PRODUCTION, MODELING, AND EDUCATION

Effect of incubation humidity and flock age on hatchability traits and posthatch growth in Pekin ducks

A. M. El-Hanoun,* R. E. Rizk,* E. H. A. Shahein,* N. S. Hassan,* and J. Brake†[1]

*Animal Production Research Institute, Agricultural Research Center, Ministry of Agriculture, Alexandria, Egypt 21311; and †Department of Poultry Science, North Carolina State University, Raleigh 27695-7608

ABSTRACT This study was conducted to determine the effect of incubation relative humidity (RH) from 14 to 24 d of incubation during 3 parental ages on hatchability and posthatching growth of Pekin ducklings. Egg production was divided into 3 age groups (25–35, 36–55, and 56–65 wk). A total of 21,600 hatching eggs was subjected to 55, 60, 65, and 70% RH from 14 to 24 d, whereas standard conditions were used from 0 to 14 d and 24 to 28 d of incubation. All eggs were individually weighed before setting in the incubator and again at 14 and 24 d of incubation to determine egg weight loss. A sample of 20 eggs from unhatched and hatched eggs from each group were randomly taken on the hatching day and used to determine eggshell thickness and pore number. Duckling weight at hatching was recorded and BW gain, feed consumption, feed conversion, and viability were then recorded to 21 d of age. Egg weight increased with hen age but did not differ by incubation treatment. Increasing RH from 55% to 60, 65, and 70% decreased percentage egg weight loss in a stepwise manner irrespective of parental age. Shell thickness was less for hatched eggs compared with nonhatched eggs within each parental age. Shell thickness decreased while pore density increased with increased parental age for both nonhatched and hatched eggs. The lowest embryonic mortality among the incubation periods (14–24 and 0–24 d) and best hatchability of fertile eggs was recorded with 60% RH during the first parental age (25–35 wk), 65% RH during 36–55 wk of age, and 70% RH during 56–65 wk of age. The best incubation results were directly associated with the greatest duckling BW at hatching and at 21 d of age, BW gain, feed conversion, and viability during each parental age period. It was concluded that duck eggs produced within a specific parental age period require a specific incubation RH to attain the best hatchability and posthatching duckling performance.

Key words: incubation, shell thickness, pore density, hatchability, duckling growth

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INTRODUCTION

Eggshell thickness, eggshell water vapor conductance, and pore density are important properties of eggs that influence the success of embryonic development in poultry (Soliman et al., 1994; Balkan et al., 2006). Rokitka and Rahn (1987) mentioned that regional shell conductance and pore density decreased from the blunt end to the pointed end in all avian species. Several other studies have provided evidence that there were regional differences in shell thickness, shell conductance, and pore structure in eggs and these properties changed during incubation (Booth, 1989; Soliman et al., 1994). Balkan et al. (2006) reported that pore density was correlated with hatchability of Pekin duck eggs. The mortality of Pekin duck embryos during the late stages of incubation has been reported to be up to 19.4% as a result of thick eggshells with few pores (El-Hanoun and Mossad, 2008). However, it has also been reported that hatching of duck eggs has been more difficult than that of chicken eggs because of the reported characteristics of large size, thick eggshells, and high numbers of pores (Changkang et al., 1999). The reason for these conflicting data may have been differences in management and nutrition as higher calcium intakes can increase shell thickness, reduce pore numbers, and reduce gaseous exchange (Peebles, 1986), and vice versa. Eggs from young breeders have been reported to possess thick shells and produce smaller chicks, resulting in increased embryo mortality after pipping (Pedroso et al., 2005). Moreover, the lower eggshell conductance of eggs from young breeders has been suggested to result in inadequate movement of water vapor and respiratory gases during the incubation process (Christensen et al., 2005). Furthermore, parent flock age has been reported to influence embryonic metabolism during the latter days of incubation, which coincided with an incidence

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[1]Corresponding author: jbrake@ncsu.edu

of greater embryonic mortality during these periods of incubation (Hamidu et al., 2007).

Most of the energy needed for embryonic development has been shown to be taken from the fat stores of the yolk, and for every gram of fat burned, an almost equal mass of metabolic water has been shown to be generated. Therefore, the relative water content of the egg will increase during incubation unless water is lost (Rahn et al., 1979). It logically followed that proper RH would be important to attaining maximum hatchability (Ar and Rahn, 1980), and manipulation of RH during incubation may be a practical method to optimize embryonic development, hatchability, and posthatching performance by optimizing gas exchange across the eggshell (Peebles, 1986). The objective of the present study was to assess the effect of Pekin duck parental age on hatchability and posthatching duckling growth as influenced by manipulation of RH during 14 to 24 d of incubation, which has been shown to be a period of rapid embryonic development where clear relationships between incubation RH, embryonic development, and posthatching effects might be most easily discerned.

MATERIALS AND METHODS

The present study was conducted during the period from July 2009 to May 2010. Pekin ducks, 25 wk of age at the beginning of the study, had been reared in floor pens under standard husbandry conditions and were fed a standard breeder diet containing 16% CP and 2,825 kcal of ME/kg during this study. The egg production period of 40 wk was divided according to parental age into 3 age groups that represented young, prime, and old flock production (25–35, 36–55, and 56–65 wk, respectively). A total of 21,600 hatching eggs was used. There were 2,400 hatching eggs set 3 times during each parental age period. Eggs were collected daily for 4 d, fumigated, and stored with the pointed end down in a cool room (18°C and 75% RH) before setting in the incubators. Hatching eggs for each of the 9 sets were randomly distributed into 4 equal groups of 600 eggs each. Four similar incubators that electronically controlled temperature and RH were used and sets were rotated among the machines. The traditional temperatures used for all incubators were 37.8°C during the incubation period (0–24 d) and 37.3°C during the hatching period (24–28 d). The traditional RH was 55% from 0 to 14 d and 80% from 24 to 28 d of incubation. The RH during 14 to 24 d of incubation was altered to be 55, 60, 65, or 70% within one of the 4 incubators of each set of eggs to create 4 RH treatments. Eggs were distributed randomly within a single incubator trolley in each machine. As was standard commercial industry practice, all eggs were removed from the incubators for cooling at 30 to 32°C for 15 min twice daily from 14 to 24 d of incubation. Eggs were turned every 2 h to 24 d of incubation. At 24 d of incubation, the eggs were candled, and those with evidence of living embryos were transferred individually into hatching baskets and then placed into hatchers for the remainder of incubation. At 28 d of incubation (hatching day), ducklings that had fully emerged from their shells were removed and weighed. Fertile eggs with embryos that had failed to hatch and those removed at 24 d of incubation were classified by macroscopic examination as dead in shell among 2 incubation periods (0–14 and 14–24 d) or as pipped eggs, which were eggs with ducklings that had not fully emerged from the shell. In most cases the pipped eggs contained ducklings that were deemed to not be able to complete hatching successfully within a reasonable length of time or were already dead. Percentage embryonic mortality, fertility, and hatchability for each treatment group were calculated. Hatched ducklings were then brooded in separate floor pens according to incubation treatment under standard husbandry conditions. Duckling BW, BW gain, feed consumption, feed conversion, and viability were recorded through 21 d of age.

Eggs in each RH treatment group within each parental age were individually numbered and weighed before setting. All eggs were reweighed individually at 14 and 24 d of incubation for calculation of percentage egg weight loss by the following equation: (Initial egg weight − weight of egg on a certain day of incubation period/initial egg weight) × 100. There were 480 eggshells used for measuring shell thickness, with 20 shells from unhatched eggs (embryonic death through all incubation periods) and 20 from hatched eggs from each group and flock age ($20 \times 2 \times 4 \times 3$) taken randomly on each hatching day. Three shell fragments from the blunt, equator, and pointed end of each egg were boiled in a 5% NaOH solution for 10 min to remove organic material and shell membranes, rinsed 3 times in distilled water, and left to dry. Shell thickness was measured with a micrometer capable of 0.01-mm accuracy (Rokitka and Rahn, 1987). Methylene blue (0.5 g of 89% dye/1 L 70% ethanol) was applied to the shell interior and allowed to diffuse through the eggshell such that the pores could be visualized externally (Peebles, 1986). Pores were counted using a dissecting microscope at 2.5× power and expressed as pore number/cm^2 within each eggshell region as described by Booth (1989). No attempt was made to measure pore diameter.

Data were statistically analyzed with SPSS 8 (1997) for Windows. Significant differences among treatment means were partitioned according to Duncan (1955). Statements of statistical significance are based upon $P < 0.05$, unless otherwise stated.

RESULTS AND DISCUSSION

Egg Weight Loss

The effect of parental age and incubational RH on percentage egg weight loss is shown in Table 1. Percentage weight loss increased with parental age for all incubation periods (Table 1) in an age-related manner, which probably simply reflected the greater amount of

Table 1. Percentage egg weight loss of Pekin duck eggs during different incubation periods as influenced by parental age and incubation humidity

Parental age (wk)	Incubation RH (14–24 d)	Incubation period (%)		
		0−14 d	14−24 d	0−24 d
25–35	55	3.48 ± 0.01	7.12 ± 0.01[a]	10.45 ± 0.05[a]
	60	3.47 ± 0.01	7.00 ± 0.02[b]	10.23 ± 0.02[b]
	65	3.50 ± 0.01	6.40 ± 0.02[c]	9.68 ± 0.02[c]
	70	3.46 ± 0.01	6.23 ± 0.02[d]	9.48 ± 0.02[d]
	Age mean	3.48 ± 0.01[c]	6.69 ± 0.02[c]	9.96 ± 0.02[c]
36–55	55	3.88 ± 0.01	8.65 ± 0.02[a]	12.22 ± 0.02[a]
	60	3.91 ± 0.01	8.23 ± 0.02[b]	11.83 ± 0.02[b]
	65	3.89 ± 0.01	7.82 ± 0.02[c]	11.41 ± 0.02[c]
	70	3.90 ± 0.01	7.43 ± 0.02[d]	11.04 ± 0.02[d]
	Age mean	3.89 ± 0.01[b]	8.03 ± 0.01[b]	11.63 ± 0.01[b]
56–65	55	4.22 ± 0.01	9.99 ± 0.02[a]	13.79 ± 0.02[a]
	60	4.20 ± 0.01	9.67 ± 0.02[b]	13.47 ± 0.02[b]
	65	4.21 ± 0.01	9.24 ± 0.02[c]	13.07 ± 0.02[c]
	70	4.24 ± 0.01	8.93 ± 0.02[d]	12.79 ± 0.02[d]
	Age mean	4.21 ± 0.01[a]	9.46 ± 0.01[a]	13.28 ± 0.01[a]

[a–d]Means ± SE within each column within each parental age or for overall parental age means with different superscripts are significantly different ($P \leq 0.05$).

water in the larger eggs. However, there were no differences in egg weight loss among any of the groups of eggs intended for the various RH treatments during the 0 to 14-d incubation period at any parental age when the RH was 55% in all machines. Thus, standard conditions produced equivalent results to 14 d of incubation. These data, and the absence of differences in early dead embryos to 14 d as shown in Table 2, suggest that there were no great differences in the eggs and eggshells before the beginning of the RH treatment period. As might be expected, increasing RH from 55% to 60, 65, and 70% during 14 to 24 d of incubation produced a remarkably consistent stepwise significant decrease in percentage weight loss during that time and from 0 to 24 d as well. It has been established that incubation RH regulates weight or water loss of eggs during incubation (Lundy, 1969; Meir et al., 1984). The present data suggested that there was a relationship between incubation RH and the conductive capacity of the shell by which variation in RH of the incubator directly influenced the rate of water loss from Pekin duck eggs. This finding compared favorably with the results of Burton and Tullett (1985), who indicated that both incubation RH and eggshell conductance controlled the evaporative water loss from chicken eggs. Also, Swann and Brake (1990) showed that chicken egg water loss was affected by the RH directly through the establishment of a water vapor pressure gradient. Abd-Allah et al. (1995) reported that percentage chicken egg weight loss exhibited a significant decrease due to an increase in RH. Evidence from Table 1 also showed that Pekin duck parental age had significant effects on egg weight loss irrespective of incubation period and RH as percentage egg weight loss was increased stepwise with increase in parental age, which would reflect the decreasing surface area to egg volume (embryo weight) situation with larger eggs (Peebles, 1986) that necessitated a thinner shell (shorter pore) as part of a compensatory mechanism. In fact, as shown in Table 3, this was indeed what occurred.

Eggshell Thickness

The relationship between parental age and incubation RH from 14 to 24 d of incubation as they related to eggshell thickness of nonhatched and hatched eggs is shown in Table 3. Eggshell thickness for all eggshell regions was significantly decreased in a stepwise manner with increased parental age for either nonhatched or hatched eggs. Studies in chickens have shown the same trend (Rizk et al., 2008). Moreover, hatched eggs exhibited lower overall shell thickness (shorter pore length) compared with nonhatched eggs within each parental age. There was also regional variation in shell thickness in either nonhatched or hatched Pekin duck eggs. In hatched eggs, the shell was numerically thicker at the pointed end compared with that for the equator across all parental ages. Whereas, the data of the hatched eggs showed that the pointed end of the eggshell became thinner than that of the blunt end. This result was in keeping with those reported previously in Pekin duck eggs by Balkan et al. (2006), who showed that this change could be due to altered calcium uptake by the embryo, which would have been due either directly or indirectly to RH in the present experiment. The percentage eggshell thickness for hatched eggs compared with those for nonhatched eggs was reduced by 7.53, 6.99, and 5.76% for successive parental ages (25–35, 36–55, and 56–65 wk, respectively), which may mean that the successful embryos removed more calcium from the eggshell in a manner similar to that previously documented in Pekin ducks (Balkan et al., 2006) and other species (Booth, 1989; Soliman et al., 1994) as the result of being in the presence of an incubational RH that best facilitated embryonic development. The fact that there were no differences in weight loss (Table 1) or

Table 2. Embryonic mortality at different incubation periods, fertility, and hatchability of Pekin duck eggs as influenced by parental age and incubation humidity

Parental age (wk)	Incubation RH (14–24 d)	Embryonic mortality			Pipped eggs (%)	Fertility	Hatchability of fertile eggs	Hatchability of total eggs
		0–14 d	14–24 d	0–24 d				
25–35	55	4.58 ± 0.27	7.08 ± 0.11^{a}	11.93 ± 0.23^{a}	14.56 ± 0.21^{a}	84.72 ± 0.34	73.48 ± 0.29^{d}	62.28 ± 0.31^{b}
	60	4.29 ± 0.24	4.68 ± 0.28^{c}	8.97 ± 0.14^{c}	10.36 ± 0.35^{c}	84.22 ± 0.31	80.71 ± 0.31^{a}	67.94 ± 0.31^{a}
	65	4.39 ± 0.15	5.90 ± 0.31^{b}	10.29 ± 0.28^{b}	11.34 ± 0.31^{c}	84.78 ± 0.56	78.42 ± 0.46^{b}	66.44 ± 0.89^{a}
	70	4.62 ± 0.16	6.87 ± 0.22^{ab}	11.50 ± 0.19^{a}	12.75 ± 0.36^{b}	84.11 ± 0.65	75.76 ± 0.72^{c}	63.72 ± 0.95^{b}
	Age mean	4.47 ± 0.12^{a}	6.13 ± 0.29^{a}	10.67 ± 0.36^{a}	12.25 ± 0.49^{a}	84.46 ± 0.22^{c}	77.12 ± 0.44^{c}	65.10 ± 0.73^{c}
36–55	55	3.91 ± 0.20	6.06 ± 0.39^{a}	9.97 ± 0.56^{a}	11.54 ± 0.40^{a}	88.06 ± 0.40	78.03 ± 0.58^{c}	68.72 ± 0.75^{c}
	60	3.85 ± 0.16	4.67 ± 0.04^{b}	8.52 ± 0.19^{b}	10.41 ± 0.13^{b}	88.06 ± 0.46	81.16 ± 0.39^{b}	71.39 ± 0.40^{b}
	65	3.88 ± 0.09	3.65 ± 0.14^{c}	7.53 ± 0.24^{c}	7.31 ± 0.23^{d}	88.17 ± 0.59	86.11 ± 0.40^{a}	75.83 ± 0.26^{a}
	70	3.90 ± 0.08	4.61 ± 0.21^{b}	8.51 ± 0.26^{b}	9.28 ± 0.17^{c}	88.00 ± 0.75	82.24 ± 0.72^{b}	72.33 ± 0.86^{b}
	Age mean	3.89 ± 0.16^{b}	4.75 ± 0.28^{b}	8.63 ± 0.42^{b}	9.64 ± 0.48^{b}	88.07 ± 0.24^{a}	81.79 ± 0.63^{a}	72.07 ± 0.81^{a}
56–65	55	3.85 ± 0.21	6.00 ± 0.42^{a}	9.85 ± 0.56^{a}	13.75 ± 0.25^{a}	85.22 ± 0.68	75.88 ± 0.61^{c}	64.72 ± 0.64^{c}
	60	3.86 ± 0.13	5.17 ± 0.28^{ab}	9.03 ± 0.39^{b}	12.39 ± 0.35^{b}	86.11 ± 0.95	78.16 ± 0.86^{bc}	67.33 ± 1.17^{bc}
	65	3.74 ± 0.11	4.99 ± 0.62^{ab}	8.73 ± 0.57^{c}	11.15 ± 0.39^{c}	84.72 ± 0.59	80.09 ± 0.92^{b}	67.89 ± 1.16^{b}
	70	3.82 ± 0.17	4.04 ± 0.17^{b}	7.86 ± 0.33^{d}	9.39 ± 0.31^{d}	85.22 ± 0.15	83.16 ± 0.32^{a}	70.89 ± 0.43^{a}
	Age mean	3.82 ± 0.13^{b}	5.05 ± 0.27^{ab}	8.87 ± 0.38^{b}	11.67 ± 0.51^{a}	85.32 ± 0.32^{b}	79.46 ± 0.63^{b}	67.71 ± 0.77^{b}

$^{a–d}$Means within each column within each parental age or for overall parental age means with different superscripts are significantly different ($P \leq 0.05$).

early embryo deaths (Table 2) before starting the RH treatments supports this line of thought. However, one should remember that eggshell mass was greater with increasing parental age so that there would have been more calcium carbonate to draw upon, which would have influenced the percentages indicated above. Tuan (1987) stated that toward the end of incubation, calcium was dissolved from the shell and presumably diffused through a liquid water film covering the surface of the fibers of the inner and outer membranes to the chorioallantoic membrane where it was actively transported into the blood stream. This calcium was used by the embryo to ossify the developing skeleton (Packard and Packard, 1984). The presence of an optimum incubational RH and gaseous exchange environment that contributed to optimum embryonic development was also suggested by the simple fact that the ducklings from RH treatments that hatched the best also performed the best posthatching (Table 4). Obviously, optimum skeletal development to support locomotor activity required for feeding would be pivotal to posthatching success.

The importance of shell thickness (pore length) has been documented by different authors. Koneva (1968) found that the contribution of shell thickness of turkey eggs to their hatchability was around 40%. In a study of goose eggs, Tsarenko et al. (1978) reported that hatchability of eggs with thicker shells was 20% higher. Kurova (1986) presented data indicating that chicken eggs with extremely thick or thin shells resulted in increased embryonic mortality when compared with embryonic mortality from eggs of average thick-

Table 3. Eggshell thickness in different regions of Pekin duck eggs from nonhatched and hatched eggs as influenced by parental age and incubation humidity

Parental age (wk)	Incubation RH (14–24 d)	Eggshell thickness (μm)							
		Nonhatched egg regions				Hatched egg regions			
		Blunt	Equator	Pointed	Mean	Blunt	Equator	Pointed	Mean
25–35	55	424 ± 0.9^{c}	442 ± 1.2^{b}	462 ± 1.0^{a}	443 ± 1.0^{x}	418 ± 0.9^{a}	401 ± 1.4^{b}	410 ± 1.2^{ab}	410 ± 1.1^{y}
	60	419 ± 0.9^{c}	440 ± 1.0^{b}	461 ± 1.1^{a}	440 ± 0.9^{x}	414 ± 1.0^{a}	397 ± 1.3^{c}	406 ± 1.2^{b}	406 ± 1.2^{y}
	65	415 ± 1.0^{c}	436 ± 1.2^{b}	455 ± 1.0^{a}	435 ± 1.0^{x}	412 ± 1.0^{a}	395 ± 1.2^{c}	404 ± 1.1^{b}	404 ± 1.1^{y}
	70	413 ± 0.9^{c}	433 ± 1.0^{b}	453 ± 0.8^{a}	433 ± 0.9^{x}	409 ± 1.3^{a}	394 ± 1.4^{b}	402 ± 1.3^{ab}	402 ± 1.3^{y}
	Age mean	418 ± 0.5^{a}	438 ± 0.6^{a}	458 ± 0.5^{a}	438 ± 0.5^{a,x}	413 ± 0.6^{a}	397 ± 0.7^{a}	406 ± 0.6^{a}	405 ± 0.6^{a,y}
36–55	55	414 ± 0.8^{c}	432 ± 0.9^{b}	452 ± 0.9^{a}	433 ± 0.8^{x}	412 ± 0.9^{a}	394 ± 1.4^{c}	404 ± 1.1^{b}	403 ± 1.1^{y}
	60	412 ± 0.9^{c}	431 ± 0.9^{b}	450 ± 1.0^{a}	431 ± 0.9^{x}	409 ± 1.0^{a}	391 ± 1.0^{b}	401 ± 1.0^{ab}	401 ± 0.9^{y}
	65	409 ± 0.9^{c}	428 ± 1.0^{b}	448 ± 0.9^{a}	428 ± 0.9^{x}	406 ± 1.0^{a}	389 ± 1.0^{c}	399 ± 1.0^{b}	398 ± 1.0^{y}
	70	406 ± 0.8^{c}	424 ± 1.7^{b}	443 ± 1.9^{a}	429 ± 1.4^{x}	403 ± 1.2^{a}	387 ± 1.2^{c}	396 ± 1.2^{b}	396 ± 1.2^{y}
	Age mean	410 ± 0.4^{b}	429 ± 0.6^{b}	448 ± 0.6^{b}	429 ± 0.5^{b,x}	408 ± 0.5^{b}	391 ± 0.6^{b}	400 ± 0.5^{b}	399 ± 0.5^{b,y}
56–65	55	389 ± 1.6^{c}	406 ± 1.8^{b}	420 ± 2.8^{a}	405 ± 1.9^{x}	386 ± 1.6^{a}	374 ± 1.6^{b}	381 ± 1.9^{ab}	380 ± 1.6^{y}
	60	385 ± 1.7^{c}	402 ± 1.8^{b}	417 ± 2.6^{a}	401 ± 1.9^{x}	383 ± 1.6^{a}	371 ± 1.5^{b}	378 ± 1.5^{ab}	377 ± 1.5^{y}
	65	382 ± 1.7^{c}	396 ± 2.1^{b}	413 ± 2.1^{a}	397 ± 1.9^{x}	381 ± 1.7^{a}	370 ± 1.6^{b}	376 ± 1.6^{ab}	376 ± 1.6^{y}
	70	379 ± 1.6^{c}	395 ± 1.7^{b}	409 ± 1.7^{a}	394 ± 1.6^{x}	377 ± 1.6^{a}	366 ± 1.7^{b}	372 ± 1.6^{ab}	372 ± 1.6^{y}
	Age mean	384 ± 0.8^{c}	400 ± 0.9^{c}	415 ± 1.2^{c}	399 ± 0.9^{c,x}	382 ± 0.8^{c}	370 ± 0.8^{c}	377 ± 0.8^{c}	376 ± 0.8^{c,y}

$^{a–c}$Means ± SE within each column within each parental age or for overall parental age means with different superscripts are significantly different ($P \leq 0.05$).

^{x,y}Region means with different superscripts within each row are significantly different ($P \leq 0.05$).

Table 4. Body weight at hatching, BW gain, feed consumption, feed conversion, and viability rate of Peking ducklings through the brooding period (0–21 d of age) as influenced by parental age and incubation humidity

Parental age period (wk)	Relative incubation humidity (14–24 d)	Initial egg weight	BW (g)			Feed consumption (g/bird)	Feed conversion (g:g)	Viability rate (%)
			At hatching	At 21 d	Gain			
25–35	55	67.4 ± 0.34	44.26 ± 0.18^{d}	688.15 ± 2.93^{d}	643.89 ± 2.92^{d}	1,247.66 ± 28.23^{a}	1.93 ± 0.026^{a}	87.16 ± 0.64^{b}
	60	68.7 ± 0.29	48.64 ± 0.26^{a}	741.92 ± 4.52^{a}	693.27 ± 4.50^{a}	1,143.33 ± 7.79^{c}	1.64 ± 0.003^{d}	92.33 ± 0.85^{a}
	65	67.2 ± 0.41	46.57 ± 0.21^{b}	717.73 ± 4.16^{b}	671.16 ± 4.13^{b}	1,174.00 ± 5.85^{bc}	1.75 ± 0.005^{c}	91.10 ± 1.36^{a}
	70	67.9 ± 0.33	45.45 ± 0.18^{c}	704.07 ± 3.83^{c}	658.62 ± 3.83^{c}	1,207.33 ± 13.22^{ab}	1.83 ± 0.006^{b}	90.06 ± 0.75^{ab}
	Overall mean	67.8 ± 0.35^{c}	46.23 ± 0.12^{C}	712.97 ± 2.08^{C}	666.73 ± 2.05^{C}	1,193.08 ± 13.61^{C}	1.79 ± 0.032	90.29 ± 0.73^{B}
35–55	55	73.4 ± 0.40	49.01 ± 0.24^{d}	713.96 ± 3.70^{d}	664.94 ± 3.71^{d}	1,279.66 ± 7.51^{a}	1.92 ± 0.088^{a}	91.60 ± 0.32^{c}
	60	74.2 ± 0.34	50.60 ± 0.24^{c}	742.33 ± 3.67^{c}	691.72 ± 3.69^{c}	1,260.33 ± 2.90^{b}	1.82 ± 0.018^{b}	93.63 ± 0.12^{b}
	65	73.0 ± 0.51	53.21 ± 0.15^{a}	776.85 ± 3.71^{a}	723.63 ± 3.68^{a}	1,236.33 ± 1.45^{c}	1.70 ± 0.017^{c}	96.46 ± 0.37^{a}
	70	73.1 ± 0.46	51.21 ± 0.17^{b}	756.51 ± 3.86^{b}	705.30 ± 3.83^{b}	1,240.00 ± 3.60^{c}	1.76 ± 0.020^{c}	93.53 ± 0.47^{b}
	Overall mean	73.4 ± 0.41^{b}	51.01 ± 0.12^{B}	747.41 ± 2.05^{B}	696.40 ± 2.02^{B}	1,254.08 ± 5.57^{B}	1.80 ± 0.025	93.80 ± 0.54^{A}
55–65	55	76.4 ± 0.36	50.71 ± 0.21^{d}	735.71 ± 2.73^{d}	684.99 ± 2.71^{d}	1,334.66 ± 4.84^{a}	1.95 ± 0.005^{a}	88.50 ± 0.25^{d}
	60	77.5 ± 0.44	51.75 ± 0.14^{c}	764.95 ± 2.91^{c}	713.19 ± 2.91^{c}	1,316.33 ± 2.33^{ab}	1.84 ± 0.008^{b}	90.46 ± 0.26^{c}
	65	76.7 ± 0.37	52.55 ± 0.13^{b}	780.25 ± 4.77^{b}	725.98 ± 4.78^{b}	1,306.00 ± 6.08^{ab}	1.80 ± 0.008^{c}	91.30 ± 0.05^{b}
	70	76.9 ± 0.41	54.26 ± 0.12^{a}	803.75 ± 3.27^{a}	751.19 ± 3.26^{a}	1,280.00 ± 7.01^{b}	1.73 ± 0.008^{d}	93.62 ± 0.28^{a}
	Overall mean	76.9 ± 0.38^{a}	52.32 ± 0.09^{A}	771.16 ± 1.98^{A}	718.84 ± 1.96^{A}	1,313.16 ± 8.46^{A}	1.82 ± 0.023	91.17 ± 0.55^{B}

$^{a–d}$Means ± SE within each column within each parental age or for overall parental age means with different superscripts are significantly different ($P \leq 0.05$).

$^{A–C}$Overall means ± SE with different superscripts within each column are significantly different ($P \leq 0.01$) for overall parental age means.

ness. Peebles (1986) detailed changes in broiler hatching eggs that demonstrated how the thick eggshells and associated reduced pore number of young breeder flocks as well as shells that were not thin enough (pores not short enough) to fully compensate for the reduced shell surface area (respiratory surface) to egg weight (embryo weight) ratio in older breeder flocks contributed to reduced hatchability at those breeders ages.

Pore Density

The relationship between parental age and incubation RH as they related to the pore density of egg shells of nonhatched and hatched eggs is shown in Table 5. Pore density significantly increased with increased parental age for both nonhatched or hatched eggs. This was consistent with the compensatory requirement to increase gas exchange capacity as the surface area to egg weight ratio decreased (Peebles 1986), which was evidently linked to decreasing shell thickness (Table 3). Pore density was lowest in the equatorial region and highest in the blunt end for nonhatched eggs within each incubation RH among all parental ages. However, in hatched eggs, pore density was greatest in the equatorial region followed by the blunt end and finally by the pointed egg region among all parental ages. Regional variation in pore density has been correlated with regional differences in eggshell gas conductance in several avian species (Rokitka and Rahn, 1987; Booth, 1989). This outcome agreed with the data previously reported in Pekin duck eggs by Balkan et al. (2006).

It may be hypothesized that some pores were plugged inside the shell surface when the egg was laid and that during incubation, the shell thinning process presumably led to the unplugging of these pores, making them functional. It may be that the inside mouths of plugged pores contained loosely packed crystals of calcium carbonate that were dissolved away during incubation (Booth, 1989). Also, hatched eggs exhibited greater overall pore concentration compared with nonhatched eggs among all parental ages. These percentage increments of pore concentration were 3.49, 4.10, and 3.44% for the 3 parental age periods (25–35, 36–55, and 56–65 wk), respectively. The results indicated that pore density was greater for hatched eggs compared with nonhatched eggs with advances in parental age. The differences in shell porosity between hatched and nonhatched eggs confirmed previous reports that defined shell porosity as one of the features of shell structure that most greatly influenced gas exchange of the developing embryo and affected hatchability (Burton and Tullett, 1985; Soliman et al., 1994; Sahan et al., 2003). Nevertheless, in both the case of shell thickness (pore length) and pore number, it was not possible to distinguish between eggs that would and would not hatch before setting, so it was unknown exactly how much shell thickness and porosity changed during incubation for these 2 groups. It remains unknown if the differences observed at hatching reflected differences that were present before incubation or were created during incubation, as indicated by other authors as detailed above, or if the differences were a combination of both preexisting and treatment differences.

Embryonic Mortality, Fertility, and Hatchability

The effects of parental age and RH during incubation on fertility, embryo mortality, and hatchability are shown in Table 2. Embryonic deaths during 0 to 14 d of incubation were significantly decreased from 4.47% during 25 to 35 wk of age to 3.89% and 3.82% for the 36 to 55 and 56 to 65 wk of age periods, respectively. Embryo deaths during 14 to 24 d of incubation were

Table 5. Pore density in different regions of Pekin duck eggs in nonhatched and hatched eggs as influenced by parental age and incubation humidity

		Pore density (pores/cm^2)							
		Nonhatched egg regions				Hatched egg regions			
Parental age (wk)	Incubation RH (14–24 d)	Blunt	Equator	Pointed	Mean	Blunt	Equator	Pointed	Mean
25–35	55	127.0 ± 0.8^{a}	107.3 ± 0.8^{c}	118.4 ± 0.8^{b}	117.6 ± 0.7^{y}	121.1 ± 0.8^{b}	131.0 ± 0.9^{a}	111.1 ± 0.7^{c}	121.1 ± 0.8^{x}
	60	126.6 ± 0.8^{a}	107.3 ± 0.7^{c}	118.4 ± 0.7^{b}	117.4 ± 0.7^{y}	122.8 ± 0.7^{b}	131.6 ± 0.8^{a}	112.0 ± 0.6^{c}	122.2 ± 0.7^{x}
	65	126.3 ± 0.7^{a}	107.2 ± 0.7^{c}	118.9 ± 0.6^{b}	117.5 ± 0.6^{y}	122.4 ± 0.7^{b}	131.6 ± 0.7^{a}	111.7 ± 0.6^{c}	121.9 ± 0.6^{x}
	70	126.4 ± 0.6^{a}	107.8 ± 0.7^{c}	119.3 ± 0.6^{b}	117.8 ± 0.6^{y}	122.1 ± 0.6^{b}	131.1 ± 0.7^{a}	111.5 ± 0.5^{c}	121.6 ± 0.6^{x}
	Age mean	126.6 ± 0.4^{c}	107.4 ± 0.4^{c}	118.7 ± 0.3^{c}	117.6 ± 0.3^{c,y}	122.1 ± 0.3^{c}	131.3 ± 0.4^{c}	111.6 ± 0.3^{c}	121.7 ± 0.3^{c,x}
36–55	55	136.1 ± 0.4^{a}	115.4 ± 0.4^{c}	127.0 ± 0.4^{b}	126.2 ± 0.4^{y}	132.9 ± 0.6^{b}	141.8 ± 0.5^{a}	120.0 ± 0.4^{c}	131.6 ± 0.5^{x}
	60	137.2 ± 0.4^{a}	116.3 ± 0.4^{c}	128.2 ± 0.4^{b}	127.2 ± 0.4^{y}	134.1 ± 0.6^{b}	142.9 ± 0.4^{a}	120.9 ± 0.4^{c}	132.6 ± 0.5^{x}
	65	136.2 ± 0.5^{a}	115.4 ± 0.4^{c}	127.5 ± 0.5^{b}	126.3 ± 0.4^{y}	132.5 ± 0.6^{b}	141.4 ± 0.5^{a}	119.6 ± 0.4^{c}	131.1 ± 0.5^{x}
	70	136.8 ± 0.4^{a}	115.8 ± 0.4^{c}	128.2 ± 0.4^{b}	127.0 ± 0.4^{y}	134.1 ± 0.6^{b}	142.9 ± 0.4^{a}	120.4 ± 0.4^{c}	132.4 ± 0.4^{x}
	Age mean	136.6 ± 0.2^{b}	115.7 ± 0.2^{b}	127.7 ± 0.2^{b}	126.7 ± 0.2^{b,y}	133.4 ± 0.3^{b}	142.3 ± 0.2^{b}	120.3 ± 0.2^{b}	131.9 ± 0.2^{b,x}
56–65	55	150.2 ± 0.6^{a}	126.1 ± 0.5^{c}	141.9 ± 0.5^{b}	139.4 ± 0.5^{y}	145.9 ± 0.6^{b}	155.1 ± 0.7^{a}	130.6 ± 0.7^{c}	143.9 ± 0.6^{x}
	60	150.0 ± 0.6^{a}	125.5 ± 0.5^{c}	141.7 ± 0.6^{b}	139.0 ± 0.6^{y}	146.2 ± 0.6^{b}	155.4 ± 0.6^{a}	130.0 ± 0.5^{c}	143.8 ± 0.5^{x}
	65	150.3 ± 0.5^{a}	125.8 ± 0.4^{c}	141.9 ± 0.5^{b}	139.4 ± 0.4^{y}	146.5 ± 0.6^{b}	155.8 ± 0.7^{a}	131.1 ± 0.6^{c}	144.5 ± 0.6^{x}
	70	150.3 ± 0.6^{a}	125.6 ± 0.5^{c}	142.0 ± 0.6^{b}	139.3 ± 0.6^{y}	146.4 ± 0.6^{b}	155.5 ± 0.6^{a}	130.3 ± 0.6^{c}	144.0 ± 0.6^{x}
	Age mean	150.2 ± 0.3^{a}	125.8 ± 0.2^{a}	141.9 ± 0.3^{a}	139.3 ± 0.3^{a,y}	146.2 ± 0.3^{a}	155.4 ± 0.3^{a}	130.5 ± 0.3^{a}	144.1 ± 0.3^{a,x}

$^{a–c}$Means ± SE within each column within each parental age or for overall parental age means with different superscripts are significantly different ($P \leq 0.05$).

^{x,y}Region means with different superscripts within each row are significantly different ($P \leq 0.05$).

greater at 25 to 35 wk of age than at 36 to 55 wk of age with the 56 to 65 wk of age period intermediate. During 0 to 24 d of incubation, embryonic deaths were greater for the young flock eggs (25 to 35 wk of age) than during the following 2 parental age periods. Pipped eggs were greater in the 25 to 35 and 56 to 65 wk of parental age periods than at the 36 to 55 wk of age period. Thus, hatchability of fertile eggs as well as hatchability of total eggs was greatest for the prime flock at 36 to 55 wk of age, as expected, followed by the older flock age and finally by the younger flock age. Fertility followed the same statistical trend. The higher embryonic mortality of eggs from young parents may be due to their thicker shell that probably arises from a high intake of calcium relative to eggshell surface area (Peebles, 1986). Because the shells of eggs from young parents are thick and because embryonic metabolism, such as lipid utilization and respiration, increases with embryonic growth (Mcloughlin and Gous, 1999), there may be insufficient pores to support optimum nutrient assimilation, which could negatively affect embryo development and the hatching process.

Embryonic mortality during the 14 to 24 and 0 to 24 d of incubation periods was affected by changing the RH during each parental age in a differential manner (Table 2). Percentage pipped eggs was significantly affected by parental age and RH, within parental age. Irrespective of incubation RH, the percentage pipped eggs was greater at 25 to 35 and 56 to 65 wk of parental age than during 36 to 55 wk. The highest percentage pipped eggs was observed with 55% RH at all parental ages while the lowest percentage pipped eggs was observed at 60 and 65%, 65%, and 70% RH for parental ages of 25–35, 36–55, and 56–65 wk, respectively. Thus, statistically superior hatchability of fertile eggs was found with 60% RH during the young parental age (25–35 wk), 65% RH during the prime 36 to 55 wk of age period, and with 70% RH during the older 56 to 65 wk of age period. This overall effect generally reflected the mortality trends observed for 14 to 24 d and 0 to 24 d incubation periods and pipped eggs. These hatchability data clearly suggested that within each parental age there was a need to adjust incubation humidity to attain the best hatchability. Peebles et al. (1987) also suggested that manipulation of incubation humidity may improve hatchability.

There has been adequate evidence to support the concept that either excessive or insufficient RH during Pekin duck egg incubation exerted a parental age-related influence on the rate of late embryonic mortality, as clearly demonstrated by the present data. Landauer (1967) and Lundy (1969) indicated that the amount of water lost from an egg influenced the rate of embryo mortality. Likewise, Christensen and McCorkle (1982) suggested that embryonic mortality may increase due to a failure of the embryo to lose water at an appropriate rate. Swann (1989) postulated that decreased eggshell conductance had its greatest effect due to the absence of an embryonic compensatory mechanism. The present results clearly demonstrated that RH during the 14 to 24 d of incubation period should be changed according to parental age and the present data provide evidence of exactly what the optimum rate of water loss should be at various breeder ages.

Duckling Performance

The effects of parental age and incubation RH on initial egg weight, duckling BW at hatching and at 21 d of age, BW gain, feed consumption, feed conversion, and viability to 21 d of age are shown in Table 4. Egg weight increased with hen age but did not differ by

incubation treatment. Duckling BW at hatching and at 21 d of age as well as BW gain were significantly increased by increased parental age. The present results showing a positive trend between duckling growth and parental age that were in agreement with those reported in ducks by Braun et al. (2002). Shanawany (1987) suggested that this trend may be due to various factors. Eggs from older flocks are larger in size and the embryos used yolk nutrients for growth more effectively than those from young parents. Also, parents become more efficient in depositing essential embryonic nutrients with increasing parental age. Knizetova et al. (1982) also determined that Pekin duckling weight at hatching was positively correlated with early posthatching growth. In the present study, it was also clear that larger ducklings produced from older breeders simply consumed more feed and thus grew larger (Table 4). The increased feed consumption with increased parental age in this study was similar to the report of Braun et al. (2002) with Pekin ducks. However, duckling feed conversion was not significantly affected by parental age. Nevertheless, the best viability was exhibited by the prime parental age (36–55 wk) ducklings that probably had experienced the most appropriate incubation. The results of viability rate in this work were in partial agreement with those reported by Washburn and Guill (1974) and McNaughton et al. (1978) that mortality rate appeared to be higher in chicks from young chicken breeders. Also, Braun et al. (2001) reported that mortality was highest in ducklings from young breeders. The present results were slightly different in that viability of the ducklings initially increased with increased parental age and then decreased again at the older parental age. Different explanations have been given for the poorer results from young parents. Noble et al. (1986) suggested that this may be associated with a malfunction of yolk lipid assimilation and mobilization. Christensen et al. (2005) found that the lower eggshell conductance of eggs produced by young breeders resulted in inadequate movement of water vapor and respiratory gases during the incubation process. Pedroso et al. (2005) reported that eggs from young breeders had thicker eggshells and produced smaller chicks that had less physical strength to break the shell during hatching, resulting in embryo mortality after pipping. Hamidu et al. (2007) showed that parent flock age influenced daily embryonic metabolism during the latter days of incubation, which coincided with the incidence of greater embryonic mortality during these periods of incubation.

However, if one considers BW at hatching, BW at 21 d of age, BW gain, feed conversion, and viability (Table 4) and compares these results to those of fertile hatchability shown in Table 2, it was absolutely clear that the incubation RH within each parental age that produced the best fertile hatchability also produced the best duckling performance to 21 d of age. Ducklings produced from eggs subjected to 60% RH during the young parental age (25–35 wk), 65% RH during the prime parental age (36–55 wk), and 70% RH during the older parental age period (56–65 wk) exhibited both the best fertile hatchability and live performance posthatching. Moreover, ducklings produced from eggs subjected to 55% RH consumed the greatest amount of feed and exhibited the poorest feed conversion among all parental ages. Viability was also reduced by the 55% RH. Shahein (2002) reported that effect of low incubation RH on posthatching growth and viability could be explained through 2 means. The first one was chick dehydration and loss of chick weight that negatively affected subsequent growth and viability. The second one was attributed to the direct effect of RH during the setting phase on the rate of water vapor loss and consequently on embryo development and duckling weight. This conclusion confirmed the finding of Swann (1989), who reported that loss of chick weight due to inappropriate incubation RH may never be regained due to the age when broilers are marketed.

It was clear from these data that the rate of egg weight loss percentage in Pekin duck eggs was controlled to a great extent by RH from 14 to 24 d of incubation and was linked to parental age. It was clear that selection of an appropriate RH during incubation within each parental age to achieve optimum weight loss, hatchability, and posthatching live performance would be an important aspect of management of duck incubation.

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