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Research Article
Effects of Dietary Silicon Derived from Rice Hull Ash on the Meat Quality and Bone Breaking Strength of Broiler Chickens

Tossaporn Incharoen, Wandee Tartrakoon, Sarawoot Nakhon and Sarawut Treetan

Department of Agricultural Science, Faculty of Agriculture Natural Resources and Environment, Naresuan University, Phitsanulok 65000, Thailand

Abstract
Objective: The aim of the present study was to investigate the effects of dietary silicon derived from rice hull ash on the meat quality and bone breaking strength of broilers. **Methodology:** One hundred and sixty 10 days old Arbor Acres male broiler chicks were randomly divided into 4 dietary treatments, each with 4 replicates of 10 birds. Birds were fed the basal diet supplemented with silicon at 0 (control), 0.50, 0.75 and 1.00% until 42 days old. **Results:** No significant data on growth performance and carcass characteristics were observed among the dietary groups. However, the breast meat of broilers fed the dietary silicon presented a significantly lower ($p<0.05$) thawing loss compared with the control. In these dietary-silicon-fed birds, cooking loss for the breast sample tended to decrease and the 0.75% silicon group displayed a significantly lower value ($p<0.05$). The thigh meat showed the lowest thawing and cooking losses ($p<0.05$) in birds fed the dietary 0.75% silicon compared with other dietary groups. A significant difference in femur breaking strength was not found among treatments, but the strongest femur appeared in birds receiving the dietary 0.75% silicon. In addition, the tibia breaking strength of broilers fed the dietary 0.75% silicon resulted in the highest ($p<0.05$) value compared with other groups. This evidence implies that dietary silicon is associated positively with bone health. **Conclusion:** The current results suggest that dietary silicon can be used as a mineral additive to improve the meat and bone quality in broilers, particularly silicon at a level of 0.75% in broiler diets.

Key words: Bone breaking strength, broilers, dietary silicon, meat quality, rice hull ash

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Corresponding Author: Tossaporn Incharoen, Department of Agricultural Science, Faculty of Agriculture Natural Resources and Environment, Naresuan University, Phitsanulok 65000, Thailand Tel: +66-055-962-734

Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Silicon is an essential trace mineral for normal bone and cartilage growth and development[1]. Though it is normally present in all body tissues, the highest concentrations of silicon are understood to be related to the production and strength of bone and the connective tissues, including skin, hair, arteries and nails[2]. Some evidences suggest the involvement of silicon in the formation and/or stabilization of extracellular matrix as well as the Ca metabolism[2,3]. *In vitro* studies have described an effect of silicon on stimulating bone-forming osteoblasts[3-5]. It seems that silicon is associated with calcium in the early stages of biocalcification[6]. Indeed, *in vivo* studies have shown silicon-supplemented drinking water improved bone mineral density of tibia and femur[7] as well as increasing the femoral bone mineral content in aged rats[8]. Likewise, silicon supplementation in diet of ovariectomized rats increased bone mass and reduced bone turnover[9]. Concurring with these findings, Kim *et al.*[10] also observed the positive effects of silicon supplementation on bone mineral density in Ca-deficient rats by reducing bone resorption, resulting in osteoporosis prevention. According to the evidence accumulated over two decades has suggested that silicon increased bone formation and reduced bone resorption in the animal model[11]. Recently, there has also been increasing testimony indicating that silicon may have an important role in the normal health of bones and connective tissues[2,12-17].

In the broiler industry, bone problems have been accepted as one of the important factors seriously affecting animal health and resulting in economic loss. Fast-growing strains of broilers have manifested skeletal deformities such as leg weakness, resulting in lameness and consequently poor animal welfare[18]. Bone mineralization affects bone tissue strength, which enables the skeleton to withstand gravity and additional loading[19]. Thus, the mineral component of diets is one of the most analyzed parameters in investigating the cause of these bone problems. Primarily, it is the calcium and phosphorus contents in the diets that are evaluated; other trace minerals in diets have been overlooked, especially silicon. In Thailand, the main rice mill by-product is rice hull ash, which can be an economically viable raw material for the production of silicon. Previous research found that the addition of rice hull ash in broiler diets could improve meat quality and bone breaking strength. In the current study, rice hull ash was extracted and purified to obtain silicon. The final silicon product is mainly comprised of 96.15% SiO_2, 0.91% Na_2O and 0.60% K_2O. Therefore, we aim to investigate the effects of dietary silicon derived from rice hull ash on the meat quality and bone breaking strength of broiler chickens from 10-42 days of age.

MATERIALS AND METHODS

Preparation of silicon from rice hull ash: In this study, rice hull ash was obtained from the commercial milling process in Phitsanulok, Thailand and burned in an electric furnace at 700°C for 24 h. Sodium hydroxide solution (3.0 N) was added to the ash and boiled in covered flasks at 100°C for 3 h with constant stirring to produce a sodium silicate solution. The solutions were filtered through filter paper and the residues were washed with boiling water. The filtrates and washings were cooled down to room temperature and were titrated with 5.0 NH_2SO_4 by constantly stirring until pH 2. During this step, the solution started to precipitate and NH_4OH was added until pH 8. The slurry was filtered through filter paper and the filtrates were collected and dried in a hot-air oven at 120°C for 18 h to produce the silicon. Then, a dried sample was ground using an electric grinder and kept at room temperature until used in the feeding trial.

Animals and experiment design: A total of 200 day-old Arbor Acres male broiler chicks were purchased from a commercial hatchery (Charoen Pokphand Foods PCL., Lamphun, Thailand). All birds were reared in a brooding zone and promptly provided ad libitum access to water and a commercial starter diet. A 3-phase feeding program was applied, with a starter diet provided until 10 days old, a grower diet until 28 days old and a finisher diet until 42 days old. At 10 days of age, the chicks were individually weighed and 160 birds of uniform weight were randomly divided into 4 dietary treatments, each with 4 replicates of 10 birds. Dietary treatments comprised a basal diet (control), as shown in Table 1 and the 3 other diets which were identical to the basal diet in nutrient composition but were supplemented with silicon at 0.50, 0.75 and 1.00%, respectively. All diets were formulated to meet the requirements of all nutrients for broiler chickens (Arbor Acres broiler nutrition specifications) using FeedLIVE software (FeedLIVE 1.52, Thailand). The body weight and feed intake of each bird were recorded weekly until 42 days old. At the end of the experiment, 10 birds from each treatment were euthanized to measure carcass characteristics, meat quality and bone breaking strength. All animal procedures were approved by the Naresuan University Animal Care and Use Committee (NUACUC).

Sample preparations and evaluation: At the end of the experiment, the 10 broiler chickens from each group were

Table 1: Ingredients and chemical composition of the basal diets

Item	Grower	Finisher
Ingredients (%)		
Corn	30.00	30.00
Broken rice	35.70	40.70
Soybean meal (45% CP)	13.10	12.40
Plam oil	1.60	2.00
Fish meal (57% CP)	19.00	14.00
Dicalcium phosphate	0.10	0.40
Calcium carbonate	0.10	0.10
DL-methionine	0.20	0.20
Concentrate mixture[1]	0.20	0.20
Total	100.00	100.00
Analyzed chemical composition		
CP (%)	22.15	20.20
ME (kcal kg^{-1})	3140	3210
Crude fat (%)	5.12	5.61
Crude fiber (%)	4.60	4.82
Crude ash (%)	5.30	6.82

[1]Supplied per 100 kg of diet: vitamin A: 15,000,000 IU, vitamin D: 3,000,000 IU, vitamin E: 26,000 IU, vitamin K: 35 g, vitamin B1: 2.5 g, vitamin B2: 6.5 g, vitamin B6: 257.5 g, vitamin B12: 26 mg, pantothenic acid: 11.04 g, nicotinic acid: 35 g, folic acid: 1.2 g, biotin: 15.1 mg, choline chloride: 250 g, copper: 1.6 g, manganese: 60.2 g, iron: 1.6 g, zinc: 45 g, iodine:, 400 mg and selenium: 160 mg

slaughtered according to the NUACUC guidelines for animal procedures. Birds were weighed and euthanized by cutting the jugular veins. The carcasses were scalded in warm water (60±5°C), the feathers plucked and the birds washed and eviscerated. The carcass was left for 1 h to remove excess water before being weighed. Breast, wings, fillet, thighs and drumsticks were dissected and weighed individually.

Muscle (10 samples/treatment) from both sides of the breast and thigh were used to measure the meat quality. In the cooking loss determination, the raw meat samples, after being weighed and packed in cooking bags, were boiled in hot water at 100°C for 30 min. Afterwards, each sample was cooled down to room temperature and reweighed. Cooking loss was reported as the weight lost during cooking divided by the initial weight and expressed as a percentage. In the thawing loss measurement, the raw meat samples were weighed before being placed in a freezer at -21°C for 48 h. Then, frozen samples were thawed overnight in a commercial refrigerator at 4°C and reweighed. Thawing loss was reported as the weight lost during freezing divided by the initial weight and expressed as a percentage. In determining bone strength, the tibias and femurs from ten birds from each group were prepared after removing the remaining meat and drying in a hot oven overnight at 95°C. Bone breaking strength was measured using the universal testing machine (UTM) model 441 (Instron, Ltd., Buckinghamshire, England), according to the method proposed by Shim *et al.*[19].

Statistical analysis: Statistical analysis was performed with one-way analysis of variance (ANOVA) followed by Duncan's multiple range test. Differences between means were considered to be significant at p<0.05. All data are expressed in the form of Mean±SE.

RESULTS AND DISCUSSION

All data on the final body weight, weight gain, feed intake and feed conversion ratio (FCR) of broilers from 10-42 days old were not different among the dietary groups (Table 2). This suggests that the growth performance was unaffected by dietary silicon, which is partially in agreement with some researchers who used silicon-based supplementations in pig diets[20-22]. Similarly, Bintas *et al.*[23] found that there was no significant effect on the growth performance of broiler chickens fed the dietary silicon-based supplement. From these studies, authors may able to confirm that dietary silicon has no adverse effects on broiler performance. On the other hand, Tran *et al.*[24] found that dietary silicon had a positive effect on the weight gain and feed conversion of turkey, as well as decreasing the conversion of NH_4^+ to NH_3. Karamanlis *et al.*[25] demonstrated that the inclusion of the silicon-based clinoptilolite (67.54%) both in diet and into the litter had a positive effect on growth rate and also on the litter quality. Broiler chickens fed diets containing a silicon-based mineral also showed a higher growth rate compared with those of the control group[26,27]. Pasha *et al.*[28] reported that the addition of silicon-based clays in broiler diets might have increased feed retention time, enzymatic action and nutrient digestibility resulting in improved body weight gain. Besides, a concentrated mixture of more than 70% silicon was observed to have an improvement in the nutrient digestibility in growing-finishing pigs[22]. In addition, a mineral additive with 61.90% SiO_2 can have some antibacterial and antimycotic properties due to its three-dimensional structure and ion-exchange capacity[20].

The effects of dietary silicon on carcass characteristics, meat quality and bone breaking strength of broilers are shown in Table 3. No significant data on carcass characteristics were observed among the groups. However, the breast meat of broilers fed the dietary silicon presented a significantly lower (p<0.05) thawing loss compared with those fed the basal diet without silicon. Yu *et al.*[29] reported that higher thawing rates correlate with myofibrillar disruption. In these dietary silicon-fed birds, cooking loss for the breast sample tended to decrease and the 0.75% silicon group displayed a significantly lower value (p<0.05). The thigh meat showed the lowest thawing and cooking losses (p<0.05) in the birds fed the dietary 0.75% silicon compared with the other groups. Prvulovic *et al.*[30] also suggested that supplementation of

Table 2: Effects of dietary silicon on growth performance of broilers (Mean±SE)

	Dietary silicon (%)			
Item	0	0.5	0.75	1.00
Final body weight, gram per bird	2174±12.91*	2176±33.41	2113±12.65	2114±22.91
Weight gain, gram per bird	1957±12.82	1960±33.58	1897±12.69	1897±22.89
Feed intake, gram per bird	2999±39.53	2943±72.61	2880±25.90	2868±48.93
FCR	1.53±0.02	1.50±0.04	1.52±0.01	1.51±0.02

*p>0.05

Table 3: Effects of dietary silicon on carcass characteristics, meat quality and bone breaking strength of broilers (Mean±SE)

	Dietary silicon (%)			
Item	0	0.5	0.75	1.00
Carcass characteristics (%)				
Dressing without giblets	78.72±0.87	81.42±1.01	78.46±0.74	77.72±1.86
Breast	17.11±0.35	17.24±0.41	16.92±0.38	18.47±0.60
Fillet	3.67±0.10	3.67±0.10	3.53±0.03	3.70±0.09
Wings	8.99±0.84	9.09±0.91	8.43±0.78	8.65±0.73
Thighs+drumsticks	13.39±0.29	14.23±0.28	13.73±0.28	13.75±0.21
Breast meat quality (%)				
Thawing loss	10.14±0.34[a]	8.98±0.47[b]	6.45±0.32[bc]	8.11±0.23[b]
Cooking loss	12.12±0.21[a]	11.93±0.19[a]	9.87±0.34[b]	11.56±0.27[a]
Thigh meat quality (%)				
Thawing loss	6.21±0.20[b]	7.46±0.33[a]	5.85±0.27[b]	5.40±0.36[b]
Cooking loss	17.18±0.57[a]	16.81±0.60[a]	13.30±0.39[b]	17.62±0.45[a]
Bone breaking strength (kg)				
Tibia	44.24±2.39[b]	36.76±1.12[b]	52.27±1.62[a]	41.03±4.32[b]
Femur	34.29±3.12	31.11±1.88	38.62±2.74	29.80±1.86

[a-c]Mean values within a row having different superscript letters are significantly different by Duncan's multiple range test (p<0.05)

hydrated aluminosilicates affected the chemical composition of breast meat, especially the increasing protein content. Yan *et al.*[22] noted that mineral products with 72% SiO_2 have beneficial effects on muscle firmness might be due to its affection of the interaction or metabolism with those metal ions and consequently alter the mineral component in tissue. Thus, it is possible to suggest that the reduction of thawing and cooking losses observed in this experiment that are potentially due to the dietary silicon may have some positive impact on mineral component in tissue and consequently improve meat quality. However, no related reference is available to compare this effect. Further study is still necessary to investigate the effect of silicon derived from rice hull ash on the meat quality.

Significant differences in femur breaking strength were not found (p>0.05) among treatments, but the strongest femur appeared in birds that received the dietary 0.75% silicon. In addition, the tibia breaking strength of broilers fed the dietary 0.75% silicon resulted in the highest (p<0.05) value when compared with the other groups. Shim *et al.*[19] described that bone mineralization affects bone tissue strength, which enables the skeleton to withstand gravity and additional loading. The current data are similar to those of Short *et al.*[31], who also demonstrated that dietary silicon supplements had the ability to reduce lameness in broiler chickens. Moreover, dietary silicon-based supplement affected to Japanese quail long bone morphometry to a certain extent[32]. Some evidences suggest the involvement of silicon in the formation and/or stabilization of extracellular matrix as well as the Ca metabolism[2,3]. Kim *et al.*[10] also noted the positive effects of silicon supplementation on bone mineral density by reducing bone resorption, resulting in osteoporosis prevention when calcium intake is insufficient. Likewise, Jugdaohsingh *et al.*[2] noted that the highest concentrations of silicon related to the production and strength of bone and the connective tissues. Thus, our finding on bone breaking strength may suggest that dietary silicon derived from rice hull ash has a positive associations with bone health.

CONCLUSION

The authors can confirm that dietary silicon derived from rice hull ash has no adverse effect on the growth performance and carcass characteristics of broiler chickens. In addition, thawing and cooking losses tended to be reduced in dietary silicon-fed birds as well, the data for bone breaking strength were higher after providing dietary silicon. Overall, these results suggest that dietary silicon can be used as a mineral additive to improve the meat and bone quality, particularly silicon at a level of 0.75% in broiler diets.

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