The physiological effects of dietary boron on growth performance and bone strength in female rats

Fares K. Khalifa, Nagwa I. Hassanin & Hala S. Abd El-Fattah
Biochemistry and Nutrition Department, Faculty of Girls,
Ain Shams University

ABSTRACT

The trace element boron (B) is essential for animals and humans as well as plants. It is required for bone, mineral metabolism and has a physiological role in animal nutrition. The extent and nature of possible physiological effects or potential risks of boron in animals and humans are still at primary stage and require further investigations. The aim of this study was to evaluate the effect of dietary boron supplementation as sodium tetraborate (0, 5, 10,15,20,25.30, and 35 mgB/100 g diet) on growth performance, bone ash content, and bone strength in adult female albino rats. The results indicated that, boron supplementation affected body weight gain, femur and tibia bone weight, density, mechanical properties (moment of inertia and stress) , total lipids, and minerals ash content (calcium, inorganic phosphorous, magnesium, and copper). On the other hand, different experimental doses of boron did not have any effect on food intake, femur and tibia bone length, mineral ash content of zinc, and bending moment of tibia bone. In addition, the results revealed that, a statistical significant increase was observed in mean values of femur bending moment in the experimental rat groups fed on diets containing high doses of boron as sodium borate. These results suggest that physiologic amounts of boron may have beneficial effects upon bone minerals metabolism and, consequently, bone characteristics.

Key words: *Growth performance, Bone minerals density, Bone strength.*

INTRODUCTION

Boron (B) is a ubiquitous element in the human environment. It is widely distributed and combined with oxygen to form inorganic borates. Boron is an essential micronutrient for growth of plants and, as such, occurs naturally at trace levels in fruits and vegetables that are part of the human diet[(1)]. Bone, nails, and hair have a higher level of boron than other tissues[(2,3)]. It has been reported that, boron may be beneficial for optimal calcium metabolism and, as a consequence, optimal bone metabolism[(4)]. Chronic suboptimal intake of boron in association with other nutrients and vitamins may predispose a person to osteoporosis[(5)]. The effects of dietary boron on bone strength have been evaluated in animals with positive results. In pigs, boron supplementation showed beneficial effects on bone characteristics[(6,7)]. In chickens, it is generally accepted that boron increases the strength of bone and augments the bone ash content[(8,9)]. In rats, results showed an increase in strength of the axial skeleton[(10)]. Boron supplementation to a low-B diet increased measures of bone mechanics and bone ash percentage in barrows [(11)]. In addition, B has been linked to the metabolism of macrominerals [(12)], energy metabolism [(13)], and the immune system [(14)]. The study of B essentiality in animal and human nutrition has increased as it was found that boron partially corrected leg abnormalities in cholecaciferol-deficient chicks [(15)].Research has demonstrated that B may have a physiological role in both animal and human nutrition [(11)].

MATERIALS & METHODS

MATERIALS:

Boron:

Sodium tetraborate decahydrate ($Na_2B_4O_7.10H_2O$) was used as a source of Boron. It was brought from El-Nasr pharmaceutical chemicals company.

Experimental animals:

Eight groups each of eight weaning female Albino rats (Sprauge-Dawley) strain, mean weight varied between 156.2 to 158.8 g were used. They obtained from Helwan breeding farm, Cairo, Egypt. The animals housed in the animal room of the department individually in plastic cages fitted with a wire mesh bottoms, and maintained at 25-30°C with about 50% relative humidity. The room lighted on a daily photoperiod of 12h light and dark. Then they allocated to the various experimental diets for six weeks. During the conditioning period and throughout the experiment, food and tap water provided ad libitum.

Experimental diets

The experimental diets used in the present study were the balanced diets prepared according to ***AIN*** [(16)]. Group I (control group); rats were feed on a balanced basal diet. Group II; rats fed on basal diet+5 mg B/100 g diet. Group III; rats fed on basal diet+10 mg B/100 g diet. Group IV; rats fed on basal diet+15 mg B/100 g diet. Group V; rats fed on basal diet+20 mg B/ 100 g diet. Group VI; rats fed on basal diet+25 mg B/100 g diet. Group VII; rats fed on basal diet+30 mg B/100 g diet. Group VIII; rats fed on basal diet+35 mg B/100 g diet for six weeks.

METHODS

A-Bone:

At the end of an experiment (42 days), animals were fasted for 16 hours. They were anesthetized with diethyl ether. Right and left entire long bones (femur and tibia) were obtained from all experimental rats under investigation. Femurs and tibiae cleaned up from adhering muscle and connective tissue using scalpel blade and cotton gauze. Bone samples rinsed in chilled saline solution then blotted on filter paper and weighed separately to calculate the absolute weight.

B-Analytical Procedures:

I-Bone Characteristic:

The length of each femur and tibia measured with a vernier caliper, before measurement of the bone density, each bone segment treated with H_2O_2 diluted with deionized water (DI) to remove remaining tissue fragments and blood residues and rinsed with DI water. Bone volume and density measured by Archimedes' principle [17], and the density (g\cm^3 bone volume) were calculated. After that, bones frozen at -20°C until mechanical properties, bone ash and lipids content were determined.

II-Bone Mechanical tests:

Bones were thawed and all specimens kept moist during the testing process in order to avoid variability resulting from uneven moister content. Numerous kinds of tests used to determine the strength of materials. The most commonly used to evaluate the mechanical properties of bone is a flexure test (bending test) according to ***Baker and Haugh*** [18]. In a flexure test, the bone is simply supported at each end and a force is applied at midspan. Mechanical properties determined were; bending moment (kg-cm), moment of inertia (cm^4), and stress (kg/cm^2). These mechanical properties of bone have been previously described by ***Crenshaw et al.***,[19,20] and ***Armstrong et al.,***[11].

Bending Moment is simply the force applied to the bone adjusted for the distance (length) over which it is applied [19,20]. Bending moment is calculated by the following equation:

$$\text{Bending moment (kg-cm)} = \frac{\text{Force (kg) x Length (cm)}}{4}$$

Where, Force is a measure of the maximum load, and length is the distance between the two fulcra points that support the bone.

Moment of inertia was determined for the cortical bone. Moment of inertia is a measure of the area distribution around the axis of the center load in the direction of the applied force [21]. Moment of inertia takes into account both the size and the shape of an object shaped as an ellipse. The equation used for calculating the area moment of inertia from measurements of the diameter of the section is:

$$\text{Moment of inertia (cm}^4\text{)} = 0.0491(BD^3 - bd^3)$$

Where, B and D are outside diameters (centimeters) of the bone at the point of loading, and b and d are inside diameters (centimeters) at the same points. The constant 0.0491 equals (л/64).

Bone stress takes into account both bending moment and moment of inertia. Stress is defined as force per unit of bone area. In a flexure test, stress is calculated as follows:

$$\text{Stress (kg / cm}^2\text{)} = \frac{\text{Force (kg) x Length (cm) x C (cm)}}{\text{4 x Moment of inertia (cm}^4\text{)}}$$

Where, C is the radius of the femur cross section.

Bone mechanical properties were determined using an Instron Universal Testing Instrument (Model 1122; Instron, Canton, MA).

III-Bone Lipids:

Cross section of the femur and tibia weighed and dried for 18 h at 100°C. The bone sections weighed again, wrapped in filter paper, placed in a side-arm Soxhlet extraction apparatus, extracted with petroleum ether for 48 h and allowed to air dry for 48 h. Bone sections dried at 100°C for 18 h and weighed. The percentage of bone lipids was calculated based on weight loss after solvent extraction of dry bone [11].

IV-Bone Ash:

The percentage of bone ash was calculated after heating the cross sections of fat-free bone in a muffle furnace at 700°C for 48 h. Bone ash was dissolved in 5 ml 6 mol/L HCl and brought to 50 ml with deionized water. Bone ash calcium, phosphorus, magnesium, zinc and copper concentrations were determined by atomic absorption spectrophotometry, (Model Unicam 929 A.A) with computer system.

Statistical Analysis:

Statistical analyses of data were performed by ANOVA using SPSS 10.0 version. All data were expressed as means ±SD. P-value:>0.05 insignificant, <0.05 significant, <0.01 highly significant.

RESULTS

The results presented in table (1) show the mean values of biological indices, such as food intake (g/day), and body weight gain (g) when rats consumed the different experimental diets. The results of the present study showed that, there were non-significant differences in the mean values of feed intake (g/day) among the different experimental groups. Body weight gain showed highly significant differences ($p<0.01$) between different experimental groups.

The effect of different diets on femur bone characteristics (weight, length, and density) and mechanical properties (bending moment, moment of inertia and stress) are shown in table (2). The results revealed that, there was no significant effect on femur length through the experimental periods (42 days). On the other hand, a significant increase ($p<0.01$) in femur weight was observed in rats fed on diet supplemented with 25 mg B/100 g diet (G_6) compared with control group.

Femur density was significantly higher ($p<0.01$) in rat groups fed diets containing high doses of sodium tetraborate (from G_5 to G_8 respectively). In addition, the results demonstrated that, there was a significant decrease in G_3 and significant increase in G_5 in the mean values of the bending moment when compared with other experimental groups. With more boron supplementation there was significant decrease in femur bone stress and significant increase in moment of inertia when compared to control group.

Table (3) summarizes the effect of feeding different boron doses on femur bone total lipids and minerals ash concentrations (calcium, phosphorus, magnesium, zinc, and copper).

The results of the present study showed that, femur bone total lipids were significantly reduced ($p<0.01$) in rats fed diets containing high doses of boron as sodium borate (20, 25, 30, and 35 mg B/100 g diet). It is clear that, a highly significant increase ($p<0.01$) in femur bone ash calcium level between all treated rats. There was no significant difference in the mean values of femur bone ash zinc among different experimental groups. Bone ash copper femur had the same trend of bone ash phosphorus levels throughout the experimental period (42 days). The results of present study showed that, femur bone total lipids were significantly reduced ($p<0.01$) in rats fed diets containing high doses of boron (from G_5 to G_8).

Table (4) illustrates the effect of different experimental diets on tibia bone characteristics (weight, length, and density) and mechanical properties (bending moment, moment of inertia, and stress). It is clear that, there were no significant differences in tibia bone length and bending moment throughout 42 days of experiment. While, tibia bone weight and density recorded significant increases in all rat groups as compared to control group. Supplementation with boron decreased significantly moment of inertia of tibia bone in rat group, which fed diets containing 10 mg B/100 g diet (G_3). On the other hand, tibia bone stress was increased significantly in G_4 and G_6 when compared to other experimental groups.

Table (5) summarizes the effect of different doses of boron on tibia bone total lipids concentration and the levels of calcium, phosphorus, magnesium, zinc, and copper. Data showed that, tibia total lipids were significantly reduced by increasing boron supplementation (20-35 mg B/100 g diet) when compared with other experimental groups. It is clear from table (5) that, tibia calcium levels were significantly increased in all rat groups when compared with control group. On the other hand, the concentration of phosphorus, magnesium, and copper showed significant reduction in all rat groups as compared with control group. The results also showed that, there was no significant difference in the mean values of tibia bone ash zinc concentration.

Table (1): The effect of dietary boron supplementation on food intake (g/day) and body weight gain (g).

Parameters	**Initial weight** *(g)*	**Final weight** *(g)*	**Weight gain** *(g)*	**Food intake** *(g/day)* **(N.S.)**
G1	158.8	194	35.2±0.001 a	**7.64±0.48**
G2	158.3	195.3	37±0.004 a	**7.72±0.43**
G3	157.1	185.8	28.7±0.001 a	**8.31±0.61**
G4	156.2	204.8	48.6±0.003 a	**8.69±0.62**
G5	156.3	168.1	11.8±0.007 a	**6.28±1.05**
G6	157.6	166.5	8.9±0.001 a	**6.53±0.63**
G7	156.2	174.2	18±0.002 a	**7.31±0.745**
G8	158.1	165.1	7±0.0006 a	**5.89±0.30**

-Values are expressed as means ± S.D. (n= 8). -N.S: Non-Significant.
-Mean within the same column bearing similar alphabetic subscripts are significantly different at (P<0.01).

Table (2): The effect of boron supplementation on femur bone characteristics (weight, length, and density) and mechanical properties (bending moment, moment of inertia, and stress).

Parameters	Groups							
	G1	**G2**	**G3**	**G4**	**G5**	**G6**	**G7**	**G8**
Weight *(g)*	**0.541±0.03** [1,2,3a]	**0.382±0.0437** [1bcde]	**0.486±0.0544** [4fgh]	**0.48±0.0327** [5ijk]	**0.665±0.0362** [4,5b]	**0.798±0.0459** [acfi]	**0.706±0.0694** [2dgj]	**0.729±0.0851** [3ehk]
Length *(mm)* **(N.S.)**	**29.85±0.809**	**29.75±1.436**	**32.665±0.59**	**32.2±0.938**	**29.87±0.415**	**30.025±0.886**	**31.15±0.651**	**30.365±0.347**
Density *(g /cm³)*	**0.992±0.0375** [abcd]	**1.025±0.0876** [efgh]	**1.104±0.0791** [1,2ij]	**1.0±0.0369** [klmn]	**1.405±0.0398** [1aek]	**1.44±0.156** [2bfl]	**1.51±0.125** [cgim]	**1.567±0.0877** [dhjn]
Bending moment *(Kg-cm)*	**4.248±0.17**	**3.854±0.33** [1]	**3.425±0.356** [2,3a]	**4.672±0.414** [2]	**5.061±0.513** [1,4ab]	**4.016±0.184** [4]	**4.728±0.21** [3,5]	**3.645±0.483** [5b]
Moment of inertia *(cm⁴)*	**0.167±0.064** [1,2,3]	**0.152±0.028** [4,5a]	**0.227±0.027**	**0.354±0.048** [1a]	**0.349±0.047** [2,4]	**0.328±0.07** [3,5]	**0.283±0.06**	**0.244±0.037**
Stress *(Kg/cm²)*	**8.03±1.68** [1,2,3abc]	**7.14±0.476** [4,5,6]	**4.34±0.327** [4a]	**4.55±0.881** [5b]	**4.66±0.161** [1]	**4.19±0.652** [6c]	**4.9±0.611** [2]	**4.85±1.08** [3]

-Values are expressed as means ± S.D. (n= 8). *- N.S : Non Significant*

-1, 2, a, b…Mean within the same raw bearing similar numerical (L.S.D at P < 0.05) or alphabetic (L.S.D at P < 0.01) subscripts are significantly different.

Table (3): The effect of boron supplementation on femur bone total lipids (mg/g bone) and bone ash calcium, phosphorus, magnesium, zinc and copper.

Parameters	**Groups**							
	G1	**G2**	**G3**	**G4**	**G5**	**G6**	**G7**	**G8**
Total lipids *(mg/g bone)*	$\mathbf{16.31 \pm 1.0}^{1abcd}$	$\mathbf{12.24 \pm 0.97}$	$\mathbf{9.82 \pm 1.81}^{1}$	$\mathbf{12.21 \pm 0.87}$	$\mathbf{9.51 \pm 2.05}^{a}$	$\mathbf{9.53 \pm 1.42}^{b}$	$\mathbf{9.57 \pm 2.84}^{c}$	$\mathbf{7.43 \pm 1.47}^{d}$
Calcium *(g/g ash)*	$\mathbf{0.216 \pm 0.003}^{abc}$	$\mathbf{0.303 \pm 0.01}^{adef}$	$\mathbf{0.371 \pm 0.0012}^{ag}$	$\mathbf{0.384 \pm 0.0179}^{bdhi}$	$\mathbf{0.462 \pm 0.001}^{ah}$	$\mathbf{0.474 \pm 0.003}^{agij}$	$\mathbf{0.554 \pm 0.005}^{abej}$	$\mathbf{0.555 \pm 0.004}^{cfgh}$
Phosphorus *(g/g ash)*	$\mathbf{0.163 \pm 0.005}^{,2ab}$	$\mathbf{0.186 \pm 0.007}^{1cdefg}$	$\mathbf{0.155 \pm 0.006}^{3c}$	$\mathbf{0.138 \pm 0.009}^{2d}$	$\mathbf{0.156 \pm 0.005}^{4eh}$	$\mathbf{0.133 \pm 0.008}^{3,4af}$	$\mathbf{0.143 \pm 0.004}^{g}$	$\mathbf{0.124 \pm 0.007}^{bch}$
Magnesium *(g/100g ash)*	$\mathbf{0.807 \pm 0.019}^{,2,3}$	$\mathbf{0.917 \pm 0.076}^{4abc}$	$\mathbf{0.811 \pm 0.032}^{5,6,7}$	$\mathbf{0.762 \pm 0.067}^{4}$	$\mathbf{0.774 \pm 0.065}$	$\mathbf{0.651 \pm 0.056}^{1,5a}$	$\mathbf{0.652 \pm 0.028}^{2,6b}$	$\mathbf{0.642 \pm 0.034}^{3,7c}$
Zinc *(g/100 g ash)* **(N.S.)**	**0.114±0.002**	**0.112±0.005**	**0.113±0.004**	**0.111±0.0016**	**0.114±0.002**	**0.109±0.002**	**0.117±0.001**	**0.111±0.002**
Copper *(g/100g ash)*	$\mathbf{0.016 \pm 0.003}^{1,2abc}$	$\mathbf{0.023 \pm 0.002}^{1def}$	$\mathbf{0.0192 \pm 0.003}^{3ghi}$	$\mathbf{0.01 \pm 0.0004}^{2,4dg}$	$\mathbf{0.013 \pm 0.003}^{3ejk}$	$\mathbf{0.004 \pm 0.001}^{4aeh}$	$\mathbf{0.002 \pm 0.008}^{bdij}$	$\mathbf{0.00}^{cfgk}$

-Values are expressed as means ± S.D. (n= 8). -N.S : Non Significant.

-1, 2, a, b…Mean within the same raw bearing similar numerical (L.S.D at P < 0.05) or alphabetic (L.S.D at P < 0.01) subscripts are significantly different.

Table (4): The effect of boron supplementation on tibia bone characteristics (weight, length and density) and mechanical properties (bending moment, moment of inertia and stress).

Parameters	Groups							
	G1	G2	G3	G4	G5	G6	G7	G8
Weight *(g)*	1,2ab **0.36±0.025**	3,4 **0.452±0.035**	5,6 **0.444±0.058**	7c **0.427±0.032**	1 **0.599±0.054**	2 **0.614±0.127**	3,5,7a **0.673±0.059**	4,6bc **0.725±0.114**
Length *(mm)* **(N.S.)**	**35.97±0.58**	**37.2±0.98**	**36.95±0.75**	**35.47±0.91**	**35.35±0.71**	**35.05±0.58**	**35.65±0.19**	**34.92±0.25**
Density *(g/cm^3)*	abcd **0.93±0.05**	egfh **0.96±0.042**	ijkl **1.08±0.037**	mnop **1.04±0.1**	aeim **1.5±0.11**	bfjn **1.48±0.072**	cgko **1.45±0.036**	dhlp **1.47±0.022**
Bending moment *(Kg.cm)* **(N.S.)**	**2.59±0.23**	**2.47±0.15**	**2.86±0.16**	**2.88±0.2**	**2.69±0.43**	**2.75±0.34**	**2.90±0.157**	**2.47±0.086**
Moment of inertia *(cm^4)*	1a **0.152±0.017**	2b **0.151±0.016**	3ab **0.0589±0.01**	1,2 **0.0869±0.01**	**0.104±0.027**	**0.11±0.011**	3 **0.123±0.22**	**0.105±0.006**
Stress *(Kg/cm^2)*	1a **4.608±0.49**	2,3b **4.397±0.2**	4,5c **4.41±0.63**	6,7abc **7.307±0.55**	2,4 **6.08±1.0**	1,2,3 **6.609±0.2**	6 **5.455±0.605**	7 **5.385±0.388**

-Values are expressed as means ± S.D. (n= 8). *- N.S : Non Significant.*
-1, 2, a, b…Mean within the same raw bearing similar numerical (L.S.D at P < 0.05) or alphabetic (L.S.D at P < 0.01) subscripts are significantly different.

Table (5): The effect of boron supplementation on bone tibia lipids (mg/g bone) and bone ash (calcium, phosphorus, magnesium, zinc and copper).

Parameters	Groups							
	G1	G2	G3	G4	G5	G6	G7	G8
Total lipids *(mg/g bone)*	abcde **27.51±0.74**	1,2af **15.64±1.54**	fghij **27.75±3.70**	1klmn **22.52±3.45**	bgk **9.71±1.81**	chl **11.54±1.52**	dim **9.71±1.95**	2ejn **8.14±1.87**
Calcium *(g/g ash)*	ab **0.297±0.009**	cdef **0.327±0.002**	acg **0.375±0.001**	1ad **0.427±0.007**	1bchi **0.469±0.02**	aehj **0.527±0.01**	afi **0.578±0.002**	bdgj **0.594±0.016**
Phosphorus *(g/g ash)*	1,2ab **0.176±0.017**	1,3 **0.149±0.002**	2,4 **0.151±0.002**	3,4acde **0.124±0.008**	c **0.157±0.006**	b **0.141±0.002**	d **0.160±0.004**	e **0.159±0.003**
Magnesium *(g/100g ash)*	1,2ab **0.918±0.078**	3 **0.837±0.043**	4,5 **0.870±0.058**	6 **0.843±0.051**	,4,6a **0.692±0.031**	1 **0.763±0.051**	5b **0.706±0.020**	2 **0.769±0.034**
Zinc *(g/100 g ash)* **(N.S.)**	**0.115±0.003**	**0.117±0.004**	**0.107±0.005**	**0.107±0.001**	**0.104±0.001**	**0.113±0.003**	**0.111±0.003**	**0.107±0.003**
Copper *(g/100g ash)*	abcd **0.025±0.003**	1,2,3ef **0.022±0.002**	1ag **0.013±0.001**	2bh **0.013±0.001**	3cij **0.014±0.002**	de **0.009±0.003**	afhi **0.003±0.001**	begj **0.00**

-Values are expressed as means ± S.D. (n= 8). *-N.S : Non Significant*

-1, 2, a, b…Mean within the same raw bearing similar numerical (L.S.D at P < 0.05) or alphabetic (L.S.D at P < 0.01) subscripts are Significantly different.

DISCUSSION

The findings of the present study demonstrated that, although no weight loss was observed in all experimental rat groups, the rate of body weight gain was reduced as the intake of boron was increased. The lowest mean value were observed in rat group fed on diet supplemented with high dose of B (35 mg B/100 g diet), while the highest value were found in rats fed on diets containing 15mg B/100 g diet. Loss of body weight has been reported in studies utilizing high doses of boron and has been postulated to be the result of intestinal malabsorption[22,23] and/or reduced nutrient intake[24]. ***Naghii and Samman*** [25] reported that, body weight gain increased at lower doses of B supplementation in rats, with no change at the highest concentration of supplemental B. ***Armstrong et al.***[11] reported that, B supplementation to a semipurified diet did not affect average daily gain but did improve gain/feed in weanling pigs.

Boron has been examined as a possible nutritional factor in calcium (Ca) metabolism and utilization, and thus as a factor in the development and maintenance of normal bone[26]. Bone-breaking strength and bone ash are often used as criteria for assessing the values of various dietary supplements for preventing bone breakage[27].The results of the present study showed that, femur and tibia characteristics affected significantly by boron supplementation. The results revealed that femur and tibia weight were significantly increased as the intake of boron was increased. The result of the current study were consistent with a study by ***Wilson and Ruszler***[9] who found significant differences in bone weight and ash content of growing pullets fed on diets supplemented with 50, 100, and 200 mg B/kg diet.

Bone density was significantly higher in experimental rat groups fed on diets containing high doses of boron (20-35 mg B/100 g diet) when compared with control group. ***Wilson and Ruszler*** [9] reported that bone ash content, which is a measure of bone density, increased significantly with the highest value at 50 mg/kg. This increase in bone density could account for the increase in the strength properties of the bone tissue. As the bone tissue becomes denser, the molecular structure altered in such a way as to allow the bone to support an additional load.

Boron plays a regulatory role in the metabolism of several micronutrients, such as calcium, phosphorus (P), magnesium (Mg), and vitamin D [8, 28]. Boron was observed to be positively influence the metabolism of these dietary substances by improving their absorption or reducing the urinary losses, which all play a role in maintaining bone health[28, 29].

It is clear from the results of the current study that, femur and tibia calcium level increased gradually as the supplementation of dietary boron was increased. The current findings are in agreement with the results of ***Nielsen***[30] who postulated that boron supplementation increased tibia calcium concentration. Present data give evidence that boron alters calcium levels by different mechanisms. The influence of boron on vitamin D and magnesium metabolism (and thus Ca hemostasis) may be controlled by its influence on cell membrane activity[31], what is known is that large amounts of dietary boron benefit Ca and vitamin D status in humans and animals[32]. On the other hand, femur and tibia bone ash phosphorus, magnesium, and copper concentrations showed significant reduction in all experimental rat groups when compared to control group. The lowest value for femur bone magnesium was noticed by supplementing boron at a tested dose level of 35 mg B/100 g diet.

Armstrong and Spears[6] reported that boron supplementation did not affect calcium concentrations of the fat-free bone ash, but supplemental B increased phosphorus (P) concentrations of bone ash compared to controls. Boron did not affect the fat-free ash percentage of the bone; therefore, the increase in bone ash P by B is not clear. One hypothesis to explain the increase in bone ash P by the physiological amounts of dietary boron may be possible that B will decrease the concentrations of other minerals, such as Mg, Cu, or Zn, in the bone ash.

The results of the present study showed that, femur bone copper concentrations were increased significantly in rat groups fed diets containing 5 and 10 mg B/100 g diet and then gradually decreased by increasing boron supplementation. The lowest concentration for femur bone copper was observed in rat groups fed diets supplemented with high doses of dietary boron (25, 30, and 35 mg B/100 g diet).

Zinc is an essential element for normal skeletal growth and development. Thus, significant changes in bone zinc concentration may reflect striking changes in bone characteristics [33]. The results of the present study showed that, tibia zinc concentration insignificantly reduced by increasing boron supplementation as in case of femur bone. ***Nielsen et al.***[33] found that 3 mg/kg boron supplementation reduced bone zinc concentration. ***Kurtoglu et al.***[34] concluded that both low plasma and tibia zinc concentration and conversely greater tibia boron and calcium concentrations of boron-supplemented chicks might be a characteristic of normal bone. The present results confirmed and agreed with the results of ***Armstrong et al.***[7] who postulated that fat-free ash percentage of the femur and the concentration of zinc were not affected by B supplementation.

The results of the present study showed that, the concentration of total lipids in femur bone were significantly reduced in rats fed diets supplemented with different doses of boron (5-35 mg B/100g diet) when compared with control group. Data also showed that tibia total lipids reduced significantly by increasing boron supplementation (20-35 mg B/100g diet). ***Armstrong and Spears***[6] indicated that the percentage of lipids of the femur was affected by B supplementation. In addition, ***Armstrong et al.***[11] demonstrated a response in bone lipid percentage and maximum bending moment in male pigs fed supplemental B, whereas the female pigs did not. The variation in response is due to the animals used were at two different physiological states[11].

In addition to its interaction with other nutrients, supplemental boron has been shown to increase bone strength. The results of the current study showed that boron supplementation affects bone mechanical properties significantly by increasing or decreasing the bending moment, moment of inertia, and stress of femur bone. ***Armstrong et al.***[7] found that supplemental B. increased measures of bone mechanical properties. The total applied force at the yield point and the bending moment at the yield point of the femur increased in B-supplemented gilts. Intrinsic strength of the femur was increased by B supplementation. Technically, bone strength is an intrinsic property of bone. Therefore, bone strength is independent on bone size or shape, and bone stress may be the best representation of bone strength [21]. Research in poultry[35,36] and rats [37] had demonstrated that B could increase the mechanical properties of bone. ***Nielsen*** [30] reported that boron supplementation increased femur strength measured by the breaking variable bending moment.

The results of the present study showed that, feeding diets supplemented with different doses of boron (5-35 mg B/100 g diet) had no effect on the values of bending moment of tibia bone, while, there was a significant decrease in the moment of inertia and significant increase in the mean values of tibia bone stress as the supplementation of boron increased. Results from human studies have also shown that dietary boron may be useful in preventing osteoporosis. The effects indicated that dietary boron might benefit calcium metabolism and help in the prevention of bone deterioration. The fact that adequate dietary levels of boron decreased serum calcitonin levels is important, because calcitonin has been shown to increase calcium loss in humans [28].

Findings to date suggest that boron and calcium actions are inter-related on that the two elements affect similar systems, including the modification of hormone action, the alteration of cell membrane characteristics and/or trans-membrane signaling. Boron appears to be a very important partner in calcium metabolism and consequently, it is expected to play an important role in the prevention of osteoporosis[38,39].

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التأثيرات الفسيولوجية للبورون الغذائى على معدلات النمو و قوة العظام في إناث الفئران

فارس خيري خليفه– نجوى ابراهيم يحيى حسنين –هاله صلاح عبد الفتاح
قسم الكيمياء الحيوية والتغذية– كلية البنات– جامعة عين شمس

يعتبر عنصر البورون من العناصر المعدنية النادرة التى يحتاجها الأنسان والحيوان والنبات . وهو هام للعظام وكذلك فى التمثيل الغذائي للمعادن ، كما أن البورون له دور فسيولوجي في تغذية الحيوانات. تهدف هذه الدراسة الى تقييم دور البورون المضاف للغذاء في صورة ملح بورات الصوديوم بجرعات (٥ ، ١٠، ١٥، ٣٠,٢٥,٢٠ و ٣٥ مجم/١٠٠جم من الغذاء) بالأضافة الى المجموعة الضابطة على: معدلات النمو، نسبة رماد العظام و تقدير قوة العظام في أناث الفئران٠ وقد أثبتت نتائج الدراسة أن أضافة البورون الى الغذاء بجرعات مختلفة تؤثر على كل من : أوزان فئران التجارب ، أوزان عظام الساق والفخذ ، كثافة العظام، الخواص الميكانيكية للعظام (القصور الذاتي و قوة تحمل العظام) ، محتوى العظام من الدهون و محتوى الرماد من المعادن (الكالسيوم ،الفوسفور الغير عضوي ، المغنيسيوم والنحاس) . كما أوضحت نتائج الدراسة أن إضافة جرعات البورون المختلفة لم تؤثرعلى المتناول من الغذاء ، طول عظام الفخذ والساق ، محتوى رماد العظام من الزنك وعزم أزدواج عظم الساق. كما أظهرت نتائج الدراسة ان هناك زيادة معنوية في قيم عزم أزدواج عظام الفخذ في الفئران المغذاة على الوجبات التي تحتوي على نسب مرتفعة من البورون بالمقارنه بالمجموعات المختبره الأخرى ذات القيم المنخفضه من البورون . وتشير نتائج الدراسة الى أن أضافة الجرعات الفسيولوجيه للبورون في صورة ملح بورات الصوديوم لها تأثيرات إيجابية ومفيدة لكل من التمثيل الغذائي للمعادن في العظام و كذلك الخصائص الميكانيكية للعظام .