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Research Article

Studies on Physical Characteristics, Mineral Composition and Nutritive Value of Bone Meal and Bone Char Produced from Inedible Cow Bones

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Abstract

Background and Objective: Bone meal and bone char produced from inedible cow bones could be an alternative renewable and low-cost dietary Phosphorous (P) source in poultry diets. This study aimed to evaluate the physical characteristics, mineral composition and nutritive value of bone meal and bone char meal produced from inedible cow bones derived from different body parts of the animal. **Materials and Methods:** A field survey was carried out to collect data on inedible bones taken from 30 slaughtered cows at sites involved in three meat processing steps: Slaughter house, local meat shops and beef offal processors. Samples of inedible bones grouped into three body parts: Head, ribs and legs were collected and processed into bone meal and bone char meal by soaking in lime water and open-air burning, respectively. The nutritive values of the bone meals were also evaluated by mixing 3% bone meal and bone char with a basal diet that was fed to 150 laying quails. Parameters measured included: Inedible bone weight, percentage of meal yield, content of crude ash and minerals (Ca, P, Fe, Zn, Mn and Cu), physical properties and particle size distribution, egg production, egg shell quality, digestibility and tibia bone mass and mineralization. **Results:** Present study showed that on average inedible bones represented 13.8 kg/animal or 3.4% b.wt., that could be used to produce bone meal. Percentage of meal yield for bone meal (91.4%) was significantly higher ($p<0.01$) than bone char processed by open-air burning (67.3%). However, crude ash, Ca and P content of bone char meal were significantly higher ($p<0.05$) than that for bone meal. Bone char produced a higher response angle due to a higher percentage of small-sized particles ($p<0.05$). There was no significant effect of bone origin (i.e., head, rib and leg) on meal yields, mineral composition or particle sizes. Supplementation of diets with bone char yielded better quail egg shell quality, mineral digestibility and bone weight than that for bone meal. **Conclusion:** Production of bone char meal by open-air burning gave lower meal yield but higher essential mineral concentrations and better nutritive values than that of bone meal.

Key words: Inedible bones, bone meal, bone char meal

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

INTRODUCTION

Calcium (Ca) and Phosphorus (P) are two minerals that are normally included in dietary formulations for livestock animals due to their important roles in various body functions and in metabolism. The Indonesian province of West Sumatra has abundant Ca sources, including rock flour, limestone and oyster shells[1,2] but there are no natural feed sources for P. The use of local Ca sources in poultry diets in this region is thus restricted and has no significant positive effects on egg production, egg quality, growth rate and feed utilization efficiency, presumably due to the limited P concentration in these materials[3-6].

Proper use of Ca is affected not only by the source and concentration but also by the ratio between Ca and P. The optimum Ca:P ratio is about 1.5-2:1[7]. Phosphorus accounts for over 25% of total body mineral matter and is second only to Ca[8]. A marginal P supply in chicken feed may have negative effects on performance, health and bone development, particularly because, next to Ca, P is one of the most important minerals for the formation of bone tissue. The orthophosphate form (PO_4^{3-}) of P plays a key role in numerous metabolic reactions and in poultry P is needed for normal tissue growth and egg formation. The P is a critical component of nucleic acids and phospholipids as well as an activator of enzyme systems. Phosphorus also aids in maintaining osmotic and acid-base balance and is important for energy metabolism (ATP), amino acid metabolism and protein synthesis[9,10].

Most poultry diets are primarily composed of plant-based ingredients. In plants, most P is present as phytic acids and its salts. Since phytic acid P is only partly available to poultry (0-50%), inorganic P must be added to the diet to meet the P needs of the bird. The use of commercial dicalcium phosphate for use as a primary dietary P source must be imported and thus is extremely expensive. Moreover, the extensive use of non-renewable resources such as phosphate rock to produce P for poultry diets has led to excessive P excretion and environmental pollution[9]. Bone meal could be an alternative renewable and low-cost dietary P source. Cow bones are composed of 65-70% of inorganic substances, mainly hydroxyapatite ($Ca_{10}(PO_4)_6(OH)_2$)[11]. The contents of Ca and P of bone meal are 19.3 and 9.39% respectively and are present at a 2:1 ratio, which is an optimal proportion for body absorption[12].

Bone meal could be locally produced from inedible cattle bone as a byproduct of slaughter house activity that occurs throughout the provincial areas of Indonesia. In 2012, 123,203 large ruminants (109,836 and 13,367 head of cattle and buffalo, respectively) were slaughtered in the province of West Sumatra[13]. With an average body weight of 400 kg/head and 15% of carcass weight attributed to bones[14], an estimated 10 t of fresh cattle bones per day are produced in West Sumatra. Bones are slaughter house byproducts that cannot be sold as meat or used in meat-products. The quantity of inedible bones may vary according to the type and body size of the slaughtered animal[15]. Currently, inedible bones are underutilized and often create disposal problems and environmental concerns. The use of inedible bones for livestock feed could serve as an additional revenue source for meat packers and butchers and could in turn reduce environmental pollution.

A widely applied method for producing bone meal from animal bones is steaming with boiling water and soaking in lime water[12]. Intact fresh bones can be crushed into chips, boiled and soaked in lime water to remove fat, meat and other soft tissues as well as to reduce odor. The clean and dry bone chips can then be ground to produce bone meal. Dried bone chips can also be burned to produce bone charcoal meal (bone char) that has increased mineral concentration. The bone charring process is simple and the production of bone char could likely be undertaken by local poultry farmers. Bones consist of about 30 and 70% organic and inorganic compounds respectively[16], whereas bone char contains about 22% Ca and 13% P and has a higher Ca:P ratio (1.7:1) than that of bone meal[17]. Converting dry bone chips to bone char also has many other advantages. First, thermal processing can eliminate unpleasant odors and kill pathogens that induce botulism, foot and mouth disease and other conditions that can be transmitted from inadequately processed bone meal. Raw material and processing methods for bone meal and bone char affect the meal yield rate, physical properties and mineral composition of the products and consequently, their nutritive values. This study aimed to investigate the potential availability of inedible bones as a nutrition source and measured physical characteristics and mineral composition of bone meal produced from cow bones from different body parts using open-air burning or lime water soaking processes. Nutritive value of supplemental bone meal as a mineral source in diets for laying quail was also evaluated.

MATERIALS AND METHODS

Survey of inedible bone availability: This study was initiated with a field survey to collect data for inedible bones that could be used to produce bone meal in Payakumbuh city, a center of beef cattle production in West Sumatra, Indonesia. Thirty slaughtered cows were observed at three different steps of meat processing: Slaughter house, local butcher (meat) shops and a beef offal processor located in Payakumbuh. The animals were divided into three groups of 10 that each had a different body weight: Small (<400 kg), medium (400-500 kg) and heavy (>500 kg/head). The age of the cattle ranged between 3.9 and 4.6 years.

Data collected included: Live weight, age and inedible bone weight. The age of slaughtered animals was estimated through dentition[18]. Live weights were measured by Shaffer's formula[19]:

$$W = \frac{L \times G^2}{300\ \text{lb}}$$

where, W is animal weight in pounds, L is length from the point of the shoulder to the pin bone in inches and G is heart girth in inches.

The weight in lb was divided by 2.2 to convert values to kg. The inedible bones were grouped into four body parts: Mandibles and skulls, shoulder blades, ribs and fore and back legs. The weight of various inedible bones was measured in kilograms and recorded in previously prepared data collection sheets.

Bone sampling and processing: During the survey, inedible bone samples were collected and put into labeled plastic bags for further processing and analysis. The samples were grouped into three different body parts: Head, ribs and legs. Fresh bone samples for each body part were washed and then boiled in a pressure cooker for about 4 h to remove fat, muscle and soft tissues. The boiled bones were washed and the cleaned bones were dried in the sun. The sun-dried samples were then crushed to chips with a uniform length of 2-3 cm. The bone chips were mixed, soaked for 5 days in 10% lime water and then dried in an oven at 60°C for 48 h. The dried bone chips (12 kg/body part) were divided into six sub-groups of about 2 kg each to yield 18 U that consisted of 3 body parts with 2 processing methods and 3 samples as replicates.

The first three samples of each body part were then directly ground into a coarse meal form to produce bone meal. The other three samples were subjected to open-air burning, referred to as bone charring, according to the method described by Lurtwitayapont and Srisatit[17]. The bone samples were burned at 150°C for 3 h on a metal plate until the smoke disappeared. The samples were then cooled and manually ground with a mortar to produce bone char meal. The meal yield was calculated by dividing the total weight of clean and dry intact bones by the weight of bone meal and then multiplied by 100.

Mineral analysis: The meal was passed through a sieve with No. 60 mesh prior to analysis of crude ash, dry matter (DM) and mineral (Ca, P, Fe, Cu, Mn and Zn) content. The DM and crude ash were determined using proximate analysis procedures described by the Association of Analytical Communities[20]. Samples for mineral analysis were prepared by wet digestion using concentrated sulfuric acid and hydrogen peroxide. The concentration of minerals was determined using an atomic absorption spectrophotometer[21]. All results were reported with respect to DM values.

Physical properties and particle size measurement: The physical properties measured included angle of response, bulk density, compacted bulk density and particle size. The color of the end products was also observed. Angle of response is the angle formed by stacks of poured feed with horizontal surfaces and is expressed as degree (°). Bulk density is the ratio of sample weight to the volume occupied by the sample, whereas compacted bulk density is the ratio of sample weight to the volume occupied after compaction. The physical properties were determined according to the method described by Ruttloff[22].

Particle size distribution of the bone meal was determined by sieve analysis. About 300 g sample was first dried in an oven for 24 h. The dried samples were then sieved for 10 min using a set of sieves with discrete mesh sizes ranging from 0.02-4.7 mm. The fraction retained in the sieve was weighed and the percentage of each particle size was then calculated by dividing the weight of the retained fraction by the total sample weight and multiplying by 100. The cumulative percentage of the retained fraction in the sieve was no. n of the sum of retained sample percentages relative to -n.

Feeding trial: A feeding trial was conducted at the Poultry Farm of the Faculty of Animal Husbandry, Andalas University, which is located in Limau Manis, Padang. Bone meal and bone char were mixed with a basal diet to an amount of 3%. As a control, another diet was mixed with limestone from Bukit Kamang, so that there were in total three experimental diets. The basal diets were prepared using three main components of commercial layer concentrate, corn and rice bran at 44, 43 and 5.5%, respectively, which is in compliance with typical mineral levels used by quail farmers in West Sumatra. The formulation of the experimental diets as well as the nutrient and energy contents are shown in Table 1. The nutrient and energy compositions that were calculated based on chemical analysis of the feed components were normalized

Table 1: Feed components, crude nutrient composition and energy concentration of experimental diets

	Mineral source for experimental diets		
Parameters	Control (T0)	Bone meal (T1)	Bone char (T2)
Feed component (%)			
Layer concentrate 126	44.0	44.0	44.0
Yellow corn	43.0	43.0	43.0
Rice bran	5.5	5.5	5.5
Limestone meal	5.0	2.0	2.0
Bone meal	-	3.0	-
Bone char	-	-	3.0
Coconut oil	2.0	2.0	2.0
Premix[1]	0.5	0.5	0.5
Total	100.0	100.0	100.0
Calculated nutrient and energy compositions			
Crude protein (%)	19.62	19.62	19.62
Crude fiber (%)	5.31	5.31	5.31
Crude fat (%)	6.95	6.95	6.95
Ca (%)	3.66	3.63	3.55
Total P (%)	0.73	0.97	0.97
Available P (%)	0.57	0.76	0.77
ME (kcal kg^{-1})	2573.40	2573.40	2573.40

[1]Supplied per kilogram of diet: Vitamin A 10,000 IU, cholecalciferol 2,000 IU, vitamin E 10 mg, vitamin K3 2 mg, thiamine 1 mg, riboflavin 5 mg, pyridoxine 2 mg, vitamin B12 0.0154 mg, niacin125 mg, calcium pantothenate 10 mg, folic acid 0.25 mg, biotin 0.02 mg, BHT 30 mg, selenium 0.1 mg, iron 40 mg, copper 12 mg, zinc 120 mg, manganese 100 mg, iodine 2.5 mg, cobalt 0.75 mg, Ca: Calcium, P: Phosphorus

to the standard requirements of laying quail during the production period as recommended by the NRC[23].

A total of 150 laying quail, aged 6-7 weeks and having an average body weight of 147.8±14.4 g/bird were fed the experimental diets for 6 weeks. The quails were divided into three groups in accordance with the number of treatments. Each group, consisting of 50 birds, was subdivided into 5 subgroups (10 birds each), so that each treatment consisted of 5 groups as replicates and each replication had 10 birds. The birds were randomly placed in individual battery cages that were equipped with feed and drinking water troughs. The feeding trial was started by about 20% of quail-day egg production. Parameters measured included: Egg production, egg shell quality, mineral digestibility and mineralization of tibia bones.

Statistical analysis: Data on meal yield, mineral composition and bone product particle size distribution were analyzed using two-way analysis of variance (ANOVA). Data concerning the availability of inedible bones were analyzed in a completely randomized design with 3 different body weights and 10 animals each as replicates. Data on meal yield, physical properties, crude ash content, mineral composition and bone product particle size distribution were analyzed in a completely factorial design of 2×3×3. There were 2 processing methods, 3 different bone retrieval sites and 3 replications. Data for the feeding trials were also analyzed using a completely randomized design with 3 diets and 5 groups of laying quail (at 10 birds) as replicates. Duncan's Multiple Range Test (DMRT) was applied to separate means. Differences were considered significant at $p<0.05$[24].

RESULTS AND DISCUSSION

Availability, meal yield and physical properties of inedible bones: Among the animals in this study, the average total weight of inedible bones accounted for 13.8 kg/animal or 3.35% of body weight (Table 2). Neither body weight nor age significantly affected inedible bone proportion but increased weight was associated with increased weights of inedible bones, which is consistent with the findings of Hasan *et al.*[25]. As the overall body weight increased from 340-552 kg/head, the inedible bone weight increased from 12.1-16.0 kg/head, whereas the percentage decreased from 3.6-2.9%. The largest proportion of inedible bone came from mandibles and skulls (4.9 kg/head), followed by fore and back legs (3.9 kg/head) and ribs (3.7 kg/head), while shoulder blades were present in the smallest quantity (1.1 kg/head) (Table 2).

Bone meal had a light yellow white to white color, whereas bone char was largely dark brown likely because of increased oxygen availability[26] and charring temperature (Table 3). Bone char is reported to change in color from black to grey to white upon increasing the temperature from 350-600°C[27,28]. According to Dahi[26], upon heating organic material can be converted to inorganic carbon (graphite), which has a black color.

Table 2: Availability of inedible bone from slaughtered cows of different body weights

	Body weight			
Parameters	<400	400-500	>500	Mean
Body weight (kg/head)	340.11 (12.41)^{c}	439.57 (7.53)^{b}	552.34 (24.12)^{a}	410.19 (17.68)
Age (years)	4.00 (0.31)	4.61 (0.44)	3.93 (0.62)	4.17 (0.24)
Inedible bone				
Total weight (kg/head)	12.10 (0.44)	14.71 (0.53)	15.98 (1.12)	13.79 (0.47)
Body weight (%)	3.58 (0.09)	3.35 (0.13)	2.90 (0.19)	3.35 (0.09)
Inedible bone source (kg/head)				
Mandibles and skulls	4.55 (0.16)	5.02 (0.30)	5.46 (0.22)	4.91 (0.14)
Shoulder blades	0.98 (0.08)	1.14 (0.02)	1.29 (0.09)	1.10 (0.05)
Ribs	3.19 (0.20)	4.42 (0.27)	4.49 (0.73)	3.86 (0.23)
Fore and back legs	3.38 (0.13)	4.12 (0.17)	4.74 (0.28)	3.92 (0.14)

$^{a-c}$Values in the same row with different superscripts are significantly different (p<0.05)

Table 3: Meal yield (%), physical properties and particle size of bone meal and bone char produced from inedible cow bones from different body parts

	Bone meal				Bone char			
Parameters	Head	Leg	Rib	Mean	Head	Leg	Rip	Mean
Meal yield (%)	91.88 (0.79)^{a}	92.14 (1.52)^{a}	90.31 (1.33)^{a}	91.44 (1.18)^{A}	71.72 (0.61)^{b}	64.55 (0.73)^{b}	65.51 (0.76)^{b}	67.26 (0.65)^{B}
Physical properties								
Bulk density (g mL^{-1})	0.99 (0.00)	0.75 (0.01)	0.84 (0.01)	0.86 (0.00)	0.94 (0.01)	0.85 (0.02)	0.88 (0.01)	0.89 (0.01)
Compacted bulk density (g mL^{-1})	11.70 (0.85)	23.67 (0.44)	16.00 (0.58)	17.12 (0.52)	15.50 (0.29)	16.67 (0.33)	15.33 (0.44)	15.83 (0.10)
Angle of response (°)	43.46 (0.79)^{b}	44.83 (0.17)^{b}	45.31 (0.66)^{b}	44.53 (0.12)^{B}	49.94 (0.41)^{a}	50.48 (0.35)^{a}	51.14 (0.22)^{a}	50.52 (0.23)^{A}
Proportion of particle size (%)								
Fine ($\leq$0.30 mm)	32.80 (4.45)^{b}	23.54 (1.68)^{b}	29.28 (0.07)^{b}	28.54 (1.63)^{B}	50.40 (0.59)^{a}	52.02 (1.04)^{a}	54.03 (1.24)^{a}	52.15 (0.18)^{A}
Medium (0.30<x$\leq$0.60 mm)	26.22 (1.32)^{a}	31.15 (1.19)^{a}	25.16 (0.47)^{a}	27.51 (0.45)^{A}	17.6 (0.40)^{b}	16.60 (1.04)^{b}	16.93 (0.22)^{b}	17.05 (0.35)^{B}
Coarse (>0.60 mm)	40.98 (5.80)^{a}	45.31 (0.52)^{a}	45.56 (0.54)^{a}	43.95 (1.92)^{A}	31.97 (0.44)^{b}	31.38 (1.51)^{b}	29.03 (1.02)^{b}	30.80 (0.30)^{B}

^{a,b}Values in the same row with different superscripts are significantly different (p<0.05), ^{A,B}Values with different superscripts are significantly different (p<0.05) between mean

There was no significant effect of body parts from which the bones originated on meal yields (Table 4). In total, the bones consisted of about 30% organic matter[16]. The average meal yield of bone char was 67.3%, which was significantly lower (p<0.01) than that for bone meal (91.4%) and is likely due to loss of organic materials after open-air burning. Bone char showed a significantly lower crude ash content (66.4%) compared to that of bone meal (85.8%) (Table 4). The decline in crude ash content could be due to combustion of most organic substance and release as carbon dioxide during the charring process[26].

Bulk density and compacted bulk density of bone meal and bone char ranged from 0.75-0.99 and 11.7-23.7 g mL^{-1}, respectively and did not differ significantly (Table 3). However, bone meal had a significantly (p<0.05) lower angle of response (44.5°) compared to bone char (50.5°) (Table 3). The angle of response indicates the degree of freedom that particles have to move in the stack and the flow characteristics of feed. A lower angle of response is associated with better flow and hence is important for efficient bulk material handling, mixing and automatic weighing. A smaller particle size combined with a coarse surface produces a higher angle of response. Bone char had a significantly higher percentage of small particles ($\leq$0.300 mm) due to its fragile structure, while the larger sizes had irregular shapes and coarser surfaces compared to bone meal and in turn bone char had a significantly higher angle of response (Table 3, Fig. 1).

Mineral composition and quail laying performances: Bone meal produced by soaking in lime water showed a significantly lower content of Ca and P (Ca: 26.7%, P: 1.8%) than that of bone char (Ca: 33.9%, P: 7.9%) (Table 4). Bone meal had an average P content of 1.8%, which was much lower than that of bone char produced by open-air burning (7.9%). Phosphorus content of bone meal was also significantly affected by the site of bone origin. Bone meal produced from rib and head bones had a considerably low P concentration (p<0.05) (rib: 0.36%, head: 0.43%) compared to that of leg bones (4.5%). Meanwhile, the Ca content of bone meal obtained in this study was similar to, whereas the P content was much lower than the values reported by Klock and Taber[29].

The average P content of bone char (7.9%) and bone meal (1.8%) in the present study was much lower than that reported by Kling and Wohlbier[12] (14 and 19% for meal and

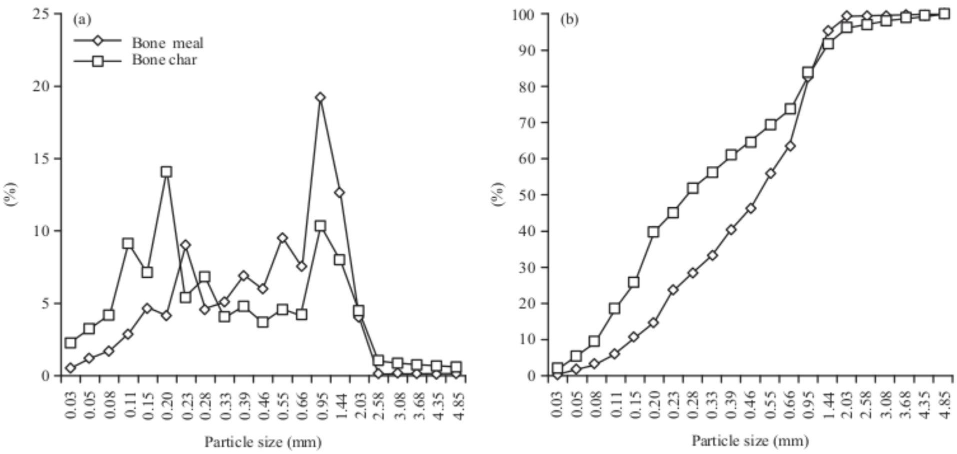

Fig. 1(a-b): Distribution of particle size in bone meal and bone char produced from inedible cow bones (a) Percentage of each particle size and (b) Cumulative percentage

Table 4: Mineral composition and crude ash content of bone meal and bone char produced from inedible cow bones from different body parts

	Bone meal				Bone char			
Parameters	Head	Leg	Rib	Mean	Head	Arm	Rib	Mean
Minerals (g kg^{-1} DM)								
Ca	29.27 (0.49)^{b}	27.95 (1.33)^{b}	27.95 (1.33)^{b}	26.68 (1.37)^{B}	32.43 (2.47)^{a}	34.71 (0.34)^{a}	34.43 (0.09)^{a}	33.86 (0.77)^{A}
P	0.43 (0.12)^{c}	4.52 (0.43)^{b}	0.36 (0.13)^{b}	1.77 (0.19)^{B}	7.75 (0.52)^{a}	8.06 (0.17)^{a}	7.86 (0.09)^{a}	7.89 (0.23)^{A}
Trace minerals (mg kg^{-1} DM)								
Fe (mg kg^{-1} DM)	34.61 (6.10)	33.84 (2.22)	42.53 (7.27)	36.99 (4.63)	45.38 (3.97)	43.12 (7.81)	48.81 (6.54)	45.77 (5.12)
Zn (mg kg^{-1} DM)	6.52 (0.26)	5.80 (0.05)	6.41 (0.10)	6.24 (0.11)	6.72 (0.34)	8.07 (0.11)	7.77 (0.12)	7.52 (0.18)
Mn (mg kg^{-1} DM)	2.07 (0.49)	0.39 (0.35)	0.26 (0.07)	0.91 (0.28)	2.17 (0.67)	0.78 (0.24)	0.38 (0.13)	1.11 (0.27)
Cu (mg kg^{-1} DM)	0.11 (0.03)	0.21 (0.03)	0.05 (0.00)	0.12 (0.01)	0.15 (0.03)	0.50 (0.11)	0.17 (0.02)	0.28 (0.05)
Crude ash (% DM)	72.69 (1.09)^{b}	64.37 (0.96)^{b}	62.07 (2.96)^{b}	6[illegible].38 (1.01)^{B}	87.05 (0.65)^{a}	85.76 (1.36)^{a}	84.72 (0.95)^{a}	85.85 (0.47)^{A}

Ca: Calcium, P: Phosphorus, Fe: Iron, Zn: Zinc, Mn: Manganese, Cu: Copper, $^{a-c}$Values in the same row with different superscripts are significantly different (p<0.05), ^{AB}Values with different superscripts are significantly different (p<0.05) between mean

char, respectively). Meanwhile, Warren *et al.*[30] showed that bone char produced from animal bone chips subjected to pyrolysis at about 600°C contains 10-15% P (w/w).

Bone char is composed mainly of bone minerals, i.e., compounds derived from hydroxyapatite ($Ca_{10}(PO_4)_6(OH)_2$) and small amounts of calcite ($CaCO_3$)[31]. Gulyas *et al.*[32] reported that bone char contained about 30% Ca, 13.3% P and 6% Mg, whereas, Rugayah *et al.*[33] reported that bone char produced from bones obtained from cattle in Indonesia contains 29.5% Ca, 18.1% P and 1.2% carbon.

Bone char also had a higher concentration of trace minerals (Fe, Zn, Mn and Cu) relative to bone meal but there was no significant difference because of high variation among the data. The Fe had the highest concentration at 33.8-48.8 mg kg^{-1} DM. The Zn concentration in bone products ranged between 5.5 and 8.1 mg kg^{-1} DM, which is a much lower value than that observed by Klock and Taber (130 ppm)[29]. However, the Fe, Mn and Cu contents of bone char obtained in this study are comparable to that of Gulyas *et al.*[32], who reported that bone char used for plant fertilizer contained 63 mg kg^{-1} Fe, 1 mg kg^{-1} Mn and 5 mg kg^{-1} Cu. Similar to the Klock and Taber[29] study, the value of Zn found by Gulyas *et al.*[32] was 152 mg kg^{-1} and was higher than the values we determined (Table 4). These data demonstrated that bone char had a higher quality than bone meal in terms of the concentration of essential nutrients such as trace minerals. However, based on NRC recommendations for quail[23], the Cu, Mn, Se and Zn levels in both bone meal and bone char products are still insufficient.

Concerning the effect of dietary supplementation with bone products on quail productivity, quail fed diets containing bone meal (T1) or bone char (T2) had similar egg mass and percentage of quail-day egg production compared to the control diet (T0) containing only limestone (Table 5). However, supplementation with bone meal or bone char had a positive effect on egg shells, mineral digestibility and tibia bone mass and crude ash content (Table 5). The egg shell thickness was significantly improved (p<0.05) by supplementing quail diets

Table 5: Egg production, egg shell quality, mineral digestibility and weight and mineral composition of tibia bones from layer quail fed diets supplemented with bone meal or bone char

	Experimental diets with mineral sources		
Parameters	Control (T0)	Bone meal (T1)	Bone char (T2)
Egg production			
Egg production (egg/bird)	28.51 (3.21)	28.64 (1.66)	28.03 (1.53)
Egg production (g/bird)	304.06 (43.22)	308.48 (17.94)	305.75 (10.85)
Quail-day egg production (%)	67.87 (7.65)	68.18 (3.94)	66.75 (3.63)
Egg shell quality			
Egg weight (g/egg)	10.68 (0.24)	10.70 (0.06)	10.80 (0.07)
Egg shell weight (g/egg)	0.79 (0.03)	0.78 (0.00)	0.81 (0.02)
Egg shell thickness (mm)	0.28 (0.00)^{b}	0.33 (0.00)^{a}	0.31 (0.00)^{a}
Digestibility (%)			
Crude ash	23.33 (4.71)^{b}	25.23 (2.93)^{b}	37.86 (3.43)^{a}
Ca	21.59 (7.05)^{b}	29.36 (2.94)^{b}	45.65 (4.96)^{a}
P	49.46 (4.99)	33.76 (5.44)	51.65 (13.20)
Tibia bones			
Dry weight (g/bird)	0.63 (0.05)	0.69 (0.02)	0.74 (0.04)
Crude ash (% DM)	55.42 (1.32)	57.62 (1.07)	58.73 (3.81)
Ca (% DM)	16.79 (1.54)	20.10 (0.09)	18.44 (0.54)
P (% DM)	7.96 (0.69)	9.51 (0.51)	8.85 (0.52)

Ca: Calcium, P: Phosphorus, ^{a,b}Values in the same row with different superscripts are significantly different ($p<0.05$)

with bone meal or bone char. This improved shell thickness could be associated with the significant increase in crude ash and Ca digestibility in the supplemented diets (Table 5). The better digestibility of crude ash and Ca may have also increased tibia bone mass and mineralization, which is consistent with the findings of Li *et al.*[9] who reported that Ca is an essential element for bone and egg shell formation.

Even though the difference was not statistically significant, quail fed diets supplemented with bone char produced heavier egg shells and had higher dry tibia bones mass as well as better digestibility of crude ash (Table 5). In general, the results indicated that bone char had a higher nutritive value and greater potential as a natural source of P in local feed fortification. There are only a limited number of studies on the use of bone char as a mineral source in feed. Instead, more attention has been given to the application of animal bones for production of bone char that could be used for removing heavy metals from aqueous solutions[34-36], decolorizing palm oil[37] and for plant fertilizer manufacture[30,32].

CONCLUSION

It is concluded that inedible cow bones in this study represented 3.35% of total body weight and mainly originated from mandibles, skulls, legs and ribs. Cattle with higher body weights tended to produce higher weights of inedible bones. These inedible bones could be processed into bone meal and bone char with an average meal yield of 91.4 and 67.3%, respectively. Supplementation of feed for laying quail with bone meal and bone char resulted in better egg shell quality, greater mineral retention and higher tibia bone mass relative to quail fed the unsupplemented diet. Although the charring process reduced meal yields, bone char contained a higher concentration of essential minerals and tended to have better nutritive values than bone meal. Bone char was therefore a better source of P compared to bone meal for fortification of local mineral poultry feed in West Sumatra, Indonesia.

SIGNIFICANCE STATEMENTS

This study examined the potency of underutilized inedible cow bones to produce bone meal and bone char meal as a renewable dietary P source. This study will help optimize the local use of available Ca sources for poultry diets, which can in turn minimize the use of imported feed.

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