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Research Article

The Anti-Osteoporotic Effect of Moringa Oleifera Leaves On Glucocorticoids-Induced Osteoporosis In Female Rats

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Abstract
Glucocorticoid-induced osteoporosis and fragility fractures are a significant human and social burden worldwide. All existing pharmaceutical remedies have numerous side effects and are expensive. Thus, the current study sought to assess the anti-osteoporotic benefits of *Moringa oleifera* (MO) leaves in female rats. Thirty-five adult female albino rats (180 ± 10 g) were divided into two groups, the first (n = 7) as a normal control group fed on a baseline diet only, and the second (n = 28) were injected with dexamethasone (1 ml/100g) once a day for 6 weeks to induce osteoporosis. The second main group (n = 7) was broken into four subgroups. As a positive control, Subgroup 1 was given a baseline diet. The other three subgroups treated with dried moringa leaves (2.5, 5 and 10%), respectively. Results indicated that, **S**upplementation with MO leaves significantly enhanced (P<0.05) serum Ca and P. There was a considerable increase (P<0.05) in serum free thyroxin (T4) and drop in parathormone (PTH) in osteoporotic rats. Femur bone mineral density (BMD) increased dramatically. It caused significant improved lipid profile and liver function. Conclusion: The present research suggested that *Moringa oleifera* leaves have anti-osteoporotic effect.

Keywords: *Moringa oleifera*, Glucocorticoids, Osteoporosis, Femur bone, Rats.

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Introduction:
As the world's population ages, the global prevalence of osteoporosis rises **(Saadeh *et al.*, 2022)**. One prevalent systemic skeletal condition is osteoporosis, which is characterized by disrupted bone microarchitecture and a significant risk of bony fractures. After the age of fifty, one in eight men and one in four women have osteoporosis **(Sáez-López *et al.*, 2019)**. The onset of postmenopausal osteoporosis typically starts 5-10 years after menopause begins in women. The most common cause of postmenopausal osteoporosis is a decrease in oestrogen levels **(Almeida *et al.*, 2017)**.
Glucocorticoids (GCs) are the most common iatrogenic cause of secondary osteoporosis, with fracture risk increasing by up to 75% within the first three months of treatment **(Weinstein, 2011)**. Routine osteoporosis treatment is costly and frequently linked with inconvenient side effects **(Arceo and Camacho 2021)**. These limitations result in poor patient compliance. Consequently, more effective and safer therapeutic

choices are required. Previous research has shown that certain plants and natural items boost bone mineral density (BMD), improve bone microstructure, and have high safety profiles **(Rondanelli *et al*., 2021)**.

As a kind of tropical plant, *Moringa oleifera* (MO) is a traditionally medicinal Indian herb found primarily in subtropical and tropical areas **(Kim and Kim, 2019)**. MO leaves are the most nutritious component of the plant. They are a good source of vitamin D, B vitamins, vitamin C, provitamin A in the form of beta carotene, manganese, vitamin K, and proteins **(Raja *et al*., 2016)**. Moreover, it contains nutrients, including iron, zinc, calcium, potassium, magnesium, and phosphorus, which have been linked to an increase in bone density have a significant impact on bone health and calcium absorption. **(Falowo *et al*., 2018)**.

Flavonoids, saponins, tannins, and phytoestrogens are among its natural components, which give it the ability to promote osteoblastic growth and indirectly induce osteo-inductive properties **(Kresnoadi *et al*., 2019)**. These flavonoids promote bone mineralization and the production of bone nodules. They also include kaempferol and quercetin. Kaempferol was discovered to inhibit osteoclastic resorption and to stimulate osteoblastic development and cell mineralization **(Guo *et al*., 2012)**. **Adak and Khan, (2019)** discovered that fermented moringa enhanced development, calcium deposition, blood mineral density, femoral wet weight, cortical bone thickness, bone development, and reduced bone resorption in calcium-deficient rats. Furthermore, the ethanolic extract of MO phytoestrogens content has been demonstrated to have a preventive function against ovarian hormone insufficiency-related bone resorption. These phytoestrogens resemble endogenous oestrogens, such as estradiol. As a result, they are regarded as natural selective oestrogen receptor modulators, as steroidal oestrogens with a stimulatory effect on osteoblast activity and a protective role in postmenopausal women **(Burali *et al*., 2010)**. Therefore, the present study aimed to assess the anti-osteoporotic benefits and mechanisms of *moringa oleifera* leaves in osteoporosis female rats.

Materials and methods

Materials:

Plant: Fresh leaves of moringa were acquired from the National Research Institute.

Chemicals: Casein, vitamins, cellulose, minerals, methionine and Dexamethasone were acquired from Morgan Company for Chemicals, Cairo, Egypt.

Kits: Biochemical analysis kits were purchased from Morgan Company, Dokki, Egypt.

Rats: 35adult female albino of (Sprague- Dawley strain) rats weighing (180 ±10 g) (3 months old) were purchased from Helwan Experimental Animals Farm.

Methods:

Preparation of Moringa leaves powder

The plant's leaves were properly cleaned. Then leaves was shade-dried for 4 days then they were milled into fine powder with the aid of electric blender. Moringa leaves were ground to fine powder in an electric stainless steel mill and sieved through an 80-mesh screen then the powder was stored in plastic container at room temperature (25˚C ± 2˚C) until use.

Chemical analysis of moringa leaves:

The gross chemical composition and phytochemical screening were carried out at the National Research Center, and analyzed by standard methods for moisture, protein fat, ash and crude fiber according to **A.O.A.C, (2020)**. Carbohydrates content was calculated by difference.

- Using an emission flam photometer, calcium was measured in a diluted solution of ash samples. Atomic absorption spectrophotometer was used to determine the other minerals (iron, phosphorus, and magnesium) (**Nzikou *et al*., 2009)**.

Determination of total phenolic compounds (TPC) and total flavonoids compounds (TFC) of Moringa leaves.

Folin-Ciocalteu colorimetric method was used to estimate TPC by **Eghdami and Sadeghi, (2010)**. TFC were determined using a colorimetric method of **Menichini, *et al*., (2009)**.

High-performance liquid chromatography analysis (HPLC) of Moringa leaves.

The assay methodology was followed according to **Kim *et al*., (2006)**.

Biological study:

35 adult female albino rats of (180 ± 10 g) were housed in well aerated cages under sanitary conditions and fed a basal diet for one week for adaption, then were divided into two groups, the first (n = 7) as a normal control group fed on a baseline diet only according to **Reeves *et al*., (1993)**, and the second (n = 28) were injected with dexamethasone (1 ml/100g) once a day for 6 weeks to induce osteoporosis according to **Laste *et al*., (2013)**. The second main group (n = 7) was broken into four subgroups. As a positive control, Subgroup 1 was given a baseline diet. The other three subgroups treated with dried moringa leaves (2.5, 5 and 10%), respectively.

The rats were fasted for 12 hours and then slaughtered under ether anaesthesia when the trial is over (7 weeks). Blood samples were taken in order to get serum from the medial canthus of rats' eyes using fine capillary glass tubes in a centrifuge tube without any anticoagulant and centrifuged for 20 minutes at 3000 r.p.m.

Biological Evaluation:

Feed intake (FI), feed efficiency ratio (FER) and body weight gain percent (BWG %) were determined according to **(Chapman *et al*., 1959)** using the following equation:

$$\text{BWG\%} = \frac{\text{Final body weight} - \text{Initial body weight}}{\text{Initial body weight}} \times 100$$

FER= Body weight gain (g) / Feed intake (g)

Chemical analysis:

Serum was analyzed for the following biochemical parameter: Total cholesterol (TC) **(Richmond, 1973)**,

triglycerides (TG) **Fossati and Principe, (1982)**, High Density Lipoprotein (HDL) **(Albers *et al*., 1983)** were determined. Meanwhile, Low Density Lipoprotein (LDL) and Very Low Density Lipoprotein (VLDL) were calculated according to **(Fridewald *et al*., 1972)**.

LDL-c = TC-[HDL-c + (TG/5)] VLDL-c = TG/5

Calcium and phosphorus levels were evaluated by **Gindler and King, (1972) and El-Merzabani *et al*., (1977)**, respectively. According to **Norazlina *et al*., (2010)** serum parathyroid hormone (PTH) was also measured using an enzyme linked immunosorbent test (ELISA). The radioimmunoassay (RIA) method of **Wang *et al*., (2009)** was used to assess free thyroxine (T4) concentrations. Serum aspartate aminotransferase (AST), alanine aminotransferase (ALT), and alkaline phosphatase (ALP) were tested according to **Reitman and Frankel, (1957) and Belfield and Goldberg (1971)**, respectively. Bone mineral density (BMD) was measured in anaesthetized rats using dual energy X-ray absorptiometry on the whole skeleton, femur, and tibia **(Gao *et al*., 2013)**.

Statistical analysis.

The obtained results were analyzed according to SPSS program. ANOVA test was used to compare results among groups and P<0.05 was considered to be significant (**Snedecor and Cochron, 1989)**.

Results and Discussion

M. *oleifera* leaves have a high amount of moisture, carbohydrates, and fibre, but a low amount of proteins and lipids shown in **Table (1)**. In terms of mineral composition, Moringa oleifera leaves have a high concentration of Ca, P, Fe, and Mg. These findings were also consistent with previous research **Salem *et al*., (2020)** showed that M. oleifera is a good source of -carotene (vitamin A precursor) and vitamins B complex, C, D, and K, as well as some important macro elements like calcium, potassium, zinc, iron, copper, and selenium. Also, **Glover *et al*., (2017)** observed that M. oleifera is high in vitamins, and minerals, particularly iron. The current findings are consistent with those of **EL-Bushuty and Shanshan, (2020) and Rabeh *et al*., (2021)** who found moringa leaves powder to be high in protein, ash, and fibre. Similarly, **Habib and Al-Moalem, (2018)** were discovered to be moringa leaves one of the greatest plant sources of vitamins and minerals like calcium, iron, potassium, magnesium, manganese, and zinc. These findings were consistent with the current investigation.

Table (1): Nutritive value of Moringa leaves powder (g/ 100g)

Nutrients		Fresh Leaves
Nutrients (g/100 g)	Moisture	8.70
	Proteins	24.56
	Fats	2.9
	Carb.	41.14
	Fiber	13.31
	Ash	9.39
Minerals (mg/100 g)	Ca	389
	P	205
	Iron	19.00
	Magnesium	247

Data are the mean of three samples of Moringa oleifera leaves.

Tabulated data in table (2) presented the TPC, TFC, and antioxidant activity of moringa leaves which a high active component found in raw materials. Table (2) showed that MLP contained TP (186.60) mg GAE/g, TF (31.26) mg QE/g and antioxidant activity (56.95%) respectively. These contents were much higher than those obtained by **Abdel Fattah *et al*., (2020)**. They were, however, lower than the TPC and TFC obtained by **Mabrouki *et al*., (2020)**. Variations in the levels of moringa phytochemical components, TFC, and TPC detected might be explained by differences in agro climatic locales, seasons, and plant age **(Nobossé *et al*., 2018)**. **El-Bashshuti and Shanshan, (2020); Abdel Fattah *et al*., (2020) and Rabeh *et al*., (2021),** showed that HPLC analysis moringa leaves extract (MOLE) contained different bioactive components that were responsible for its antioxidant capacity.

Table (2): Total phenolic, total flavonoid and antioxidant activity of moringa leaves

Components	Moringa leaves
Total Phenolic (mg GAE /g)	186.60
Total Flavonoids (mg QE/g)	31.26
Antioxidant activity (DPPH %)	56.95

GAE: Gallic acid equivalent, QE: Quercetin

Table (3) shows the impact of moringa leaves powder (MLP) on the body weight of osteoporosis rats. In all treated groups, there were no significant changes in initial body weight (IBW). According to, **Malkawi *et al*., (2018) and El-Zeiny *et al*., (2023)** reveled that after the injection of DEX in rats suffered from osteoporosis and about ∼20% reduction in weight gain. This is consistent with **Negm, (2023)**; **Negm and Aboraya, (2023) and Poualeu *et al*., (2022)** who reported that dexamethasone significantly reduced body weight in rats. Osteoporosis rats experienced a considerable rise in final body weight (FBW) when compared to healthy rats. The statistical analysis revealed that the mean values of the positive osteoporosis control group's FBW, BWG%, and FER were significantly (P<0.05) lower than the negative control group.

However, Osteoporosis rats treated with varied concentrations of MLP, but experienced a substantial (P0.05) increase in FBW, BWG%, and FER when compared to the positive group (osteoporosis rats). There were no differences in FBW, BWG%, or FER between osteoporosis rats treated with (10 or 15%) MLP. Furthermore, the groups given 15% MLP experienced the greatest rise in BWG%. These findings are consistent with those of **Rabeh *et al*., (2021)** who observed that treatment with M. oleifera leaf extract at dosages of (5, 10, and 15%) increased body weight in anaemic rats. The current findings are consistent with those of **Ameh and Alafi (2018)**, who found that the extract group (rats given solely M. oleifera extract at

500mg/kg body weight) experienced a progressive increase in body weight. Also, **Sarkiyayi and Abubakar, (2018)** discovered that treating rats with an extract of M. *oleifera* leaves at doses of 300 and 600 mg/kg resulted in an increase in body weight when compared to the negative control.

Table (3). Effect of Moringa leaves powder (MLP) on BW, BWG%, FI and FER of osteoporosis female rats.

Parameters Groups	IBW	FBW	BWG%	FI	FER
Control (-ve)	186.00±1.52a	231.00±2.15a	24.20±0.47a	18	0.089±0.001a
Control (+ve)	187.00±1.58a	214.33±2.88d	14.62±0.48d	13	0.075±0.002c
MLP 5 %	185.33±1.85a	220.33±1.85c	18.89±0.39c	15	0.083±0.001b
MLP 10 %	189.00±1.57a	225.33±1.33b	19.40±0.52bc	16	0.084±0.001ab
MLP 15 %	189.66±1.66a	230.00±2.57ab	21.26±0.22b	17	0.084±0.002ab

Values are expressed as means ± SE.
Values at the same column with different letters are significantly different at P<0.05.

Table (4) revealed that the control positive group had a significant increase (P<0.05) in the mean values of serum TC, TG, LDL-c, and VLDL-c, whereas the control negative group had a significant drop in the mean value of HDL-c. This is consistent with **Negm, (2023a)**;**Negm and Aboraya, (2023) and Poualeu *et al*., (2022)** noted that dexa significantly altered biochemical parameters to increase lipid profile.

Osteoporosis rats given M. oleifera leaves at different levels exhibited substantial decreases in blood TC, TG, LDL-c, and VLDL-c, while the mean value of HDL-c was significantly enhanced (P<0.05) in every group that was treated in contrast to the positive control group. Furthermore, serum levels of TC, TG, and LDL-c differed significantly between the three treatment groups. The group added to with 15% MLP showed the greatest improvement in lipid profile.

These findings were consistent with **Hu *et al*., (2023) and El-Shehawi *et al*., (2021)** observed that MLP significantly improved lipid profile in an ovariectomized osteoporosis rat model. Also, **Alkhudhayri *et al*., (2021) and El-Bashshuti and Shanshan, (2020)** found that Moringa leaves decreased TC, TG, and LDL concentration, while raised serum HDL. **Lacorte *et al*., (2021)** discovered that using extract of M. *oleifera* reduced obesity and dyslipidemia. Similarly, **Mabrouki *et al*., (2020) and Saleh and Sarhat, (2019)** observed that supplementing HFD-fed rats with methanolic extract of M.oleifera leaves (MEML) at 200 and 400 mg/kg doses significantly reduced TC, TG, and LDL-c while, elevated HDL-c levels in the serum in comparison to the HFD-only group. The reduction in TC, TG, LDL-c, and an increase in HDL- clevels show that moringa leaves have strong hypolipidemic action, which could be explained by the existence of flavonoids, which have antioxidant properties **(Negm, 2019 and Lacorte *et al*., 2021)**.

Table (4). Effect of Moringa leaves powder (MLP) on lipid profile of osteoporosis female rats.

Parameters / Groups	TC	TG	HDL-C	LDL-C	VLDL-C
	(mg/dl)				
Control (-ve)	84.71±0.43e	43.39±0.32d	39.59±0.37a	35.44±0.36e	9.67±0.09c
Control (+ve)	112.45±0.63a	86.48±0.52a	28.76±0.54d	66.40±0.59a	17.29±0.10a
MLP 5 %	101.52±0.66b	70.52±0.45b	30.66±0.68cd	56.75±1.26b	14.10±0.08b
MLP 10 %	95.93±0.41c	62.94±0.25c	33.35±0.57bc	49.99±0.91c	12.58±0.65b
MLP 15 %	89.13±0.29d	54.67±0.55d	35.40±0.54b	42.70±0.87d	10.93±0.11c

Values are expressed as means ± SE.
Values at the same column with different letters are significantly different at P<0.05.

The results shown in Table (5) demonstrated the impact of MLP on serum calcium (Ca) and phosphorus (P) levels in osteoporotic rats. The positive control group's serum Ca and P levels were significant (P<0.05) lower, when compared to the negative control rats. The decreased serum calcium levels were induced by oestrogen deficiency in rats with osteoporosis **(Choi and Seo, 2013 and Negm, (2023b)**.
Feeding rats on MLP increased serum Ca and P levels significantly (P<0.05) when compared to the positive control group. No significant differences in serum Ca and P levels between osteoporosis rats treated with (10 or 15 %) MLP. The serum Ca and P concentrations were highest in the group fed a basic diet supplemented with 15% MLP. These result are acceptance of **Hu *et al*., (2023)** showed that MLP dramatically boosted bone mineral density and improved bone metabolism-related markers, bone microstructure in osteoporosis rat. Increases in Ca and P enhance calcium and phosphorus deposition from the blood into bone tissue and delay BMD declines caused by bone tissue resorption. **Soliman *et al*., (2021)** reported that MO leaves a strong plant can be considered a successful remedy for osteoporosis. **Dai *et al*., (2020)** reported that microbial fermentation increased the calcium bioavailability of M. *oleifera* leaves (MOL), promoting calcium deposition, bone formation, enhancing bone strength, reducing bone

resorption, and the growth and development of rats lacking calcium and preventing calcium deficiency.
M. *oleifera* leaves include myricetin, quercetin, and kaempferol, all of which have been shown to help with osteoporosis **(Wong *et al*., 2020 and Liu *et al*., 2021)**. Similarly, **Habib and Al-Moalem, (2018)** observed that an experimental diet supplemented with Moringa leaves significantly enhanced (P<0.05) the mean values of these biochemical indicators (Ca and P) and consequently enhancing bone formation.

Table (5): Effect of Moringa leaves powder (MLP) on serum calcium and phosphorus contents of osteoporotic female rats.

Parameters / Groups	Ca (mg/dl)	P (mg/dl)
Control (-ve)	14.63±0.32a	8.72±0.38a
Control (+ve)	8.52±0.17d	3.37±0.02d
MLP 5 %	9.59±0.19cd	4.47±0.10cd
MLP 10 %	10.20±0.14bc	5.48±0.28bc
MLP 15 %	11.26±0.58b	6.18±0.14b

Values are expressed as means ± SE.
Values at the same column with different letters are significantly different at P<0.05.

The impact of MLP on serum T4 and PTH on osteoporosis in rats was shown in **Table (6)**. The positive control rats experienced a significant (P<0.05) decreased in serum T4 but increased in serum PTH, when compared to the negative control group. Supplementation with MLP considerably increased (P<0.05) the levels of serum T4 but dramatically decreased (P<0.05) the levels of serum PTH, when compared to the positive control rats. Furthermore, serum levels of T4 osteoporosis rats treated with (10 or 15%) MLP showed no significant difference. These findings were consistent with **Habib and Al-Moalem, (2018); Ghadhban *et al*., (2019) and Al –Hadidy and Dawood, (2021**) showed that Moringa leaves are necessary in hypothyroidism because they increase T3 and T4 hormone levels. **Tabassum *et al*., (2013)** discovered that the group given a large dose (500 mg/kg bw, 14days) of Moringa saw the greatest percentage increase in hormone levels of T3 and T4 when compared to the other dose levels, proving that Moringa leaves extracts can be used in hypothyroidism to normalise hormone levels, which agrees with our findings. Anthocyanin compounds found in M. *oleifera* in sufficient amounts boost Adiponectin biosynthesis, which increases thyroid hormone synthesis, particularly T4 hormone, due to C- terminal globular interaction with receptors found in thyroid gland mitochondria **(Vergara *et al*., 2017)**.

Table (6): Effect of Moringa leaves powder (MLP) on serum thyroxin and parathyroid hormone of osteoporotic female rats

Parameters / Groups	T4 (µg/dl)	PTH (pg/mL)
Control (-ve)	9.19±0.13a	0.95±0.005d
Control (+ve)	4.51±0.17d	3.04±0.045a
MLP 5 %	6.31±0.16c	2.04±0.040b
MLP 10 %	7.55±0.03b	1.81±0.07c
MLP 15 %	8.00±0.06b	1.01±0.066d

Values are expressed as means ± SE.
Values at the same column with different letters are significantly different at P<0.05.

Table (7) shows the impact of MLP supplementation on bone mineral density (BMD) in osteoporotic rats. The mean (BMD) of the positive group was considerably lower (P<0.05) when compared to the negative rats. The current study found that bone weakening and degradation were clearly visible in the osteoporotic group as measured by BMD reduction. Similar **Govindarajan *et al*., (2013)** found that BMD was considerably lower in ovarictomised (OVX) rats.
Supplementation with Moringa leaves improved the mean value of bone mineral density substantially (P<0.05), when compared to the positive control group. There was no statistically significant difference in BMD between the groups receiving Moringa leaves. These result are agreement with **Patel *et al*., (2015) and Soliman *et al*., (2021)** showed that a daily oral dose of 200mg/kg body weight of MO extract for 30 days resulted in a substantial increase in BMD in the MO-treated group versus the osteoporotic group. Furthermore, the BMD in the MO-treated group was substantially identical to that of healthy rats. Similarly, **Ezzat and Abbass (2014), Haggag and Mahmoud, (2018) and Habib and Al-Moalem, (2018)** demonstrated that BMD increased considerably in a glucocorticoid model of osteoporotic rats fed dried moringa leaves. This could be due to the minerals present in MO, which have both a therapeutic and preventative effect on osteoporosis.

Table (7): Effect of Moringa leaves on Bone Mineral Density in femur bone of osteoporotic rats.

Parameters / Groups	Bone Mineral Density (g/cm^3)
Control (-ve)	0.089±0.001b
Control (+ve)	0.059±0.001c
MLP 5 %	0.094±0.001ab
MLP 10 %	0.095±0.001a
MLP 15 %	0.097±0.001a

Values are expressed as means ± SE.
Values at the same column with different letters are significantly different at P<0.05.

The data in Table (8) demonstrated the impact of Moringa leaves on osteoporotic rats' serum liver functions. The activities of liver functions were considerably elevated (P<0.05) when compared to the negative group. This is consistent with **Negm and Aboraya, (2023) and Poualeu *et al*., (2022)** revealed that dexa treatment significantly increased liver function. Supplementation with MLP significantly decreased (P<0.05) levels of serum AST, ALT and ALP when compared to the positive control group. Furthermore, there was no difference in serum ALT between osteoporosis rats treated with (10 or 15%) MLP. The group fed a basic diet supplemented with 15% MLP had the greatest liver function level. This aligns with **Negm, (2019) and Habib and Al-Moalem, (2018)** revealed that supplementation with MLP significantly reduced (P<0.05) levels of serum AST, ALT, and ALP, when compared to the positive control group. Also, **Rabeh *et al*., (2021)** reported that M. oleifera extract has a hepato-nephroprotective therapeutic effect on obese rats, as evidenced by a significant improvement in AST, ALT, and ALP activities. This finding is consistent with the findings of **Mabrouki *et al*., (2020)**, who discovered that administration of both low and high MEML doses in the HFD-treated group efficiently relieved these abnormalities of liver enzyme, which could be due to M. *oleifera* phytochemical content and antioxidant capacity. Similarly, **El-Bashshuti and Shanshan, (2020)** demonstrated that M. *oleifera* has a hepatoprotective impact on the liver of obese female rats, as evidenced by a significant decrease in AST, ALT, and ALP enzyme activity.

Table (8): Effect of Moringa leaves powder (MLP) on liver functions of osteoporosis female rats.

Parameters / Groups	AST (µ/L)	ALT	ALP
Control (-ve)	94.69±0.60e	53.63±0.50d	61.75±1.85e
Control (+ve)	132.43±0.23a	59.56±0.33a	115.47±1.40a
MLP 5 %	118.55±0.63b	51.03±0.47b	100.30±1.09b
MLP 10 %	102.48±0.52c	44.56±0.58c	93.67±1.45c
MLP 15 %	99.43±0.43d	42.22±0.63c	81.68±2.51d

Values are expressed as means ± SE.
Values at the same column with different letters are significantly different at P<0.05.

5. Conclusions

The current study empirically demonstrated that Moringa leaves can effectively improve dexamethasone-induced osteoporosis, MLP have a powerful anti-osteoporotic effect, remarkable bone healing regenerative potential, and a great safety profile, and thus it might be useful in osteoporosis treatment through oral intake. This role of MLP is linked to its abundance of nutrients. The current work offers new information on MLP's anti-osteoporosis mechanisms and opens up new avenues for the advancement of novel MLP-based functional and therapeutic products.

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