Abstract

FUNDERBURK, SARAH LYNN. Egg Size, Eggshell Conductance and Incubation Temperature Influences on Maturity of Commercial Turkey Poults. (Under the direction of Vern L. Christensen).

The purpose of this study was to describe characteristics of the egg and incubation conditions that may improve the viability of turkey poults at the time they are placed in brooders.

In part one, the objective was to measure the size of the egg and the eggshell conductance and their effects on poult viability. After recording an initial egg weight prior to incubation, the eggshell conductance (G) of large and small eggs was determined following weighing at d25 (transfer) of incubation. Eggs were then sorted according to G group (Low, Average and High) and placed randomly into the incubator for hatching. At hatching poults were identified by treatment group and mortality was recorded until Day 7 of the brooding period. BW were taken at Day 1 and Day 4 post placement. Egg size and conductance, as well as, egg size and poult sex interacted to affect BW at Day 1 and Day 4. The best quality poult came from a large egg with Low eggshell conductance and conversely poor quality poults came from small eggs with a Low conductance.

In part two, two trials determined the effects of G and incubation temperature on poult maturation. Using eggs from an induced molted flock and a first cycle flock, G of eggs incubated under two temperature profiles (high temperature profile (HP) or low temperature profile (LP)) was calculated. Poults from each treatment were followed for growth, intestinal maturation and thyroid function. The best quality poult came from an egg incubated at a HP. The overall worst quality poults came from eggs with Low G regardless of incubation profile. Among eggs from an induced molted flock and a new

flock the temperature throughout incubation and the G influenced the maturity of the turkey poult during the brooding period.

In part three, using two trials the effect of sex combined with G and incubation temperature profile on the ability of a poult to mature were observed. Using eggs from an induced molted flock and a first cycle flock, G of eggs incubated under two temperature profiles (HP or LP) was calculated. At hatching poults were marked according to treatment group and vent sexed. Poults from each treatment were followed for growth, intestinal maturation and thyroid function. Males were more physiologically mature with increased ability to grow during the brooding period than females. Eggs incubated under a HP provided a more viable hatchling. Regardless of sex, eggs with Average or High conductance provided a better quality poult at hatching than Low conductance eggs.

EGG SIZE, EGGSHELL CONDUCTANCE AND INCUBATION TEMPERATURE INFLUENCES ON MATURITY OF COMMERCIAL TURKEY POULTS

By

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Biography

Sarah was born in Monroe, NC to Calvin and Renee Funderburk on December 15, 1980. She graduated from Forest Hills High School (Marshville, NC) in 1999. Sarah came to North Carolina State University in August, 1999 to study Animal Science and later also began studying Poultry Science. Throughout her undergraduate career she was very involved in the Animal Science Club, Poultry Science Club, Sigma Alpha Professional Agricultural Sorority, and Alpha Zeta Agricultural Honor Fraternity. In May, 2004 she graduated Cum Laude, as a College of Agriculture and Life Sciences honor student with a Bachelor of Science degree in Animal and Poultry Science and a minor in Agricultural Business Management. In August, 2004 she embarked on a Master of Science degree program in Poultry Science at North Carolina State University under the direction of Dr. Vern L. Christensen.

In her spare time, the author enjoys spending time with her family, Shannon, and of course Scooby-Doo (Stetson). She enjoys being active, enjoying nature, reading, putting together puzzles, playing cards, laying by the pool, traveling, church (including teaching the children), and watching Blue Collar Comedy. She loves to laugh!

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Introduction

Poultry provide a large portion of meat that is consumed annually in the world. The poultry industry consists mostly of meat and egg production from chickens and turkeys. Understanding the physiology of these animals is required to maximize production. Although both avian species are precocial animals, there are differences in their physiology. It is known that chicks are more resilient at hatch than neonatal turkeys or poults. Turkey poults have been observed to be weaker and require more care during the brooding period, than does the chick. They are more difficult to care for than are other species of poultry due to excessive mortality occurring around days 3 and 5 of age. Although extensive care may be provided during the brooding period, the turkey industry still suffers economic losses due to mortalities or reduced growth. The focus of this review is to explore the maturity of neonatal turkeys at hatching by understanding the incubation physiology of the turkey egg and to review the relationship of the intestinal and thyroid functions in relation to the growth of the poult.

Formation of the Egg

A follicle is the compact structure of tissue surrounding the yolk of an oocyte (Burley and Vadera, 1989). During the maturation process follicles attain a developmental state of yellow yolk deposition and are then ready for ovulation (Etches *et al.,* 1983). The yolk provides lipids and many of the proteins required for embryonic growth (Johnson, 2000). Ovulation occurs when the follicle ruptures along the stigma and releases the egg. Once this happens, the egg falls into the body cavity of the hen, where it is then engulfed by the infundibulum. The infundibulum is where fertilization takes place (Tullett, 1984).

Once fertilization has occurred the egg passes to the magnum and remains for 2-3 hours (Tullett, 1984; Johnson, 2000), where albumen is secreted by tubular glands (Johnson, 2000). There are 4 layers of albumen: 1) the chalaziferous (inner thick) layer, attached to the yolk; 2) the inner thin (liquid) layer; 3) the outer thick layer; and 4) the outer thin (fluid) layer. The function of the egg albumen layer is likely to prevent invasion of microorganisms into the yolk and to serve as a source of water, protein, and minerals to the embryo during development. Also in the magnum, the chalazae are formed, which connect the yolk to the thick albumen and stabilize the yolk in the center of the egg (Johnson, 2000).

The ovum then passes into the area of the oviduct called the isthmus, residing for approximately an hour, where the shell membranes are deposited around the ovum (Tullett, 1984). There is an inner and an outer shell membrane lying in close proximity to one another, except at the blunt end of the egg where they separate to form an air cell (Tullett, 1984; Johnson, 2000). The air cell is important during the hatching process. This portion of the egg will provide oxygen and begin pulmonary respiration when the hatching embryo internally pips the egg. The shell membranes help prevent bacteria from entering the egg and harming the embryo (Garibaldi and Stokes, 1958). The membranes are semi-permeable and permit the passage of gases, water, and crystalloids, but not albumen (Johnson, 2000). The inner and the outer membranes are made up of varying sizes of protein fibers. These fibers form a mesh like network of fibers that are cross-linked by disulfide and lysine-derived bonds and are parallel to the surface of the egg (Bellairs and Boyde, 1969; Johnson, 2000). As the hen ages the shell membrane thickness decreases (Johnson, 2000). During embryonic development, the chorioallantois, acting as the respiratory surface or lung of the embryo, attaches to the shell membranes (Wangensteen *et al.,* 1970/71).

The shell gland is where the developing egg spends most of its time (approximately 18-20 hours). When the egg first enters the shell gland the membranes that were applied in the isthmus loosely cover the albumen and the yolk. Throughout the first 6 hours in the shell gland water and electrolytes are secreted into the neck region of the shell gland, passing through the shell membranes into the albumen (Bakst and Bahr, 1993). This process is referred to as "plumping" and it forms the final shape of the egg before the shell is deposited (Tullett, 1984). The act of plumping causes stretching of the shell membranes bringing them in close proximity to the shell gland walls, which leads to shell formation (Tullett, 1984).

Shell formation begins with the formation of crystals on the outer membrane. The growth of these crystals occurs inwards, but does not invade beyond the shell membranes. There is a continued deposition of the crystals on the surface of the shell membranes to form the true shell of the egg (Tullett, 1984). The hard shell consists of inorganic solids, primarily calcium carbonate (Romannoff and Romannoff, 1949), and an organic portion of the shell consisting of shell membranes, the mammillary cores, the shell matrix and the cuticle (Johnson, 2000). The mammillary cores are the projections from the outer membrane that make up the largest portion of the organic matrix. The last step in shell formation is the application of cuticle around the outermost portion of the shell. The cuticle is a waxy material that covers the outermost surface of the egg, protecting the egg from water evaporation and microbial invasion (Johnson, 2000).

Regardless of species, as a hen ages the egg size increases and plateaus near the end of the laying cycle due to an increase in yolk deposition (Moran and Reinhart, 1980; French and Tullett, 1991). The age of the hen influences the proportion of shell, albumen and yolk to embryo mass in turkey eggs (French and Shaw, 1989)

Pore Formation

When the calcium carbonate is secreted it forms columnar calcite crystals that incorporate a small amount of organic material. These crystals are not packed around the egg in an orderly fashion. They are packed in such a way that there are spaces between them that pass through the thickness of the shell, leading to the microscopic pores of the avian egg (Rahn *et al.,* 1979; Tullett, 1984). As mentioned previously, the inner and outer shell membranes form a meshwork of organic fibers. The fibers of the outer shell membrane are attached to the inside of the eggshell via the mammillary cones. The mammillary cones are the centers of crystallization of the eggshell during shell formation (Rahn *et al.,* 1979; Johnson, 2000). Spaces between the network of fibers of the two shell membranes are filled with gas soon after the egg is laid (Rahn *et al.,* 1979).

The pores of the avian egg are cylindrical in shape and sometimes the openings are covered with the cuticle. These microscopic pores are important because they are the structures that allow gaseous communication between the outside environment and the chorioallantoic membrane. Pores also allow water vapor molecules to passively diffuse out of the shell because the amount of water inside the shell is greater than the air outside the shell. This allows the egg to loose water throughout incubation.

The size, shape and number of pores in the eggshell vary among bird species (Rahn *et al.,* 1979). A typical chicken egg will have approximately 10,000 pores distributed over its surface. The dimensions and number of pores of the egg are established in the shell gland before the egg is laid and from that moment on it remains unchanged. The turkey egg has the greatest pore density over the air cell when compared to the rest of the egg (Christensen, 1983).

Variations in Porosity

There are variations in porosity among differing avian species. Additionally, among any sample of eggs from a single species there is considerable variation of shell porosity (Tullett, 1981; Tullett and Deeming, 1982). Changes in shell porosity have been seen among flocks as the flock ages (Tullett, 1981; Tullett, 1982). These changes were found to be a result of the number and cross-sectional area of the pores and not due to the thickness of the eggshell (Tullett, 1981). An increase in the total number of pores is similar to the increase in the surface area of the shell (Rahn *et al.,* 1981). The porosity of the shell allows the passage of oxygen for the respiration of the embryo and for the elimination of carbon dioxide crucial to the embryo's metabolism and growth (Rahn *et al.,* 1979).

Embryos that have eggshells with a high porosity can satisfy most of their oxygen needs, while embryos in a low porosity egg have difficulty meeting their oxygen needs resulting in a reduced metabolism (Tullett and Deeming, 1982). Tullett and Burton (1985) demonstrated that the variation in shell porosity between eggs at the same stage of incubation affects the metabolism and growth of the developing embryo and therefore influences the blood-gas and acid-base status of the embryo. Eggs with a low porosity eggshell have an increased retention of carbon dioxide within the egg, which could lead to an increased level of bicarbonate in the blood (Tullett and Burton, 1985). Therefore low porosity eggshells limit the oxygen available to the embryo (Tullett and Deeming, 1982) and result in reduced embryonic metabolism and a slower growth rate (Burton and Tullett, 1985).

Hen Age Effects on Porosity

As the hen ages effects on the porosity of the eggshell can be seen, with the pore concentrations decreasing over the air space and the equator of the egg but not on the small

end of the egg. Pore concentrations on hatching and nonhatching eggs laid early in the cycle are different than the pore concentrations laid late in the laying cycle (Christensen, 1983). Changes in the weight of eggs and in the eggshell porosity have been observed among domestic ducks in their first laying cycle. During the first weeks of lay the egg weight and shell porosity is low, but by the fifth week of lay both characteristics have increased to values that can be found in a mature flock (Tullett and Smith, 1983).

Egg weight and porosity vary with season, with eggs tending to be larger in the spring and smaller during periods of high temperatures. Tullett and Smith (1983) found that in a mature flock of domestic ducks the porosity of the eggshells decreases in the summer. Although egg weight varies with season, the age of the bird has a greater effect on the egg weight, albumen volume, Haugh units and solids in the albumen (Cunningham *et al.,* 1960).

Egg Size and Porosity

Egg size can have an effect on the pore structure of an egg. Within any group of eggs there will be a variation in the egg weight and the shell porosity (Tullett and Deeming, 1982). As the mass of the egg increases, the pore structure can also increase. Rahn *et al.* (1981) found contradictory results in a 20 week breeding cycle, where the egg mass increased but, the individual pore dimensions did not change. Rahn *et al.* (1979) did find that when there is a ten fold increase in egg mass the length of the pores increase about 2.7 times and the pore area will increase about 18 fold. Although egg mass may increase across a laying cycle no significant changes can be seen in the thickness or density of the shell (Rahn *et al.,* 1981), but Tullett and Deeming (1982) noticed that large eggs tend to have unusual pore arrangements.

Water Loss

The porosity of the shell and the humidity of the incubator affect the amount of water loss from the egg, thus the amount of weight the egg looses throughout incubation (Tullett and Burton, 1982). Loosing weight at a relatively constant rate is due to the diffusion of water vapor through the pores of the egg shell (Rahn and Ar, 1974; Rahn *et al.,* 1979). Weight loss from eggs is due solely to the loss of water because embryonic respiratory exchange involves equal masses of oxygen entering and carbon dioxide leaving the egg and therefore no overall weight change (Rahn and Ar, 1974; Tullett, 1981; Tullett and Burton, 1982). The amount of water loss from an egg is independent of metabolism and depends on eggshell porosity (Burton and Tullett, 1985), the pore geometry of the shell and the water vapor pressure difference between the inside of the shell and the pressure of the incubator (Rahn and Ar, 1974; Rahn, 1981).

During early incubation optimal egg temperature is not reached, influencing the amount of water that is lost from the egg. As the embryo begins rapidly growing around day 12 of incubation and after pipping, eggs undergo an increased water loss (Rahn and Ar, 1974). Ar and Rahn (1985) found that the rate of water loss in the nest for a single pore is similar for eggs of different sizes, shell thickness and incubation durations. The amount of water loss in any given egg is independent of the metabolic rate by which is necessary for successful hatching (Rahn *et al.,* 1979).

Tullett and Burton (1982) found the fresh egg weight and the weight loss during incubation to explain the variation in chick weight at hatch. The weight of the whole chick at hatch is determined by the weight of the fresh egg and the amount of weight the egg looses during incubation. When eggs are incubated in a moist rather than a dry environment, chicks

are heavier at hatch and contain a higher water to dry matter ratio (Tullett and Burton, 1982). The relative water content of an egg will increase during incubation due to the metabolism of the fat stores in the yolk (Rahn *et al.,* 1979). Chicks hatching from eggs with a high porosity shell are not at risk for oxygen deprivation, but are in danger of dehydration, due to the loss of excessive amounts of water. These hatched chicks have reduced size and water content (Tullett and Burton, 1982). An embryo that pips the shell and escapes quickly will lose less water by evaporation through the pip hole while emerging from the shell than one that makes a large pip hole and emerges slowly from the shell. Thus, the variation that is seen in chick weight upon emerging from the shell is partly accounted for by the weight lost from the egg during the hatching process (Tullett and Burton, 1982).

The amount of water loss from an egg during incubation is in direct proportion to the eggshell porosity. For example, the wet embryo weight initially increases with decreasing shell porosity, but at higher porosities it begins to decrease. The effects of eggshell porosity and egg weight on the yolk sac mirror their effects on embryonic growth (Burton and Tullett, 1985). The increase in egg mass can also result in an increase in water loss from the egg. The daily rate of water loss increase 5.6 times for every ten fold increase in egg mass (Rahn *et al.,* 1979). When a late cycle and an early cycle egg are exposed to similar incubation temperature and humidities, the absolute water loss of a late cycle egg will be 17% greater than an early cycle egg due to the porosity of the eggshell (Rahn *et al.,* 1981).

Respiration

The respiration of an avian egg occurs via diffusion, where gas molecules passively move from an area of high concentration to an area of lower concentration. The egg "breathes" by diffusion through thousands of microscopic pores in the shell. Gas moves

across the pores using passive diffusion, therefore requiring no metabolic energy expenditure (Rahn *et al.,* 1979). The respiration in fish and mammals is convective and driven by muscles whose rate of pumping is determined by a metabolic demand and controlled by the nervous system, but the eggs of birds show no respiratory movements. There are no air currents in the egg that could transport oxygen to the capillaries of the growing embryo. The capabilities of the gases to diffuse are controlled by the available pore area in the shell, the length of the pores, and the concentration differences of the gases diffusing across the egg shell. Each pore transports similar amounts of oxygen and carbon dioxide per unit of time at equivalent stages of embryonic development (Ar and Rahn, 1985).

During embryonic growth the embryo is using diffusion instead of convection to breath. Respiration of the embryo within the egg occurs by the chorioallantosis. The chorion fuses with the allantois to form the chorioallantoic membrane or chorioallantosis. The chorioallantosis forms the circulatory system on the inside surface of the eggshell and serves as a site of respiratory gas exchange, therefore acting as the "lung" of the embryo. Throughout the prenatal period oxygen and carbon dioxide are exchanged across the chorioallantosis (Rahn *et al.,* 1979). During development the oxygen demand will increase and it will eventually exceed the capacity of the diffusion process for adequate amounts of oxygen to be delivered into the egg. At this point the embryo internally pips the egg and pulmonary respiration is initiated. The chorioallantosis is still the major respiratory organ (Tullett and Deeming, 1982) until the hatchling is fully able to breathe via convection. In the chicken embryo the transition from diffusive transport of gases to convective transport is accomplished in approximately 24 hours (Visschedijk, 1968).

Domestication and Respiration

Domestication of the turkey has lead to many changes to the egg. Christensen *et al.* (1982) found that domestication of the turkey egg has significantly increased the initial egg weight, volume and surface area compared to the wild turkey. The increases in physical dimensions that were observed among the domestic turkey eggs are proportional to their corresponding dimensions in the wild turkey egg. The increases in egg size have affected the gas exchange abilities of the egg. The egg weight and egg volume has increased by 53% in domestic turkey eggs, but the shell surface area available for gas exchange has only increased 32%. The number of pores on the turkey egg has not been altered by domestication, but the pores are spread over a larger surface area, thus the respiration for embryos of domestic eggs may be more difficult than for eggs from wild turkeys (Christensen *et al.,* 1982).

Porosity and Respiration

The partial pressure of oxygen across the eggshell of the domestic fowl does not generally increase above 48 mmHg, even in low porosity eggshells. In low porosity eggshells when the partial pressure of oxygen does not increase the embryo must respond by showing a reduction in the oxygen consumption to a level that is then determined by the porosity of its eggshell (Tullett and Deeming, 1982). Shell porosity affects the partial pressure of oxygen in the airspace and in the blood from the allantoic vein and the pH of the blood from the allantoic artery and vein (Tullett and Burton, 1985).

The cause of death of embryos in low porosity eggshells is unclear. Tullett and Deeming (1982) demonstrated that embryo deathin low porosity eggshells is not due to drowning. They found that embryos die in low porosity eggshells a few days before hatching

before the air cell has been pipped, before they begin lung ventilation and thus before drowning can occur. Therefore drowning seems like an unlikely cause of death because the embryo develops in an amniotic environment, the cause of death probably results from asphyxiation (Tullett and Deeming, 1982). As shell porosity decreases the amount of carbon dioxide which can escape across the eggshell is reduced (Tullett and Burton, 1985). Therefore increased retention of carbon dioxide among low porosity eggshells can lead to an increase in the amount of bicarbonate in the blood. Burton and Tullett (1985) noticed that there is a dramatic reduction in the growth rate of embryos at low eggshell porosities.

Conductance

During embryonic growth the gas exchange of the avian embryo is limited by the diffusion of gases through the pores of the eggshell. The embryo does not have the ability to control its gas exchange, so the permeability of the shell membranes to gases must adjust to meet the embryo's metabolic needs. The permeability to gas is expressed as the conductance, which is the reciprocal of the membranes resistance to diffusion. Gas conductance is a functional property of the shell that can be related to the embryo's metabolic requirements and the oxygen-pressure difference across the egg shell (Rahn *et al.,* 1979). Conductance acts functionally to ensure that three conditions are attained at the plateau stage in oxygen consumption. Rahn (1981) stated that the egg must have lost 15% of its initial mass as water vapor, the shell must have conducted 100mL of oxygen per gram of initial egg weight and the partial pressure of oxygen within the air space should have declined to 14% while carbon dioxide reaches a value of 6 %.

Conductance can be calculated if the measurement of the flux of a gas can be measured and divided by the concentration difference of that gas across the pores (Rahn *et*

al., 1979). The eggshell conductance can also be measured by looking at physical properties of the egg. There is interdependence among gas conductance, egg weight and the incubation period of an egg. This is explained by the conductance constant. Therefore egg weight and the incubation period of an embryo can be used to determine the conductance of an egg (Ar and Rahn, 1978). The amount of water vapor lost per unit of shell area and the shell conductance data are similar for all hen types and times of the laying period (Christensen and McCorkle, 1982).

Porosity and Conductance

Eggshell conductance is inversely proportional to shell thickness. Shell thickness mainly provides structural support to the egg, but also plays a vital role in the gas exchange of the embryo (Ar and Rahn, 1985). Differences in the thickness of the eggshell can be seen among different breeds of birds. The egg of the Sinai fowl (which is a desert breed of bird) has a low permeability to water vapor compared to the egg of a White Leghorn; this difference is due to the Sinai having a thicker eggshell. The thick shell of the Sinai contributes to reduced water vapor conductance to conserve embryonic water and does not interfere with the total functional pore area (Arad and Marder, 1982).

There is a systematic decline in shell conductance and pore density from the blunt end of the egg to the pointed end of the egg (Rokitka and Rahn, 1987) leading to different conductance rates on differing parts of the egg. Too much functional pore area on the air space and equator may cause embryonic mortality during pipping in eggs laid early in a cycle, but embryonic mortality in eggs laid mid or late laying cycle may be due to little functional pore area on the air space and the equator (Christensen, 1983). On average, in all eggs, the same ratio of cross-sectional area to pore length explains the constant diffusive

conductance per pore and that this constant dimensional ratio is achieved irrespectively of egg size and shell thickness (Ar and Rahn, 1985). Within a species the average pore dimension and therefore the conductance per pore are similar, so conductance differences are established by proportional changes in total pore number (Rokitka and Rahn, 1987).

Egg Weight and Conductance

As previously mentioned egg weight can have an effect on conductance. A gradual increase in egg weight results in a gradual increase in water vapor conductance as flocks age (Tullett, 1981). It has been observed that the conductance of eggshells from late cycle eggs allows smaller fractional water losses than early cycle eggs (Rahn *et al.,* 1981). Pore number and/or the cross sectional area of pores must change in order to change the gas conductance at a given egg mass and as egg mass increases, the resistance to diffusion of a single pore for any particular form of gas remains the same (Ar and Rahn, 1985). Research conducted using varying species has shown that among those varying species, as the size of the egg increased the conductance also increased (Rahn *et al.,* 1979)

The gas conductance of the eggshell is calibrated to the mass of the embryo to yield nearly the same final concentrations of oxygen and carbon dioxide in eggs of differing sizes. Gas conductance increases with the size of the egg, due to the oxygen demand of the embryo prior to internal pipping, which is greater in large eggs than in small eggs. Although conductance increases with egg size, the rate of increase in conductance is not proportional to the mass of the egg. With every ten fold increase in the mass of the egg there is a 6.5 fold increase in the oxygen conductance of that egg. The oxygen conductance of the eggshell appears to be matched to the egg's uptake of oxygen to "anticipate " the oxygen demand of

the embryo prior to internal pipping and to provide air cell oxygen and carbon dioxide pressures that are characteristic of the adult bird (Rahn *et al.,*1979).

Domestication and Conductance

When comparing domestic turkey eggs to wild turkey eggs the increase in conductance may have occurred because of a greater individual pore radius or a decreased pore length. The conductance of domestic turkey eggs has increased by 31% and the shell surface area has increased by 32%, these combined changes in pore radius and length are sufficient to account for increased shell surface area, but may not be enough to account for the 53% increase in egg weight. Therefore the domestic turkey lays an egg that is 50% larger than the wild turkey and exchanges vital gases through only 32% more surface area, so the domestic turkey eggs have a more difficult time with gas exchange than wild turkey embryos (Christensen *et al.,* 1982).

Incubation

Avian embryo development is an amazing cledoic system. Everything that is required for growth and development of the embryo is included in the egg at the time of lay, except for heat and oxygen. For the embryo to develop properly, appropriate amounts of heat and oxygen must be applied. Proper incubation conditions must be used in order to provide the developing embryos with the needed requirements for growth and development, much like the duties of the hen as she sits on the nest. When a bird is sitting on the nest it performs two major functions during incubation: it warms the eggs to an optimal temperature and maintains the humidity of the nest air (Rahn *et al.,* 1979). The highest hatchability for domesticated species is obtained when the eggs are losing a mean of 12-18% of their fresh

weight up until the time the eggshell is pipped (Rahn and Ar, 1974; Rahn *et al.,* 1979; Rahn, 1981; Tullett, 1981).

The amount of incubation time required for a given egg weight is inversely proportional to the water vapor conductance (Rahn and Ar, 1974; Rahn *et al.,* 1974). Due to differences in egg size and porosity, different incubation conditions may be needed with turkey eggs produced by hens in different stages of the reproductive cycle (Rahn *et al.,* 1981). The shell porosity of turkey eggs is related to egg weight such that generally the use of one suitable incubator humidity regime through the life of a flock is adequate (Tullett, 1982). An incubator can be set to provide a mean water loss of 12% but when this is done, the variability in the porosity of eggshells formed by different birds exhibits a wide range in percentage water loss between eggs (Tullett, 1981). Thus, the incubator can be set to give the proposed optimum percentage water loss for the majority of eggs and then we have to assume the variation in shell porosity between eggs is such that the resultant range in water losses experienced by the other embryos can be tolerated (Tullett, 1981). The wide variation that is found in the blood physiology between eggs at the same stage of incubation is partly due to the effect of the differing eggshell porosities (Tullett and Deeming, 1982).

Hatching is determined by: the total amount of oxygen that will be consumed during incubation, the oxygen and carbon dioxide concentration in the air cell shortly before pipping, and the loss of 12-15% of the eggs initial egg weight as water vapor (Rahn, 1981). The water loss of an egg during incubation is mandatory if the relative water content of an egg at the end of incubation is to remain essentially the same as at the beginning (Ar and Rahn, 1980). Turkey eggs that are laid early in a laying period loose less weight than eggs

laid in the middle of the cycle, and eggs laid in the mid portion loose less weight than eggs laid late in the breeding cycle (Christensen and McCorkle, 1982).

The incubation period of an embryo is related to the size of the egg. Individual turkey eggs vary in the time necessary to complete their incubation (Olsen, 1942). Williams *et al.* (1951) found that the larger the egg the longer time that is needed for incubation and hatching. A maximum of five hour variation can be attributed to the different weights in eggs (Olsen, 1942). Each strain and size of the turkey egg may require a unique environmental condition for optimum embryonic livability (Christensen and McCorkle, 1982).

The oxygen demand of an embryo of the domestic fowl (the chicken) is low up to about the twelfth day of incubation (Freemann and Vince, 1974; Burton and Tullett, 1985). This low requirement of oxygen can be met even by shells with a low porosity. So, there is little influence of eggshell porosity and conductance on growth of the embryo up until this stage. However, by this time the chorioallantoic membrane extension around the inside of the shell has been completed and as incubation continues the embryo begins demanding more oxygen for metabolism and growth, which then becomes limited by the porosity of the eggshell (Burton and Tullett, 1985).

During incubation when the embryo reaches a point of peak oxygen consumption the chorioallantosis is bringing in the maximum amount of oxygen that it can to support the metabolic needs of the growing embryo. It has been found that on about day 15 of incubation in chickens and day 22 in turkeys, the peak oxygen demand is not reached by embryos in the low porosity eggshells, which were requiring the maximum oxygen flux permitted by the porosity of the shell that it is in, but embryos in high porosity eggshells do

not use all the oxygen potentially available to them (Tullett and Deeming, 1982). Therefore in the latter part of incubation the permeability of the eggshell limits the gaseous exchange of the embryo, affecting the metabolism and growth, especially in low conductance eggshells.

Poult Maturity

Nice (1962) hypothesized that avian hatchling maturity at the time of emergence from the shell was a continuum among species as no two species seemed alike. It should be noted that this may also be the case within a species as different hatchlings show different degrees of cardiac and intestinal maturity (Christensen *et al.,* 2003b). The physiological maturity of an animal can be measured using numerous methods. For the purpose of this review, these aspects of poult maturity will be discussed: livability, growth, feed consumption, yolk sac absorption, intestinal maturation and thyroid function.

Early Poult Mortality

Early poult mortality has been a common problem in the turkey industry for many years. This problem has lead to many economic losses for the turkey grower (Enos *et al.,* 1971; Nestor *et al.,* 1974). Infectious agents may lead to significant amounts of mortality, but there are also numerous non-infectious agents that cause early poult mortality. A large portion of the total mortality for the growing period occurs during the first two weeks after hatching and is seen to be due to two basic phenomena: a dehydration problem during the third and fourth day, post-hatching, and starvation occurring about the sixth and seventh day of age, giving rise to starveout poults (Enos *et al.,* 1971; Nestor *et al.,* 1974).

Although a great amount of mortality is seen among starveout poults there are also other causes. Some mortalities that are observed are due to poults displaying a "flip-over" behavior that is of unknown etiology (Noble *et al.,* 1999). There could be dehydrated poults

due to low moisture in the hatcher or from poults that are held in the hatcher for a long period (Jordan, 1980). Chicks that are held in the hatchery for longer than 30 hours prior to placement also suffer increased mortality (Fanguy *et al.,* 1980). Mortalities can occur in small weak poults that have leg problems or other deformities that should have been culled at the hatchery. Poults that are in transit for to long may get chilled, overheated or be in an area of poor ventilation, thus leading to mortality during the brooding period (Jordan, 1980).

Fanguy *et al.* (1977) examinedthe mortality of poults placed on litter within 72 hours after hatch, 72 - 121 hours posthatch and 96 - 121 hours after hatch. Mortality rates were 6.14%, 35.14% and 59% respectively. Delaying placement caused an increase in mortality and there was a decrease in bursa and body weight. Fanguy *et al.* (1980) found that when there is a delayed placement of chicks that hatch early there is increased mortality during the first week of brooding. The increased mortality seen among delayed placement poults could be due lack of feed and water.

When food and water are withheld from a poult for 24, 48, or 72 hours after hatching there is a 4.8, 11.5, and 29.3 percent mortality rate that can be observed through 12 weeks of age. To ensure their best performance and to lessen the chances of mortality, turkey poults should be given feed and water as soon after hatching as possible (Chilson and Patrick, 1946). Jordan (1980) states it is very important to get poults to eat and drink as soon after placement as possible.

Although poults may be placed in a timely manner, some poults may fail to learn to eat and drink after placement even in the presence of other poults that are eating and drinking (Hammond, 1944). After an animal has been off of feed for two days the body temperature begins to decline and then as starvation progresses the body temperature continues to

decrease (Bierer *et al.,* 1965). This decrease in temperature could be due to lack of metabolizing of nutrients by the animal.

Stress can be a major contributing factor to poult mortality and has been shown to accentuate the mortality rate in poults (Enos *et al.,* 1971). Poults are stressed at the hatchery during sexing, desnooding, vaccinating and toe trimming. Renner *et al.* (1989) found that beak trimming at hatch can increase the mortality. These traumatic hatchery activities may cause the poults to loose their desire to eat and drink (Jordan, 1980) and can compromise the already low energy reserves that the poult has at hatching (Donaldson and Christensen, 1991). Poults that are stressed have increased hematocrits which indicate dehydration (Ross and Fanguy, 1983).

Mortality may be related to the adrenal cortical responsiveness to stressors at hatching and in the brooding environment. Corticosterone is a steroid hormone that is important for the conversion of amino acids to carbohydrate and glycogen in the liver and thus important metabolically. The adrenal cortical tissue of the poult is equally functional at the beginning and the end of the first two weeks of life (Davis and Siopes, 1989). This data indicates that the circulating corticosterone in poults has the ability to respond to stressors. Davis and Siopes (1985) found a delayed responsiveness and an absence of consistent circulating corticosterone response to acute cold stress, coinciding with the peak period of early poult mortality. This indicates that there could be an inability to cope physiologically with stress leading to mortality. Therefore, the circulating corticosterone in poults has the ability to respond to stressors. During the first two weeks of age turkeys encounter many stressors. Until two weeks of age, the stressors that poults will encounter can result from bad poults,

bad litter, bad water, bad feed and overcrowding (not enough access to feed and water) (Gonder, 1981).

Mortality can also be affected by the age of the progeny's parents and genetic selection. Hays and Spear (1952) found that the mortality rate in chicks was significantly higher in chicks from young verses older parents. This could be due to the size and composition of the egg. Moran (1989) found that older hens lay larger eggs that contain a larger yolk. Eggs from older hens contain more solids that are represented by higher ether extracts than eggs from young hens (Moran and Reinhart, 1980). These differences in egg composition may affect the maturity of the poult at hatching. It has also been demonstrated that the age of the dam has a more pronounced effect on mortality than the age of the sire (Hays and Spear, 1952).

Nestor *et al.* (1974) found that when turkeys are selected for genetic increases in egg production in a medium weight strain of turkeys there is a significant increase in poult mortality until eight weeks of age while turkeys selected for increased body weight at 16 weeks of age show no significant changes in early poult mortality. These differences in mortality may be due to a more mature intestine among poults selected for increased body weight. Noble *et al.* (1999) observed that there was a greater incidence of early poult "flip-overs" in a line of turkeys selected for increased egg production, indicating a genetic basis for this condition. Poults selected for increased egg production that hatched later had a greater incidence of early poult "flip-over" than those hatching earlier.

Sexual dimorphic differences have been reported for hatchlings. Females have been shown to dominate during the first part of hatching (Cherms, 1969). Hays and Spear (1952) observed that more male chicks die during the first 8 weeks than do female chicks.

Phelps *et al.* (1987c) found that there is a dimorphic effect on the developmental pattern of the hematology of the poult. Males respond more rapidly to physiological anemia than do females. This response is important since it has been observed that the mortality is higher in males than in females. Davis and Siopes (1989) showed that the sex differences commonly observed in early poult mortality are not the result of different adrenal cortical responses between males and females.

Managing Mortality

There are ways that the grower can attempt to reduce the incidences of early poult mortality. Growers can have everything ready in the house when poults are put down and then allow the poults time to get acclimated to their new environment. It is suggested not to interfere with the poults for 24 hours after placement, so that they are able to adapt to their new surroundings. Growers must make sure that air and litter temperatures are warm enough for the poult. If the poults are cool it will encourage them to be inactive and they will not seek out food or water, leading to starveout poults. If the light intensity is to low this too will encourage the poults to be inactive (Jordan, 1980).

Various methods have been attempted to reduce the incidence of mortality among newly hatched turkey poults. Administering a vitamin B injection or injecting with a commercial vitamin-mineral solution has no effect on mortality rates (Snetsinger *et al.,* 1963; Renner *et al.,* 1989). Poults that were given a supplement of whole milk demonstrated a higher viability. When milk and additional water were made available to drink the abnormally high mortality levels were reduced (Snetsinger *et al.,* 1963).

Pre-feeding poults prior to placement is a method that has been utilized in an attempt to lower mortality rates. Pre-feeding caused a reduction in mortality (Moreng *et al.,* 1970)

and these poults exhibited more activity and drinking time than control poults (Phelps *et al.,* 1987a). Moreng *et al.* (1970) found that dehydration appeared to be the largest contributor to early poult mortality among poults that were not pre-fed. Soluble antibiotic and vitamin-electrolyte preparations used during the first critical weeks of a poult's life have been shown to improve performance (Waldroup *et al.,* 1974). Poults that were fed a vitamin plus neomycin mixture had the lowest mortality (Moreng *et al.,* 1970). When soluble antibiotics and vitamin-electrolyte preparations were added to the poults' drinking water for the first 14 days the mortality rate was reduced, demonstrating an improvement in the flock health (Waldroup *et al.,* 1974). Pre-feeding an antibiotic and nutrient solution improves the welfare of poults during the first week after hatching (Phelps *et al.,* 1987a). When poults are pre-fed with water or a liquid nutrient there is a significant reduction in poult mortality due to dehydration and starvation (Enos *et al.,* 1971).

Feed additives increase livability among turkey poults. Reduced mortality can be seen among birds given penicillin in the feed when compared to control birds (Harper and Babcock, 1953). Glucose has also been used to improve viability. Moran (1989) found that giving glucose at hatch provides aid to the poults as they transition to self sufficiency.

Growth and Feed Consumption

The body weight, gain and feed consumption of birds are a common measurement used to determine the growth and viability of that animal. Within the poultry industry, it is generally accepted that if the birds are gaining weight and consuming feed, then they are growing properly leading to optimal meat production. There are numerous factors that can influence a bird's ability to grow, such as egg size, hatch speed, environmental temperatures, nutrition and genetics.

A common practice in the turkey industry is to hold poults in the hatchery overnight prior to placing on feed and water. Poults that are delayed access to feed for 48 hours posthatch show depressed body weights (Potturi *et al.,* 2005). Turner *et al.* (1999) showed that poults denied access to feed and water for 48 hours were 4 grams lighter at 5 days post feeding, but weight differences could not be seen at 13 days postfeeding. Poults delayed access to feed and water for 48 hours lost 10.7% of their initial posthatch weight prior to placement (Pinchasov and Noy, 1993). Stressors that poults incur could also increase the amount of time it will take for them to begin eating and affect the amount of feed that they will eat. When poults are stressed by being held in the hatcher for 72 hours they have significantly lower body weights than poults that are held in the hatcher for less than 24 hours post hatch. When poults are not stressed they initiated eating and drinking sooner and at a higher rate than stressed poults (Ross and Fanguy, 1983).

Water is important for sustaining life and promoting growth because it is essential to many chemical and physiological functions in the body, therefore life cannot exist without it. Research has shown that prolonged time without water lowers the body temperature of the poult (Charles, 1982). Bierer *et al.* (1965) demonstrated how chicks that are given feed but not water have a very tired appearance. This appearance could be due a lack of energy from not eating, indicating that birds will not consume adequate amounts of feed unless there is water available. Although water deprived chickens appear very tired, Kellerup *et al.* (1965) showed that when chickens were water restricted the mortality was not significantly affected, but the body weights and feed consumption were decreased.

Many of the methods used to increase the livability of the neonate have also affected the body weight of the growing poult. Injecting poults with a commercial vitamin-mineral

solution increased the body weight at 8 weeks of age (Renner *et al.,* 1989). Snetsinger *et al.* (1963) saw improved growth among poults given a vitamin B injection. The addition of soluble antibiotics and vitamin-electrolytes to the drinking water for the first 14 days improved growth rate and feed efficiency, thus the overall flock health (Waldroup *et al.,* 1974). Harper and Babcock (1953) found that adding penicillin to the fed starter ration lead to an increased growth rate when compared to control birds.

Prefeeding and providing glucose to new hatchlings increases body weight gain and causes significant increases in body weight (Moreng *et al.,* 1970; Phelps *et al.,* 1987a). Poults that were pre-fed had higher body weights and feed consumption at one week post hatch than birds that were not prefed (Moreng *et al.,* 1970). There was an increased feed consumption until day three in pre-fed poults, which continued until day five post placement, while poults delayed placement began eating at placement, but feed intake decreased from 4-6 days post hatching (Phelps *et al.,* 1987a). Poults that are held prior to placing with feed and water for 12 hours and given a nutrient solution orally have greater weight gain than poults held for 12 hours without the oral dosage prior to placing on feed and water. When an oral dose of nutrient solution is given to newly hatched poults a greater weight gain is observed during the first 2 weeks of brooding than poults that were not given a nutrient dosage (Waldroup *et al.,* 1974). Moren (1989) saw similar results when he administered glucose to turkey hatchlings. Poults that were provided with feed and water shortly after hatching gained weight and consumed more feed, when they were administered glucose. Poults that were fasted lost weight even when they were given glucose.

Residual Yolk Sac

Observing the amount of residual yolk in a poult post hatching can provide information on the ability of that bird to absorb and utilize the nutrients within the yolk sac. The residual yolk sac serves as an energy reserve for the poult before complete resorption occurs at 5 to 6 days of age (Phelps *et al.,* 1987b; Noy and Sklan, 1998). The relative size of the yolk in poults is smaller than in chicks, consequently the source of endogenous energy supply is more limited in the young poult verses the chick (Noy and Sklan, 1998). This may explain the poor viability of turkey poults at hatch compared to chicks.

Variations that can be seen in the poult's yolk sac originate with the hen. Moran (1989) found that older hens lay larger eggs that contain a larger yolk. Eggs from older hens contain more solids that are represented by higher ether extracts when compared to eggs from young hens. Therefore the yolks of older hens occupy a greater percentage of the total egg than the eggs of younger hens (Cunningham *et al.,* 1960; Moran and Reinhart, 1980). The amount of moisture in the yolk is lower with eggs from the older hens than with the younger hens, this could be related to the increased conductance seen among eggs from older hens. Cunningham *et al.* (1960) found that the total volume of albumen and yolk varies with the season and the age of the bird. Moran and Reinhart (1980) demonstrated that poult sex or age of the hen do not affect the amount of residual yolk found at the time of placement, but the relative weight of the egg has an effect on residual yolk. Large eggs tend to have larger embryos when compared to small eggs. The solids found in older eggs may allow for increased growth and development. Applegate and Lilburn (1998) found that an increase in hen production age led to proportionately more yolk deposited in the egg at the expense of albumen, but this did not influence the poult weight at hatch relative to the initial egg weight.

Lines of chickens selected for greater adult body weights also displayed greater residual yolk weights in the progeny of the high body weight line than the progeny of the low body weight line (Anthony *et al.,* 1989; Nitsan *et al.,* 1991). The difference in embryo size can explain differences seen among the yolk weights from varying egg sizes. Heavier egg weights have heavier yolk sacs and the yolk sac occupies a greater proportion of the poult than if the poult came from a small egg (Moran and Reinhart, 1980). This difference in yolk weight may be correlated to the difference in embryo size seen among large eggs and small eggs. Yolk weights are heavier in heavy body weight embryos and poults than light body weight progeny. The larger yolk mass in the heavy body weight embryos may allow for increased growth earlier in development (Suvarna *et al.,* 2004).

Due to the mobilization of moisture and lipid, within 48 hours of placement, the yolk sac weight decreases to approximately half of its weight at hatch. Poults that are fasted by delaying placement, for example, have a reduced uptake of yolk compared to fully nourished birds (Moran and Rinehart, 1980). A delay in removing poults from the commercial hatchers extended their complete dependence on their yolk reserve (Moran, 1989). The poults ability to utilize the yolk over an extended period may be decreased due to delayed access to feed and water.

Yolk digestion and absorption by the embryo is primarily from the lipid content found in the yolk (Donaldson and Christensen, 1991). The yolk sac membrane contains lipid digestive enzymes and provides the mechanisms for absorption in the shell and for the first few days following hatching (Romanoff, 1960; Noy and Sklan, 1998; Denbow, 2000). Yolk utilization occurs by two different routes. The first route occurs in the embryo via endocytosis and involves the transport of lipid into the circulatory system (Lambson, 1970;

Esteban *et al.,* 1991; Noy and Sklan, 1998). The second route of utilization involves the intestine. This occurs by the transport of yolk to the gastrointestinal tract, where antiperistaltic movements of the digesta transfer some of the lipids to the duodenum and jejunum for lipolysis and absorption (Noy and Sklan, 1998). The routes of yolk utilization are reflected in the decrease in yolk weight. The amount of antiperistalsis increases post hatching and thus digestion and uptake of the yolk is enhanced (Noy and Sklan, 1998). Incubation temperatures above 38°C at the plateau stage of embryo development depressed yolk utilization (Christensen *et al.,* 2004).

Intestinal Maturation

At hatching the avian intestine undergoes major functional demands. Before the poult hatches the embryo depends primarily on lipid stores from the yolk. The yolk sac, in addition to the intestine, transports sugar actively into the chick prior to hatching (Holdsworth and Wilson, 1967). Even though the small intestine undergoes considerable development during incubation, it is still functionally immature at hatch in terms of digestive and absorptive capabilities (Sell *et al.,* 1991). At hatching the young bird makes a transition to an adult-based diet that has variable composition. In addition, the hatchling uses the remaining yolk lipids as a supplemental source for energy for a few days after hatching (Uni *et al.,* 1998). In comparison with the chick, the morphological development of the turkey intestine indicates that poult growth is slower than chick growth (Uni *et al.,* 1995; Uni *et al.,* 1999). Approximately 60% of the total energy of the neonate may be devoted to the maturation and growth of the intestine during the first few days following hatching (Fan *et al.,* 1997). Therefore, the gastrointestinal tract must adapt to digest the carbohydrates and the proteins that are available in the feed.

The gastrointestinal tract is the major site of nutrient uptake. Selection for larger body weight has changed the rate of development of body organs and tissues in the chicken (Katanbaf *et al.,* 1988). In previous studies it was noted that selection for rapid growth rate results in changes in the length and the weight of the small intestine (Katanbaf *et al.,* 1988). Therefore changes in the small intestinal growth or anatomy due to genetic selection may significantly impact the energetic efficiency of body growth (Croom *et al.,* 1993). The response to selection for rapid growth causes an increase in the absolute length and mass of the small intestine, but a decrease in these values relative to body weight (Mitchell and Smith, 1991; O'Sullivan *et al.,* 1992). When birds are selected for increased body weight, the small intestine adapts readily to meet the demands for increases in the nutrient needs (Mitchell and Smith, 1991; O'Sullivan *et al.,* 1992; Fan *et al.,* 1996; Fan *et al.,* 1997).

According to Fan *et al.* (1997) the selection of turkeys for rapid growth at 16 weeks of age did not increase efficiency of jejunual glucose uptake in 14 day old turkey poults. These results suggest that there is no improvement in the energetic efficiency of glucose transport as a result of genetic selection for rapid growth in poults. Although there is not greater usage of glucose, studies have shown that a more rapid posthatching intestinal growth leads to a greater final body weight and muscle growth in lines of chickens selected for high juvenile body weight compared to lines selected for low juvenile body weight (Katanbaf *et al.,* 1988; Anthony *et al.,* 1989; McNabb *et al.,* 1989). The intestine in chicken lines selected for a low juvenile body weight is more mature at hatch than that of lines selected for high juvenile body weight.

In birds, energy supply available for growth is partly limited by the size of the digestive tract. The early investment of growth resources in development of this supply

organ favors subsequent high growth rate capacity (Mitchell and Smith, 1991). The rapid increase in intestinal mass ensure that the animal is ready to meet the increase demand of nutrients to maintain tissue and promote growth as well as accommodate some reserve capacity (Ferrais and Diamond, 1997) Increased relative size of the intestine suggests that at hatching the intestine of a poult from a light sire (LBW) is capable of greater amounts of digestion and absorption than poults from a heavy sire (HBW), of not only carbohydrates but also lipids and proteins in the LBW poults (Ferrais and Diamond, 1997; Suvarna *et al.,* 2004).

The jejunum weight for the LBW progeny was greater than the HBW when compared relative to body weight, but the absolute jejunum weights and lengths did not differ between the HBW and LBW. The larger surface area of LBW poults may improve the availability of energy sources such as glucose at hatching. The difference in body growth may be due to increase absorption of all nutrients due to greater intestinal mass rather than to difference in glucose uptake. Differences in the survival rates of poults from two sires may be due to the relatively larger intestine in the LBW compared to the HBW. Maltase or alkaline phosphatase activities differed between the body weight groups. Maltase activity increased 5-fold from 25 days of embryonic growth to hatching (Suvarna *et al.,* 2004). Glucose transport mechanisms and intestinal enzymes are functional at approximately 48 hours posthatch and can adjust rapidly to different types of food. When poults were fed increased amounts of carbohydrate higher levels of maltase activity were seen (Suvarna *et al.,* 2005).

Development of the intestine may also be influenced by the functional quality of the eggshell or the conductance. Optimal intestinal development and overall growth may be dependant upon larger or shorter developmental periods as determined by conductance

constants. The energy available and the delay in intestinal maturation post hatching may also be a result of decreased conductance, increased egg weight or both (Christensen *et al.,* 2003b). Therefore, poults may rely on gluconeogenesis to sustain life and support growth (Donaldson and Christensen, 1991). During incubation temperatures above 38°C the intestinal maturation of poults is depressed (Christensen *et al.,* 2004).

Physical development of the gastrointestinal tract can be a more limiting factor to early growth than increases in digestive and absorptive performance (Uni *et al.,* 1995 and Uni *et al.,* 1996). Physiologic maturation of the gastrointestinal tract occurs mainly through increased production of pancreatic and intestinal enzymes (Nistan *et al.,* 1991; Sell *et al.,* 1991; Pinchasov and Noy, 1993), such as maltase and alkaline phosphatase. Uni *et al.* (1999) found that the enzyme activity of the intestine in poults is 30 to 60% of the activity found in the chick at hatch.

Increases in the relative weight of the small intestine, intestinal diameter and villus length only occur after feeding (Baranyiova, 1972; Baranyiova and Holman, 1976). The small intestinal mass increases parallel to the nutrient intake early in life (Uni *et al.,* 1999). Therefore placement of poults in a timely manner is important. Intestinal villi growth is more advanced developmentally at hatch in poults from older hens; however post-hatch growth of the intestine or the poult is not affected by hen age or egg weight class (Applegate *et al.,* 1999b). Applegate and Lilburn (1999a) found that neither egg weight or hen age consistently affected small intestinal weight, length, or density.

Noy and Sklan (1999) reported that one effect of delayed placement of both chicks and poults is that the organs of the gastrointestinal system grow less by 48 hours posthatch than did organs of chicks or poults placed immediately on feed or water. Delaying access to

feed and water for 48 hours posthatch decreases growth of the small intestine and limits the ability for the intestine to absorb nutrients (Potturi *et al.,* 2005). When placed, poults fed a diet with supplemental animal-vegetable fat consumed more feed than poults fed a high carbohydrate diet. The supplemental fat may ease the metabolic shift toward glycolysis after hatching and improve growth through 2 weeks of age (Turner *et al.,* 1999).

Thyroid Function

Thyroid hormones have an effect on the differentiation or maturation of the body, in other words growth. This involves increased mass from cell proliferation and cell hypertrophy without the formation of new cells. The primary hormonal stimulation of body growth results from circulating growth factors under the control of growth hormone (McNabb, 2000). McNabb and King (1993) showed that, in general, thyroid hormones appear to act permissively or indirectly with other control substances in their stimulation of growth in birds.

Thyroid hormones are required for optimal growth of birds as demonstrated by the reduced growth resulting from a thyroidectomy or goitrogen administration, but there is little evidence of thyroid hormone in the stimulation of general body growth (McNabb and King, 1993). Thyroid hormones are important in triggering tissue-specific differentiation and maturation processes in many tissues. Thyroid hormone effects on the maturation of mammalian muscle, skeletal and the central nervous system have been studied (McNabb, 1992; McNabb and King, 1993). Turkey embryonic hatching times are affected by thyroid hormones (Christensen and Ort, 1990). High thyroid hormone concentrations among embryos are associated with the beginning of pulmonary respiration and the high metabolic demands of the hatching process (McNabb *et al.,* 1981). Hen age can affect the amount of

thyroid present in turkeys. Thyroid hormones in the plasma of embryos from hens of different ages indicate that significant differences in the ratio of T_3:T_4 occur as the hen ages. Christensen *et al.* (1996) saw that embryos from young hens demonstrated increased levels of T_4, while embryos from older hens had increased T_3 activity. Therefore thyroid hormones can also have an effect on the development of the neonatal turkey poult.

It is generally accepted that thyroid hormones regulate the metabolism of an animal. Increases in thyroid hormone cause increases in the metabolic and heart rates of an animal, with the opposite occurring during a deficiency of thyroid hormone. Factors that influence thyroid function include dietary iodine availability, food availability, food consumption, season, age and time of day (Decuypere *et al.,* 1985; Sharp and Klandorf, 1985). Cold temperatures can increase the amount of thyroid stimulating hormone, therefore leading to an increase in thyroid hormone (Wentworth and Ringer, 1986). Warm temperatures depress and cold temperatures increase plasma T_3 concentrations. Diurnal patterns of plasma thyroid hormone concentration occur in birds. During the dark period plasma T_4 concentrations rise and peak and T_3 concentrations are the highest during the light period, indicating thyroidal conversion of T_4 to T_3 is highest during the light period (McNabb, 2000). Thyroid hormones are considered to be the key controllers of metabolic heat production that is necessary for the maintenance of high and constant body temperature in homoeothermic birds and mammals. Due to the effect of thyroid hormones on the metabolism, the thermoregulation of animals can also depend on the amount of circulating thyroid hormone present. Therefore, the mechanisms used by this hormone can affect the ability of a young turkey to adapt to and regulate its body temperature or its thermoregulatory abilities.

Research indicates that the thyroid hormones affect the maturation of the intestine. Glucocorticoids can also influence the intestinal development of chickens. The accumulation of glycogen in the chicken intestine after day 14 of incubation is stimulated by cortisone and then during day 19-21 and early in posthatching life the thyroid hormones will trigger increased glucose metabolism and glycogen depletion (Black, 1988). Thyroid and adrenal hormones play major roles during the plateau in maturation of intestines (Black, 1978). Black and Moog (1978) were the first to demonstrate a relationship within a culture between intestinal enzymes (maltase and alkaline phosphatase) and thyroid production

Moog (1962) showed that hypothyroidism inhibits the development of alkaline phosphatase and the development can be restored with a T_4 treatment. Prager *et al.* (1990) showed that T_3 can also affect intestinal maturation. The intestine is capable of T_3 production that may play a role in triggering intestinal differentiation and maturation (Suvarna *et al.,* 1993).

Thyroid hormones are directly related to the carbohydrate metabolism in avian embryos (Wittmann and Weiss, 1981). Greater dietary carbohydrate in the turkey poult increases plasma T_3 levels with no differences in T_4 levels. The ratio of T_3:T_4 is also higher in poults fed more compared to those fed less carbohydrate, which indicates a greater conversion of T_4 to T_3 (Suvarna *et al.,* 2005). Prager *et al.* (1990) suggest that T_3 increases the entry of glucose into intestinal epithelium through stimulation of a low affinity transport system. Christensen *et al.* (2003a) also observed depressed T_3 and T_4 concentrations in weak poults displaying "flip-over" behavior.

Thesis Objectives

Previous experiments have been concerned with evaluating the relationship of egg size and eggshell conductance among different species. To the author's knowledge, research has not been completed regarding the association between egg size and conductance within a single species, as well as, incubation temperature and sexual dimorphic influences on the physiological and metabolic development of turkey poults. Therefore, the overall objective of this thesis was to identify a relationship between egg size and conductance among eggs from turkey breeder hens and measure a poult's ability to mature post hatching dependant upon these egg characteristics and incubation conditions. The specific objectives of the three experiments were to:

1) Establish if egg size and eggshell conductance interact to affect growth and survivability of the turkey poult.
2) Examine the influence of incubation temperatures in conjunction with egg characteristics on poult maturation.
3) Observe the sexual dimorphic effects of incubation temperature and eggshell conductance on turkey poults.

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Manuscript I. Effects of Egg Size and Eggshell Conductance on Poult Viability and Body Weight Gain

Abstract

A high rate of poult mortality can occur within 10 days after neonates are placed in brooders. Therefore a better understanding of how egg size and eggshell conductance (G) affect the viability of a poult can benefit both producers and consumers. The objective of this study was to determine the effects of egg characteristics, i. e. size and G on the viability of commercial turkey poults. An equal number of eggs from a first cycle flock (Cycle 1) and an induced molted flock (Cycle 2) were individually numbered, weighed and incubated under standard operating procedures in a commercial turkey hatchery. All eggs were weighed a second time at D25 (transfer) and G (or moisture loss) was calculated. Cycle 2 eggs were significantly larger than Cycle 1 eggs. The eggs were then divided and sorted into 3 groups: Low, Average and High G. At hatch poults were marked for identification according to G group and egg size. The poults were then processed by the hatchery. Thirty poults from each group and sex were randomly selected and individually weighed on the day of hatch (D1) and again at D4 of the brooding period. Poult mortality for each group and sex were also monitored through D7 of brooding. There was a flock by G interaction for D1 body weight (BW) and a flock by sex interaction for D4 BW. Poults with a higher viability were among the Cycle 2 eggs with a Low G and conversely poults with poor viability came from Cycle 1 eggs with Low G. The percent mortality was lower for the Cycle 2 poults. At D4 tom poults weighed more than hen poults. Among the two egg sizes each of the Low G groups weighed more at hatch than the other G groups. This could be due to the amount of residual yolk that is present in the poult and therefore could have affected the viability of that

poult. It is concluded that the status of the poult at hatching and during the brooding period may be a function of both egg weight and G.

Key Words: incubation, poult, egg size, livability, eggshell conductance

Introduction

Turkey poults have been observed to be weaker and require more care during the brooding period, than does the chick. The observation of Nice (1962) indicated that within the poultry industry it is understood that chicks are stronger and more precocial at hatch than neonatal turkeys. Turkeys can be more difficult to care for than are other species of poultry due to excessive mortality occurring around days 3 and 5 of age. Multiple factors can have an influence on the ability of poults to survive, grow and provide optimal meat production at market. Poult mortality leads to many economic losses for the turkey grower (Enos *et al.,* 1971; Nestor *et al.,* 1974). Early poult mortality occurs during the first two weeks of brooding and is a characteristic of neonates that usually refuse to eat or drink, leading to starveout poults. Starveouts account for a large part of the mortality that occurs within 10 days of age (Moreng *et al.,* 1970; Waldroup *et al.,* 1974; Jordan, 1980). The incidence of mortality may be due to many factors such as disease, stress and mismanagement. There may also be physiological parameters of the hatching eggs including egg size and eggshell conductance that may affect poult mortality.

Eggshell conductance (G) is a functional property of the shell that can be related to the embryo's metabolic requirements and the oxygen-pressure difference across the eggshell (Rahn *et al.,* 1979). According to Rahn (1981), G functions to ensure that three conditions are attained at the plateau stage in oxygen consumption. The egg must have lost 15% of its initial mass as water vapor, the shell must conduct 100 mL of oxygen per gram of initial egg

weight and the partial pressure of oxygen within the air space should have declined to 14% while the carbon dioxide reaches a value of 6 %. The conductance constant (k) demonstrates the interdependence between the egg weight, incubation period and eggshell G (Ar and Rahn, 1978). This interrelationship may affect the growth of the poult post hatching. It is poorly understood how G or the permeability of the eggshell can have an effect on the physiology of the growing turkey poult. Therefore the focus of this experiment was to identify how the size of the egg and the eggshell G can affect the neonatal turkey poult. The goals of this study were to determine if these egg properties have effects on the growth and viability of poults to 7 days of age.

Materials and Methods

Fertilized turkey eggs (6,240) were numbered and weighed (nearest 0.01g) individually. Two commercial flocks of turkey breeders of the same strain (Nicholas, Sonoma, CA) produced the eggs. Half (3,120) of the eggs came from a first cycle flock (Cycle 1) in their 11^{th} week of lay and the other half (3,120) came from an induced molted flock (Cycle 2) in their 12^{th} week of lay. A significant difference was observed among egg size between the flocks, therefore Cycle 2 eggs will be referred to as large eggs and Cycle 1 eggs will be referred to as small eggs. The eggs were incubated in a commercial single stage incubator (Jamesway, ACI), operating using the standard single stage profile for the integrated operation. At the beginning of the 25^{th} day of incubation, all eggs were weighed a second time to determine the moisture loss and G of each individual egg (Tullett, 1981). The weight loss from eggs is due solely to the loss of water because the embryonic respiratory exchange involves equal masses of oxygen entering and carbon dioxide leaving the egg, therefore no overall weight change (Rahn and Ar, 1974; Tullett, 1981; Tullett and Burton,

1982). G values were evaluated using a computer assisted program to identify low (Low), average (Avg) and high (High) G groups and then the eggs were sorted according to the computed G. Eggs were then candled, injected with antibiotic, transferred to hatching baskets and placed into a hatching machine operating under a standard hatcher profile for the integrated operation.

Growth of hatchlings:

At hatching, poults were marked for identification using a colored wax marker to identify birds by treatment (egg size and G). The poults were then processed by the hatchery, held overnight and then delivered to commercial turkey houses for brooding. Hens and toms were sent to different farms. Mortality of the poults according to egg size and conductance group was recorded until day 7 of age. Approximately 800 poults were placed per conductance group. A random sample of body weights were taken at Day 1 and Day 4 of age.

Statistical Analysis:

Data were arranged in a 2 egg sizes (Cycle 1 or Cycle 2) by 3 levels of G (Low, Avg and High) factorial for analysis of a completely random experimental design using the general linear models procedure (SAS Institute, 2001). All data were sorted by day of poult age prior to analysis. All possible interactions were tested for significance, but will be reported only when they were significant. Means determined to differ significantly were separated by the least square means procedure based on a probability of $P \leq 0.05$, unless otherwise noted. Mortality data was analyzed using a chi-square analysis based on a significance of $P \leq 0.05$.

Results

Egg Size:

Eggs from different age flocks on average varied in egg weight. Significant differences were also seen in the moisture loss, G and k values of the eggs (Table 1). Eggs from the Cycle 2 flock were larger and had higher G than eggs from the Cycle 1 flock (Table 1). Therefore, throughout the remainder of this Manuscript, the eggs from the Cycle 2 flock will be referred to as Large eggs, while eggs from a Cycle 1 flock are referred to as Small eggs. Growth data between the egg sizes is shown in Table 2. Among the BW at Day1 and Day 4 the poults hatching from Large eggs weighed more than poults from Small eggs. The amount of weight gained between poults from the two egg sizes did not differ (Table 2).

Conductance:

Initial egg weight and percent water loss between the G groups differed significantly. The Low, Avg and High G eggs lost different amount of weights from the initial egg weight to the weight at transfer (Table 3). Therefore, both the eggshell G and k are different between the percent loss groups (Table 3). BW among the G groups were different at Day 1. Low G poults were heaviest (Table 4), while High G poults had the lowest body weight. No differences in BW or gain at Day 4 were observed between the G groups (Table 4).

Egg size and Conductance Interactions:

An egg size by percent water loss interaction was demonstrated for functional egg properties as well as BW (Tables 5 and 6). Differences were observed by egg size for the percent water loss, G and k. Regardless of egg size, High G eggs lost more moisture, while the Low G eggs lost the least amount of moisture (Table 5). At Day 1 poults hatching from Large eggs had the heaviest BW, while within each egg size; Low G poults had the heaviest

BW. High G poults from large eggs and Low G poults from Small eggs had the worse livability (Table 6). Egg size by sex interaction differences were observed among the Day 4 BW and gain. Male poults from Small eggs had the lowest BW at Day 4 and gained the least amount of weight than males from Large eggs and the female poults (Table 7).

Discussion

The results from the current study suggest that properties of the egg, egg size and eggshell G, affect the ability of neonatal turkeys to grow post hatching.

Egg Size:

Egg size may affect the incubation requirements of an egg. Williams *et al.* (1951) found that larger eggs required more time for incubation and hatching than small eggs. Therefore each strain and size of the turkey egg may require a unique environment condition for optimum embryonic livability (Christensen and McCorkle*.,* 1982). As egg size increases the size of the embryo also increases. Thus, a larger embryo has a greater metabolism than the smaller embryo. Significant differences between the eggs of each flock indicate that Cycle 2 eggs are larger on average than Cycle 1 eggs. These findings are consistent with prior data that showed variation in egg size among different age flocks. As a flock ages, across a laying cycle the egg mass increases (Moran and Reinhart, 1980; Moran, 1989). The Cycle 2 eggs used in this study were larger and provided a larger poult at hatching. This difference in size at hatching may provide a more viable poult during the brooding period.

Conductance:

The porosity of the shell allows the diffusion of oxygen for the respiration of the embryo and for the elimination of carbon dioxide, so eggshell G is crucial in supporting the embryo's metabolism and growth (Rahn *et al.,* 1979). G determines the characteristic length

of the incubation period for each species (Rahn, 1981). Due to the interdependence of egg weight, incubation period and G (Ar and Rahn, 1978) the length of the incubation period and the egg weight predict a required G of an egg to hatch an offspring of specie characteristic maturity. Therefore, as egg weight increases the G of an egg must change. The significant differences seen among the egg weights according to percent water loss are consistent with a previous study done exploring conductance and flock age (Tullett, 1981). The conductance values for the large eggs were on average higher than the values for the small eggs. Tullett (1982) found that when there is a gradual increase in egg weight there is a gradual increase in the water vapor conductance with flock age. The differences that are seen here may be due to the porosity of the eggshell. Difference in flock age has lead to changes in the porosity of the eggshell. Previous research shows that as a flock ages the porosity of the eggshell increases (Tullett, 1981; Tullett, 1982). This increase in porosity may lead to increases in the G of the eggshell. Rahn *et al.* (1979) found that among varying species as the size of the egg increases the conductance of that egg also increases. One can conclude from the current data that an increase in conductance due to increase in egg size can be observed with in one species.

Egg size and Conductance Interactions:

Chick weight variation upon emerging from the shell is accounted for by the fresh egg weight, the weight lost from the egg during incubation and the weight of the shell and residues at hatch (Tullett and Deeming, 1982). A significant difference in the body weights indicates differential effects of the egg size and the G. The heavier body weights seen among the poults from large eggs indicate that these embryos are larger at hatch and have a higher growth rate than the poults from small eggs. The high body weights among the Low G

poults from both large and small eggs could be related to the inability of these poults to metabolize their yolk, due to a lack of oxygen, as efficiently as the Avg and High G poults. Embryos that have eggshells with a high porosity can satisfy their oxygen demand providing them with adequate oxygen to metabolize the yolk for energy. Low porosity eggshells limit the amount of oxygen available to the embryo and therefore result in reduced embryonic metabolism and slower growth rate (Tullett and Deeming, 1982; Burton and Tullett, 1985).

In conclusion, poults with the highest viability seen in this study seemed to come from a large egg (Cycle 2), with Low eggshell G, while the overall poults with the worst viability came from a small egg (Cycle 1), with a Low eggshell G. These differences may be due to many factors such as residual yolk, intestinal maturation and thyroid hormone levels. The permeability of the eggshell influences the ability of the turkey embryo and poult to mature and survive. Overall, it is concluded that there is a difference in poult viability depending on the functional abilities of the egg. To the best of our knowledge this is the first time this has been demonstrated within one species.

TABLE 1. Physical and functional characteristics of Large and Small turkey eggs[1]

Data analyzed using egg size as treatment

	Large	Small	Overall SE	P value
Initial Egg Weight (g)	92.51	85.62	0.46	0.0001
Percent Water Loss	11.01	11.05	0.008	0.0001
Eggshell Conductance[2]	17.82	16.56	0.03	0.0001
Conductance constant	5.40	5.42	0.002	0.0001

[1]N=3,120 for both treatment groups. All values are means.
[2](mg/torr/day)

TABLE 2. Effects of egg size on growth of neonatal turkey poults hatching from Large and Small eggs[1]

Data analyzed using egg size as treatment

	Large	Small	Overall SE	P value
Body Weight Day 1 (g)	57.62	54.09	0.93	0.0001
Body Weight Day 4 (g)	88.18	83.07	3.09	0.0001
Body Weight gain (g)	30.56	28.98	4.09	NS

[1]N=180 for both treatment groups. All values are means.

TABLE 3. Physical and functional characteristics between eggs of Low, Average and High conductance[1]

Data analyzed using percent water loss as treatment

	Low	Average	High	Overall SE	P value
Initial Egg Weight (g)	89.53[a]	89.05[b]	88.61[c]	0.46	0.0001
Percent Water Loss	9.59[c]	10.96[b]	12.54[a]	0.008	0.0184
Eggshell Conductance[2]	15.03[c]	17.08[b]	19.45[a]	0.03	0.0001
Conductance constant	4.70[c]	5.37[b]	6.15[a]	0.002	0.0184

[a,b,c]Row means with different superscripts differ significantly.
[1]N ~2071 for each treatment group. All values are means.
[2](mg/torr/day)

TABLE 4. Effects of Low, Average and High eggshell conductance on growth of neonatal turkey poults[1]

Data analyzed using percent water loss as treatment

	Low	Average	High	Overall SE	P value
Body Weight Day 1 (g)	56.99[a]	55.74[ab]	54.83[b]	0.93	0.0004
Body Weight Day 4 (g)	86.30	86.24	84.33	3.09	NS
Body Weight gain (g)	29.31	30.50	29.49	4.09	NS

[a,b,c]Row means with different superscripts differ significantly.
[1]N=120 for each treatment group. All values are means.

TABLE 5. Effects of egg size and eggshell conductance on physical and functional characteristics of the egg[1]

Data analyzed using egg size x percent water loss as treatment

Egg Size	Eggshell Conductance	Initial Egg Weight (g)[2]	Percent Water Loss[3]	Eggshell Conductance[4]	Conductance constant[5]
Large	Low	92.97	9.53[d]	15.51[e]	4.67[d]
	Average	92.47	10.92[b]	17.67[c]	5.35[b]
	High	92.08	12.57[a]	20.26[a]	6.16[a]
Small	Low	86.10	9.65[c]	14.55[f]	4.73[c]
	Average	85.66	11.00[b]	16.48[d]	5.39[b]
	High	85.14	12.51[a]	18.64[b]	6.13[a]

[a,b,c]Columnar interaction means with different superscripts differ significantly.
[1]N ~1,037 for each treatment group. All values are means.
[2]NS
[3]Overall SE = 0.008; P-value = 0.0002
[4](mg/torr/day) Overall SE = 0.03; P-value = 0.0001
[5]Overall SE = 0.002; P-value = 0.0002

TABLE 6. Effect of egg size and eggshell conductance on growth and mortality of neonatal turkey poults[1]

Data analyzed using egg size x percent water loss as treatment

Egg Size	Eggshell Conductance	Body Weight D1(g)[2]	Body Weight D4 (g)[3]	Body Weight gain (g)[4]	Percent Mortality[5]
Large	Low	59.33[a]	89.13	29.80	0.058
	Average	57.68[b]	88.93	31.25	0.91
	High	55.85[c]	86.47	30.62	1
Small	Low	54.65[cd]	83.47	28.82	1
	Average	53.80[d]	83.55	29.75	0.4
	High	53.82[d]	82.18	28.37	0.24

[a,b,c]Columnar interaction means with different superscripts differ significantly.
[1]N = 60 for each treatment group. All values are means.
[2]Overall SE = 0.93; P-value = 0.0445
[3]NS
[4]NS
[5]Chi-square critical value = 5.99 for P <0.05; Observed critical value = 7.35

TABLE 7. Effect of egg size and poult sex on growth of neonatal turkey poults[1]

Data analyzed using egg size x sex as treatment

Egg Size	Sex	Body Weight D1(g)[2]	Body Weight D4 (g)[3]	Body Weight gain (g)[4]
Large	Female	57.12	86.41[b]	29.29[bc]
	Male	58.12	89.94[a]	31.82[a]
Small	Female	53.77	84.61[b]	30.84[ab]
	Male	54.41	81.52[c]	27.11[c]

[a,b,c]Columnar interaction means with different superscripts differ significantly.
[1]N=90 for each treatment group. All values are means.
[2]NS
[3]Overall SE = 3.09; P-value = 0.0001
[4]Overall SE = 4.09; P-value = 0.0008

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Manuscript II. The Effects of Incubation Temperature and Eggshell Conductance on Poult Maturation

Abstract

Eggshell conductance (G) and egg weight affect poult viability. Poor viability has been suggested to be related to intestinal maturation and thyroid function of the neonate, and thus the overall maturation of the poult. The objectives of this study were to test if incubator temperature and G determine poult maturity. Maturation was assessed by measuring body weight, feed per gain, jejunal maltase, alkaline phosphatase (ALP) and thyroid function of commercial turkey poults. Two trials were conducted using eggs from a first cycle flock (Cycle 1) and an induced molted flock (Cycle 2). Eggs were individually numbered, weighed, and incubated under standard operating procedures in a commercial turkey hatchery. For each trial eggs were divided and each half was incubated using either a high temperature profile (HP) or a low temperature profile (LP). All eggs were reweighed at 25d and G was calculated. The eggs were then sorted into three groups: Low, Average and High G. At hatch poults were identified by G group and incubation profile. Poults from each experimental group were placed in battery brooders and grown for 7d and BW and feed consumption were measured at D1, 3 and 7. At D1 and D3 post hatching, blood and intestinal samples were taken from each treatment group. Among poults hatching from Cycle 2 eggs; poults incubated under the HP showed increased jejunal weight, maltase, ALP and T_3:T_4 compared to LP poults. Average and High G poults showed greater jejunal ALP, BW gain and decreased feed per gain compared to Low G poults. Among poults hatching from Cycle 1eggs; poults incubated in LP showed greater total jejunal maltase, T_4 and BW, but decreased gain compared to HP poults. Average and High G poults showed greater maltase, BW and gain compared to Low G poults. Incubation profile interacted with G to

affect maltase, ALP and thyroid activities among poults from a Cycle 1 and a Cycle 2 flock. Thus, incubation profile and G may be managed to improve poult maturity.

Key Words: poults, conductance, maltase, thyroid, maturity

Introduction

Rahn *et al.,* (1979) reported differences in eggshell conductance (G) among varying poultry species. This variation was due to the demand of oxygen from the embryo prior to internal pipping. Oxygen demand is greater in larger eggs compared with smaller eggs, because large eggs contain a larger embryo. Thus, size of the egg may require unique incubation conditions for optimal embryonic growth and developmental time (Christensen and McCorkle, 1982). The permeability or G of the eggshell and the size of the egg affected the growth and livability of turkey poults until 7 days of age. The purpose of the current study was to measure the effects of egg size, G, and incubation temperature on neonatal turkey poults.

Egg characteristics influences on the post hatch physiology will be measured by looking at the maturation of the poult. The maturation of an animal can be measured in various ways. The current study will concentrate on mortality, growth, feed consumption, yolk absorption, intestinal maturation, and thyroid function. Increased development of these characteristics will indicate a more mature and viable poult than those lacking these characteristics.

Within the poultry industry, it is generally accepted that if the birds are gaining weight and consuming feed they are growing properly. During early growth the yolk sac serves as an energy reserve for the poult before complete resorption occurs at 5 to 6 days of age (Phelps *et. al.,* 1987, Noy and Sklan, 1998). Poults that are fasted by delaying

placement, for example, have a reduced uptake of yolk compared to fully nourished birds (Moran and Reinhart, 1980). Poult growth may be related to the functionality of the gastrointestinal tract and endocrine systems because of dependence on nutrient uptake and absorption.

The intestine experiences major functional demands at hatching. Prior to hatching the embryo depends mainly on lipid stores from the yolk sac for energy. Although the small intestine in poults undergoes considerable development during incubation, it is still functionally immature in terms of the digestive and absorptive capability at hatching (Sell *et al.,* 1991). Immediately upon hatching, the poult makes a transition from a lipid based diet to a carbohydrate based diet. Therefore, the gastrointestinal tract must adapt to digest the carbohydrates and the proteins available in the feed.

Thyroid hormones act permissively or indirectly, in conjunction with other substances, in the stimulation of growth in birds (McNabb and King, 1993). Black (1978) showed that thyroid and adrenal hormones play major roles during the maturation of the intestine. Limited research has been conducted to determine the differences in poult maturity resulting from incubation temperatures and egg characteristics. Therefore the objectives of this study were: (1) to observe the ability of poults from different egg sizes and differing G to grow and mature and (2) to observe the influence of incubation temperatures in conjunction with egg characteristics on poult maturation.

Materials and Methods

Two trials were conducted with newly hatched poults from commercial turkey eggs (Nicholas Large White). Trials were identical with Trial 1 performed with eggs from an

induced molted flock (Cycle 2), and Trial 2 performed with eggs from a first cycle turkey flock (Cycle 1).

Trial 1 and 2

Fertilized turkey eggs (6,240) were numbered and weighed (nearest 0.01g) individually. A commercial Cycle 2 flock of turkey breeders (Nicholas, Sonoma, CA) in their 10th week of lay produced the eggs for Trial 1. A Cycle 1flock of turkey breeders of the same breed in their 3rd week of lay produced the eggs for Trial 2. Eggs were randomly placed into two single stage incubator cabinets (Jamesway, ACI). The temperature profile varied on the cabinets. The temperature was set with a beginning temperature of 37.8°C on the low temperature profile cabinet (LP) and the other was set with a beginning temperature of 38°C for the high temperature profile cabinet (HP), each with an average relative humidity of 53% (Table 1). At the beginning of the 25th day, all eggs were weighed a second time to determine the moisture loss and G of each individual egg (Tullett, 1981). G values were evaluated using a computer assisted program to identify low (Low), average (Avg) and high (High) G groups. Eggs were sorted into the three groups according to the computed G. Eggs were then candled, injected with antibiotic, transferred to hatching basket, and placed into a machine for hatching operating under a standard hatcher profile for the integrated operation.

Growth of hatchlings:

At hatching, poults were marked for identification using a colored wax marker to identify birds by treatment. The poults were then processed by hatchery personnel, held overnight and then delivered to commercial turkey houses for brooding. Hens and toms were sent to different farms. Mortality of the poults according to temperature profile, G group and

sex was recorded until Day 7 of age. Differences observed according to sex will be discussed in manuscript 3.

A random sample of 30 poults from each temperature by G by sex treatment was grown in battery brooders at North Carolina State University until 7 days of age. Prior to placement poults were necktagged. Body and feed weights were recorded at Days 1, 3, and 7. Mortality was recorded daily. No differences were observed in mortality, very few poults died, so data will not be presented. Once the poults were placed in the brooders the time (minutes) required for the poults to begin eating was recorded for each pen.

Sampling procedures:

Tissues were sampled at day of hatch and Day 3 of age from 10 randomly selected poults from each of the temperature by G by sex treatments. BW was measured with and without the yolk sac (nearest 0.01g). Blood was collected following decapitation into a vial containing 10 mg EDTA. The blood was centrifuged at 700 x g for 15 minutes under refrigeration (4°C). Blood plasma was recovered following centrifugation, placed into vials, and frozen (-22°C) preparatory to analysis for thyroid hormone concentrations.

Intestinal tissue sampling:

The abdominal cavity was opened and two cuts, one at the duodenal loop and the other at Meckel's diverticulum or the yolk stalk attachment were made to remove the jejunum. The jejunum was flushed with physiological saline to remove residual feed, measured (unstretched length), and weighed (nearest 0.0001g) then placed into a tube containing physiological saline and frozen at (-22°) preparatory to analysis for maltase, alkaline phosphatase, and protein content.

Maltase Assay:

Immediately prior to analysis jejunal samples were thawed and homogenized in 2 mL of physiological saline. Homogenization was done by using a Janke & Kunkell Ultra Turrax ® T25 instrument fitted with a S25N-8G dispersing element from IKA ® Work, Inc. (Cincinnati, OH), at the highest speed setting for 30s. Homegenates were kept on ice and dilutions of samples were used immediately to assay for maltase activity (Dahlquvist, 1964). Tissues were analyzed following a microtiter plate protocol. Diluted homogenate (20µl for each well) was incubated at 37°C for 30min with 20ul of 28mM maltase which was dissolved in a 50mM maleate buffer (pH=5.8) . After the incubation period 250µl of tris-glucose oxidase reagent was added. Tris-glucose oxidase oxidized the glucose that was released by the action of the maltase. Plates were read spectrophotometrically at 450nm, using a Spectramax microplate reader (Molecular Devices, CA). Units of maltase specific activities were defined as micromoles of substrate hydrolyzed per milligram of protein in jejunal tissue per hour.

Alkaline Phosphatase assay:

Alkaline Phosphatase (ALP) was assayed following a microtiter plate protocol (Suvarna, 1999). Diluted homogenate (10µl for each well) was mixed with 250µl alkaline phosphatase reagent for 3s. Plates were read at 0min and 5min spectrophotometrically at 415nm on a prewarmed (37°C) Spectramax microplate reader (Molecular Devices, CA). Units of ALP specific activities were defined as micromoles of substrate hydrolyzed per milligram of protein in jejunal tissue per hour.

Total Protein analysis:

Tissue protein values were determined by using the microtiter plate procedure for the BCA^{TM} protein assay kit (Pierce Biochemicals, Rockford IL). Diluted homogenate (10µl for each well) was mixed with 200µl of BCA^{TM} working reagent for 30s. Plates were incubated at 37°C for 30min then read spectrophotometrically at 562nm on a Spectramax microplate reader (Molecular Devices, CA). The total protein content from the jejunum was measured using the reduction of Cu^{+2} to CU^{+1} by protein in an alkaline medium. A reagent containing bicinchoninic acid (BCA) is chelated with Cu^{+1} to form a colorimetric reaction.

Plasma Thyroid Hormone analysis:

Plasma triiodothyronine (T_3) and thyroxine (T_4) concentrations were assayed by RIA (McMurtry *et al.*, 1988). Thyroid hormone concentrations were measured by John McMurtry, USDA, Beltsville, MD. Interassay variation was less than 1.4% for T_3 and less than 2.0% for T_4.

Statistical analysis:

Data were analyzed as 2 sexes (Male and Female) by 2 incubation temperatures (HP and LP) by 3 levels of G (Low, Avg, High) factorial arrangement of a completely random experimental design using the general linear models procedure (SAS Institute, 2001). All data were sorted by day of poult age prior to analysis. Means determined to differ significantly ($P \leq 0.05$) were separated using the least square means procedure. Mortality data were analyzed using a chi-square analysis based on a significance of $P \leq 0.05$. Significance was based on $P \leq 0.05$ unless otherwise noted. All possible interactions were tested, but will be reported only when they were significant.

Results

Trial 1

Temperature:

BW with and without residual yolk at Day 1 among sampled poults from eggs incubated at a HP and a LP were not significantly different (Table 2). The amount of residual yolk differed between the temperature groups. The LP poults had a heavier yolk weight at Day 1 than the HP poults (Table 2). Jejunum weights taken from the HP group were heavier than LP on both absolute basis and relative to BW (Table 2). No significant differences in lengths of the jejuna were observed.

Maltase and ALP activities in the jejunum at Day 1 due to temperature profile at are presented in Table 2. Total jejunal maltase activity (µmol glucose/h/jejunum) and total jejunal ALP activity (µmol phosphorus/h/jejunum) was higher for HP than for LP poults (Table 2). No significant differences were observed among the jejunal protein for the temperature groups. Specific maltase activity (µmol glucose/h/µg protein) and tissue specific maltase activity (µmol glucose/h/mg jejunum) were greater in HP poults than in LP poults at Day 1 (Table 2). HP poults also displayed greater ALP specific activity (µmol phosphorus/h/µg protein) than the LP poults (Table 2). Plasma T_3 values were not different between temperature treatments. Plasma T_4 levels increased in LP poults compared to HP (Table 2). Ratios of plasma T_3:T_4 were found to be significantly higher for HP than for LP poults.

BW at Day 3 with and without residual yolk differed between HP and LP poults (Table 3). HP poults had heavier BW with and without the residual yolk compared to the LP poults, but there was no significant difference between the residual yolk weights. Jejunum

samples taken from the LP group had heavier jejuna when expressed on a percentage basis per gram of BW (Table 3). No differences were observed in lengths of the jejuna and absolute jejuna weights. No significant differences were observed among the intestinal enzymes and the thyroid function between groups at day 3 (Table 3).

The amount of time required for poults to begin eating and drinking at placement was not significant between the treatment groups (Table 4). Day 1 and Day 7 BW (reported on a pen basis) were not different. At Day 3, HP poults weighed more than the LP poults. Feed per gain values (g feed eaten/g BW gained) were also determined on a pen basis. No differences in the amount of BW gain, feed consumed and feed per gain were observed between the temperature profiles.

Conductance:

Day 1, poult BW were not significantly different (Table 5). There was a difference in the amount of residual yolk between the G groups. The Low G poults had heavier yolks at Day 1 than the Avg and the High G poults. No differences in the weights and lengths of the jejuna between the G groups were observed.

Total jejunal ALP activity was lower at Day 1 for Low than the Avg or High G poults (Table 5). No significant differences were observed among the jejunal maltase activities for the G groups. Low G poults demonstrated significantly less specific ALP activity than the Avg and High G poults (Table 5). Plasma thyroid hormone concentrations at Day 1 did not differ between G groups (Table 5).

Avg and High G poults had heavier BW with and without the residual yolk at Day 3 compared to the Low G poults. Avg and High G poults also had significantly smaller residual yolk sacs compared to Low G poults (Table 6). Jejunum samples taken from the

Low G group had significantly heavier jejuna than Avg and High when expressed on a percentage basis per gram of body weight (Table 6). No significant differences in lengths of the jejuna and jejuna weights were observed. No significant differences were observed among the intestinal enzymes and the thyroid function among G groups at day 3 (Table 6).

Low G poults required a significant longer amount of time to begin eating than High G, but not the Avg G poults (Table 7). Avg and High G poults gain more weight compared to the Low G poults from placement until day 3. From placement until day 7 the High G poults gained more than the Avg and the Low G poults (Table 7). No differences were observed among the amount of feed consumed between the G groups up to Day 3, but Low G poults consumed less feed than the Avg and the High G poult from placement until Day 7 and had higher feed per gain values (Table 7).

Temperature and Conductance Interactions:

When data were analyzed for temperature profile by G interactions a significant difference was observed among the BW with residual yolk and the amount of residual yolk at Day 1 (Table 8). LP poults with Low G and HP poults with Avg G had the heaviest body weights at hatch. LP poults with Low G had the highest amount of residual yolk at hatch. Poults from eggs with Low G and incubated at LP had a higher feed per gain value at Day 1 and Day 3 compared to the other G groups (Table 8). No other temperature by G interactions were significant.

Trial 2

Temperature:

BW, residual yolk, jejunal length and weights at Day 1 among sampled poults from eggs incubated at a HP and LP were not significantly different (Table 9). Total jejunal

maltase differed between the temperature groups. Total jejunal maltase activity was higher in LP poults (Table 9). No differences were observed among the jejunal ALP and protein for the temperature groups at Day 1. Maltase and specific activities did not differ. Plasma T_4 levels increased in LP poults compared to HP, but T_3 did not differ (Table 9). Ratios of plasma T_3:T_4 were found to be higher for HP poults.

BW, amount of residual yolk, jejunal lengths and weights at Day 3 between sampled HP and LP poults were not significantly different (Table 10). LP poults had significantly higher amounts of total maltase and specific maltase activity compared to the HP poults (Table 10). No significant differences were observed among ALP activities and the thyroid function between groups at Day 3 (Table 10).

The amount of time required for poults to begin eating and drinking at placement was not significant between the treatment groups (Table 11). BW did not differ at Day 3 and Day 7. At Day 1, LP poults weighed more than the HP poults. HP poults gained more weight from placement to 7 days of age than the LP poults (Table 11). No differences in the amount of feed consumed and feed per gain (g feed/ g BW gained) were observed between the temperature profiles.

Conductance:

Low G poults were heavier and had the largest amount of residual yolk at Day 1 (Table 12). No differences in the weights and lengths of the jejuna were observed. Day 1 total jejunal maltase activity was lower for Low G poults compared to Avg and High (Table 12). No differences were observed among the jejunal ALP and protein activities for the G groups. No differences were observed as well in intestinal enzyme specific activities or

thyroid hormone levels among the G groups at Day 1 (Table 12). Day 3 data showed no differences among, BW, yolk weights, jejunal characteristics and thyroid function (Table 13).

The amount of time required for poults to begin eating and drinking at placement was not different among the G groups (Table 14). BW among the treatment groups was also not different. Avg and High G poults gained more weight compared to the Low G poults from placement until Day 3 (Table 14). From placement until Day 7 weight gain was not different. No differences were observed among the amount of feed consumed and the feed per gain among the G groups (Table 14).

Temperature and Conductance Interactions:

When data were analyzed for temperature profile by G interactions no significant differences were observed. Therefore the interaction means are not shown.

Discussion

The hypothesis in the current study was that the functional quality of an egg (G) determines poult maturity (or quality) at hatching. Limited research has been done relating G to poult maturation. Evidence from the current study also supports the interdependence of G, egg weight, and the length of the incubation period (Ar and Rahn, 1978) and their effects on poult maturity. There are numerous methods to determine the maturity in a young animal. Within the poultry industry BW, gain and feed consumption of birds are frequently measured to assess poult quality. In this study poult maturity was measured as the ability to find feed, eat and grow. Additional characteristics measured were jejunua growth and function and thyroid hormone plasma concentrations.

Maturation of the intestine post hatch is well understood (Sell *et al.*, 1991; Fan *et al.,* 1997; Uni *et al.,* 1995; Survana, 1999; Uni *et al.,* 1999). Physical development of the

gastrointestinal tract can be a more limiting factor to early growth than physiological maturation (Uni *et al.,* 1995; Uni *et al.,* 1996). Physical development is measured by the ability of the intestine to digest and absorb nutrients. The physiological maturation of the gastrointestinal tract occurs mainly through increased production of pancreatic and intestinal enzymes (Nistan *et al.,* 1991; Sell *et al.,* 1991; Pinchasov and Noy, 1993), such as maltase and ALP.

Thyroid hormones control the basal metabolism of an animal and can be influenced by factors such as feed consumption, age and time of day (Decuypere *et al.,* 1985; Sharp and Klandorf, 1985). Thyroid hormones are considered to be key controllers of that part of metabolic heat production that is necessary for the maintenance of high and constant body temperature in homoeothermic animals (Danforth and Burger, 1984). Due to thyroid hormone effects on every known cell in the body, the thermoregulation of poults may also depend on the amount of circulating thyroid present. The current study gives an indication that depending upon the incubation profile and eggshell G neonatal growth, intestinal growth and function, and thyroid hormone levels can be determined.

Temperature:

Temperature is the most critical factor that affects embryonic growth and hatching, and should be under precise control during incubation. The embryo will respond to temperature by increasing or slowing down growth during the incubation period (Wilson, 1991; Tazawa and Whittow, 2000), thus causing the embryo to attain the plateau in oxygen consumption earlier in development (Rahn, 1981). Temperature had pronounced effects on the intestinal function in both Trials. An increase in intestinal mass corresponds to a higher amount of nutrient intake. Although the mass of the intestine may increase an increase in

function is not always observed (Noy and Sklan, 1999; Uni *et al.,* 1999). In Trial 1, HP poults had a larger jejunum and demonstrated a more metabolically active intestine when compared to the LP poults. Body weights at Day 3 of age among the HP poults hatching from Cycle 2 eggs mirrored the maturity of the intestine. In order for nutrients to be properly absorbed physiological maturation and an increase in physical characteristics of the intestine are required (Nitsan *et al.,* 1991; Pinchasov and Noy, 1993; Sell *et. al.,* 1991; Uni *et al.,* 1995; Uni *et al.,* 1996; Fan *et al.,* 1997; Survarna, 1999; Uni *et al.,* 1999). The results from Trial 1 also support these findings.

In Trial 2, LP poults demonstrated a more metabolically active intestine although there was not a significant difference in the sizes of the intestine. The active intestine seen among the LP poults was not reflected in the growth of the birds, these poults were not able to utilize the nutrients they consumed more efficiently. Although the LP lead to a more metabolically active intestine the physical characteristics did not increase, which may explain the depressed growth of the poults. The increased intestinal enzymes observed among the LP poults may be due to a compensatory mechanism in an attempt to reach the maturity level of the HP poults.

The action of temperature on the thyroid function also mirrors the actions on intestinal maturation and growth. In both Trials the HP poults had a higher T_3:T_4 ratio, indicating that they have more T_3 than T_4. This implies that HP poults are more proficient at converting T_4 to T_3. Thus, these poults have more of the key metabolic hormone and can utilize the nutrients they are consuming in a more efficient manner. These findings agree with previous data reports that poults fed diets containing higher amounts of carbohydrate are able to convert more T_4 to T_3 (Survana, 2005). HP poults may consume more feed, therefore

are digesting more carbohydrate, leading to the observed increased weight gain. Thus, we conclude that HP poults are more mature at hatching, giving them a growth advantage over poults from eggs incubated at the LP.

Conductance:

Eggshell G influenced the status of the poult at hatching and its ability to grow. In Trial 2 the G caused BW to differ as well as affected the amount of residual yolk. Low G poults weighed more than the Avg and High G poults. The high BW can be explained by the large amount of residual yolk found at hatching. Differences in the amount of residual yolk were probably due to the permeability of the eggshell. Embryos with high porosity eggshell, or increased permeability, can satisfy their oxygen demand and provide them with adequate oxygen to metabolize the yolk for energy. Conversely, low porosity eggshells limit the amount of oxygen available to the embryo and thus results in a reduced metabolism and growth rate, leading to a larger residual yolk at hatch (Tullett and Deeming, 1982; Burton and Tullett, 1983). The relative size of the yolk in poults is smaller than in chicks, consequently the source of endogenous energy supply is more limited in the young poult verses the chick (Noy and Sklan, 1998). This difference may explain the poor viability of turkey poults at hatch compared to chicks.

At hatching, the metabolic activity of the Low G poults was significantly lower than for Avg and High G poults for both Trials. Jejunal samples in Trial 1 from Low G poults were heavier at Day 3, but no differences in metabolic activity were observed. The increase in intestinal mass among the Low G poults may be due to a compensatory mechanism in attempt to overcome the decreased metabolically mature intestine at hatching. The energy supply that is available for growth is limited by the size of the digestive tract, thus investment

of growth resources during early development into the intestine provides the ability for birds to have a higher growth rate (Mitchell and Smith, 1991). To increase the amount of energy available to the poult an increase in intestinal mass is necessary, therefore the larger jejunal mass at Day 3 among the Low G poults could be providing them with the ability to utilize more nutrients and increase their growth rate. Although an increase was observed, Low G poults still consumed significantly less feed and had a higher feed per gain value compared to the Avg and High poults. The differences in behavior, among poults in Trial 1, at placement support the depressed maturation of the Low G poults. At placement the Low G poults required more time to become active than Avg and High poults. In Trial 2 the Low G poults gain significantly less weight compared to the Avg and High G poults. Therefore, the intestine of a Low G poult is less able to metabolize nutrients. These results indicate that Low G poults are of poor quality at hatching and can exhibit reduced growth during the brooding period.

Temperature and Conductance Interactions:

In Trial 1 there was an interaction between temperature and G, leading to differences in hatchling BW and amount of residual yolk. Although high body weights were observed among LP and HP poults it is evident that those differences may be explained by the amount of residual yolk. As previously stated, differences seen in the amount of residual yolk may be due to the permeability of the eggshell. Low G poults have significantly more yolk compared to the average and high.

In summary, I found that the a more mature poult came from an egg incubated at HP. The overall worst viable poults tend to come from eggs with low eggshell G regardless of incubation profile. In conclusion, I have found that among eggs from a Cycle 2 and a Cycle

1 flock the temperatures throughout incubation and the G of the eggshell influence the ability of the turkey poult to mature and survive during the brooding period. Therefore the characteristics of the egg may predispose embryos to become weak poults at hatching. The incubation profile and egg shell conductance may be managed to improve poult maturity.

TABLE 1. Temperature profiles used in incubating eggs from Cycle 2 and Cycle 1 flocks to Day 25[1]

Day	High Temperature Profile (HP) °C	Low Temperature Profile (LP)°C	Percent Relative Humidity
0	38	37.8	60
2	38	37.7	60
4	38.7	37.7	60
8	37.6	37.5	60
10	37.6	37.4	60
12	37.5	37.4	60
14	37.5	37.1	45
16	37.4	37.1	45
18	37.4	36.8	42
20	37.4	36.8	42
22	37.1	36.7	42
25	36.6	36.7	42

[1]Trial 1 and Trial 2

TABLE 2. Effects of different incubation temperature profiles on anatomic and physiologic factors determining maturity of poults hatching from egg of a Cycle 2 flock at Day 1 posthatch[1]

Data analyzed using temperature profile as treatment

	HP[2]	LP[3]	Overall SE	P value
Total Body Wt at hatch (g)	60.93	62.43	3.39	NS
Body Wt w/o yolk sac (g)	52.46	52.79	2.63	NS
Yolk Sac Wt. (g)	8.48	9.64	0.60	0.0482
Jejunal Length (cm)	14.28	14.41	0.66	NS
Jejunal Weight (g)	0.53	0.40	0.001	<.0001
Relative Jejunal Weight	0.0100	0.0080	0.0000003	<.0001
Total Maltase activity[4]	496.19	304.34	80.48	<.0001
Total ALP activity[5]	27582.42	17904.50	9310.47	<.0001
Jejunal Protein (μg)	25772.15	24874.60	18847.40	NS
Maltase specific activity-mg P[6]	19.82	12.21	2.30	<.0001
Maltase specific activity-mg tissue[7]	9.48	7.82	0.49	0.0015
ALP specific activity-mg P[8]	1.06	0.71	0.01	<.0001
ALP specific activity-mg tissue[9]	52.44	45.01	37.32	NS
Plasma T_3 (ng/mL)	3.11	2.94	0.04	NS
Plasma T_4 (ng/mL)	9.27	11.27	0.88	0.0116
Ratio T_3:T_4	0.35	0.27	0.0007	0.0004

[1]N=36 for both treatment groups. All values are means. Trial 1.
[2]HP=poults from eggs incubated at a high temperature profile
[3]LP=poults from eggs incubated at a low temperature profile
[4](μmol glucose/h/jejunum)
[5](μmol phosphorus/h/jejunum)
[6](μmol glucose/h/μg Protein)
7(μmol glucose/h/mg jejunum)
[8](μmol phosphorus/h/μg Protein)
[9](μmol phosphorus/h/mg jejunum)

TABLE 3. Effects of different incubation temperature profiles on anatomic and physiologic factors determining maturity of poults hatching from eggs of a Cycle 2 flock at Day 3 posthatch[1]

Data analyzed using temperature profile as the treatment

	HP[2]	LP[3]	Overall SE	P value
Total Body Wt. posthatch (g)	89.25	82.49	7.53	0.0007
Body Wt w/o yolk sac (g)	86.02	79.71	8.61	0.0027
Yolk Sac Wt.(g)	3.23	2.78	0.43	NS
Jejunal Length (cm)	22.31	22.43	2.63	NS
Jejunal Weight (g)	1.53	1.45	0.004	NS
Relative Jejunal Weight	0.176	0.183	0.002	0.0222
Total Maltase activity[4]	1759.56	1721.42	1906.70	NS
Total ALP activity[5]	187107.36	185050.89	2329966	NS
Jejunal Protein (μg)	119272.22	115908.33	1704040.4	NS
Maltase specific activity-mg P[6]	14.72	14.82	1.04	NS
Maltase specific activity-mg tissue[7]	11.62	11.83	0.53	NS
ALP specific activity-mg P[8]	1.56	1.58	0.002	NS
ALP specific activity-mg tissue[9]	123.24	126.30	78.73	NS
Plasma T_3 (ng/mL)	4.65	4.54	0.15	NS
Plasma T_4 (ng/mL)	7.37	7.99	0.90	NS
Ratio T_3:T_4	0.701	0.656	0.008	NS

[1]N=36 for both treatment groups. All values are means. Trial 1.
[2]HP=poults from eggs incubated at a high temperature profile
[3]LP=poults from eggs incubated at a low temperature profile
[4](μmol glucose/h/jejunum)
[5](μmol phosphorus/h/jejunum)
[6](μmol glucose/h/μg Protein)
[7](μmol glucose/h/mg jejunum)
[8](μmol phosphorus/h/μg Protein)
[9](μmol phosphorus/h/mg jejunum)

TABLE 4. Effects of different incubation temperature profiles on growth of poults hatching from eggs of a Cycle 2 flock from Day 1 to Day 7[1]

Data analyzed using temperature profile as the treatment

	HP[2]	LP[3]	Overall SE	P value
Time to feed (min)	105.13	143.61	97.56	NS
Pen Weight-Day 1 (g)	606.17	599.72	81.97	NS
Pen Weight-Day 3 (g)	942.00	910.83	234.70	0.0200
Pen Weight – Day 7 (g)	1227.17	1245.28	1260.17	NS
Gain Day 1 to Day 3 (g)	335.83	311.11	302.70	NS
Gain Day 1 to Day 7 (g)	621.00	645.56	1329.61	NS
Feed consumed up to Day 3 (g)	261.44	254.50	131.09	NS
Feed consumed up to Day 7 (g)	756.50	758.89	406.0	NS
Feed per gain – Day 1 to Day 3	0.791	0.835	0.001	NS
Feed per gain – Day 1 to Day 7	1.28	1.19	0.06	NS

[1]N=18 pens of 10 birds for both treatment groups. All values are means. Trial 1.
[2]HP=poults from eggs incubated at a high temperature profile
[3]LP=poults from eggs incubated at a low temperature profile

TABLE 5. Effects of different eggshell conductance values on anatomic and physiologic factors determining maturity of poults hatching from eggs of a Cycle 2 flock at Day 1 posthatch[1]

Data analyzed using G as treatment.

	Low	Average	High	Overall SE	P value
Total Body Wt at hatch (g)	61.27	62.22	61.55	3.39	NS
Body Wt w/o yolk sac (g)	50.94	53.78	53.14	2.63	NS
Yolk Sac Wt (g)	10.33[a]	8.44[b]	8.41[b]	0.60	0.0024
Jejunal Length (cm)	14.64	14.34	14.06	0.66	NS
Jejunal Weight (g)	0.466	0.464	0.465	0.001	NS
Relative Jejunal Weight	0.0093	0.0086	0.0088	0.0000003	NS
Total Maltase activity[2]	415.51	387.29	398.00	80.47	NS
Total ALP activity[3]	20182.56[b]	26590.68[a]	21457.67[ab]	9310.47	0.0019
Jejunal Protein (µg)	25373.57	25645.72	24950.83	18847.40	NS
Maltase specific activity-mg P[4]	16.61	15.26	16.18	2.30	NS
Maltase specific activity-mg tissue[5]	9.18	8.33	8.44	0.49	NS
ALP specific activity-mg P[6]	0.799[b]	1.016[a]	0.8443[ab]	0.01	0.0019
ALP specific activity-mg tissue[7]	43.54[b]	56.38[a]	46.25[ab]	37.32	0.0141
Plasma T_3 (ng/mL)	2.93	3.22	2.92	0.04	NS
Plasma T_4 (ng/mL)	10.40	10.95	9.46	0.88	NS
Ratio T_3:T_4	0.290	0.210	0.330	0.0007	NS

[a,b,c]Row means with different superscripts differ significantly.
[1]N=24 for each treatment group. All values are means. Trial 1.
[2](µmol glucose/h/jejunum)
[3](µmol phosphorus/h/jejunum)
[4](µmol glucose/h/µg Protein)
[5](µmol glucose/h/mg jejunum)
[6](µmol phosphorus/h/µg Protein)
[7](µmol phosphorus/h/mg jejunum)

TABLE 6. Effects of different eggshell conductance values on anatomic and physiologic factors determining maturity of poults hatching from eggs of a Cycle 2 flock at Day 3 posthatch[1]

Data analyzed using G as treatment.

	Low	Average	High	Overall SE	P value
Total Body Wt. posthatch (g)	81.76[b]	87.04[a]	88.81[a]	7.53	0.0094
Body Wt w/o yolk sac (g)	77.73[b]	84.29[a]	86.58[ab]	8.61	0.0020
Yolk Sac Wt. (g)	4.03[a]	2.75[b]	2.23[b]	0.43	0.0059
Jejunal Length (cm)	22.03	22.23	22.84	2.63	NS
Jejunal Weight (g)	1.45	1.49	1.51	0.004	NS
Relative Jejunal Weight	0.0185[a]	0.0177[b]	0.0174[b]	0.002	0.0099
Total Maltase activity[2]	1647.37	1748.00	1826.08	1906.7	NS
Total ALP activity[3]	178437.25	183361.17	196438.96	2329966	NS
Jejunal Protein (µg)	114262.50	118770.83	119737.50	1704040.4	NS
Maltase specific activity-mg P[4]	14.44	14.65	15.22	1.04	NS
Maltase specific activity-mg tissue[5]	11.42	11.67	12.10	0.53	NS
ALP specific activity-mg P[6]	1.54	1.54	1.63	0.002	NS
ALP specific activity-mg tissue[7]	121.91	121.88	130.51	78.73	NS
Plasma T_3 (ng/mL)	4.35	4.67	4.76	0.15	NS
Plasma T_4 (ng/mL)	7.52	7.97	7.55	0.90	NS
Ratio T_3:T_4	0.648	0.677	0.711	0.008	NS

[a,b,c]Row means with different superscripts differ significantly.
[1]N=24 for each treatment group. All values are means. Trial 1.
[2](µmol glucose/h/jejunum)
[3](µmol phosphorus/h/jejunum)
[4](µmol glucose/h/µg Protein)
[5](µmol glucose/h/mg jejunum)
[6](µmol phosphorus/h/µg Protein)
[7](µmol phosphorus/h/mg jejunum)

TABLE 7. Effects of different eggshell conductance values on growth of poults hatching from eggs of a Cycle 2 flock from Day 1 to Day 7[1]

Data analyzed using G as treatment.

	Low	Average	High	Overall SE	P value
Time to feed (min)	162.67[a]	129.25[ab]	81.19[b]	97.56	0.0387
Pen Weight-Day 1 (g)	594.92	601.50	612.42	81.97	NS
Pen Weight-Day 3 (g)	899.00[b]	931.42[a]	948.83[a]	234.70	0.0112
Pen Weight – Day 7 (g)	1181.00[b]	1224.25[b]	1303.42[a]	1260.17	0.0071
Gain Day 1 to Day 3 (g)	286.58[b]	329.92[a]	353.92[a]	302.70	0.0026
Gain Day 1 to Day 7	568.58[b]	622.75[b]	708.50[a]	1329.61	0.0030
Feed consumed up to Day 3	247.17	257.67	269.08	131.09	NS
Feed consumed up to Day 7	726.83[b]	753.58[ab]	792.67[a]	406.0	0.0116
Feed per gain – Day 1 to Day 3	0.882[a]	0.792[b]	0.765[b]	0.001	0.0109
Feed per gain – Day 1 to Day 7	1.33[a]	1.26[ab]	1.12[b]	0.06	0.0387

[a,b,c]Row means with different superscripts differ significantly.
[1]N=12 pens of 10 birds for each treatment group. All values are means. Trial 1.

TABLE 8. Effect of incubation temperature profile and eggshell conductance on anatomical factors determining poult maturity from Day 1 to Day 3 posthatch among eggs from a Cycle 2 flock[1]

Data analyzed using temperature profile x G as treatment.

Temperature Profile	Eggshell Conductance	Total body weight posthatch Day 1(g)[4]	Residual yolk Day 1(g) [5]	Feed per gain Day 1 to Day 3[6]
HP[2]	Low	54.24[b]	8.66[b]	0.80[b]
	Average	62.65[a]	8.06[b]	0.80[b]
	High	61.91[ab]	8.71[b]	0.78[b]
LP[3]	Low	64.29[a]	11.99[a]	0.97[a]
	Average	61.78[ab]	8.81[b]	0.78[b]
	High	61.19[ab]	8.11[b]	0.75[b]

[a,b,c]Columnar interaction means with different superscripts differ significantly.
[1]All values are means. Trial 1.
[2]HP=poults from eggs incubated at a high temperature profile
[3]LP=poults from eggs incubated at a low temperature profile
[4]N = 12 for each treatment group. Overall SE=3.39 P value=0.0507
[5]N = 12 for each treatment group. Overall SE=0.60 P value=0.0235
[6]N = 6 pens of 10 birds for each treatment group. Overall SE=0.001 P-value= 0.0208

TABLE 9. Effects of different incubation temperature profiles on anatomic and physiologic factors determining maturity of poults hatching from eggs of a Cycle 1 flock at Day 1 posthatch[1]

Data analyzed using temperature profile as the treatment.

	HP[2]	LP[3]	Overall SE	P value
Total Body Wt at hatch (g)	52.41	53.53	1.81	NS
Body Wt w/o yolk sac (g)	48.20	49.30	1.49	NS
Yolk Sac Wt (g)	4.21	4.23	0.15	NS
Jejunal Length (cm)	12.96	13.44	0.80	NS
Jejunal Weight (g)	0.455	0.482	0.0009	NS
Relative Jejunal Weight	0.009	0.010	0.0000003	NS
Total Maltase activity[4]	327.84	367.25	73.11	0.0393
Total ALP activity[5]	18113.32	18465.56	74085.25	NS
Jejunal Protein (g)	19327.68	20457.78	19057.67	NS
Maltase specific activity-mg P[6]	17.39	18.63	2.98	NS
Maltase specific activity-mg tissue[7]	7.23	7.92	0.44	NS
ALP specific activity-mg P[8]	0.960	0.890	0.01	NS
ALP specific activity-mg tissue[9]	39.51	39.11	32.18	NS
Plasma T_3 (ng/mL)	3.41	3.76	0.09	NS
Plasma T_4 (ng/mL)	10.60	12.75	1.53	0.0151
Ratio T_3:T_4	0.344	0.302	0.0010	0.0538

[1]N=36 for both treatment groups. All values are means. Trial 2.
[2]HP=poults from eggs incubated at a high temperature profile
[3]LP=poults from eggs incubated at a low temperature profile
[4](µmol glucose/h/jejunum)
[5](µmol phosphorus/h/jejunum)
[6](µmol glucose/h/µg Protein)
[7](µmol glucose/h/mg jejunum)
[8](µmol phosphorus/h/µg Protein)
[9](µmol phosphorus/h/mg jejunum)

TABLE 10. Effects of different incubation temperature profiles on anatomic and physiologic factors determining maturity of poults hatching from eggs of a Cycle 1 flock at Day 3 posthatch[1]

Data analyzed using temperature profile as the treatment.

	HP[2]	LP[3]	Overall SE	P value
Total Body Wt. (g)	76.50	75.05	6.22	NS
Body Wt w/o yolk sac (g)	75.40	74.11	6.44	NS
Yolk Sac Wt. (g)	1.10	0.95	0.04	NS
Jejunal Length (cm)	21.75	21.53	0.66	NS
Jejunal Weight (g)	1.48	1.41	0.008	NS
Relative Jejunal Weight	0.020	0.019	0.0000010	NS
Total Maltase activity[4]	1501.89	1717.42	210.49	0.0345
Total ALP activity[5]	174756.42	185033.64	2634874.4	NS
Jejunal Protein (g)	123138.89	118088.89	3664707.70	NS
Maltase specific activity-mg P[6]	12.38	14.96	2.26	0.0152
Maltase specific activity-mg tissue[7]	10.40	12.40	1.03	0.0058
ALP specific activity-mg P[8]	1.43	1.56	0.01	NS
ALP specific activity-mg tissue[9]	120.21	132.29	104.76	NS
Plasma T_3 (ng/mL)	5.41	5.25	0.20	NS
Plasma T_4 (ng/mL)	9.06	7.63	1.89	NS
Ratio T_3:T_4	0.739	0.864	0.03	NS

[1]N=36 for both treatment groups. All values are means. Trial 2.
[2]HP=poults from eggs incubated at a high temperature profile
[3]LP=poults from eggs incubated at a low temperature profile
[4](µmol glucose/h/jejunum)
[5](µmol phosphorus/h/jejunum)
[6](µmol glucose/h/µg Protein)
[7](µmol glucose/h/mg jejunum)
[8](µmol phosphorus/h/µg Protein)
[9](µmol phosphorus/h/mg jejunum)

TABLE 11. Effects of different incubation temperature profiles growth of poults hatching from eggs of a Cycle 1 flock from Day 1 to Day 7[1]

Data analyzed using temperature profile as the treatment

	HP[2]	LP[3]	Overall SE	P value
Time to feed (min)	110.68	146.72	86.33	NS
Pen Weight-Day 1 (g)	525.83	534.83	20.14	0.0216
Pen Weight-Day 3 (g)	840.89	812.17	359.62	NS
Pen Weight – Day 7 (g)	1175.22	1130.11	1027.22	NS
Gain Day 1 to Day 3 (g)	315.06	277.33	365.71	0.0237
Gain Day 1 to Day 7 (g)	649.39	595.28	1018.48	0.0487
Feed consumed up to Day 3 (g)	268.83	252.67	155.58	NS
Feed consumed up to Day 7 (g)	757.50	723.56	658.75	NS
Feed per gain – Day 1 to Day 3	0.87	0.96	0.006	NS
Feed per gain – Day 1 to Day 7	1.18	1.26	0.006	NS

[1]N=18 pens of 10 birds for each treatment group. All values are means. Trial 2.
[2]HP=poults from eggs incubated at a high temperature profile
[3]LP=poults from eggs incubated at a low temperature profile

TABLE 12. Effects of different eggshell conductance values on anatomic and physiologic factors determining maturity of poults hatching from eggs of a Cycle 1 flock at Day 1 posthatch[1]

Data analyzed using conductance as treatment.

	Low	Average	High	Overall SE	P value
Total Body Wt at hatch (g)	54.29[a]	53.23[ab]	51.39[b]	1.81	0.0398
Body Wt w/o yolk sac (g)	49.46	49.01	47.78	1.49	NS
Yolk Sac Wt (g)	4.83[a]	4.23[ab]	3.61[b]	0.15	0.0015
Jejunal Length (cm)	13.10	12.90	13.60	0.80	NS
Jejunal Weight (g)	0.465	0.453	0.488	0.0009	NS
Relative Jejunal Weight	0.009	0.009	0.010	0.0000003	NS
Total Maltase activity[2]	325.38[b]	336.10[ab]	381.17[a]	73.11	0.0410
Total ALP activity[3]	16980.46	18450.68	19437.17	74085.25	NS
Jejunal Protein (g)	19323.33	19304.86	21050.00	19057.67	NS
Maltase specific activity-mg P[4]	17.17	18.39	18.48	2.98	NS
Maltase specific activity-mg tissue[5]	7.16	7.45	8.12	0.44	NS
ALP specific activity-mg P[6]	0.906	0.939	0.930	0.01	NS
ALP specific activity-mg tissue[7]	37.24	40.15	40.53	32.18	NS
Plasma T_3 (ng/mL)	3.58	3.45	3.72	0.09	NS
Plasma T_4 (ng/mL)	10.94	11.79	12.29	1.53	NS
Ratio T_3:T_4	0.335	0.302	0.331	0.0010	NS

[a,b,c]Row means with different superscripts differ significantly.
[1]N=24 for each treatment group. All values are means. Trial 2.
[2](µmol glucose/h/jejunum)
[3](µmol phosphorus/h/jejunum)
[4](µmol glucose/h/µg Protein)
[5](µmol glucose/h/mg jejunum)
[6](µmol phosphorus/h/µg Protein)
[7](µmol phosphorus/h/mg jejunum)

TABLE 13. Effects of different eggshell conductance values on anatomic and physiologic factors determining maturity of poults hatching from eggs of a Cycle 1 flock at Day 3 posthatch[1]

Data analyzed using conductance as treatment.

	Low	Average	High	Overall SE	P value
Total Body Wt. (g)	76.79	75.62	74.92	6.22	NS
Body Wt w/o yolk sac (g)	75.65	74.58	74.03	6.44	NS
Yolk Sac Wt.(g)	1.14	1.04	0.87	0.04	NS
Jejunal Length (cm)	21.89	21.35	21.68	0.66	NS
Jejunal Weight (g)	1.47	1.43	1.44	0.008	NS
Relative Jejunal Weight	0.194	0.191	0.193	0.0000010	NS
Total Maltase activity[2]	1692.92	1610.54	1525.50	210.49	NS
Total ALP activity[3]	179960.71	182031.17	177693.21	2634874.40	NS
Jejunal Protein (g)	118708.33	119200.00	123933.33	3664707.70	NS
Maltase specific activity-mg P[4]	14.89	13.67	12.47	2.26	NS
Maltase specific activity-mg tissue[5]	11.81	11.59	10.79	1.03	NS
ALP specific activity-mg P[6]	1.52	1.52	1.45	0.01	NS
ALP specific activity-mg tissue[7]	124.68	127.88	126.19	104.76	NS
Plasma T_3 (ng/mL)	5.34	5.33	5.32	0.20	NS
Plasma T_4 (ng/mL)	8.44	8.49	8.10	1.89	NS
Ratio T_3:T_4	0.891	0.739	0.774	0.03	NS

[a,b,c]Row means with different superscripts differ significantly.
[1]N=24 for each treatment group. All values are means. Trial 2.
[2](µmol glucose/h/jejunum)
[3](µmol phosphorus/h/jejunum)
[4](µmol glucose/h/µg Protein)
[5](µmol glucose/h/mg jejunum)
[6](µmol phosphorus/h/µg Protein)
[7](µmol phosphorus/h/mg jejunum)

TABLE 14. Effects of different eggshell conductance values on growth of poults hatching from eggs of a Cycle 1 flock from Day 1 to Day7[1]

Data analyzed using conductance as treatment group.

	Low	Average	High	Overall SE	P value
Time to feed (min)	143.08	132.71	110.31	86.33	NS
Pen Weight-Day 1 (g)	535.83	531.17	540.00	20.14	NS
Pen Weight-Day 3 (g)	803.42	847.42	828.75	359.62	NS
Pen Weight – Day 7 (g)	1123.67	1180.58	1153.75	1027.22	NS
Gain Day 1 to Day 3 (g)	267.58[b]	316.25[a]	304.75[ab]	365.71	0.0450
Gain Day 1 to Day 7	587.83	649.42	629.75	1018.48	NS
Feed consumed up to Day 3	255.33	265.67	261.25	155.58	NS
Feed consumed up to Day 7	728.50	757.58	735.50	658.75	NS
Feed per gain – Day 1 to Day 3	1.01	0.867	0.863	0.006	NS
Feed per gain – Day 1 to Day 7	1.23	1.20	1.17	0.006	NS

[a,b,c]Row means with different superscripts differ significantly.
[1]N=12 pens of 10 birds for each treatment group. All values are means. Trial 2.

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Manuscript III. The Effects of Incubation Temperature, Eggshell Conductance and Sex on Poult Maturity

Abstract

Incubation temperature and eggshell conductance (G) affect the maturity of turkey poults to 7 days of age. The objectives of this study were to test if incubator temperature, G and sex of the poult determine maturity. Maturation was assessed by measuring BW, feed per gain, jejunal maltase, alkaline phosphatase (ALP) and thyroid function of commercial turkey poults. Two trials were conducted using eggs from an induced molted flock (Cycle 2) and eggs from a first cycled flock (Cycle 1). Eggs were individually numbered, weighed, and incubated under standard operating procedures in a commercial turkey hatchery. For each trial the eggs were divided and each half was incubated using either a high temperature profile (HP) or a low temperature profile (LP). All eggs were reweighed at 25d and G was calculated. The eggs were then sorted into three groups: Low, Average, and High G. At hatch poults were identified by incubation profile, G group and sexed. Poults from each experimental group were placed in battery brooders and grown for 7d during which body weight and feed consumption were measured at Days 1, 3, and 7. At Days 1 and 3 posthatching blood and intestinal samples were taken from each treatment group. Among poults hatching from Cycle 2 eggs; male poults from High G eggs incubated at the HP had higher levels of maltase than Average and Low G males incubated under the HP. Females incubated at HP with an Average and Low G had greater maltase than High G females at the HP. The greatest body weight was seen among HP males with Average G and HP females with High G. Among poults hatching from Cycle 1 eggs; Average G males possessed the greatest concentration of T_3, while the Average G females had the lowest amount of T_3. Females had a heavier jejunum relative to body weight than the males as well as a higher

feed per gain value. Incubation profile, G and sex of the poult interacted to affect the intestinal maturation, thyroid activities and overall growth of poults from a Cycle 2 and a Cycle 1 flock. Therefore, incubation profile, G and sex may be utilized to determine proper measure to improve poult maturity.

Key Words: poult, conductance, maltase, thyroid, sex

Introduction

Characteristics of the egg and incubation conditions influence the ability of a poult hatchling to eat, grow and mature during the brooding period. Poult maturity may also differ between male and female poults in different types of eggs. Limited research has been reported on the different physiologies between male and female poults. Cherms (1969) reported that females tend to dominate during the hatching process and tend to survive better than the males (Hays and Spear, 1952).

I have observed that characteristics of the eggshell and incubation temperature have an effect on poult maturity. Functional egg characteristics and egg weight may interact with sex of the poult to affect the rate of maturity. The objectives of this study were to observe what effect incubation temperature and eggshell conductance (G) have on the sex of the poult. The object of the current study was to measure the livability, growth and intestinal and thyroid functions of male and female neonatal turkeys.

Materials and Methods

Materials and methods for Experiment 3 were identical to those of Experiment 2, so the methods will not be repeated. For details refer to Manuscript 2. The poults were separated by sex following vent sexing in the current study. Sex (M or F) was added to the statistical model to determine sex effects.

Results

Trial 1

Sex:

Body and yolk weights at Day1 among M and F poults were not different (Table 1). M at hatching had longer and heavier jejuna than F (Table 1). Total jejunal maltase activity expressed as μmol glucose/h/jejunum was greater in M than for F (Table 1). No significant differences were observed among the jejunal total alkaline phosphatase (ALP), intestinal specific enzyme activities or thyroid hormones between the sexes at Day 1 (Table 1).

Body weight with and without residual yolk at Day 3 between M and F poults differed (Table 2). Male poults had heavier BW with and without the residual yolk compared to the F, but there was no difference between the residual yolk weights. Jejunum samples taken from M were longer and heavier than F (Table 2). Male have more total maltase and total ALP than F (Table 2). No differences were seen among specific intestinal enzyme activity. Male had greater concentrations of T_4 than F at Day 3, while F had a higher T_3:T_4 ratio (Table 2). No significant differences were observed among the T_3 values between the groups at Day 3 (Table 2).

The amount of time required for poults to begin eating and drinking at placement was not different between the sexes (Table 3). Body weight at Days 1, 3, and 7 were different. Male had heavier BW and greater BW gain and feed consumption than F (Table 3). No differences in the feed per gain value (g feed/ g BW gained) from Day 1 to Day 3 were observed. From Day 1 to Day 7, F had a greater feed per gain value than M (Table 3).

Data were analyzed for temperature by sex (Table 4 and Table 8), eggshell G by sex (Table 5), and sex by temperature by eggshell G (Table 6 and Table 7) interactions.

Temperature and Sex Interactions:

Male poults incubated at a HP had the heaviest body weight with and without residual yolk compared to all other interaction means. Overall, M had a heavier jejuna and more total maltase activity than F. The M incubated at HP had heavier jejunal weights and higher total maltase activity compared to the other treatment groups (Table 4). Male poults incubated at the LP had higher amounts of T_4 compared to the HP M or F (Table 4). Males had higher BW than F and the HP increased BW. Among the M, the HP poults gained more weight, while among the F the LP poults gained more weight. Males consumed more feed than the F, with HP M consuming the more than the other treatments (Table 5). No other temperature by sex interactions were significant at Day 1 or Day 3. Therefore, the means are not shown

Conductance and Sex Interactions:

Males exhibited more jejunal maltase activity than F (Table 6). Males with Low G had the greatest total ALP activity, while F with Low G possessed the lowest total jejunal ALP activity. M with Low and High G had the greatest amount of specific ALP activity, while F with Low G had the least amount of activity. No other G by sex interactions were significant at Day 1 or Day 3. Therefore, the other interaction means are not shown.

Temperature, Conductance and Sex Interactions:

Female, LP poults at Day 1 had lower total maltase activity than the HP poults or M poults. Avg G, HP poults showed the greatest total maltase activity. Specific maltase activity per tissue mass of High G, HP and Avg G, LP poults had the least activity. In contrast, these treatments had the greatest specific ALP activities (Table 7). Among M poults at Day 1, the LP poults had less total maltase activity and maltase activity specific to the jejunum than the HP poults while the High G, HP poults had the most activity (Table 8).

The HP had the most ALP specific activities while the least amount of activity was in the Avg G, LP group (Table 8).

At Day 3, HP F had heavier BW than LP F, with the heaviest BW among the High G, HP group. By Day 7 the heaviest BW was among the High G, LP poults (Table 7). High temperature profile M had heavier BW at Day 7, while the Avg G, HP M had the heaviest BW (Table 8). No other significant temperature by G by sex interactions were noted therefore, the interaction means are not shown.

Trail 2

Sex:

Body and yolk weights at Day 1 among M and F poults were not different (Table 9). F had heavier jejunua relative to body weight than the M (Table 9). No significant differences were observed in jejuna length and weight. No significant differences were observed among the intestinal enzyme activities and the thyroid hormones between the sexes (Table 9).

Male poults at Day 3 had heavier BW with and without the residual yolk compared to the F, but there was no significant difference between the residual yolk weights. Jejunum samples taken from the M were significantly heavier than F (Table 10). No differences were observed among jejuna length and weight relative to the body weight. No significant differences were seen among the intestinal enzyme activities. Males had a higher amount of T_4 than F at Day 3 (Table 10). No significant differences were observed T_3:T_4 ratios between the groups at Day 3 (Table 10).

The amount of time required for poults to begin eating and drinking at placement was not different between the sexes (Table 11). BW at Days 1, 3 and 7differed. Males had

heavier BW and greater BW gain and feed consumption than F (Table 11). No differences in the feed per gain value (g feed/ g BW gained) from Day 1 to Day 3 were observed. From Day 1 to Day 7, F had higher feed per gain value than M (Table 11).

Data were analyzed for temperature profile by sex (Table 12), eggshell G by sex (Table 13) and sex by temperature profile by eggshell G (Table 14) interactions.

Temperature and Sex Interactions:

Females demonstrated greater specific maltase activities than the M, with the highest amount of activity seen among the LP poults (Table 12). No other temperature profile by sex interactions were significant at Day 1 or Day 3, therefore, the other interaction means are not shown.

Conductance and Sex Interactions:

Males had heavier jejuna that F, with High G M having the heaviest jejuna and High G F having the lightest jejuna (Table 13). Males had greater concentrations of T_3 than F at Day 3. Avg G M had the greatest T_3 concentration, while Avg G F had the lowest concentration of T_3 (Table 13). No other G by sex interactions were significant at Day 1 or Day 3, therefore, the remaining means are not shown.

Temperature, Conductance and Sex Interactions:

Female, HP poults had significantly heavier residual yolk, and the Low G, HP poults demonstrated the heaviest yolk weight (Table 14). M, HP poults also had the heaviest residual yolk at Day 3. Avg G, HP M poults had the heaviest yolk weight, while High G, LP poults showed the lightest yolk weight (Table 14). No other sex by temperature by G interactions were significant, therefore, the remaining means are not shown.

Discussion

The hypothesis of the current study tested the affects of incubation temperature profile, G and sex of the bird on the poult maturity or quality. Limited research has been done relating conductance and sex of the bird to poult maturation. Evidence from the current study support the interdependence of G, egg weight and length of incubation period (Ar and Rahn, 1978) or conductance constant and their consequent effect on different sexes of poults. From the current study, one can conclude that the sex of the bird, G, and incubation temperature profile may interact to affect neonatal growth, intestinal growth and function, and plasma thyroid hormone concentrations.

Sex:

In both trials sexual dimorphism was apparent between hatchlings. Although previous data reported that F appear to dominate M at hatching, M poults tended to have larger jejuna and a more metabolically active intestine. Males also weighed significantly more than F, while F had a higher feed per gain ratio than the M. Thus it is concluded, that M are more efficient at utilizing nutrients, giving them the ability to grow and gain more weight.

Production of hormone from the thyroid may also be related to the ability of poults to mature. Females demonstrated higher amounts of T_3, the major metabolic hormone; but are not able grow as quickly as M. On the other hand, M poults demonstrated increased overall growth with higher T_4 values than F. Avian thyroid receptors are "T_3 receptors" and the effects from T_4 are due to the conversion of T_4 to T_3 by deiodination (McNabb, 2000). Therefore F may be more suited to convert T_4 to T_3. Just as in mammals, T_3 has been shown to be responsible for most thyroid hormone action in birds (Oppenheimer *et al.,* 1987).

Therefore, the presence of more T_3 over T_4 should lead to greater growth among birds. Results from the current study do not agree with the research mentioned above. M were able to gain more weight than F, although they had higher amounts of T_4. The F may have an increased thyroid function compared to the M, but the increased function may not be sufficient to provide F poults the ability to gain weight as readily as the M. Due to the observed differences in intestinal maturation and growth between the sexes, M may have a metabolic advantage over the F at hatching.

Temperature and Sex Interactions**:**

As stated in manuscript II, incubation temperature is the most critical factor regulating embryonic growth and maturity (Wilson, 1991; Tazawa and Whittow, 2000). Temperature had significant effects on the intestinal maturation and growth of poults depending on the sex of the birds. Poults that were incubated using a HP weighed more than LP poults, while the M weighed significantly more than the F. In Trial 1, the M incubated at the HP exhibited a larger and more metabolically active intestine than the F at the HP. The HP may provide the necessary conditions needed by the embryo for maximum growth to occur. Among the HP, the M poults were more mature than the F at hatch. The reverse was noted in Trial 2. F incubated at the LP demonstrated a more metabolically active intestine. No differences were seen among the growth data between the M and F for Trial 2, indicating that more intestinal activity among the F did not necessarily lead to increased growth. At hatching the M were more equipped for growth outside of the shell, incubation using the HP provided the M embryo an optimal growing advantage. Regardless of sex, due to the results observed in Manuscript II, the HP consistently provided a more developed poult at hatching.

Conductance and Sex Interactions:

G and sex of the poult interacted to influence intestinal maturation and the thyroid function. In agreement with previous reports, M had a more metabolically active intestine than F in Trial 1 and larger jejuna in Trial 2. Trial 1 showed that Low G, M poults had greater intestinal enzyme activities, while Low G, F poults exhibited the least amount of intestinal activity. Trial 2 showed that High G, M had a larger jejuna while High G, F had the smallest jejuna. Among Cycle 2 eggs, M poults from Low G eggs and among Cycle 1 eggs, F poults from Low G eggs might be better prepared to grow post hatching. That observation may contradict results discussed in Manuscript II, where Low G poults had slower intestine growth at hatching. The intestinal characteristics observed in the current study may be due to the Low G poult utilizing a compensatory mechanism to reach the maturity of the Avg and High G poults.

Temperature, Conductance and Sex Interactions:

In Trial 1, M weighed more and had greater intestinal enzyme activity than the F. Among the F, HP poults exhibited greater maltase and ALP activity. The maltase activity in the jejuna was variable among G for F, but increased ALP activity was observed in Avg G, F. F BW were heaviest among LP, F poults. The LP F also consumed more feed than the HP. This interaction does not agree with previous data found among the temperature profiles, as in both temperature profiles the High G, F gained more weight.

Among the M, HP poults exhibited greater maltase and ALP activity. High G, M poults from HP or LP demonstrated a higher rate of intestinal maturity. M poult BW were highest among HP poults, while Avg G poults within this temperature profile had the heaviest weight and consumed the most feed. This observation supports the report that Low

G poults are not able to mature as well as the Avg and High (Manuscript II). Again it is shown that, M had a more mature intestine and greater intestinal activity than F. The more mature intestine of the M may enable them to consume more feed, utilize nutrient intake more efficiently and ultimately lead to more weight gain.

In summary, I found that neonatal M were physiologically more mature leading to increased ability to grow during the brooding period than do F. Incubating eggs under a HP provided more viable M and F poults at hatching. Eggs with Avg and High G provided a more mature poult at hatching than did the Low G egg. Among eggs from a Cycle 2 and a Cycle 1 flock the incubation profile, eggshell G and the sex of the poult should be matched to provide a poult of optimum maturity at hatching. Thus, characteristics of the egg and their interaction with other incubation conditions do influence maturation. Sex of the embryo may also lead to weaker poults at hatching. Since we are unable to determine the G of an egg or the sex of the poult prior to incubation managing different brooding measures may be required to give poult the ability to mature adequately.

TABLE 1. Effects of sex on anatomic and physiologic factors determining maturity of poults hatching from eggs of a Cycle 2 flock at Day 1 posthatch[1]

Data analyzed using sex as treatment

	Female	Male	Overall SE	P value
Total Body Wt at hatch (g)	61.85	61.51	3.39	NS
Body Wt w/o yolk sac (g)	52.34	52.90	2.63	NS
Yolk Sac Wt. (g)	9.51	8.61	0.60	NS
Jejunual Length (cm)	13.75	14.94	0.66	0.0162
Jejunal Weight (g)	0.419	0.511	0.001	0.0001
Relative Jejunal Weight	0.008	0.010	0.0000003	<.0001
Total Maltase activity[2]	365.64	434.89	80.48	0.0356
Total ALP activity[3]	21599.31	23887.96	9310.47	NS
Jejunal Protein (µg)	24763.31	25883.44	18847.40	NS
Maltase specific activity-mg P[4]	14.79	17.24	2.30	NS
Maltase specific activity-mg tissue[5]	8.68	8.62	0.49	NS
ALP specific activity-mg P[6]	0.850	0.923	0.01	NS
ALP specific activity-mg tissue[7]	50.43	47.02	37.32	NS
Plasma T_3 (ng/mL)	3.00	3.05	0.04	NS
Plasma T_4 (ng/mL)	10.62	9.91	0.88	NS
Ratio T_3:T_4	0.295	0.324	0.0007	NS

[1]N=36 for both treatment groups. All values are means. Trial 1.
[2](µmol glucose/h/jejunum)
[3](µmol phosphorus/h/jejunum)
[4](µmol glucose/h/µg Protein)
[5](µmol glucose/h/mg jejunum)
[6](µmol phosphorus/h/µg Protein)
[7](µmol phosphorus/h/mg jejunum)

TABLE 2. Effects of sex on anatomic and physiologic factors determining maturity of poults hatching from eggs of a Cycle 2 flock at Day 3 posthatch[1]

Data analyzed using sex as the treatment

	Female	Male	Overall SE	P value
Total Body Wt. posthatch (g)	81.70	90.04	7.53	<.0001
Body Wt w/o yolk sac (g)	78.44	87.30	8.61	<.0001
Yolk Sac Wt.(g)	3.27	2.74	0.43	NS
Jejunal Length (cm)	21.64	23.10	2.63	0.0029
Jejunal Weight (g)	1.33	1.64	0.004	<.0001
Relative Jejunal Weight	0.017	0.019	0.002	<.0001
Total Maltase activity[2]	1600.61	1880.36	1906.7	0.0045
Total ALP activity[3]	165531.17	206627.08	2329966	0.0002
Jejunal Protein (µg)	108533.33	126647.22	1704040.4	<.0001
Maltase specific activity-mg P[4]	14.70	14.83	1.04	NS
Maltase specific activity-mg tissue[5]	12.04	11.42	0.53	NS
ALP specific activity-mg P[6]	1.52	1.62	0.002	NS
ALP specific activity-mg tissue[7]	124.22	125.31	78.73	NS
Plasma T_3 (ng/mL)	4.40	4.79	0.15	NS
Plasma T_4 (ng/mL)	6.54	8.83	0.90	0.0008
Ratio T_3:T_4	0.746	0.611	0.008	0.0370

[1]N=36 for both treatment groups. All values are means. Trial 1.
[2](µmol glucose/h/jejunum)
[3](µmol phosphorus/h/jejunum)
[4](µmol glucose/h/µg Protein)
[5](µmol glucose/h/mg jejunum)
[6](µmol phosphorus/h/µg Protein)
[7](µmol phosphorus/h/mg jejunum)

TABLE 3. Effects of sex on growth of poults hatching from eggs of a Cycle 2 flock from Day 1 to Day7 posthatching[1]

Data analyzed using sex as the treatment

	Female	Male	Overall SE	P value
Time to feed (min)	127.44	121.29	97.56	NS
Pen Weight-Day 1 (g)	593.39	612.50	81.97	0.0162
Pen Weight-Day 3 (g)	884.11	968.72	234.70	<.0001
Pen Weight – Day 7 (g)	1150.28	1322.17	1260.17	<.0001
Gain Day 1 to Day 3 (g)	290.72	356.22	302.70	0.0001
Gain Day 1 to Day 7 (g)	556.89	709.67	1329.61	<.0001
Feed consumed up to Day 3 (g)	238.33	277.61	131.09	0.0003
Feed consumed up to Day 7 (g)	699.33	816.06	406.0	<.0001
Feed per gain – Day 1 to Day 3	0.834	0.792	0.001	NS
Feed per gain – Day 1 to Day 7	1.30	1.17	0.06	0.0383

[1]N=18 pens of 10 birds for both treatment group. All values are means. Trial 1.

TABLE 4. Effect of sex and incubation temperature profile on anatomical and physiological factors determining poult maturity among poults hatching from Cycle 2 eggs at Day 3 posthatch[1]

Data analyzed using temperature profile x sex interaction as treatment.

Sex	Temperature Profile	Total body weight posthatch (g)[4]	Body weight w/out yolk sac (g)[5]	Jejunal Weight (g)[6]	Total Maltase Activity[7]	T_4 (ng/mL)[8]
Female	HP[2]	82.22[b]	78.44[b]	1.31[c]	1525.83[b]	6.91[b]
	LP[3]	81.19[b]	78.43[b]	1.35[c]	1675.39[b]	6.17[b]
Male	HP[2]	96.28[a]	93.60[a]	1.73[a]	1993.28[a]	7.84[b]
	LP[3]	83.79[b]	80.99[b]	1.56[b]	1767.44[ab]	9.81[a]

[a,b,c]Columnar interaction means with different superscripts differ significantly
[1]N=18 each treatment group. All values are means. Trial 1.
[2]Poults from eggs incubated at a high temperature profile
[3]Poults from eggs incubated at a low temperature profile
[4]Overall SE = 7.53; P-value = 0.0035
[5]Overall SE = 8.61; P-value = 0.0027
[6]Overall SE = 0.004; P-value = 0.0268
[7](μmol glucose/h/jejunum) Overall SE = 1906.7; P-value = 0.0523
[8]Overall SE = 0.90; P-value = 0.0419

TABLE 5. Effects of sex and incubation temperature profile on growth of poults hatching from eggs of a Cycle 2 flock from Day 1 to Day 7 posthatching[1]

Data analyzed using temperature profile x sex as treatment.

Sex	Temperature Profile	Pen Wt Day 3 (g)[4]	Pen Wt. Day 7 (g)[5]	Gain Day 1 to Day 3 (g)[6]	Gain Day 1 to Day 7 (g)[7]	Feed consumed Day 3 (g)[8]	Feed consumed Day 7 (g)[9]
Female	HP[2]	886.33[c]	1111.67[b]	284.00[c]	509.33[c]	229.11[c]	677.11[b]
	LP[3]	881.89[c]	1188.89[b]	297.44[bc]	604.44[b]	247.56[bc]	721.56[b]
Male	HP[2]	997.67[a]	1342.67[a]	387.67[a]	732.67[a]	293.78[a]	835.89[a]
	LP[3]	939.78[b]	1301.67[a]	324.78[b]	686.67[ab]	261.44[b]	796.22[a]

[a,b,c]Columnar interaction means with different superscripts differ significantly
[1]N=9 pens of 10 birds for each treatment group. All values are means. Trial 1.
[2]Poults from eggs incubated at a high temperature profile
[3]Poults from eggs incubated at a low temperature profile
[4]Overall SE = 234.70; P-value = 0.0431
[5]Overall SE = 1260.17; P-value = 0.0526
[6]Overall SE = 302.70; P-value = 0.0129
[7]Overall SE = 1329.61; P-value = 0.0262
[8]Overall SE = 131.09; P-value = 0.0121
[9]Overall SE = 406.00; P-value = 0.0173

TABLE 6. Effect of poult sex and eggshell conductance on physiological factors determining poults maturity among poults hatching from eggs of a Cycle 2 flock at Day 3 posthatch[1]

Data analyzed using sex x conductance as treatment.

Sex	Eggshell Conductance	Total ALP activity[2]	ALP specific activity-mg P[3]	ALP specific activity-mg tissue[4]
Female	Low	140420.92[d]	1.35[b]	110.86[b]
	Average	175966.75[c]	1.60[ab]	130.98[ab]
	High	180205.83[bc]	1.60[ab]	130.83[ab]
Male	Low	216453.58[a]	1.73[a]	132.96[a]
	Average	190755.58[abc]	1.48[ab]	112.78[ab]
	High	212672.08[ab]	1.67[a]	130.19[ab]

[a,b,c]Columnar interaction means with different superscripts differ significantly
[1]N=12 each treatment group. All values are means. Trial 1.
[2](µmol phosphorus/h/jejunum) Overall SE = 2329966; P-value = 0.0564
[3](µmol phosphorus/h/µg protein) Overall SE = 0.002; P-value = 0.0328
[4](µmol phosphorus/h/mg jejunum) Overall SE = 78.73; P-value = 0.0315

TABLE 7. Effects of incubation temperature profile and eggshell conductance on anatomical and physiological factors determining poult maturity among female poults hatching from eggs of a Cycle 2 flock at Day 1 and Day 3 posthatch[1]

Data analyzed using temperature profile x conductance x sex as treatment.

Temperature Profile	Eggshell Conductance	Total Maltase activity Day1[4]	Maltase specific activity-mg tissue-Day 1[5]	ALP specific activity-mg tissue-Day 3[6]	Pen Wt Day 3 (g)[7]	Pen Wt. Day 7 (g)[8]
HP[2]	Low	481.1[a]	10.56[a]	101.40[b]	851.67b	1031.00b
	Average	500.33[a]	9.73[a]	124.33[ab]	856.67b	1043.33b
	High	346.00[b]	7.19[b]	138.56[a]	950.67a	1260.67a
LP[3]	Low	298.85[b]	8.48[ab]	120.32[ab]	851.00b	1154.00ab
	Average	274.00[b]	7.46[b]	137.63[a]	892.33ab	1199.67ab
	High	293.50[b]	8.68[ab]	123.10[ab]	902.33ab	1213.00a

[a,b,c]Columnar interaction means with different superscripts differ significantly
[1]All values are means. Trial 1.
[2]Poults from eggs incubated at a high temperature profile
[3]Poults from eggs incubated at a low temperature profile
[4](µmol glucose/h/jejunum) Overall SE = 80.74; P-value = 0.0564; N=6 each treatment group.
[5](µmol glucose/h/mg jejunum) Overall SE = 0.002; P-value = 0.0328; N=6 each treatment group.
[6](µmol phosphorus/h/mg jejunum) Overall SE = 78.73; P-value = 0.0315l; N=6 each treatment group.
[7]Overall SE = 234.70; P-value = 0.0141; N=3 pens of 10 birds for each treatment group.
[8]Overall SE = 1260.17; P-value = 0.0472; N=3 pens of 10 birds for each treatment group.

TABLE 8. Effects of incubation temperature profile and eggshell conductance on anatomical and physiological factors determining poult maturity among male poults hatching from eggs of a Cycle 2 flock at Day 1 and Day 3 posthatch[1]

Data analyzed using temperature profile x conductance x sex as treatment.

Temperature Profile	Eggshell Conductance	Total Maltase activity Day 1[4]	Maltase specific activity-mg tissue-Day 1[5]	ALP specific activity-mg tissue-Day 3[6]	Pen Wt Day 3 (g)[7]	Pen Wt. Day 7 (g)[8]
HP[2]	Low	525.67^{ab}	10.17^{a}	130.66^{a}	970.67^{b}	1236.67^{b}
	Average	473.50^{b}	8.38^{ab}	125.35^{ab}	1047.67^{a}	1414.00^{a}
	High	650.50^{a}	10.87^{a}	119.10^{ab}	974.67^{b}	1378.33^{ab}
LP[3]	Low	356.33^{c}	7.51^{b}	135.25^{a}	922.67^{b}	1302.33^{ab}
	Average	301.33^{c}	7.75^{b}	100.20^{b}	929.00^{b}	1241.33^{b}
	High	305.00^{c}	7.03^{b}	141.28^{a}	967.67^{b}	1361.67^{ab}

^{a,b,c}Columnar interaction means with different superscripts differ significantly
[1]All values are means. Trial 1.
[2]Poults from eggs incubated at a high temperature profile
[3]Poults from eggs incubated at a low temperature profile
[4](µmol glucose/h/jejunum) Overall SE = 80.47; P-value = 0.0564; N=6 each treatment group.
[5](µmol glucose/h/mg jejunum) Overall SE = 0.002; P-value = 0.0328; N=6 each treatment group.
[6](µmol phosphorus/h/mg jejunum) Overall SE = 78.73; P-value = 0.0315l; N=6 each treatment group.
[7]Overall SE = 234.70; P-value = 0.0141; N=3 pens of 10 birds for each treatment group.
[8]Overall SE = 1260.17; P-value = 0.0472; N=3 pens of 10 birds for each treatment group.

TABLE 9. Effects of sex on anatomic and physiologic factors determining maturity of poults hatching from eggs of a Cycle 1 flock at Day 1 posthatch[1]

Data analyzed using sex as treatment

	Female	Male	Overall SE	P value
Total Body Wt at hatch (g)	52.34	53.60	1.81	NS
Body Wt w/o yolk sac (g)	48.32	49.18	1.49	NS
Yolk Sac Wt. (g)	4.02	4.42	0.15	NS
Jejunual Length (cm)	13.70	12.71	0.80	NS
Jejunal Weight (g)	0.487	0.450	0.0009	NS
Relative Jejunal Weight	0.010	0.009	0.0000003	0.0265
Total Maltase activity[2]	356.91	338.13	73.11	NS
Total ALP activity[3]	19437.17	16980.46	74085.25	NS
Jejunal Protein (µg)	20709.11	19076.35	19057.67	NS
Maltase specific activity-mg P[4]	17.51	18.52	2.98	NS
Maltase specific activity-mg tissue[5]	7.50	7.65	0.44	NS
ALP specific activity-mg P[6]	0.927	0.923	0.01	NS
ALP specific activity-mg tissue[7]	39.59	39.02	32.18	NS
Plasma T_3 (ng/mL)	3.75	3.42	0.09	NS
Plasma T_4 (ng/mL)	12.33	11.02	1.53	NS
Ratio T_3:T_4	0.318	0.328	0.0010	NS

[1]N=36 for both treatment groups. All values are means. Trial 2.
[2](µmol glucose/h/jejunum)
[3](µmol phosphorus/h/jejunum)
[4](µmol glucose/h/µg Protein)
[5](µmol glucose/h/mg jejunum)
[6](µmol phosphorus/h/µg Protein)
[7](µmol phosphorus/h/mg jejunum)

TABLE 10. Effects of sex on anatomic and physiologic factors determining maturity of poults hatching from eggs of a Cycle 1 flock at Day 3 posthatch[1]

Data analyzed using temperature profile as the treatment

	Female	Male	Overall SE	P value
Total Body Wt. posthatch (g)	72.25	79.30	6.22	0.0001
Body Wt w/o yolk sac (g)	71.19	78.31	6.44	0.0001
Yolk Sac Wt.(g)	1.06	0.99	0.04	NS
Jejunal Length (cm)	21.21	22.07	0.66	NS
Jejunal Weight (g)	1.36	1.52	0.008	0.0120
Relative Jejunal Weight	0.019	0.019	0.0000010	NS
Total Maltase activity[2]	1564.78	1654.53	210.49	NS
Total ALP activity[3]	175933.69	183856.36	2634874.4	NS
Jejunal Protein (µg)	114044.44	127183.33	3664707.70	0.0025
Maltase specific activity-mg P[4]	14.09	13.25	2.26	NS
Maltase specific activity-mg tissue[5]	11.71	11.09	1.03	NS
ALP specific activity-mg P[6]	1.53	1.47	0.01	NS
ALP specific activity-mg tissue[7]	130.17	122.33	104.76	NS
Plasma T_3 (ng/mL)	5.22	5.44	0.20	NS
Plasma T_4 (ng/mL)	7.39	9.30	1.89	0.0469
Ratio T_3:T_4	0.869	0.734	0.03	NS

[1]N=36 for both treatment groups. All values are means. Trial 2.
[2](µmol glucose/h/jejunum)
[3](µmol phosphorus/h/jejunum)
[4](µmol glucose/h/µg Protein)
[5](µmol glucose/h/mg jejunum)
[6](µmol phosphorus/h/µg Protein)
[7](µmol phosphorus/h/mg jejunum)

TABLE 11. Effects of sex on growth of poults hatching from eggs of a Cycle 1 flock from Day 1 to Day 7 posthatching[1]

Data analyzed using temperature profile as the treatment

	Female	Male	Overall SE	P value
Time to feed (min)	132.67	124.74	86.33	NS
Pen Weight-Day 1 (g)	524.17	536.50	20.14	0.0026
Pen Weight-Day 3 (g)	782.56	870.50	359.62	<.0001
Pen Weight – Day 7 (g)	1067.78	1237.56	1027.22	<.0001
Gain Day 1 to Day 3 (g)	258.39	334.00	365.71	<.0001
Gain Day 1 to Day 7 (g)	543.61	701.06	1018.48	<.0001
Feed consumed up to Day 3 (g)	239.33	282.17	155.58	0.0003
Feed consumed up to Day 7 (g)	683.28	797.78	658.75	<.0001
Feed per gain – Day 1 to Day 3	0.973	0.851	0.006	NS
Feed per gain – Day 1 to Day 7	1.30	1.14	0.006	0.0233

[1]N=18 pens of 10 birds for both treatment group. All values are means. Trial 2.

TABLE 12. Effect of sex and incubation temperature profile on a physiological factors determining poult maturity among poults hatching from Cycle 1 eggs at Day 3 posthatch[1]

Data analyzed using temperature profile x sex as treatment.

Sex	Temperature Profile	Maltase specific activity-mg tissue[4]
Female	HP[2]	11.59[a]
	LP[3]	11.82[a]
Male	HP[2]	9.21[b]
	LP[3]	12.97[a]

[a,b,c]Columnar interaction means with different superscripts differ significantly
[1]N=18 each treatment group. All values are means. Trial 2.
[2]Poults from eggs incubated at a high temperature profile
[3]Poults from eggs incubated at a low temperature profile
[4](μmol glucose/h/mg jejunum) Overall SE = 1.03; P-value = 0.0140

TABLE 13. Effect of sex and eggshell conductance on anatomical and physiological factors determining maturity among poults hatching from eggs of a Cycle 1 flock at Day 1 and Day 3 posthatch[1]

Data analyzed using conductance x sex as treatment.

Sex	Eggshell Conductance	Jejunal Wt D1 (g)[2]	T_3 Day 3 (ng/mL)[3]
Female	Low	1.45[abc]	5.67[ab]
	Average	1.33[bc]	4.61[bc]
	High	1.31[c]	5.39[abc]
Male	Low	1.48[abc]	5.01[b]
	Average	1.53[ab]	6.06[a]
	High	1.56[a]	5.25[abc]

[a,b,c]Columnar interaction means with different superscripts differ significantly
[1]N=12 each treatment group. All values are means. Trial 2.
[2]Overall SE = 0.0009; P-value = 0.0394
[3]Overall SE = 0.20; P-value = 0.0203

TABLE 14. Effect of sex, incubation temperature profile and eggshell conductance on an anatomical factor determining maturity among poults hatching from eggs of a Cycle 1 flock at Day 3 posthatch[1]

Data analyzed using temperature profile x conductance x sex as treatment.

Temperature Profile	Eggshell Conductance	Female Yolk Sac Day 3 (g)[4]	Male Yolk Sac Day 3 (g)[4]
HP[2]	Low	1.73[a]	0.66[b]
	Average	0.90[b]	1.38[a]
	High	0.73[b]	1.20[ab]
LP[3]	Low	1.00[b]	1.18[ab]
	Average	1.01[b]	0.88[ab]
	High	1.00[b]	0.63[b]

[a,b,c]Columnar interaction means with different superscripts differ significantly
[1]N=6 each treatment group. All values are means. Trial 2.
[2]Poults from eggs incubated at a high temperature profile
[3]Poults from eggs incubated at a low temperature profile
[4]Overall SE = 0.04; P-value = 0.0057

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General Discussion

To the author's knowledge, the current data are the first to describe relationship among egg size, eggshell conductance and incubation temperatures and their effect on the maturation of the neonatal turkey. Furthermore, the data relate scientific knowledge to important industry problems and may improve the turkey industry profitability. During the brooding period turkey poults are less precocial and require more care than chicks, therefore knowledge of the maturation of the poult during this time period can provide information to geneticist, hatchery personnel and growers to enhance the survival and growth of turkeys and in turn maximize profits. The early brooding period, first 7 days, was selected for evaluation because to excessive mortality occurring during this time (Enos *et al.,* 1971; Nestor *et al.,* 1974).

The initial study was done in an effort to describe egg characteristics (egg size and eggshell conductance) that affect the growth and survivability of neonatal turkeys. The results indicated an interaction between egg size and eggshell conductance on poult viability. Thus, the data are the first to describe this relationship within a species. Such a relationship has been suggested among species (Ar and Rahn, 1978). The results agree partially with Rahn *et al.,* (1979) who concluded that among varying species as egg size increases the eggshell conductance increases. I speculate that larger poults hatching from large eggs may provide a more viable poult during the brooding period, when compared to the poults hatching from small eggs. Differences seen in size and weight gain indicate that Low conductance eggs experience a lack of oxygen during the plateau stage of incubation reducing their ability to metabolize yolk and grow as efficiently as Avg and High G poults (Tullett and Deeming, 1982; Burton and Tullett, 1985). Thus, the current study is the first to

indicate egg size and G are related in turkeys to affect the hatchling. Results from this study lead to many questions about other mechanisms affecting a poults ability to mature physiologically and suggest strongly that the characteristics of the egg play a major role in the maturation process.

The second and third experiments examined the influence of incubation temperatures in conjunction with egg characteristics and sex of the poult on maturation. Maturation was assessed by growth, feed per gain, intestinal development and thyroid hormone levels. Knowledge of different temperature effects on poult maturity throughout the first 25 d of incubation is almost non-existent. The current study may be one of the first to determine if slight differences in incubation profile can affect poult maturity at hatching. Incubating eggs with varying G and at different incubation temperatures had significant effects on the growth, feed consumption and intestinal maturation in turkeys. HP poults were larger with a more metabolically active intestine than LP poult. These finding agree with Wilson (1991) and Tazawa and Whittow (2000) that the embryo will respond to temperature by increasing or slowing down growth during the incubation period. Poults hatching from eggs with Avg or High G have a more metabolically active intestine and are able to consume more feed and in turn utilize what is consumed more efficiently than Low G poults. Because of an inability for the Low G poult to acquire adequate oxygen during development, at hatching they are at a disadvantage compared to other poults. These results emphasize the observations of Mitchell and Smith (1991) explaining that the energy available for growth is limited by size of the digestive tract. Differences between Male and Female poults indicate that males are more physiologically mature at hatching. Although females tend to dominate during the

hatching process (Cherms, 1969), males have the ability to grow and utilize nutrients more efficiently.

These findings suggest more questions for future research on egg size, G and incubation environment. The current information can be useful genetically in determining how to select for egg characteristics fostering optimal hatchling quality. Incubation conditions may also be adjusted to match the characteristics of the egg in order to provide the growing embryo favorable incubation conditions. Lastly, brooding management may need to be adjusted to provide the extra care to poults depending on the characteristics of the egg. All three possibilities should contribute to improved viability and growth of hatchling poults.

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