ISSN 1682-8356
ansinet.org/ijps

INTERNATIONAL JOURNAL OF

POULTRY SCIENCE

ANSInet
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan
Mob: +92 300 3008585, Fax: +92 41 8815544
E-mail: editorijps@gmail.com

International Journal of Poultry Science 11 (5): 316-325, 2012
ISSN 1682-8356

Dual Energy X-Ray Absorptiometry Analysis of Broiler Breeder Eggs for Prediction of Egg Components and Evaluation of Egg Shell Quality

J.A. England[1], C. Salas[2], R.D. Ekmay[3] and C.N. Coon[1]
[1]University of Arkansas, Center of Excellence for Poultry Science, Fayetteville, Arkansas 72701, USA
[2]Universidad de Costa Rica, Escuela de Zootecnia, San Jose, Cost Rica
[3]Department of Animal Science, Cornell University, Ithaca, NY, USA

Abstract: Most methods for evaluating shell quality and egg components are destructive and time consuming. Four trials were conducted to investigate the use of Dual Energy X-ray Absorptiometry (DXA) as a fast and non-destructive method for evaluating shell quality and measuring the components of broiler breeder eggs. In Trial 1, 180 eggs were scanned with a GE Lunar Prodigy DXA. The eggs were also evaluated by traditional methods that required breaking the eggs for shell quality evaluation and egg components (shell, albumen and yolk) weighed. Values obtained from the DXA scans were subjected to stepwise regression analysis to develop prediction equations. Prediction equations were developed for the weight of egg components (egg, yolk, albumen and shell) and parameters of shell quality (shell weight, thickness and calcium content). In Trial 1, the r^2 values for the prediction equations using DXA values were 0.9961, 0.9692, 0.9843, 0.6891, 0.8499 and 0.5738 for the total egg weight, shell weight, shell calcium content, shell thickness, albumen weight and yolk weight, respectively (P>F, <0.0001). In Trial 2, 180 eggs were scanned to validate the prediction equations developed in Trial 1. Results from Trial 2 indicate that the prediction equations using DXA values are an effective method for predicting total egg weight, shell weight, shell calcium content, shell thickness, albumen weight and yolk weight (P>F, <0.0001). In Trial 3, 250 hatching eggs were scanned to determine the affect of scanning on hatchability. DXA scanning had no negative effect on hatchability, hatch chick weight or hatch residue breakout. In Trial 4, the specific gravity of 400 hatching eggs was determined by flotation in salt solutions. The eggs were then scanned with the DXA and values obtained from these scans were used to calculate SWUSA and shell:egg weight ratios. The SWUSA and shell:egg weight ratios determined by DXA scan were useful in predicting eggshell quality and correlated closely with actual specific gravity values ($r = 0.7849$, $p<0.0001$). A SWUSA of 75.1 and specific gravity of 1.081 corresponded to a shell:egg weight ratio of 0.0895 and 0.0924, respectively. Following the evaluation of egg shell quality by DXA and specific gravity, the 400 eggs were incubated to determine hatchability. Shell:egg weight ratios less than 0.0895 significantly increased the number of early dead ($p = 0.02$) during the hatchability study. By defining the scan area it is possible to scan and analyze 140 eggs per hour for all egg components and shell quality. DXA offers the primary breeder or researcher a method for selecting individual hens, based on egg component and shell quality profiles, which may improve the performance of the progeny.

Key words: Dual energy x-ray absorptiometry, egg shell quality, egg components, calcium, shell thickness, albumen, yolk

INTRODUCTION

The eggshell is an amazing thing and has many functions whether the egg is destined for the incubator or table. The eggshell functions as a container with many properties, to control moisture loss, gas exchange and as a barrier to microbial invasion. The mineralization of the eggshell plays a role in eggshell strength and its' ability to resist breaking. Shells must be strong, but still allow the hatching chick to break it. The yolk and albumen are no less amazing in providing nutrition for the developing embryo or human consumption. In quantifying the components of the egg, the traditional methods of evaluating shell quality and egg components are time consuming and destroy the egg. A quick and non-destructive method for evaluating the egg would have advantages to the researcher and primary breeder.

Hunton (2005) in a review of research on eggshell structure and quality made the statement that identifying certain hens or families of hens within foundation lines used for egg layers with improved shell quality would be of value to the primary breeder. Hunton (2005) said this

Corresponding Author: C.N. Coon, University of Arkansas, Center of Excellence for Poultry Science, Fayetteville, Arkansas 72701

must be done recognizing that the hen's primary goal is producing a shell with the primary purpose of protecting the developing embryo.

The developing embryo is totally dependent on the package of micro and macronutrients that the hen puts in the egg. These nutrients are supplies from three different compartments, shell, yolk and albumen. Wolanski *et al*. (2007) reported a strong correlation in hatched chick weight to yolk and albumen weights. Vieira and Moran (1998) reported that the portion of the egg that is yolk or albumen is influenced by the age of the hen and Peebles *et al*. (2000) found that the age of the broiler breeder hen affects the yolk: albumen ratio.

Uni *et al*. (2012) noted that the nutrient utilization of the macronutrients and micronutrients available from the yolk and albumen varied according to the day of embryonic development. Uni *et al*. (2012) also noted that the composition of the yolk depends on the egg weight, genetic strain and hen age. In would be of value to the primary breeder to quickly identify individual hens or lines of hens with different proportions of yolk to albumen that would have impact on the progeny. Many accurate methods have been used to evaluate the component parts of an egg and egg shell quality. To determine egg component parts (yolk, albumen and shell), traditional methods require breaking the egg and weighing the individual parts. Shell quality may be evaluated many different ways by determining visual defects, shell shape (calipers), shell weight (g scale), shell thickness (micrometer), breaking strength (strain gauge) and chemical analysis of the shell.

Egg specific gravity is often used as an indirect non-destructive method of evaluating shell strength. As a rule of thumb, a specific gravity of 1.08 indicates good shell quality (Bennett, 1992). Specific gravity can be easily utilized in the field (Butcher and Miles, 1991; Bennett, 1993). Bennett (1993) proposed using a single salt solution with specific gravity of 1.08 to evaluate shell quality of eggs from leghorn hens and found that eggs floating in the 1.08 specific gravity solution had three times the cracks of those not floating.

Scanning Electron Microscopy (SEM) and Laser Induced Breakdown Spectroscopy (LIBS) techniques have been used to study the gross and microscopic morphology of the shell related to shell strength and mineral content of the shell (Fathi *et al*., 2010; Abdel-Salam *et al*., 2006). Shell strength is also related to the protein matrix of the shell. ELISA assays have been used to quantify specific matrix proteins (Panheleux *et al*., 2000). Kuchida *et al*. (1999) looked at non-destructive methods of evaluating the yolk and albumen components of the egg using a computer image analysis of the egg with a light held at one end.

Dual Energy X-ray Absorptiometry (DXA) has been used for humans, mice (Nagy and Clair, 2000) and White Leghorns (Schreiweis *et al*., 2003) to determine body composition, bone density and mineralization. Salas *et al*. (2009) used a GE Lunar Prodigy DXA machine with small animal body software to determine the body composition of broiler breeder hens. Salas *et al*. (2009) scanned individual hens throughout their rearing and laying period in order to determine changes over time.

DXA technology has not been reported as a method to evaluate egg components or shell quality. If accurate, DXA technology would provide an advantage over other non-destructive and destructive methods of evaluating eggs by evaluating multiple parameters in a single scan.

MATERIALS AND METHODS

A series of trials was conducted to determine if the DXA could be used as a quick and non-destructive method to determine the egg components (yolk, albumen and shell), shell quality and shell mineral composition. Trial 1 - eggs were scanned then eggs were broken out to weigh the component parts, measure shell thickness and analyze shell calcium. Values from the DXA scan and the actual measured values were used in stepwise regression analysis to develop prediction expression equations. Trial 2 - the prediction expression equations were validated with a second set of eggs. Eggs were scanned and egg components predicted using the equations from the first trial. Then the eggs were broken out to determine actual values. Trial 3 - eggs were scanned then incubated at University of Arkansas Hatchery to determine if DXA scanning would have an effect on the subsequent hatchability of eggs. Trial 4 - eggs were scanned and eggshell quality (as predicted by DXA) was correlated with actual determined specific gravity. DXA scan technology has the potential for providing egg analysis that includes shell quality and egg components and then still use the egg in hatching studies. DXA scan technology would offer an advantage in evaluating individual hens for breeding value or additional research.

A GE Lunar Prodigy DXA machine with small animal body software was used to scan groups of 10 eggs. The GE Lunar Prodigy allows only 10 ROIs (regions of interest) to be analyzed at one time. After scanning a ROI (region of interest) is defined for each of the 10 eggs allowing each to be analyzed separately. A quality assurance program was run daily prior to scanning. The Quality Assurance (QA) program scans a phantom standard to determine that the machine is properly calibrated. The GE Lunar Prodigy DXA small animal body software reports values defined as Bone Mineral Density (BMD), expressed as g/cm^2; Bone Mineral Content (BMC) expressed as grams; Area expressed as cm^2; Tissue % Fat; Tissue (g); Fat (g) and Lean (g).

Software algorithms calculate area, lean, total mass, total tissue, bone, mineral with values based on predetermined mass attenuation coefficients of different absorber materials which is constant and unique for

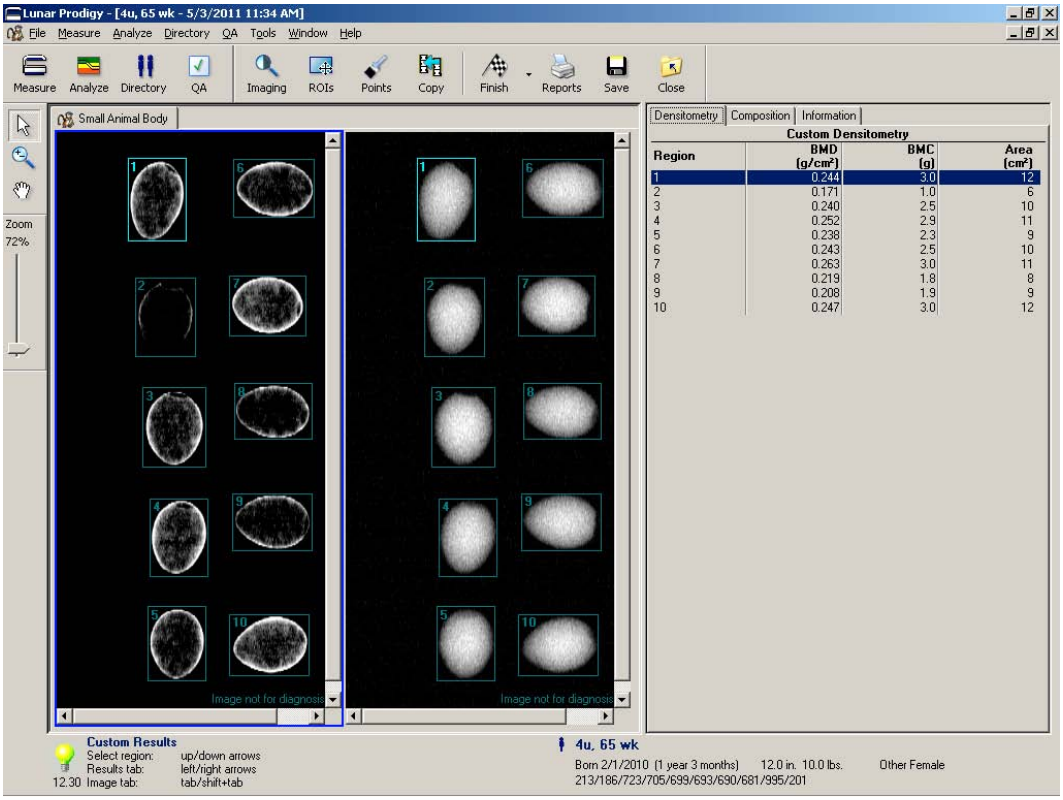


Fig. 1: DEXA scan of broiler breeder eggs

each material at any given photon energy level. The University of Vermont has a simple presentation online (http://nutrition.uvm.edu/bodycomp/dexa/dexa-toc.html) on DXA technology. Determination of body fat by the small animal software for DXA is less accurate than for lean and BMC (Pietrobelli *et al*., 1998; Johnston *et al*., 2005). Researchers have found it necessary to develop prediction equations for different DXA machines and software packages for evaluating body composition and bone mineralization (Nagy and Clair, 2000; Swennen *et al*., 2004; Johnston *et al*., 2005; Johnson *et al*., 2005; Salas *et al*., 2009). Prediction equations are needed to fine tune the DXA values in order to provide body compositions values that are in line with actual chemical analysis. Johnson *et al*. (2005) used backward elimination regression to determine which of all the DXA factors are best used in the prediction equations.

In Trial 1, all variables reported by the DXA scan were used in the Fit Model Stepwise Regression analysis, JMP® 8 program (2008). Backward regression analysis was used entering scale EW and DXA values for BMC, BMD, Tissue, Tissue % Fat, Fat and Lean into all the models. Analysis used minimum Bayesian information criteria to determine the best fit model for predicting individual egg components.

In Trial 1, 180 individually numbered broiler breeder eggs were weighed then scanned with the DXA machine (Fig. 1). After scanning the eggs were broken and parts separated. The yolk was separated in the palm of the hand to remove albumen before being weighed. The shell was carefully rinsed to remove excess albumen, leaving the shell membrane intact. The shell was then air dried before weighing. Albumen weight was calculated as the total egg weight minus the shell and yolk weights. Shell thickness was determined by taking the average of 3 measurements around the widest part of the egg shell using a micrometer (Mitutoyo Digimatic micrometer 0.001 mm). Forty-five eggshells were selected to provide a range of BMC as determined by the DXA scan and submitted to the lab for calcium analysis. The prediction expression equations developed were validated in Trial 2. Trial 2 consisted of evaluating 180 individually numbered broiler breeder eggs. The eggs were weighed and scanned. Values obtained from the DXA scan were used in the prediction expression equations developed in Trial 1 to calculate the predicted values for the total egg weight, shell weight, yolk weight, albumen weight and shell thickness of these eggs. After scanning the eggs with DXA, eggs were broken out, parts separated and measured in the same manner as Trial 1. The calculated predicted values were then correlated with the actual values by linear regression analysis. Trial 2 eggshells were not submitted for calcium analysis.

Trial 3 was conducted to determine the affect of scanning hatching eggs with the DXA on hatchability, chick weights and hatch residue breakout. Two hundred and fifty broiler breeder hatching eggs were obtained from the Cobb-Vantress Fayetteville Hatchery. The eggs were numbered and weighed individually. One hundred and twenty five eggs were scanned and the remaining 125 eggs were not scanned and served as the control group. All eggs were placed in the incubator and transferred to a hatcher on the 18th day of incubation. All hatched chicks were individually weighed. Eggs that didn't hatch were broken out to determine fertility or cause of failure to hatch. Hatched chick weights were analyzed by standard least square and the percentage data by Chi-square analysis (JMP 8®, 2008).

Specific gravity and SWUSA are widely accepted as indicators of shell quality but are time consuming. SWUSA measurements require breaking the egg. Egg shell quality determined by DXA would save time and be non-destructive. In Trial 4, the values for shell quality as determined by DXA were correlated with specific gravity and SWUSA. Trial 4 evaluated the affect of shell quality, as determined by DXA, on hatchability.

In Trial 4, 400 broiler breeder hatching eggs obtained from Cobb-Vantress were individually numbered and weighed. The specific gravity of each egg was determined prior to DXA scanning. Eight different salt solutions were used, ranging in specific gravity from 1.06 to 1.09. Values for egg component parts (shell, yolk and albumen) were calculated using the prediction expression equations developed in Trial 1. Since these eggs were to be hatched the predicted shell weight was used with the actual egg weight to calculate SWUSA (shell weight per unit surface area) and shell:egg weight ratios. Eggs were assigned to one of 23 groups based on the shell:egg weight ratios, in increments of 0.001. Eggs were placed in an incubator and transferred to a hatcher on the 18th day. Hatched chicks were weighed and unhatched eggs were broken out to determine fertility or cause of failure to hatch. Hatched chick weights were analyzed by standard least square and the percentage hatch data by Chi-square analysis (JMP 8®, 2008). The eggshell quality parameters were subjected to multivariate correlation analysis (JMP 8®, 2008).

RESULTS

In Trial 1, best fit prediction expression equations were developed for egg weight, shell weight, shell calcium, shell thickness, albumen weight and yolk weight (Table 1). Egg weight was best predicted by DXA BMC, Tissue, Tissue % Fat and Lean (r^2 = 0.9961, p<0.0001). Shell weight was best predicted by DXA Lean, Tissue % Fat and BMC (r^2 = 0.9692, p<0.0001). Chemical analysis of shell calcium was best predicted by DXA BMC, Tissue and Lean (r^2 = 0.9843, p<0.0001). Shell thickness was best predicted by DXA Lean, Tissue %Fat and BMC (r^2 = 0.6891, p<0.0001). Albumen weight was best predicted by Egg weight, DXA Tissue %Fat and BMC (r^2 = 0.8499, p<0.0001). Yolk weight was best predicted by Egg weight, DXA BMC and Tissue %Fat (r^2 = 0.5738, p<0.0001). There was a significant linear correlation between the actual parameter values and values calculated using DXA prediction expression equations for all egg components and shell quality parameters (p<0.0001) (Graph 1-6).

The GE Lunar Prodigy software allows the operator to define the area of interest to scan. In Trial 1, it was determined that by defining a small scan area of 38.6 cm in length and 15 cm in width, it was possible to scan 140 eggs per hour.

Trial 2 validated the prediction expression equations developed in Trial 1. For all egg components and shell quality parameters there was a significant linear correlation between the actual parameter values and values calculated using DXA prediction expression equations (p<0.0001) (Graph 7-11). The fit X by Y Bivariate fit analysis (JMP® 8, 2008) shows the prediction expression equations developed in Trial 1 are good models for predicting egg parameters such as total egg weight (r^2 = 0.955, p<0.0001), shell weight (r^2= 0.936, p<0.0001), shell thickness (r^2 = 0.667, p<0.0001), albumen weight (r^2 = 0.859, p<0.0001) and yolk weight (r^2 = 0.566, p<0.0001) (Table 2).

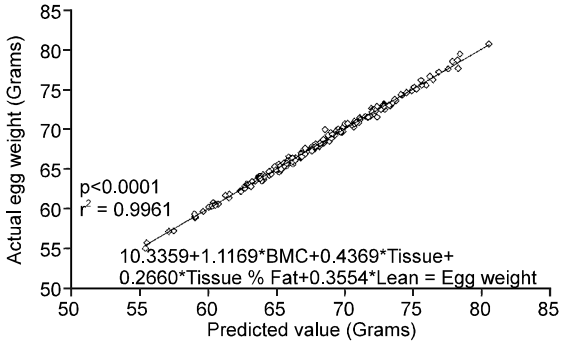
Multivariate analysis of the eggs used in Trial 1 (r = 0.7124, p<0.0001) and Trial 2 (r = 0.9326, p<0.0001) showed a strong correlation between shell weight and shell thickness. Wolanski *et al.* (2007) also reported a strong correlation between shell weight and shell thickness (r = 0.78, p = 0.0001).

In Trial 3, the average egg weight for the 250 eggs set in University of Arkansas Hatchery was 66.6 g for scanned eggs and 66.3 g for un-scanned eggs. The egg weights of scanned and un-scanned eggs were not significantly different. The average hatched chick weights were also not significantly different between the scanned eggs (averaged 47.3 g) and the un-scanned eggs (average

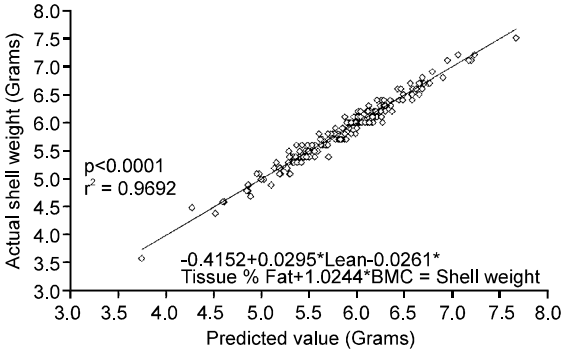
Table 1: Prediction equations for determining egg components by DEXA scan, Trial 1

Dependent variable	Prediction Equation	P>F	Model r^2	RMSE
Total egg weight (g)	10.3359+1.1169*BMC+0.4369*Tissue+0.2660*Tissue % Fat+0.3554*Lean	<0.0001	0.9961	0.3021
Shell weight (g)	-0.4152+0.0295*Lean-0.0261*Tissue % Fat+1.0244*BMC	<0.0001	0.9692	0.1067
Chemical Shell Ca (g)	0.2297+0.4150*BMC-0.0171*Tissue+0.02240*Lean	<0.0001	0.9843	0.0290
Shell thickness (mm)	0.1125-0.0005*Lean-0.0058*Tissue %Fat+0.0423*BMC	<0.0001	0.6891	0.0206
Albumen weight (g)	-12.5673+0.7040*Egg wgt-0.2293*Tissue %Fat-1.6164*BMC	<0.0001	0.8499	1.3172
Yolk weight (g)	10.6746+0.2573*Egg wgt+18.8852*BMD g/cm^2+0.2826*Tissue %Fat	<0.0001	0.5738	1.3013

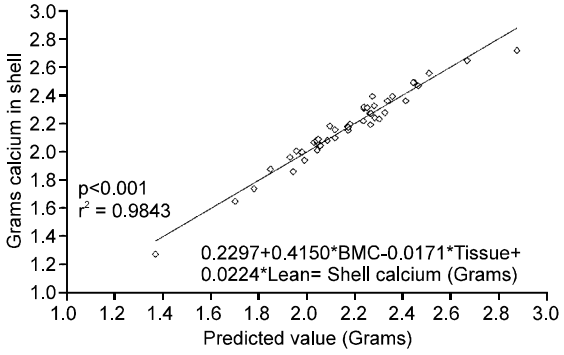
n = 180



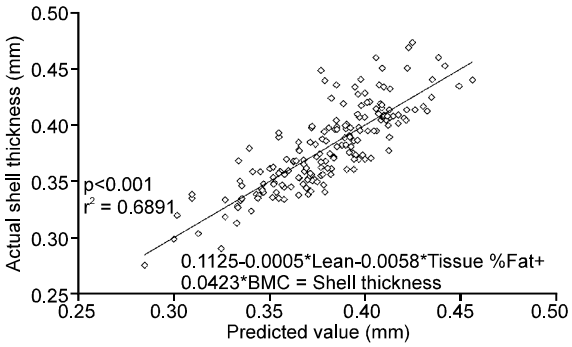
Graph 1: Prediction expression equation for egg weight (grams), Trial 1



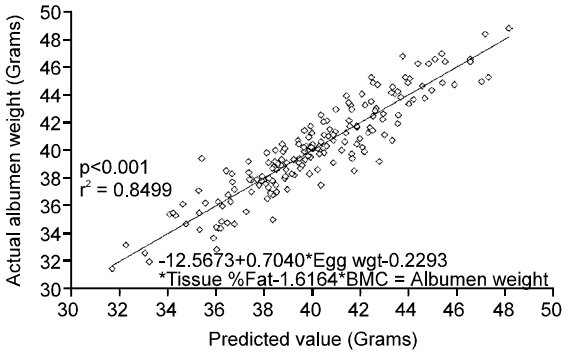
Graph 2: Prediction expression equation for shell weight (grams), Trial 1



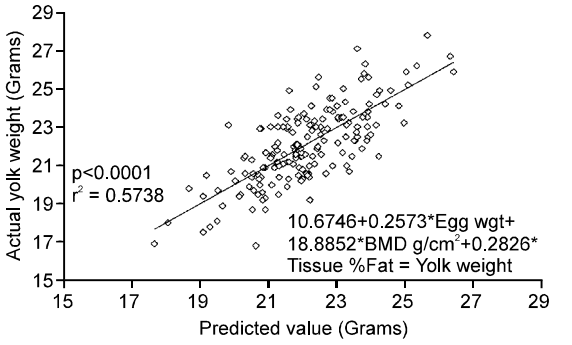
Graph 3: Prediction expression equation for grams calcium in shell (grams), Trial 1



Graph 4: Prediction expression equation for shell thickness (grams), Trial 1



Graph 5: Prediction expression equation for albumen weight (grams), Trial 1



Graph 6: Prediction expression equation for yolk weight (grams), Trial 1

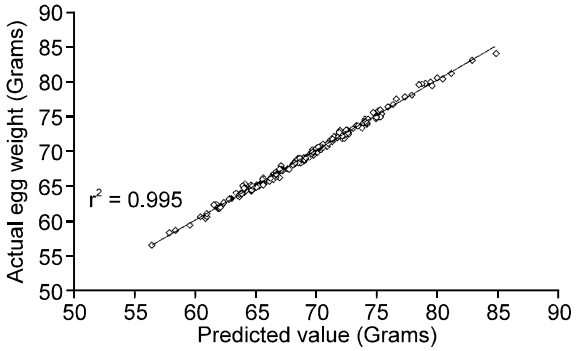
46.5 g) (p = 0.1931). Scanning the hatching eggs significantly increased the percent hatch by approximately 10 percentage points (p<0.046) (Table 3). Scanning hatching eggs with the DXA does not negatively affect the hatch. There was no effect of scanning on percent fertility, with 96 and 92% fertility for scanned and un-scanned eggs, respectively. There was no effect of scanning on percent early, mid or late dead during incubation (Table 3).

Multivariate correlation analysis (JMP® 8, 2008) shows that specific gravity is significantly correlated to SWUSA (r = 0.7849, p<0.0001), shell:egg weight ratio (r = 0.7849, p<0.0001), shell calcium (r = 0.6073, p<0.0001) and

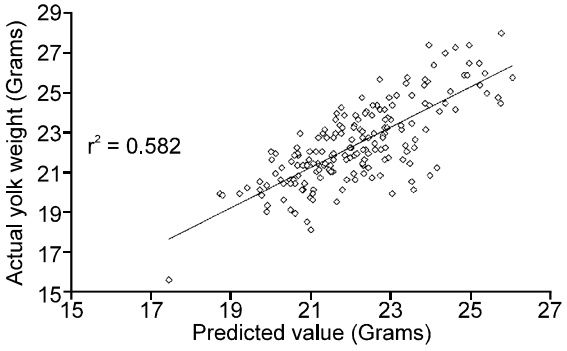
Table 2: Bivariate fit of actual weights by weights calculated with prediction equations, Trial 2.

Dependent variable	P>F	r^2	RMSE
Total egg weight (g)	<0.0001	0.9953	0.3544
Shell weight (g)	<0.0001	0.9365	0.1337
Shell thickness (mm)	<0.0001	0.8609	0.0114
Albumen weight (g)	<0.0001	0.8593	1.3304
Yolk weight (g)	<0.0001	0.5823	1.3091

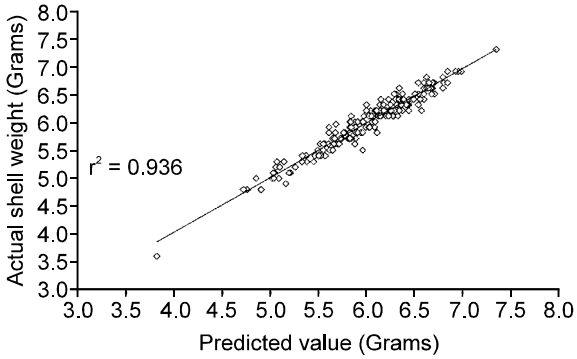
n = 180



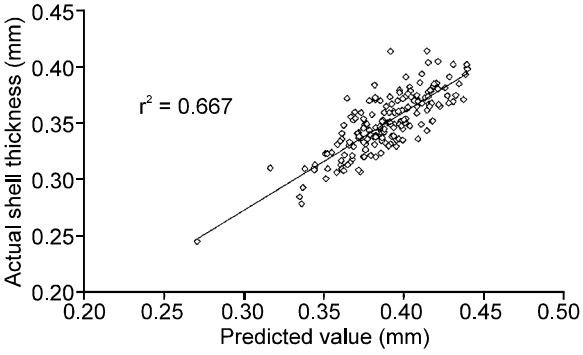
Graph 7: Correlation of predicted egg weight and actual egg weight, Trial 2



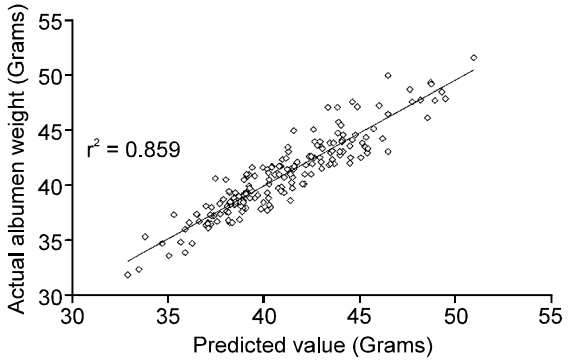
Graph 10: Correlation of predicted yolk weight and actual yolk weight, Trial 2



Graph 8: Correlation of predicted shell weight and actual shell weight, Trial 2



Graph 11: Correlation of predicted shell thickness and actual shell thickness, Trial 2



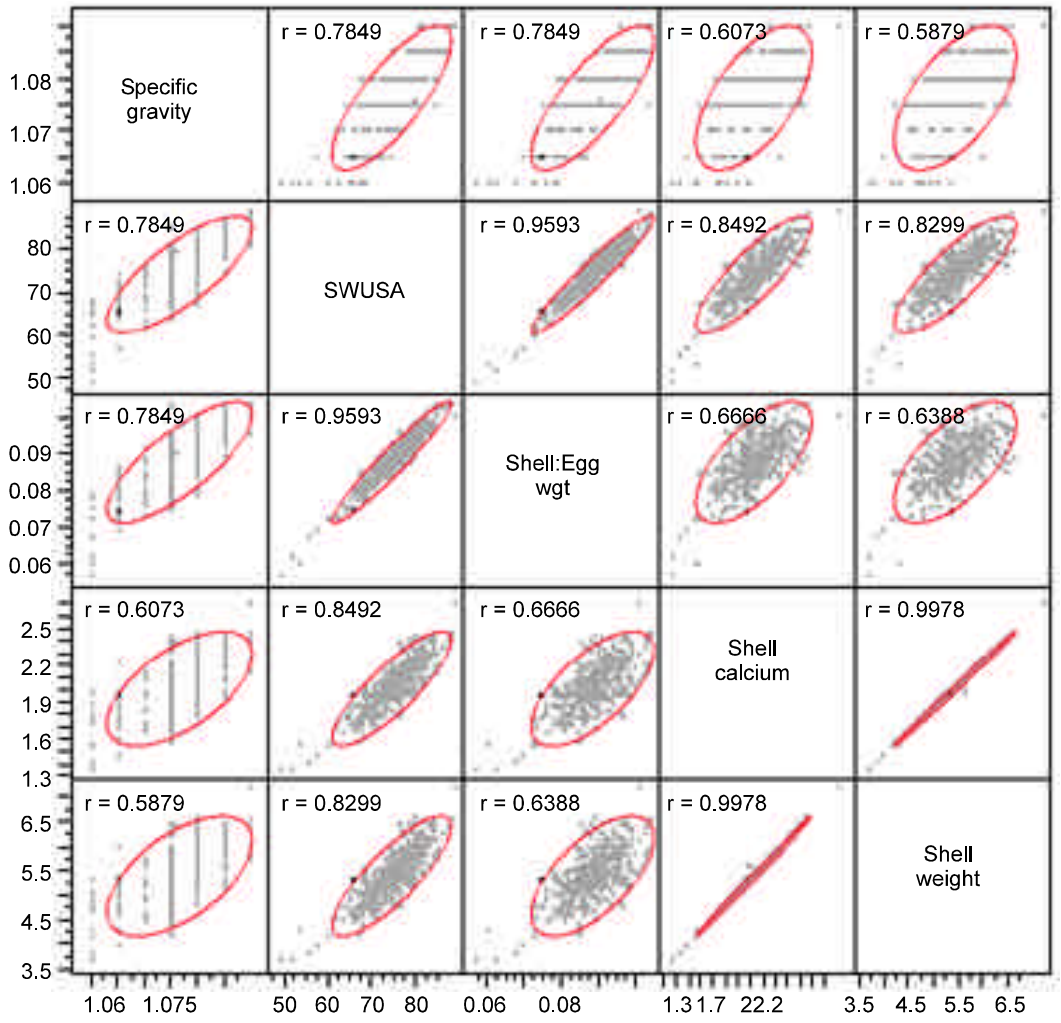
Graph 9: Correlation of predicted albumen weight and actual albumen weight, Trial 2

shell weight (r = 0.5879, p<0.0001) as determined by DXA analysis (Graph 12). SWUSA or shell:egg weight ratio as determined by DXA are good indicators of shell quality. SWUSA was also significantly correlated to shell:egg weight ratio (r = 0.9593, p<0.0001), shell calcium (r = 0.8493, p<0.0001) and shell weight (r = 0.8299, p<0.0001) (Graph 12).

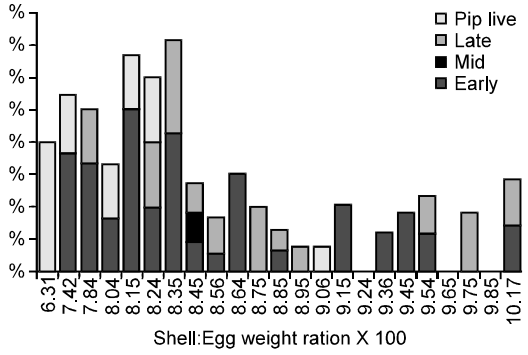
In Trial 4, 400 potential hatching eggs were divided into 23 different treatment groups based on shell:egg weight ratio as determined by DXA scan. SWUSA, specific gravity, egg weight, shell weight and shell calcium were significantly affected by treatment group (p<0.0001) (Table 4). Shell:egg weight ratio ranged from 0.0631 to 0.1017. As the shell: egg weight ratio increased, so did the SWUSA (53 to 85), specific gravity (1.061 to 1.085), average shell weight (3.89 to 6.04 grams) and shell calcium (1.43 to 2.27 grams). Egg weight was also significantly different between groups (p = 0.0123) and ranged from 58.3 to 64.8 g. Eggs with shell:egg weight ratios of 0.063 to 0.875 had SWUSA values of 53.3 to 74 which would be considered poor shell quality. Eggs with shell:egg weight ratios of 0.0885 to 0.1017 had SWUSA values of 74.9 to 85 which would be considered good

Table 3: Hatchery residue breakout of scanned and non-scanned eggs, Trial 3

Egg treatment	% Hatch	% Fertility	% Early	% Mid	% Late
Non-scanned	77.60	92.00	4.800	0.800	4.800
Scanned	87.20	96.00	1.600	0.800	2.400
Prob > ChiSq	0.046	0.179	0.142	1.000	0.304



Graph 12: Multivariate correlation coefficients between specific gravity and eggshell quality values (SWUSA, shell:egg wgt ratio, shell calcium and shell wgt) determined by DEXA, (p<.0001), Trial 4



Graph 13: Distribution of early, mid and late dead and pipped live by shell:egg weight ratio, Trial 4

shell quality. Eggs with a shell: egg weight ratio of 0.0631 to 0.0915 had specific gravities of 1.061 to 1.078 indicating poor shell quality. Eggs with a shell:egg weight ratio of 0.0924 to 0.1017 had specific gravities of 1.08 to 1.085 which would indicate good shell quality. A minimum specific gravity of 1.08 is recommended by Bennett (1993) for maintaining the shell quality of broiler breeder eggs.

Lower shell:egg weight ratios were detrimental to fertility ($p = 0.0228$) with an increase in the number of eggs determined to be infertile for the lower shell:egg weights (Table 5). Lower shell:egg weight ratios resulted in an increase in the number of early dead ($p = 0.0220$) and chicks that pipped but were unable to hatch, ($p = 0.0008$) (Table 5, Graph 13).

Hatched chick weights were significantly affected by shell: egg weight ratio ($p = 0.0085$) (Table 5). Multivariate correlation coefficient analysis showed that chick weights were positively correlated to the total egg weight ($r = 0.8501$, $p<0.0001$), albumen weight ($r = 0.8532$, $p<0.0001$), yolk weight ($r = 0.7299$, $p<0.0001$), as determined by DXA.

Table 4: Average shell:egg weight ratios, SWUSA, specific gravity, egg weights, shell weight and shell calcium of eggs, Trial 4

	Shell:egg	SWUSA		Specific gravity		Egg weight (g)		Shell weight (g)		Shell calcium (g)	
Trt	X 100	LSqMean	SE	LSqMean	SE	LSqMean	SE	LSqMean	SE	LSqMean	SE
1	6.31	53.3n	0.751	1.061m	0.002	61.9abcde	1.97	3.89k	0.17	1.43i	0.06
2	7.42	63.7m	0.506	1.065l	0.001	64.8a	1.33	4.81j	0.12	1.78h	0.04
3	7.84	67.0l	0.343	1.069k	0.001	64.0a	0.90	5.02ij	0.08	1.86h	0.03
4	8.04	68.0kl	0.485	1.073ij	0.001	61.6abcde	1.27	4.95j	0.11	1.84h	0.04
5	8.15	69.2jk	0.485	1.072jk	0.001	62.4abcd	1.27	5.08hij	0.11	1.89gh	0.04
6	8.24	69.6j	0.531	1.075ghij	0.001	61.2abcde	1.39	5.05hij	0.12	1.88gh	0.05
7	8.35	71.2i	0.449	1.072j	0.001	63.5ab	1.18	5.30fgh	0.10	1.98efg	0.04
8	8.45	71.5i	0.358	1.074hi	0.001	61.9abcd	0.94	5.24ghi	0.08	1.95fg	0.03
9	8.56	72.3i	0.280	1.076fgh	0.001	61.5bcde	0.73	5.26gh	0.07	1.96fg	0.02
10	8.64	73.5h	0.375	1.076fgh	0.001	62.9abc	0.98	5.44efg	0.09	2.02ef	0.03
11	8.75	74.0gh	0.375	1.077efg	0.001	61.8abcde	0.98	5.41efg	0.09	2.02ef	0.03
12	8.85	74.9fg	0.302	1.077efg	0.001	61.8abc	0.79	5.47def	0.07	2.04de	0.03
13	8.95	75.1f	0.329	1.078def	0.001	60.3de	0.86	5.39fg	0.08	2.01ef	0.03
14	9.06	76.8e	0.329	1.078cde	0.001	62.1abcd	0.86	5.63bcde	0.08	2.11bcd	0.03
15	9.15	76.9e	0.312	1.078def	0.001	60.6cde	0.82	5.54cdef	0.07	2.07cde	0.03
16	9.24	78.5d	0.531	1.081bc	0.001	62.6abcd	1.39	5.79abc	0.12	2.17abc	0.05
17	9.36	78.7d	0.407	1.081b	0.001	60.5bcde	1.07	5.66bcde	0.09	2.12bcd	0.03
18	9.45	79.8cd	0.506	1.080bcd	0.001	61.2abcde	1.33	5.79abc	0.12	2.17ab	0.04
19	9.54	79.9c	0.407	1.082b	0.001	59.6de	1.07	5.69bcd	0.09	2.13bc	0.03
20	9.65	80.7bc	0.485	1.081b	0.001	59.5de	1.27	5.74abc	0.11	2.15bc	0.04
21	9.75	81.7b	0.506	1.082b	0.001	59.7cde	1.33	5.82ab	0.12	2.18ab	0.04
22	9.85	81.9b	0.560	1.082ab	0.001	58.3e	1.47	5.74abcd	0.13	2.15abc	0.05
23	10.17	85.0a	0.449	1.085a	0.001	59.4de	1.18	6.04a	0.10	2.27a	0.04
Prob>F		<0.0001		<0.0001		0.0123		<0.0001		<0.0001	

Table 5: Hatchability, hatchery residue breakout and hatched chick weights of eggs with different shell:egg weight ratios, Trial 4

	Shell:egg									Hatch chick weight	
		SWUSA		Infertile	Early	Mid	Late	Cont.	Pip live		
Trt	X 100	g/cm^2	Spec Grav	%	%	%	%	%	%	Grams	SE
1	6.31	53.3	1.061	40	0	0	0	0	20	43.3abcdef	2.30
2	7.42	63.7	1.065	18	18	0	0	0	9	47.5a	1.62
3	7.84	67.0	1.069	4	17	0	8	0	0	46.0ab	0.99
4	8.04	68.0	1.073	0	8	0	0	0	8	43.9abcdef	1.26
5	8.15	69.2	1.072	8	25	0	0	0	8	43.1bcdef	1.50
6	8.24	69.6	1.075	0	10	0	10	10	10	44.3abcdef	1.62
7	8.35	71.2	1.072	0	21	0	14	0	0	44.6abcd	1.33
8	8.45	71.5	1.074	9	5	5	5	0	0	44.1abcd f	0.97
9	8.56	72.3	1.076	3	3	0	6	0	0	44.2abc	0.70
10	8.64	73.5	1.076	5	15	0	0	5	0	44.1abcd f	1.03
11	8.75	74.0	1.077	10	0	0	10	0	0	41.1e	0.99
12	8.85	74.9	1.077	0	3	0	3	0	0	43.9bcd	0.75
13	8.95	75.1	1.078	0	0	0	4	0	0	42.9cdef	0.80
14	9.06	76.8	1.078	0	0	0	0	0	4	44.1abc	0.81
15	9.15	76.9	1.078	3	10	0	0	0	0	42.4cdef	0.80
16	9.24	78.5	1.081	10	0	0	0	0	0	44.8abc	1.33
17	9.36	78.7	1.081	0	6	0	0	0	0	43.8abcdef	1.03
18	9.45	79.8	1.080	9	9	0	0	0	0	43.4abcdef	1.33
19	9.54	79.9	1.082	6	6	0	6	0	0	42.4cdef	1.06
20	9.65	80.7	1.081	0	0	0	0	0	0	42.0cdef	1.15
21	9.75	81.7	1.082	0	0	0	9	0	0	41.5cdef	1.26
22	9.85	81.9	1.082	0	0	0	0	0	0	40.8ef	1.41
23	10.17	85.0	1.085	7	7	0	7	0	0	41.2def	1.20
		Prob > Chi-Square								Prob > F	
			Intercept	0.2490	0.2423	0.9437	0.5911	0.9074	0.0198	0.0243	
			Shell:Egg Wgt	0.0228	0.0220	0.6223	0.6581	0.3981	0.0008		

DISCUSSION

Each component (shell, yolk and albumen, shell quality) of the egg makes its' own unique contribution to the success or failure of the developing embryo and contributes to the subsequent performance of the hatched chick. Egg components and shell quality parameters can be affected by genotype, genetic selection, housing system and age of hen (Mostageer and Obeidah, 1978; Grunder *et al*., 1989; Peebles *et al*., 2001; Witkowski *et al*., 2005; Tumova *et al*., 2009; Ledvinka *et al*., 2011).

Most of the work with eggshell quality has been done with commercial layers and not broiler breeder type hens. Differences in eggshell quality affects moisture

loss during incubation, yolk uptake, growth and body composition in embryos related to hen age (Peebles *et al*., 2001). Specific gravity, shell weight, % shell and SWUSA can be affected by genetic selection (Grunder *et al*., 1989). Shell quality as measured by specific gravity is used as one of the traits in estimating the breeding value of a hen for hatchability (Rozempolska-Rucinska *et al*., 2011).

Hatch chick weights are significantly correlated to egg weight, albumen and yolk weight (Wolanski *et al*., 2007). Researchers have shown that eggs of equal size with more yolk content and less albumen were better for improving hatchability (Witkowski *et al*., 2005). Mostageer and Obeidah (1978) were able to manipulate the component parts of an egg through genetic selection. The heritability estimates for yolk and albumen weights were moderate (Witkowski *et al*., 2005).

Scanning and analyzing 140 eggs per hour by DXA technology can be used to accurately predict egg components (yolk, albumen, shell, shell thickness and calcium content) in a non-destructive manner. The DXA can predict total egg weight, shell weight, shell calcium, shell thickness, albumen weight and yolk weight with a high degree of accuracy (r^2 = 0.9961, 0.9692, 0.9843, 0.6891, 0.8499 and 0.5738, respectively) (P>F, <0.0001). DXA scanning broiler breeder eggs has no deleterious effect on hatchability parameters making it possible to conduct further research on the resulting embryos and/or progeny. DXA scanning to evaluate egg component profiles for individual hens would make it possible to select eggs (hens) that can be selected for further genetic physiological and metabolic testing.

DXA scanning to evaluate egg component profiles of individual hens could be used in determining the value to the primary breeder in selecting hens with desirable egg traits. The DXA may also be an important tool for non-invasive evaluation of egg components (shell, albumen and yolk) thus allowing the follow up of progeny hatch, chick quality, livability and grow-out performance.

ACKNOWLEDGEMENTS

The authors would like to express our appreciation to Cobb-Vantress, Inc. for financial support and supplying hatching eggs for the reported studies.

REFERENCES

Abdel-Salam, Z.A., A.M. Abdou and M.A. Harith, 2006. Elemental and ultrastructural analysis of the eggshell: Ca, Mg and Na distribution during embryonic development via LIBS and SEM techniques. Int. J. Poult. Sci., 5: 35-42.

Bennett, C., 1992. The influence of shell thickness on hatchability in commercial broiler breeder flocks. J. Appl. Poult. Res., 1: 61-65.

Bennett, C., 1993. Measuring table egg shell quality with one specific gravity salt solution. J. Appl. Poult. Res., 2: 130-134.

Butcher, G.D. and R.D. Miles, 1991. Egg specific gravity - designing a monitoring program. Veterinary Medicine-Large Animal Clinical Sciences Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. http://edis.ifas.ufl.edu.VM72.

Fathi, M.M., A.K. Yousria and S.A. El-Safty, 2010. Ultrastructural diversity of eggshell quality in some Egyptian local breeds of chicken. Egypt. Poult. Sci., 30: 813-827.

Grunder, A.A., R.M.G. Hamilton, R.W. Fairfull and B.K. Thompson, 1989. Genetic parameters of egg shell quality traits and percentage of eggs remaining intact between oviposition and grading. Poult. Sci., 68: 46-54.

http://nutrition.uvm.edu/bodycomp/dexa/dexa-toc.html.

Hunton, P., 2005. Research on eggshell structure and quality: An historical overview. Braz. J. Poult. Sci., 7: 67-71.

JMP® 8, 2008. SAS Institute Inc.

Johnson, M.S., N.M. Landy, E.P. Potter and T.R. Nagy, 2005. Comparison of software versions for body composition analysis using the PIXImus dual-energy X-ray absorptiometer. Int. J. Body Compos. Res., 3: 69-72.

Johnston, S.L., W.L. Peacock, L.M. Bell, M. Lonchampt and J.R. Speakman, 2005. PIXImus DXA with different software needs individual calibration to accurately predict fat mass. Obesity Res., 13: 1558-1565.

Kuchida, K., M. Fukaya, S. Miyoshi, M. Suzuki and S. Tsuruta, 1999. Nondestructive prediction method for yolk:albumen ratio in chicken eggs by computer image analysis. Poult. Sci., 78: 909-913.

Ledvinka, Z., L. Zita, M. Hubený, E. Tùmová, M. Tyller, P. Dobrovolný and M. Hruška, 2011. Effect of genotype, age of hens and the K/k allele on eggshell quality. Czech J. Anim. Sci., 565: 242-249.

Mostageer, A. and A. Obeidah, 1978. Genetic and phenotypic parameters of the components parts of egg weight in Fayoumi and Rhode Island Reds. Ann. Genet. Sel. Anim., 10: 251-257.

Nagy, T. and A.L. Clair, 2000. Precision and accuracy of dual-energy x-ray absorptiometry for determining *in vivo* body composition of mice. Obesity Res., 8: 392-398.

Panheleux, M., Y. Nys, J. Williams, J. Gautron, T. Boldicke and M.T. Hincke, 2000. Extraction and quantification by ELISA of eggshell organic matrix proteins (ovocleidin-17, ovalbumin, ovotransferrin) in shell from young and old hens. Poult. Sci., 79: 580-588.

Peebles, E.D., C.D. Zumwalt, S.M. Doyle, P.D. Gerard, M.A. Latour, C.R. Boyle and T.W. Smith, 2000. Effects of breeder age and dietary fat source and level on broiler hatching egg characteristics. Poult. Sci., 79: 698-704.

Peebles, E.D., S.M. Doyle, C.D. Zumwalt, P.D. Gerard, M.A. Latour, C.R. Boyle and T.W. Smith, 2001. Breeder age influences embryogenesis in broiler hatching eggs. Poult. Sci., 80: 272-277.

Pietrobelli, A., Z. Wang, C. Formica and S.B. Heymsfield, 1998. Dual-energy X-ray absorptiometry: Fat estimation errors due to variations in soft tissue hydration. Am. J. Physiol. Endocrinol. Metab., 274: E808-E816.

Rozempolska-Rucinska, I., G. Zieba, M. Lukaszewicz, M. Ciechoñska, A. Witkowski and B. Slaska, 2011. Egg specific gravity in improvement of hatchability in laying hens. J. Anim. Feed Sci., 20: 84-92.

Salas, C., R.D. Ekmay, J. England and C.N. Coon, 2009. Energy requirement of broiler breeder hens reared for standard, 20% lighter and 20% heavier pullet body weights. Poult. Sci., 88 (Supplement 1): 118.

Schreiweis, M.A., J.I. Orban, M.C. Ledur and P.Y. Hester, 2003. The use of densitometry to detect differences in bone mineral density and content of live white leghorns fed varying levels of dietary calcium. Poult. Sci., 82: 1292-1301.

Swennen, Q., G.P.J. Janssens, R. Greers, E. Decuypere and J. Buyse, 2004. Validation of dual-energy x-ray absorptiometry for determining *in vivo* body composition of chickens. Poult. Sci., 83: 1348-1357.

Tumova, E., M. Skrivan, M. Englmaierová and L. Zita, 2009. The effect of genotype, housing system and egg collection time on egg quality in egg type hens. Czech J. Anim. Sci., 54: 17-23.

Uni, Z., L. Yadgary and R. Yair, 2012. Nutritional limitations during poultry embryonic development. J. Appl. Poult. Res., 21: 175-184.

Vieira, S.L. and E.T. Moran Jr., 1998. Eggs and chicks from broiler breeders of extremely different age. J. Appl. Poult. Res., 7: 372-376.

Witkowski, A., G. Zieba, M. Lukaszewicz, J. Horbañczuk and R. Gilewski, 2005. Genetic trends of egg yolk and white weights and hatchability as correlated traits in two breeds of laying hens. Poster. 4th European Poult. Gen. Sym. 2005.

Wolanski, N.J., R.A. Renema, F.E. Robinson, V.L. Carney and B.I. Fancher, 2007. Relationships among egg characteristics, chick measurements and early growth traits in then broiler breeder strains. Poult. Sci., 86: 1784-1792.