per Lu *et al*. (2016) and egg weight was recorded weekly using a digital scale (Ohaus Corporation, Model CS200, USA). Egg mass was evaluated by multiplying egg weight by the number of eggs produced (Alikhanov, 2018).

Egg Morphometry: Egg morphometry, including length and width, was determined using a digital caliper (Mitutoyo Corporation, Model 500-196-30, Japan) with an accuracy of 0.01 mm. Measurements were taken from all eggs collected from each treatment group weekly (Alikhanov, 2018). Egg Shape Index: The egg shape index was determined as the ratio of egg width to egg length. This provides an indication of the egg's shape (Akyurek and Okur, 2009). Calculation of Surface Area: The egg surface area was calculated using the formula provided by Narushin (2005): SA=4.835×W0.6336×L0.3266. Calculation of Egg Volume: The egg volume was calculated using the formula provided by Narushin (2005): V=0.6057×L×W2

Egg internal quality: Yolk Index: The yolk index was determined as the ratio of yolk height to yolk diameter (breadth). (Akyurek and Okur, 2009). Yolk Proportion: Yolk proportion was determined by dividing the yolk weight by the total egg weight and multiplying by 100 to express it as a percentage (Hanusova *et al*., 2016) Albumen Index: The Albumen index was calculated as the ratio of Albumen height to Albumen width, expressed as a percentage (Akyurek and Okur, 2009). Albumen Proportion (%): The proportion of Albumen was determined by dividing the Albumen weight by the total egg weight and multiplying by 100 to express it as a percentage (Alkan *et al*., 2010). Haugh Unit: The Haugh unit was calculated using the formula Haugh unit=100 X log10(H−1.7W0.37+7.6), where H is the egg albumen height (mm) and W is the egg weight (g) (Akyurek and Okur, 2009).

Egg shell quality: Egg Shell Weight (g): Egg shell weight was measured using a precision digital scale with an accuracy of 0.01 g. The weights of all eggshells from each treatment group were recorded weekly (Northcutt *et al*., 2022). Thickness without Membrane (mm): The thickness of the eggshell without the membrane was measured using a digital micrometer with an accuracy of 0.01 mm (Altuntaş and Şekeroğlu, 2008). Egg Shell Thickness (mm): Total eggshell thickness, including the membrane, was measured at three different points (top, middle, and bottom) using a digital micrometer to obtain an average thickness (Silversides & Scott, 2001). Egg Shell Proportion (%): The proportion of the eggshell was calculated by dividing the eggshell weight by the total egg weight and multiplying by 100 to express it as a percentage (Aygun and Yetisir, 2010). **Breeding productivity:** Egg Number: The total number of eggs produced was recorded daily for each group. Fertility: Fertility was assessed by candling the eggs at day 7 of incubation to determine the number of fertile eggs. Fertility Percentage: Fertility percentage was determined as the number of fertile eggs divided by the total number of eggs set, multiplied by 100. Hatchability: Hatchability was calculated as the percentage of chicks hatched from fertile eggs set in the incubator (Fulla *et al*., 2024).

Statistical Analysis: Data on egg production (hen-housed egg production, hen-day egg production, egg mass, and egg weight), egg quality (egg morphometry, egg internal quality and eggshell integrity), and breeding productivity (fertility, hatchability, and total egg number) were subjected to a one-way analysis of variance to determine statistically significant differences among the eight treatment groups. Tukey's post hoc test was applied to identify pairwise differences ($p \leq 0.05$). All statistical analyses were conducted using SPSS software (version 25.0; IBM Corp., Armonk, NY, USA) to ensure accuracy and reliability in interpreting treatment effects.

RESULTS AND DISCUSSION

Production performance: The results as detailed in Table 1 revealed significant differences ($p \leq 0.01$) in the productive performance of Japanese quail exposed to varying levels of Cd and supplemented with *Moringa oleifera*. The (PC) group which received *Moringa oleifera*, showed the highest body weight, HHEP, HDEP, egg weight, and egg mass, indicating the advantageous effects of *Moringa oleifera* in enhancing productive performance. In contrast, the group exposed to the highest concentration of Cd (T3) exhibited the lowest value across these parameters, highlighting the detrimental impact of high Cd exposure. Intermediate values were observed in the groups receiving both Cd and *Moringa oleifera* (T4, T5, T6), suggesting that *Moringa oleifera* mitigated some of the adverse effects of Cd. Specifically, the T4 group (Cd 25 ppm + Moringa) showed significant improvement in body weight, egg weight, and egg mass compared to the Cd-only groups, demonstrating the protective role of *Moringa oleifera* against Cd toxicity.

The significant reduction in HHEP, HDEP, and egg weight in Cd-exposed groups highlights the detrimental impact of this heavy metal on quail. Cadmium induces oxidative stress and disrupts normal cellular functions, leading to decreased body weight and overall health (Olaolu, 2018). The protective role of *Moringa oleifera* observed in this study is consistent with its known antioxidant properties. *Moringa oleifera* contains various bioactive compounds that can mitigate oxidative stress and enhance cellular resilience, thereby improving productive performance even in the presence of toxic substances like Cd (Mallya, 2017). The improved outcomes in groups receiving both Cd and *Moringa oleifera* suggest that Moringa can effectively counteract the damaging effects of Cd, promoting better health and productivity in quail (Coppin *et al*., 2013).

Table 1. Effect of $Cdcl_2$ and *M. olifera* on Production performance of Japanese quail at 24 weeks of age

Treatments	Body weight (g)	Hen-Housed Egg Production %	Hen-Day Egg Production %	Egg weight (g)	Egg mass (g)
NC	210.48 ± 1.11^{b}	39.84 ± 1.52^{a}	47.4 ± 1.81^{a}	10.82 ± 0.14^{de}	6.9 ± 0.09^{e}
PC	240 ± 2.19^{a}	40.27 ± 0.97^{a}	47.92 ± 1.16^{a}	11.35 ± 0.11^{a}	7.47 ± 0.07^{a}
T1	192 ± 0.91^{d}	37.23 ± 0.76^{b}	44.31 ± 0.9^{b}	11 ± 0.09^{cd}	7.1 ± 0.05^{cd}
T2	164 ± 0.91^{g}	35.81 ± 0.65b^{c}	42.62 ± 0.78^{bc}	$10.9\pm0.09^{c-e}$	7.26 ± 0.07^{bc}
T3	118 ± 0.91^{h}	32.04 ± 0.87^{d}	38.13 ± 1.03^{d}	10.72 ± 0.09^{e}	6.6 ± 0.09^{f}
T4	201 ± 0.91^{c}	37.62 ± 0.75^{b}	44.77 ± 0.89^{b}	11.28 ± 0.07^{ab}	7.27 ± 0.07^{b}
T5	173.6 ± 1.75^{f}	36.37 ± 0.65^{bc}	43.37 ± 0.75^{bc}	11.1 ± 0.09^{bc}	6.98 ± 0.07^{de}
T6	180 ± 0.91^{e}	35.01 ± 0.53^{c}	41.66 ± 0.62^{c}	11 ± 0.11^{cd}	7.03 ± 0.04^{de}
P value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

[abcde]Means within each column followed by different superscript letters indicate significant differences between treatments ($p \leq 0.01$).
[*]NC (Negative Control) PC (Positive Control, fed with moringa) T1 (Cd 25 mg) T2 (Cd 50 mg) T3 (Cd 75 mg) T4 (Cd 25 mg + moringa) T5 (Cd 50 mg + moringa), T6 (Cd 75 mg + moringa).

Egg Morphometry: The results as detailed in Table 2 revealed significant differences ($p \leq 0.01$) in egg morphometry parameters among the various treatment groups. The (PC) group exhibited the highest egg length, egg width, surface area, and egg volume, highlighting the beneficial effects of *Moringa oleifera*. Conversely, the group exposed to 75 mg Cd (T3) had the lowest value in these parameters, illustrating the detrimental impact of high Cd exposure. The egg shape index was highest in the group exposed to 75 mg Cd (T3), suggesting potential deformities or irregularities in egg shape due to Cd toxicity, and lowest in the positive control group (PC), which had the most optimal egg shape. Intermediate values in the groups receiving both Cd and Moringa (T4, T5, T6) indicated an improvement in egg morphometry compared to the Cd-only groups. These results suggest that *Moringa oleifera* can mitigate some of the adverse effects of Cd on egg quality, improving overall reproductive performance in Japanese quail.

The findings indicate that Cd exposure significantly affects the egg morphometry of Japanese quail, with higher concentrations of Cd leading to reduced egg length, egg width, surface area, and egg volume. This aligns with existing literature that highlights the detrimental effects of heavy metals on avian reproductive parameters (Zhao *et al*., 2017). The increase in egg shape index in the T3 group suggests potential deformities or irregularities in egg shape because of Cd toxicity. *Moringa oleifera* demonstrated a protective role in ameliorating the harmful effects of Cd introduction on egg morphometry. The groups receiving both Cd and Moringa (T4, T5, T6) showed improved egg dimensions compared to their Cd-only counterparts, highlighting the antioxidant properties of *Moringa oleifera* (Mallya, 2017). This supports previous research suggesting that *Moringa oleifera* can mitigate oxidative stress and improve reproductive health in poultry (Coppin *et al*., 2013).

Table 2. Effect of $CdCl_2$ and *M. olifera* on egg morphometry of Japanese quail at 24 weeks of age

Treatment	Egg length (mm)	Egg width (mm)	Egg shape index	Surface area (cm^2)	Egg volume (cm^3)
NC	32.26±0.2^d	25.57±0.14^b	0.79±0.31^b	21.06±0.19^{de}	10.98±0.17^c
PC	34.78±0.21^a	26.29±0.14^a	0.75±0.6^e	21.78±0.15^a	12.52±0.16^a
T1	31.26±0.17^e	24.58±0.15^d	0.78±0.08^c	21.31±0.12^{cd}	9.84±0.18^e
T2	31.26±0.17^e	23.76±0.17^e	76±0.13^e	21.17±0.12^{c-e}	9.18±0.18^f
T3	28.16±0.17^f	23.18±0.15^f	82.31±0.08^a	20.93±0.12^e	7.87±0.13^g
T4	33.22±0.18^b	25.63±0.15^b	77.15±0.22^d	21.69±0.1^{ab}	11.37±0.2^b
T5	32.78±0.18^c	25.18±0.15^c	76.81±0.06^d	21.44±0.12^{bc}	10.85±0.19^c
T6	31.88±0.18^d	25.08±0.15^c	78.66±0.06^c	21.31±0.15^{cd}	10.45±0.19^d
P value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

[abcde]Means within each column followed by different superscript letters indicate significant differences between treatments ($p \leq 0.01$).
[*]NC (Negative Control) PC (Positive Control, fed with moringa) T1 (Cd 25 mg) T2 (Cd 50 mg) T3 (Cd 75 mg) T4 (Cd 25 mg + moringa) T5 (Cd 50 mg + moringa), T6 (Cd 75 mg + moringa).

Egg internal quality: The results as detailed in Table 3. showed significant differences ($p \leq 0.01$) in yolk index, yolk proportion, Albumen index, Albumen proportion, and Haugh unit among the treatment groups. The positive control group (PC) demonstrated the highest values for yolk index, yolk proportion, Albumen index, Albumen proportion, and Haugh unit, indicating optimal egg quality. In contrast, the group exposed to the highest Cd concentration (T3) showed the lowest values in these parameters, reflecting the negative impact of high Cd exposure. Intermediate values were observed in the groups treated with both Cd and Moringa (T4, T5, T6), suggesting that *Moringa oleifera* mitigated some of the harmful effects of Cd on egg quality. Specifically, the yolk index and Albumen index were significantly improved in these groups compared to their Cd only counterparts. Moreover, the Haugh unit, which measures egg freshness, was greater in the Moringa-treated groups than in the Cd groups, further supporting the protective role of *Moringa oleifera.*

The findings of this study demonstrate that Cd exposure significantly impairs egg quality parameters in Japanese quail. Cadmium-induced oxidative stress leads to reductions in yolk index, yolk proportion, albumen index, albumen proportion, and Haugh unit, indicating poorer egg quality (Monika *et al*., 2021). These results are consistent with previous studies that highlight the harmful effects of heavy metal exposure on avian reproductive health. The detrimental impact of Cd on egg quality parameters, showing similar reductions in egg quality metrics. *Moringa oleifera* supplementation exhibited a protective effect against Cd harmfulness, as demonstrated by the improved egg quality parameters in the Moringa-treated groups. The bioactive compounds in *Moringa oleifera*, known for their antioxidant properties, likely mitigated oxidative stress and improved cellular function, resulting in better egg quality (Egbu *et al*., 2024). This aligns with earlier research indicating that *Moringa oleifera* can counteract the harmful effects of environmental stressors in poultry. The dietary supplementation with *Moringa oleifera* seeds significantly increased egg production and improved hatchability, along with some egg quality parameters. In conclusion, the results of this study underscore the importance of mitigating Cd exposure in poultry and highlight the potential of *Moringa oleifera* as a natural supplement to improve egg quality and overall poultry health (Ashour *et al*., 2020).

Egg Shell Quality: As detailed in Table 4. Egg shell quality noteworthy alterations ($p \leq 0.01$) were observed among the treatment groups for all measured eggshell quality parameters. The positive control group (PC) exhibited the highest values for eggshell weight, thickness without membrane, and eggshell thickness, indicating improved eggshell quality. Conversely, the group exposed to the highest concentration of Cd (T3) had the lowest values for these parameters, reflecting the negative impact of high Cd exposure. The eggshell proportion was highest in the T4 group (Cd 25 ppm + Moringa), suggesting a protective effect of *Moringa oleifera.* Intermediate values were observed in the groups treated with both Cd and Moringa (T4, T5, T6), indicating that *Moringa oleifera* mitigated some of the contrary effects of Cd on eggshell quality. Specifically, the thickness without membrane and eggshell thickness were significantly improved in these groups compared to their Cd counterparts.

The findings demonstrate that Cd exposure significantly impairs eggshell quality parameters in Japanese quail. Cadmium-induced oxidative stress leads to reductions in eggshell weight, thickness, and overall shell integrity, indicating poorer eggshell quality (Olaolu, 2018). These results are steady with previous studies that highlight the detrimental effects of heavy metal exposure on avian reproductive health. *Moringa oleifera* supplementation exhibited a protective effect against Cd toxicity, as evidenced by the improved eggshell quality parameters in the Moringa-treated groups. The bioactive compounds in *Moringa oleifera*, known for their antioxidant properties, likely mitigated oxidative stress and improved cellular function, resulting in better eggshell quality (Mallya, 2017). This aligns with earlier research indicating that *Moringa oleifera* can counteract the harmful effects of ecological stressors in poultry (Coppin *et al*., 2013).

Table 3. Effect of $CdCl_2$ and *M. olifera* on Egg internal quality of Japanese quail at 24 weeks of age

Treatments	Yolk index (%)	Yolk proportion (%)	Albumen index (%)	Albumen proportion (%)	Haugh unit
NC	28.04±0.05^{d}	38.34±0.24^{c}	14.9 ±0.05^{b}	39.91 ±0.34^{b}	82.25 ±0.1^{b}
PC	31.08±0.03^{a}	41.66±0.44^{a}	19.39±0.06^{a}	40.57±0.46^{a}	92.62±0.1^{a}
T1	26.49±0.07^{f}	34.05±0.18^{e}	13±0.04^{d}	35.32±0.16^{d}	77.63±0.08^{d}
T2	26.03±0.06^{g}	32.88±0.19^{f}	9.4±0.05^{f}	26.45±0.13^{g}	68.17±0.15^{e}
T3	28.45±0.12^{c}	28.93±0.31^{g}	6.51±0.04^{g}	20.66±0.23^{h}	56.73±0.1^{f}
T4	29.75±0.1^{b}	36.96±0.14^{d}	14.65±0.05^{c}	38.38±0.12^{c}	81.29±0.11^{c}
T5	27.19±0.09^{e}	40.54±0.24^{b}	13.03±0.04^{d}	34.47±0.16^{e}	77.59±0.09^{d}
T6	26.14±0.08^{g}	42.1±0.48^{a}	12.7±0.03^{e}	31.17±0.38^{f}	77.41±0.07^{d}
P value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

^{abcde}Means within each column followed by different superscript letters indicate significant differences between treatments ($p \leq 0.01$).
*NC (Negative Control) PC (Positive Control, fed with moringa) T1 (Cd 25 mg) T2 (Cd 50 mg) T3 (Cd 75 mg) T4 (Cd 25 mg + moringa) T5 (Cd 50 mg + moringa), T6 (Cd 75 mg + moringa).

Table 4. Effect of $CdCl_2$ and *M. olifera* on Egg Shell Quality of Japanese quail at 24 weeks of age

Treatments*	Egg shell weight (g)	Thickness without membrane (mm)	Egg shell thickness (mm)	Egg shell proportion (%)
NC	0.95±0.02 ^{ab}	0.16 ±0^{d}	0.26 ±0.02^{bc}	8.79 ±0.12^{d}
PC	0.97±0.01 ^{a}	0.17±0^{c}	0.28±0.01^{bc}	8.58±0.14^{c}
T1	0.92±0.01 ^{c}	0.14±0^{e}	0.24±0.01^{bc}	8.34±0.11^{e}
T2	0.88±0.01 ^{d}	0.14±0^{f}	0.21±0.02^{d}	8.03±0.07^{f}
T3	0.84±0.01 ^{e}	0.13±0^{g}	0.18±0.01^{e}	7.79±0.14^{g}
T4	0.96±0.01 ^{ab}	0.19±0^{a}	0.27±0.01^{a}	8.47±0.07^{a}
T5	0.93±0.01 ^{bc}	0.17±0^{b}	0.25±0.01^{ab}	8.34±0.08^{b}
T6	0.89±0.01 ^{d}	0.17±0^{c}	0.22±0.01^{cd}	8.05±0.15^{c}
P value	<0.0001	<0.0001	<0.0001	<0.0001

^{abcde}Means within each column followed by different superscript letters indicate significant differences between treatments ($p \leq 0.01$).
* NC (Negative Control) PC (Positive Control, fed with moringa) T1 (Cd 25 mg) T2 (Cd 50 mg) T3 (Cd 75 mg) T4 (Cd 25 mg + moringa) T5 (Cd 50 mg + moringa), T6 (Cd 75 mg + moringa).

Breeding Productivity: As represented in Table 5. reproductive performance, Significant changes ($p \leq 0.01$) were observed in egg number, fertility, and hatchability among the treatment groups. The positive control group (PC) demonstrated the highest fertility and hatchability rates, suggesting optimal reproductive performance. The group exposed to the highest concentration of Cd (T3) exhibited the lowest egg number, fertility, and hatchability, reflecting the negative impact of Cd exposure on reproductive parameters. Intermediate values were noted in the groups receiving both Cd and Moringa (T4, T5, T6), indicating that *Moringa oleifera* mitigated some of the hostile effects of Cd on egg production. Notably, the T4 group (Cd 25 ppm + Moringa) showed significant improvement in hatchability compared to Cd groups, suggesting a protective effect of *Moringa oleifera*.

The study demonstrates that cadmium (Cd) exposure significantly impairs egg production parameters in Japanese quail. Cadmium-made oxidative stress and cellular toxicity resulted in reduced egg number, fertility, and hatchability. These results are consistent with earlier research showing the negative impact of heavy metals on avian reproductive health (Nolan *et al*., 2000). Cadmium exposure disrupts normal reproductive processes and has been shown to impair egg production and hatchability in various avian species. The protective role of *Moringa oleifera* observed in this study aligns with its known antioxidant properties. The bioactive compounds in *Moringa oleifera*, such as flavonoids and phenolics, have been demonstrated to mitigate oxidative stress and improve cellular resilience (Sreelatha and Padma, 2009). These compounds can enhance the antioxidant defense system in birds, leading to improved reproductive performance despite the presence of toxic substances like Cd (Anwar *et al*., 2007). Moreover, to its antioxidant effects, *Moringa oleifera* has been shown to possess anti-inflammatory properties, which may further donate to its protective role against cadmium-induced reproductive toxicity (Fahey, 2005). The improved egg production parameters in the Moringa-treated groups suggest that *Moringa oleifera* can counter the damaging effects of Cd, promoting better fertility and hatchability rates. Overall, the study underscores the potential of *Moringa oleifera* as an effective dietary supplement to enhance reproductive performance in Japanese quail exposed to Cd. By mitigating oxidative stress and enhancing cellular function, *Moringa oleifera* can improve egg production and hatchability, promoting better reproductive outcomes in poultry.

Table 5. Effect of $CdCl_2$ and *M. olifera* on breeding productivity in Japanese quail at 24 weeks of age.

Treatment*	Egg number (n)	Fertility (%)	Hatchability (%)
NC	18.72±0.67^{a}	87.64±0.12^{d}	59.84±0.16^{f}
PC	18.9±0.42^{a}	92.64±0.12^{a}	68.46±0.14^{b}
T1	17.2±0.35^{bc}	86.64±0.12^{e}	66.46±0.14^{d}
T2	16.38±0.29^{cd}	84.56±0.14^{f}	63.66±0.14^{e}
T3	13.38±0.36^{e}	82.64±0.12^{g}	59.76±0.12^{f}
T4	18.02±0.35^{ab}	88.86±0.14^{c}	69.34±0.12^{a}
T5	17.24±0.3^{bc}	86.64±0.12^{e}	66.94±0.12^{c}
T6	15.84±0.26^{d}	90.94±0.12^{b}	63.94±0.12^{e}
P value	<0.0001	<0.0001	<0.0001

[abcde]Means within each column followed by different superscript letters indicate significant differences between treatments ($p \leq 0.01$).
*NC (Negative Control) PC (Positive Control, fed with moringa) T1 (Cd 25 mg) T2 (Cd 50 mg) T3 (Cd 75 mg) T4 (Cd 25 mg + moringa) T5 (Cd 50 mg + moringa), T6 (Cd 75 mg + moringa).

Conclusion: This study demonstrated that *Moringa oleifera* leaves powder significantly mitigates the harmful effects of cadmium chloride $CdCl_2$ exposure on productive performance and breeding productivity in Japanese quail. Supplementation improved key parameters such as fertility, hatchability, and egg production, highlighting its potential as a natural antioxidant supplement to counter heavy metal toxicity. While the findings are promising, the study's limitations including a small sample size and short duration warrant further research to validate these results. Future studies with larger sample sizes, longer durations, and controlled environmental factors are recommended. Additionally, genetic analysis should be incorporated to better understand variation among populations in response to Cd exposure and Moringa supplementation. Overall, this research underscores the practical applications of *Moringa oleifera* in enhancing poultry health and productivity under environmental stress caused by heavy metals.

Conflicts of Interest: The authors declare that there is no conflict of interest regarding the publication of this manuscript.

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