

Effects of Egg Size and Eggshell Conductance on Hatchability Traits of Meat and Layer Breeder Flocks

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ABSTRACT : Eggs obtained from 46 and 42 weeks old meat (Hybro) and layer (Leghorn) breeders flocks, respectively were used to examine the effects of genetic type of birds and egg size (small, medium and large) on variables of eggshell characteristics and hatchability traits. The variables measured were egg weight (EW), egg surface area (ESA) and eggshell characteristics (shell conductance (EC), per cent shell (PS), shell thickness (ST), shell volume (SV), shell density (SD) and hatchability traits (per cent hatchability (HP), early dead embryos (ED), late dead embryos (LD), pips with live embryos (PL) and pips with dead embryos (PD)). Genetic type of bird influenced all egg characteristics and HP of eggs. Eggs produced by the small Leghorn bird had lower EW, ESA, EC, ST, SV and HP than those produced by the heavy Hybro bird. The reduction of HP was associated with an increase in the percentage of ED and PL. Egg size influenced all variables measured except ST. Small size eggs had lower EW, ESA and EC and higher PS and SD than those of large eggs. Medium size eggs produced a higher HP when compared with that of large size eggs. The reduction of HP in large eggs was associated with higher percentage of ED, LD and PL. There were significant interactions between the genetic group of birds and egg size on LD and HP. Large egg size of Hybro birds had higher LD and lower HP than those of small size eggs produced by the same flock. However, There was no difference in HP and LD among the different egg sizes produced by Leghorn birds. It was concluded that genetic make up of birds and egg size influence eggshell characteristics and HP. The type of bird (heavy or small) influences the optimum egg size for successful hatching. Attention should be given to the size and eggshell characteristics of eggs of breeders' flocks for achieving maximum HP. (*Asian-Aust. J. Anim. Sci. 2002, Vol 15, No. 1 : 1-6*)

Key Words : Eggshell, Egg Size, Per Cent Hatchability, Breeder Flocks

INTRODUCTION

Scientists have investigated egg size, eggshell conductance (EC) and eggshell thickness (ST) as factors affecting hatchability of chicken eggs (Rahn et al., 1979; Board, 1980; Tullett, 1990). The EC of the incubated egg is physiologically important since it determines the rate of respiratory gases (Wangensteen et al., 1970, 1971) and water vapor conductance (Ar et al., 1974) and consequently hatchability (Tullett and Burton, 1982, 1986; Tullett, 1990). An egg must lose about 12% of its initial weight as water vapor during incubation (Tullett, 1981; Meir et al., 1984). Although water loss from the egg is independent of metabolic rate of the embryo, it is necessary for a successful hatching. The eggshell characteristics that determine the EC are the diffusion path length (approximated by ST) and the total functional cross-sectional area of the pores (Ar et al., 1974). Genetic selection of chickens for body size and egg production has led to the production of large sized eggs with different characteristics of eggshells. Changes in egg size and eggshell characteristics could influence embryonic mortality during incubation and consequently hatching success. The objectives of this study were to assess the effects of genetic group of birds and egg size on EC,

eggshell characteristics and hatchability traits of eggs from a commercial meat-type (Hybro) and a layer-type (Leghorn) breeder flocks.

MATERIALS AND METHODS

A total of 816 freshly laid eggs produced by flocks of 46 and 42 weeks old hens from a commercial meat-type (Hybro) and a layer-type (Leghorn, King Saud University) breeder flocks, respectively were used in this trial. Birds were fed a standard breeder ration (16% CP, 12 MJ of ME per kg, 3.4% calcium, 0.45% available phosphorus) and reared under standard husbandry conditions. Feed amounts were given for the maintenance of optimum hen-day egg production. A lighting program of 14 h light:10 h darkness commenced when the birds were caged at 22 weeks of age and this was maintained throughout the trial. Eggs were weighed (EW) individually and graded into three weight classes. Leghorn's eggs weighing between 47 and 51 g, 51 and 55 g and 55 and 60 g were considered small, medium and large sizes, respectively. Hybro's eggs weighing between 55 and 59 g, 60 and 65 g and 66 and 70 g were considered small, medium and large sizes, respectively. Eggs were assigned to fourteen replicates of nine eggs in each weight class from both genetic groups. Replicates of eggs were assigned evenly in the trays of the incubator to eliminate any effect for positions. Ten eggs were randomly

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selected from each weight class from both genetic groups and allocated for the measurement of EC and eggshell characteristics.

Shell weight (SW) and ST

Five eggs from each weight class from both genetic groups were selected at random, individually weighed, broken and emptied. Eggshells were washed with water, dried at room temperature of 25°C with paper towels, weighed and then per cent shell (PS) was calculated ($PS=SW/EW \times 100$). Eggshells were broken to obtain representative areas. Pieces from the three different areas (large end, equator and small end) of each shell were selected. Four measurements were taken from each of the three areas of the eggshell with a micrometer (Ames, Waltham, MA, USA). Measurements of SW and ST were done with the membranes intact. In addition, ST was calculated (CST) from the allometric relationship, $CST=5.126 \times 10^{-3} W^{0.456}$ where W=initial egg weight (Ar et al., 1974) and this was compared with the measured value of ST (MST).

EC, shell volume (SV) and shell density (SD)

Five freshly laid eggs from each weight class from both genetic groups were selected at random, individually weighed, placed in desiccators and maintained at 25°C for 4 days. These eggs were weighed once a day to determine the EC. The water vapor pressure inside the egg is saturated and in the desiccators it is zero. Thus, by dividing the daily mass loss by the saturation vapor pressure of 23.86 torr (25°C), the water vapor conductance expressed in $mg \text{ day}^{-1} \text{ torr}^{-1}$ is obtained. Weight loss was corrected to a barometric pressure of 1 atmosphere as described by Ar et al. (1974). The daily values for each egg were then averaged. EC was also calculated (CEC) from the equation of Ar et al. (1974), $CEC=0.432 W^{0.780}$ where W=initial egg weight and this was compared with the measured value (MEC). EC was expressed per unit of egg weight to adjust for the effect of egg weight on EC. EC/EW represents the relative EC for each egg adjusted for EW, which is correlated with egg surface area and volume (Peebles and Brake, 1987). SV was calculated from the relationship: $\text{Volume}=A \times L$, where A=surface area of the egg (cm^2), and L=thickness of the shell (cm). Surface area of the egg was estimated from the allometric relationship, $\text{area} (cm^2)=4.835 W^{0.662}$ where W=initial egg weight (Ar et al., 1974). SD was calculated from $SW (g)/SV (cm^3)$.

Incubation of eggs

Eggs were set in Maino, force-draft incubator (Model II, Maino Enrico, Co., Italy) and incubated at 37.5°C and 55% relative humidity. Eggs were turned every 2 h until they were transferred to the hatching compartment at the d 19 of

incubation. Eggs were examined by candling at 6 and 12 days of incubation and infertile eggs and eggs containing dead embryos (ED: 1-12 days) were removed, respectively. The hatching compartment was set at 37°C and 65% relative humidity until the morning 22nd day of incubation, at which time, chicks, pips (unhatched eggs with live (PL) or dead chicks (PD)) and late dead embryos (LD; unhatched eggs with unbroken shell) were counted. Late dead embryos were counted from 12 to the morning of 22nd days of incubation. The hatchability per cent (HP) was calculated based on fertile eggs.

Measurements included EW, PS, MST, CST, MST/CST per cent, egg surface area (ESA), SV, SD, MEC, CEC, MEC/CEC per cent, HP, PL, PD, ED and LD.

Data were subjected to analysis of variance (SAS Institute, 1985). All per cent data were transformed using arc sine square root percentage transformation before analysis. Differences between treatment means were tested using the least significant difference (LSD) procedures when significant variance ratios were detected.

RESULTS

The effects of genetic group of birds and egg size on EW, eggshell characteristics and HP are shown in tables 1 to 3. Genetic group of birds and egg size did not significantly influence the results of MST/CST, MEC/CEC and MEC/EW.

Eggs produced by Leghorn had significantly ($p < 0.01$) lower EW, CST, ESA, SV, MEC, CEC and MST and HP ($p < 0.05$) and higher ($p < 0.01$) PS, SD, CEC/EW, PL and ED than those of eggs produced by Hybro birds (table 3). There was no significant difference in the percentage of fertile eggs (mean \pm SE) between the two genetic groups of birds (Hybro and Leghorn, 93.8 ± 1.8 and 87.9 ± 2.3 , respectively) or among egg sizes (small, medium and large, 92.7 ± 1.8 , 91.8 ± 1.1 and 89.6 ± 2.3 , respectively).

There were positive correlations between EW and MEC (0.599, $p < 0.0006$) and between MEC and CEC (0.598, $p < 0.0006$) and between MST and CST (0.450, $p < 0.014$) in the total number of eggs used from the two genetic groups of birds. Positive correlation between EW and MST (0.520, $p < 0.056$) and SV (0.751, $p < 0.002$) in eggs produced by Hybro birds and negative correlation between EW and SD (-0.735, $p < 0.002$) and PS (-0.828, $p < 0.0001$) in eggs produced by Leghorn birds. Medium size eggs had significantly ($p < 0.01$) higher EW, CST, ESA, SV and CEC and significantly ($p < 0.01$) lower PS, SD, CEC/EW and PD than those of small size of eggs. Small size eggs had significantly ($p < 0.01$) lower EW, CST, ESA, SV, MEC, CEC, ED and LD and higher PS, SD, CEC/EW and PD than those of large eggs.

There were significant interactions ($p < 0.01$) between

Table 1. Egg weight and eggshell characteristics of different sizes of eggs from two genetic groups of birds (meat (Hybro) and layer (Leghorn) breeders)¹

Treatment	Egg weight (g)	Shell (%)	Shell thickness ²			Egg surface area (cm ³)	Shell volume (cm ³)	Shell density (g/cm ³)
			M (mm)	C (mm)	M/C (%)			
Genetic group (GG)								
Hybro (15)	63.4	11.5	0.35	0.34	103.9	75.3	2.63	2.78
Leghorn (15)	53.3**	13.6**	0.33*	0.31**	105.9	67.2**	2.22**	3.26**
SEM ³	0.53	0.37	0.01	0.002	2.5	0.43	0.06	0.07
Egg size (ES)								
Small (10)	51.0 ^c	14.1 ^a	0.33	0.31 ^c	107.9	65.2 ^c	2.15 ^b	3.34 ^a
Medium (10)	60.3 ^b	12.0 ^b	0.35	0.33 ^b	105.6	72.9 ^b	2.55 ^a	2.86 ^b
Large (10)	63.5 ^a	11.5 ^b	0.34	0.34 ^a	101.6	75.6 ^a	2.57 ^a	2.84 ^b
LSD ⁴	1.4	0.97	0.02	0.004	6.6	1.13	0.17	0.19
Probability (P)								
GG	0.0001	0.0001	0.0221	0.0001	0.3863	0.0001	0.0010	0.0001
ES	0.0001	0.0041	0.6241	0.0001	0.2792	0.0001	0.0191	0.0073
GG × ES	0.0714	0.0169	0.1646	0.1752	0.2191	0.1259	0.0916	0.1688

¹ Values are means of the number of replicates given in parentheses.² M=Measured eggshell thickness; C=Calculated eggshell thickness.³ Standard error of means. ⁴ Least significant difference (p<0.05).

* Significant difference (p<0.05), ** Significant difference (p<0.01).

Table 2. Eggshell conductance of different sizes of eggs from two genetic groups of birds (meat (Hybro) and layer (Leghorn) breeders)¹

Treatment	MEC ²		CEC ²		MEC CEC (%)
	MEC (mg day ⁻¹ torr ⁻¹)	MEC/EW ²	CEC (mg day ⁻¹ torr ⁻¹)	CEC/EW ²	
Genetic group (GG)					
Hybro (15)	9.97	15.8	10.98	17.4	90.7
Leghorn (15)	8.56**	16.1	9.60**	18.0**	89.3
SEM ³	0.35	0.62	0.06	0.03	3.5
Egg size (ES)					
Small (10)	8.49 ^a	16.6	9.29 ^c	18.2 ^a	91.4
Medium (10)	9.19 ^{ab}	15.2	10.58 ^b	17.6 ^b	86.7
Large (10)	10.11 ^b	15.9	10.99 ^a	17.4 ^c	91.9
LSD ⁴	0.97	2.0	0.19	0.09	11.5
Probability (P)					
GG	0.0001	0.8464	0.0001	0.0001	0.6915
ES	0.0041	0.4546	0.0001	0.0001	0.5045
GG × ES	0.0169	0.7612	0.1036	0.4522	0.7636

¹ Values are means of the number of replicates given in parentheses.² MEC=Measured eggshell conductance; MEC/EW =MEC/per 100 g egg weight;

CES=Calculated eggshell conductance; CES/EW =CEC/per 100 g egg weight.

³ Standard error of means. ⁴ Least significant difference (p<0.05).

* Significant difference (p<0.05), ** Significant difference (p<0.01).

^{a,b,c} Means within column followed by different superscripts are significantly different (p<0.05).

the genetic group of birds and egg size on PS, MEC, PL, PD, LD and HP (p<0.05) (table 4). There was no significant difference in MEC, HP and LD among the different egg sizes produced by Leghorn birds. However, large egg size of Hybro birds had significantly (p<0.01) higher MEC, PD and LD and lower HP than those of small size eggs produced by the same flock. Large size eggs from Leghorn had significantly (p<0.01) lower PD, PS and higher PL than

those of small size eggs produced by Leghorn birds. Whilst, there was no significant difference in PS and PL between large and small sizes of eggs produced by Hybro birds.

DISCUSSION

Results from this study showed that genetic make up of

birds influenced eggshell characteristics and HP of eggs. The heavy Hybro bird has produced large eggs by 18.9% in comparison with small size Leghorn bird. This has probably altered eggshell structure and influenced EC. Eggs produced by Leghorn birds have higher PS and SD and

Table 3. Hatchability traits of different sizes of eggs from two genetic groups of birds (meat (Hybro) and layer (Leghorn) breeders)¹

Treatment	HP	PL	PD	ED	LD
	(% of fertile eggs)				
Genetic group (GG)					
Hybro (42)	90.7	0.7	1.3	3.5	3.8
Leghorn (42)	82.1*	1.7**	1.6	10.5**	4.1
SEM ²	2.4	0.2	0.2	1.0	0.7
Egg size (ES)					
Small (28)	88.3 ^{ab}	1.2 ^{ab}	2.3 ^a	6.0 ^b	2.2 ^b
Medium (28)	92.3 ^a	0.8 ^b	0.9 ^b	3.9 ^b	2.2 ^b
Large (28)	78.6 ^b	1.6 ^a	1.2 ^b	11.1 ^a	7.4 ^a
LSD ³	8.6	0.7	0.8	3.5	2.4
Probability (P)					
GG	0.0355	0.0006	0.0812	0.0001	0.3207
ES	0.0345	0.0223	0.0042	0.0324	0.0001
GG × ES	0.0490	0.0001	0.0001	0.6200	0.0002

¹ Values are means of the number of replicates given in parenthesis.

² HP=Hatchability percentage; PL=Pips with live embryos; PD=Pips with dead embryos; ED=Early-dead embryos; LD=Late-dead embryos.

³ Standard error of means.

⁴ Least significant difference ($p < 0.05$).

* Significant difference ($p < 0.05$).

** Significant difference ($P < 0.01$).

^{ab} Means within column followed by different superscripts are significantly different ($p < 0.05$).

lower EC by approximately 18.4%, 12.5% and 14.1%, respectively than those produced by Hybro birds. Genetic differences in eggshell quality have been shown to influence EC (Christensen and Nestor, 1994; Christensen et al., 1995). Selection of large size turkey has altered EC (Christensen and McCorkle, 1982) and pore arrangements on eggshell (Christensen, 1983).

EC is determined by its structure components of the eggshell. The variables determining the EC are the diffusion path length (approximated by ST) and the total functional cross-sectional area of the pores (Ar et al., 1974). Measurements of ST showed that there was a non-significant increase in ST, as the size of the egg increased. Tullett and Board (1977) suggested that birds have the ability to change the construction of their eggshells and meet the conductance requirement for different egg sizes. These changes may be achieved via a number of well-defined changes or "scales" made possible by the mode of shell structure. They suggested four major changes for large eggs to alter their EC. Eggs may 1) contain fewer pores per cm², 2) change the area for each pore, 3) change the number of pores or 4) change the ST. It seems that small size eggs are adapted to reduce EC. This adaptation is not related to ST (diffusion path length), since the mean of ST of small size eggs was not different from that of large size eggs (table 1). It is interesting to note that the increase in EC was associated with an increase in the ST, which would have reduced EC, by increasing pore diffusion path. A negative relationship exists between ST and pore concentration (Tullett, 1984; Peebles and Brake, 1987). Thus the increase in EC of large size eggs is associated with disproportionate increase in the total functional pore area.

EC of eggs increased with the size of the egg (small vs. large size eggs). High EC for large eggs will probably promote the loss of extra water and consequently produce a

Table 4. The combined effects of genetic group of birds and egg size on the measured eggshell conductance (MEC), per cent shell (PS), hatchability per cent (HP), pips with live embryos (PL), pips with dead embryos (PD) and late dead embryos (LD) of different sizes of eggs from meat (Hybro) and layer (Leghorn) breeders¹

Treatment		MEC (mg day ⁻¹ torr ⁻¹)	PS (%)	HP	PL	PD	LD
Genetic group	Egg size			(% of fertile eggs)			
Hybro	Small	(5) 8.87 ^{bc}	12.4 ^{bc}	(14) 97.9 ^a	0.8 ^{bc}	0.6 ^c	1.6 ^c
	Medium	(5) 10.15 ^{ab}	10.8 ^d	(14) 98.2 ^a	1.6 ^b	0.4 ^c	1.2 ^c
	Large	(5) 10.87 ^a	11.4 ^{cd}	(14) 76.1 ^b	0.0 ^c	1.9 ^b	8.6 ^a
Leghorn	Small	(5) 8.11 ^c	15.8 ^a	(14) 78.7 ^b	1.6 ^b	4.0 ^a	2.8 ^{bc}
	Medium	(5) 8.23 ^c	13.2 ^b	(14) 86.4 ^{ab}	0.0 ^c	1.4 ^{bc}	3.4 ^{bc}
	Large	(5) 9.36 ^{bc}	11.7 ^{cd}	(14) 81.1 ^b	3.2 ^a	0.5 ^c	6.1 ^{ab}
LSD ²		1.37	1.37	12.2	1.0	1.1	3.4

¹ Values are means of the number of replicates given in parenthesis.

² Least significant difference ($p < 0.05$).

^{abc} Means within column followed by different superscripts are significantly different ($p < 0.05$).

sizable air cell that permits the initiation of lung ventilation. Presumably, this facilitates the transition from chorioallantoic to pulmonary gas exchange (Visschedijk, 1968). The oxygen demand of the embryo prior to internal pipping is greater in large eggs than in small eggs (Rahn et al., 1979). A positive correlation value was reported between the weight of the egg and the weight of the chick hatched from it (Wilson, 1991). In addition, large air cell will allow for the movements necessary for escape of the chick from the egg at hatching (Rahn et al., 1976). The increase in EC of large eggs was not proportional to the increase in weight and surface area of the egg. There was about 7.8 and 6.3 fold increase in EC and egg surface area, respectively, for every tenfold increase in egg weight (large vs. small size eggs). Similar results were reported previously in chickens and turkeys (Nestor et al., 1972; Moran and Reinhart, 1979; Tullett, 1978; Rahn et al., 1981; Peebles and Brake, 1987).

Changes in EC of eggs would alter the amount of water loss and vital gas exchange and consequently HP. Change in vital gas exchange causes an increase in ED mortality, whilst change in water loss from the egg causes an increase in LD (Taylor et al., 1956; Peebles et al., 1987). The reduction in HP of large size eggs was associated with an increase in the percentage of dead embryos (ED and LD). Approximately 60 percent of dead embryos died at early stage of incubation. The reduction of HP of large eggs is related to the high EC of these eggs. This increase may be due to increase in pore density or pore size. The decrease in HP of Leghorn was due to increases in the percentage of ED. The effects of egg size on hatchability traits differed in the two genetic groups. Large egg size from Hybro had lower HP and higher LD than small size eggs produced by the same genetic group. However, there was no egg size effect on HP and LD in eggs produced by Leghorn (table 4). The differences in HP between Leghorn and Hybro resulted, partly, from differences in EC. Comparison of measured and calculated values of EC and ST showed that the measured values were about 90 and 105% of the calculated values for EC and ST, respectively. The calculated values were derived from the allometric equations of Ar et al. (1974) who related EC, ST and total functional shell pore area to egg mass of a large number of bird species. These differences may be related to differences in genetic background of birds (Christensen, 1983; Christensen and McCork, 1982).

Adjusting EC for EW revealed that genetic make up of bird and egg size did not significantly influence MEC/EW value. It appears that large eggs lose more weight per day but proportionally less when expressed on the basis of their initial weight than small eggs. Large eggs have proportionally less surface area to volume ratio than small eggs (Marshall and Cruickshank, 1938). It is more likely

that any variation in the value of MEC/EW will be related to differences in EC rather than to EW. This suggests that factors other than just EC are involved in hatchability performance of eggs. The quality and distribution of pores may be involved in the hatchability traits of large size eggs.

It was concluded that type of bird (heavy or small) and egg size influence eggshell characteristics, EC and hatchability traits of eggs. Genetic make up of bird influences the optimum egg size for successful hatching. EC and EC/EW were not accurate indicators for HP.

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