On-Farm Factors Affecting the Hatchability of Broiler Eggs in Parent Breeder Operations

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Introduction

The list of challenges faced by those who work in the United States poultry industry is extensive, and continues to evolve as consumer demands shift. Over time, the number of poultry products developed for the market has grown, the size and type of bird needed has changed, the bird's environment has evolved, the timeframe in which it takes a farmer to grow a bird to market size has altered, and so on. There are no signs that these changes will slow down anytime soon. Many of these shifts are consumer driven, while others are due to industry advancements that allow for higher efficiency. Poultry companies across the industry have turned growing chicken into an exact science with predictable results through highly integrated systems using practices backed by scientific research. The one thing that hasn't changed is that the industry needs birds. This is paired with one of the biggest challenges within the industry: the inconsistent hatchability of the eggs coming from broiler breeder parent stock which supplies birds to the broiler farms. When the hatchability of breeder stock remains unpredictable and companies cannot determine a cause for low hatchability rates, research into valuable on-farm management practices can help provide the best long-term results. Published research studies into the hatchability of broiler breeder parent stock goes back for decades. Many past studies have explored areas that continue to cause industry dispute today, while some studies have shaped the practices currently employed on breeder farms. Understanding the ideas and science behind certain practices will foster effective communication to farmers and provide successful implementation in the field. These same principles can more accurately shape industry standards moving forward so that the poultry industry (and supply) can keep up with demand through consistent, higher hatchability rates.

An article published online by The Wall Street Journal in June 2017 expressed the problems faced throughout the industry by reporting that the first five months of 2017 saw the lowest level of broiler breeder hatching chicks in over a decade. The advancements in industry practices over the last decade leave many confused and at a loss for a solution regarding the low hatchability of these birds. There is no particular company that is experiencing more trouble than another according to the article, rather the problem is industry wide. Many broiler chicken-producing companies are supplied by the same pedigree stock, leading the investigation to genetic changes in the birds' pedigree, which has had a negative effect on the ability of the birds to produce a fertile egg. The parent breeder stock is producing a bird that has been bred to grow rapidly, and this trait has never been beneficial to fertility. The ratio of male-to-female breeders is also discussed in the WSJ article, with the standard of one rooster to every ten hens potentially being too high. The newer rooster breeds are more assertive and may allow for a lower rooster to hen ratio. The practice of sending younger roosters into an older, established flock of hens and roosters (commonly known as 'spiking') does have a positive impact on fertility by introducing a new wave of competition through the house. The current hatchability hurdles are not only a concern for farmers, hatchery workers, and live poultry production employees in the industry, but also consumers. The increase in chicken prices are being felt by consumers (WSJ, 2017), and could turn into a long-term supply issue if a root cause is not established. Successful management practices are needed to positively affect the hatchability of broiler breeder parent stock eggs.

While the WSJ article mentioned above focuses on the genetics of chickens from a management perspective, there are many other points throughout the life cycle of the hatching egg that may leave room for improvement of hatchability. Schaal and Cherian (2007) state that

over the past 20 years there have been advancements made in the industry in the areas of genetic selection, nutrition, and management of broiler flocks. With these improvements, current management practices do not place the needed emphasis on hatchability (Schaal and Cherian, 2007). Some factors that have been studied in previous research include, the temperature regulation during egg storage, the storage length of eggs prior to being set for incubation, the age of the hen, the handling of eggs to prevent disruptions in the egg shell quality and integrity, the chemical solutions used to clean soiled eggs, and the factors to prevent an egg from becoming soiled between being laid and being set for incubation. The management of the current birds in the breeder house also calls for industry attention. Therefore, a thorough understanding of various on-farm practices may assist the industry in increasing the hatchability of broiler breeder eggs.

Eggshell properties contributing to hatchability

As the barrier between potential contaminants and the delicate internal embryo, the eggshell is an obvious place to begin research for factors that could be strengthened to increase the hatchability of broiler breeder eggs. Some areas of interest include eggshell thickness, mammillary layer thickness, the average size of mammillary cones in relation to eggs shell hatchability, egg weight, and egg shape (Narvshin and Romanov, 2002; Liao et al., 2013). The eggshell functions to protect the embryo from external threats, and to permit the exchange of water and gas to the embryo during development (Tullett, 1984; Wilson, 1991; Fasenko et al., 1992).

The eggshells of hatching eggs need to be thick and strong to protect the embryo from external threats, while also being fragile enough to allow the hatching process to proceed without complication (Narvshin and Romanov, 2002). When the eggshell thickness is reduced, there is an

increased chance of dehydrating the embryo and internal exposure to pathogenic microorganisms (Sauter and Petersen, 1974; Narvshin and Romanov, 2002). Additionally, Narvshin and Romanov (2002) show that a thick eggshell also promotes the best use of nutrients by the developing embryo. Researchers recognized that the mammillary layer within the eggshell contributes to the amount of calcium the embryo can receive prior to hatch (Liao et al., 2013). With reduced eggshell thickness, the calcium supplied may be reduced, potentially changing the viability of the embryo and the following hatch (Liao et al., 2013). The mammillary layer, which holds the major source of calcium for the developing embryo, is correlated to higher hatchability (Liao et al., 2013). The eggs with the thickest mammillary layer also have the thickest eggshell, suggesting that eggs with thicker eggshells will hatch better. Unlike the correlations found from a thick mammillary layer, the size of the mammillary cones did not yield an effect on hatchability. The mammillary cone size did however correlate with mammillary layer thickness. The mammillary cones are the functional unit within the mammillary layer that mobilize the essential calcium to the embryo (Liao, et al., 2013). These eggshell traits direct future research towards ways to produce eggs with thicker shells, thus promoting hatchability.

The viability of eggs with hairline cracks has been studied due to the possibility that many eggs being set in incubators unknowingly contain hairline cracks. Hairline cracked eggs cannot be visually identified by the naked eye (Barnett et al., 2004). Some factors studied to determine the viability of eggs effected by hairline cracks include weight loss during incubation, embryonic mortality, hatchability, and early chick growth weights. Hairline cracks have been proven to decrease hatchability and increase mid to late embryonic mortality (Barnett et al., 2004). Barnett et al. (2004) also describes the eggshell as serving dual function, to be strong enough to provide the embryo with protection from outside threats and to be porous enough to

supply the embryo with oxygen. The shell also needs to allow water loss to prevent an increase in water content as metabolic processes of the embryo develop (Barnett et al., 2004). Water evaporates during incubation and is replaced with oxygen to form the air cell which will occupy 15% of the egg volume. Shells that are highly permeable do not threaten the oxygen intake, but rather water loss and the threat of dehydration becomes important (Barnett et al., 2004). Water loss of 12% of the initial weight is ideal, loss of 20% of initial egg weight causes decreased hatchability due to dehydration of the embryo (Barnett et al., 2004). The study performed by Barnett et al. (2004), used eggs from flocks that were 48-56 weeks old. This is interesting to note because it has been proven through various studies that the age of the hen does play a role in hatchability (Asmundson and MacIlriath, 1948; Benton and Brake 1996; Reis et al., 1997; Tona et al., 2004). In the study by Barnett et al., (2004), dehydration and microbial contamination were proven to be major factors contributing to the hatchability of hairline cracked eggs. Minimizing excessive moisture loss and bacterial contamination can improve hatchability significantly (Barnett et al., 2004). The shell porosity and permeability both influence the water status of the embryo during late incubation, predominately a few days prior to hatching. Therefore, most of the loss due to hairline cracks is seen during mid to late incubation (Barnett et al., 2004).

Developing eggs with a thick eggshell is not something that can be done on the farm. However, integrators can use this knowledge to decide which eggs will be sent to the hatchery, to handle eggs with enough care to prevent hairline cracks, and may provide an individual farm with answers for the low hatchability during a flock. Integrators can also use this information to ensure eggs with thin shells or hairline cracks do not get placed in the incubator. Further research into eggshell properties will likely lead researchers to the aspects of the hen producing the eggs.

The relationship between genetics and hatchability

The use of genetic selection for improved hatchability in the broiler industry is difficult because there are many other performance areas that are being selected for such as yield and feed efficiency (Pollock, 1999). Many of the highly valued traits are competitive and produce the type of bird that the consumer is demanding (Pollock, 1999). Hatchability, fertility, and livability are considered minor traits that are selected for by eliminating the genetic lines that perform the worst in these areas, rather than selecting the lines that perform the best to continue. Selecting for these traits would cause negative effects on the competitive traits that a company needs to thrive in a competitive marketplace. Pollock explains that in 1999, companies were selecting birds and lines based on processing characteristics rather than for fertility and hatchability. If primary breeder companies cannot select lines based on traits such as fertility and hatchability, the primary breeder companies need to manage the genetics they are working with to grow hens and roosters that can breed in a way that promotes high fertility, and hatchability.

Managing the growth traits needed in broiler production, while still maintaining the reproductive traits that are necessary for successful broiler breeder operations is a common challenge in the industry (Brillard, 2004). For example, Brillard (2004) discusses the challenges with raising fast-growing birds; explaining that males may go into sexual maturity faster than with a slow-growing bird (creating hurdles for long lasting reproductive success). Wilson et al. (1979) explains that male fertility is the most important because the male is responsible for fertilizing eggs coming from many females.

Currently, detailed industry direction on management of male breeders is provided by Cobb. Cobb is one of the leading suppliers of parent breeders throughout the international industry. Specific practices for flock advisors and breeder managers is provided in a technical

guide that is geared towards a specific line of Cobb males. Rearing a successful breeder begins when the day-old chicks are delivered. Males should be reared separately from the females until they are placed in the breeder house at 21-22 weeks of age. Stocking density of males in the pullet house is recommended at 2.5-3.0 square feet, with round feed pans allowing for 8-10 birds per pan. Even feed distribution is essential to growing a uniform flock of males. The Cobb male management guide states that males should never lose weight at any stage of growth, as this may limit their reproductive potential later in life. Mating uniformity and complete mating interactions will be accomplished when flocks are raised uniformly. Lighting programs may also be put in place to bring all males into maturity uniformly. The male to female weight ratio should remain within a ratio of 15-20% to maximize male fertility. To maintain the proper weights for successful fertility and growth, Separate Sex Feeding (SSF) should be utilized in the breeder house. Males will need to be trained to eat from the male feed pans in the center of the house. The best way to train males is to feed males out of the same type of pans in the pullet house before the males and females are put together in the breeder house. Males with low weights or of poor quality should be culled from the flock to maintain uniformity. Male weight guidelines are provided by Cobb to help managers make feeding decisions as the flock ages. Management practices that maintain a uniform flock with extended reproductive performance will help improve flock hatchability.

Animal behavior and environmental enrichments

Chicken behavior and mating activities in the breeder house play an essential role in the fertility of the eggs shipped to the hatchery. The first step to having an egg successfully hatch is having a fertile egg. Consideration should be given to animal behavior and the environment where the animal lives, so that there is promotion of mating activities. Studies have shown that

chicken houses with the proper type of enrichments would aim to have a more-even distribution of the animals throughout the house (Cornetto and Estévez, 2001b), reduced disturbances and aggression (Cornetto et al., 2002), and reduced fear and stress responses (Jones, 1982; Nicol, 1992; Reed et al., 1993; Grigor et al., 1995; Bizeray et al., 2002; Leone and Estévez, 2008).

The typical design of a commercial broiler breeder house involves a center scratch area filled with litter, with raised wooden slats are on either side of the house extending out to the house walls. The center scratch area contains a raised line of feed pans for the males and depending on the specific house design, may or may not have a line of drinkers extending the length of the house. The raised slatted area on either side of the house would be where the nest boxes sit. The nest boxes are placed just in front of the grated female feed line. In between the hen feed line there will be a hanging water line extending the length of the house. The design of the house allows the male and female chickens to be fed separately as their nutrition requirements will be different. The design of these commercial houses allows for the males to congregate in the middle scratch area, with the female birds favoring the raised slat area (Leone and Estévez, 2008). Threats to fertility occur when the males come into sexual maturity quicker than the females and the aggression exhibited by the males causes the females to retreat to the slatted area, creating fewer mating opportunities. The female stress resulting from male aggression can cause poor production performance, as well as decreased fertility (Jones, 1982; Nicol, 1992; Reed et al., 1993; Grigor et al., 1995; Bizeray et al., 2002).

A specific method of breeder house enrichment was studied by Leone and Estévez (2008) where cover panels were added to five commercial broiler breeder houses with the intended effects of decreasing aggressive interactions, increasing male dispersal throughout the house, and attracting females to the litter area. The design of the panels used in the 2008 study came from a

2001 study by Estévez and Newberry and included chicken wire and black plastic mesh stapled to each side, which had previously shown to be attractive to chickens (Newberry and Shackleton, 1997; Cornetto and Estévez, 2001a). The results of this study showed that the use of cover panels as environmental enrichment increased fertility and hatchability. The cover panels also increased male dispersal, reduced male-male competition, increased production, and positively affected male-female interactions. Conclusions can be drawn that the increase in egg production may have come from decreased stress levels in the female chickens (Leon and Estévez, 2008). The same concepts behind this specific type of enrichment to the breeder house may be applied to other enrichments that would allow for male-female interactions that are beneficial to animal welfare (increasing hatchability).

This type of on-farm management practice is aimed at the parent breeder companies, since all the chicken houses are designed to company standards. For example, chicken house design could be improved to incorporate enrichments that promote mating behavior. Flock advisors and farm owners should be observant to male aggression problems that result in a lower fertility and document behaviors. If male aggression is commonly witnessed, a change in house design may be a possible mitigation strategy.

Egg sanitation

Hatching eggs may be sanitized on the farm at the time of collection to prevent fecal matter and microorganisms found in a chicken house from contaminating that egg or those around it. The potential for an increased hatchability from sanitizing eggs has been heavily studied in previous research. Clean eggs from the nest are the most desirable, but companies may want to consider other options when soiled eggs are collected. Eggs may also be sanitized at the hatchery to prevent the internalization of harmful pathogens. Successful reduction in the number

of harmful pathogens on an eggshell surface by different sanitizers has been determined by multiple studies (Buhr et al., 2013; Musgrove et al., 2014). The use of sanitizer to reduce pathogens does not necessarily consider the effects on hatchability.

When an egg is laid it is exposed to a variety of microorganisms and has the best chance of hatching a chick if it remains free of fecal matter up to the time of collection (Buhr et al., 1994). The eggs that become dirty in the nest due to fecal matter or by bird contact, force those in the poultry industry to decide if and how to clean the egg to give it comparable hatchability to clean nest eggs. Reducing the number of microorganisms by using disinfectants while still maintaining the hatchability of a clean egg has been the topic of past studies (Funk and Forward, 1949; Rhodes and Godfrey, 1950; Huston, Palmer, and Carmon, 1950). Sanitation on the farm has been proven to make the surface of eggs initially classified as clean and those classified as dirty microbiologically indistinguishable (Berrang et al., 1997). Cleaning eggs that have become soiled to maintain the same level of hatchability of clean eggs is variable among the same studies. However, it was reported by Funk and Forward (1949) that the hatchability of soiled eggs could be increased by proper cleaning (also supported by Buhr et al. (1994) who explained that sanitized dirty eggs hatched slightly better than not sanitized dirty eggs).

The cuticle may be affected by the application of sanitizers (Brake and Sheldon, 1990). Perhaps the disruption of the eggshell cuticle and subsequently changed eggshell permeability could explain why sanitation of dirty eggs has left variable results on the hatchability of eggs compared to clean, not sanitized eggs. The method of application, type of chemical used, and the amount of fecal matter present on the egg shell surface are all variable among related research studies. Funk and Forward (1949) also made mention to a study where eggs were artificially soiled. It is predicted that artificial soiling of an egg may have a different effect on hatchability

from an egg that was naturally soiled. These variables have the potential to change in each experiment and must be taken into consideration when analyzing multiple studies together to determine the usefulness of a specific sanitizer.

It should also be considered that in addition to the hatchability of eggs, if contaminated eggs are sent to the hatchery without any type of sanitation treatment at the farm, other eggs in close proximity may also become contaminated (Berrang et al., 1997). Microorganisms found on the surface of a few eggs may easily be distributed throughout the hatchery through the air, infecting other eggs and decreasing hatchability (Berrang et al., 1997; Brake and Sheldon, 1998; Bourassa et al., 2003). The same concerns exist during transportation when the change in air temperature causes condensation to form on the egg surface resulting in the contraction of bacteria through the circulating air (Berrang et al., 1997). A few researchers found success in raising hatchability with the use of sanitizers (Funk and Forward, 1949; Brake and Sheldon, 1990), where others found a decrease in hatchability with increasing concentrations (Bourassa, Buhr, and Wilson, 2002). Without over simplifying the matter of sanitizer use to increase hatchability, removing manure can give soiled eggs an opportunity to still be used as well as reduce the chance of cross contamination. A sample of commercial sanitizers used in hatchability experiments can be seen in Table 1. Logistical concerns of applying multiple steps of sanitizers, and using specialized equipment will be a concern of those making management decisions on broiler breeder farms.

Table 1

Sanitizer	Application Method	Outcome	Study
Quaternary Ammonium Hatching Egg Sanitizer Spray® (HES Spray®) at 1.5% and 3.0%	Spraying and immersion	Hatchability increased	Brake and Sheldon, 1990
Chlor-Wash®, Quat-800®, Salmide®, Polyhexamethylene biguanidehydrochloride (PHMB®), Tek-Trol®, and Bioxy-Wash®	Spraying and immersion	Sanitizing did not enhance or depress hatchability	Buhr et al., 1994
.38% Roccal [10% Quaternary Ammonium Compound]	Immersion	Hatchability of soiled eggs was increased	Funk and Forward, 1949
BioSentry 904® and Bio-Phene® (varying concentrations)	Spraying	BioSentry 904 caused a decreased hatchability at increaased concentrations. Bio-Phene did not cause a change in hatchability	Bourassa, Buhr, and Wilson, 2002

Temperature regulation of eggs

For on-farm practices that could influence the hatchability of broiler breeder eggs, the various temperatures the egg is exposed to is one of the most often studied factors (Brake et al., 1997). After oviposition, the egg will remain in a chicken house where the temperature is regulated for optimal performance and comfort of the chickens, not the hatchability of the egg. The egg will sit on the belt for a varying amount of time from minutes to hours depending on when it is laid. The belts will be run multiple times a day to a collection room just outside of the breeder barn (Fasenko, 1997). Once the egg is collected and packed, it is placed in cool storage and maintained at or below physiological zero, to halt any further embryonic development (Fasenko et al., 2001a).

The point of physiological zero, where embryo development is minimal, has been an area of disagreement among researchers in the field (Brake et al., 1997). Funk and Biellier (1944) reported that the point of physiological zero was 80.6°F, where Decuypere and Michels (1992) describe the many different temperatures that have been identified as physiological zero, including the range of 68°F-69.8°F which was reported by Edwards (1902) and Proudfoot and Hulan (1983). It was discussed by Brake et al. (1997) that physiological zero is a range of

temperatures rather than a set point. Fasenko (2007), introduced the term embryonic dispause as an alternative to physiological zero because there may not be developmental changes seen using microscopic techniques at certain temperatures, but cellular metabolic processes may continue to occur. Current industry practices for cool egg storage may vary slightly, but all aim to minimize development prior to incubation.

Egg storage prior to incubation is logistically necessary and a common practice in broiler parent hatcheries to keep the supply in line with the demand (Dymond et al., 2013). Brake et al. (1997) along with other researchers have used egg storage length as an accompanying factor when researching storage temperatures, although changing the storage temperature based on the storage length may not be feasible for a hatchery that contains eggs stored for varying lengths of time. For this reason, temperature regulation will be discussed as an individual factor. There are a few specific areas of temperature regulation that have received research attention and may be considered by industry professionals. These include, the effects of extended nest holding time, the temperature of on-farm egg storage, and the effects of applying incubation measures during storage.

The amount of time the egg spends in the chicken house environment may influence hatchability. The optimal incubation temperature is 99.5°F (Fasenko et al., 1999), but there has been inquiry into the possibility of embryonic development just above 68°F (Proudfoot and Hamilton, 1990). High temperatures in the southern United States are often associated with low hatchability. This led to the theory that more developed embryos, often seen with eggs held in the nest for longer periods of time prior to storage, could not withstand the cold storage temperatures (Fasenko et al., 1999) that are necessary throughout the industry prior to incubation. Researchers looked at this issue during a 1981 study where eggs were split into four

treatment groups and exposed to temperatures 70°F to 75°F for 3 hours (group 1), 6 hours (group 3), 12 hours (group 5) or temperature of 95°F for 3 hours (group 2), 6 hours (group 4), or 12 hours (group 6) (Bowling and Howarth, 1981). This study looked at the effects of high temperature exposure followed by proper cold storage before incubation. The results yielded no difference in hatchability among the groups, showing that proper cold storage after warm exposure would allow for properly hatching eggs. The results of this study are in agreement with prior findings (Fasenko, et al., 1999) that also show nest holding time does not affect hatchability. It should be noted that the sample used in this study came from the same flock over the course of a month and only consisted of three settings of 900 eggs each. Thus, the age of the hens and the sample size may have affected the resulting hatchability.

Along with the above stated theory of possible embryonic development at temperatures just above 68°F (Proudfoot and Hamilton, 1990), and the findings of high temperature exposure followed by cold storage not harming the hatchability (Bowling and Howarth, 1981; Fasenko et al., 1999), there has also been research into increasing the holding temperature on the farm to decrease the energy costs for farmers, decrease the chance of the eggs sweating during transportation, and allowing for the less developed embryos to reach a stage of development that would allow them to better tolerate holding times (Bourassa et al., 2003). While hatchability is the main concern, energy savings for farmers would be an appreciated side effect (or positive outcome). When an egg sweats, there is potential for contamination by the egg internalizing dust and debris collected on the shell surface during transportation that may have a negative effect on hatchability (Berrang et al., 1997; Brake and Sheldon, 1998; Bourassa et al., 2003). The final motivation of researchers for lowering the holding temperature on the farm to benefit hatchability is impacting the developmental progress of the blastoderm. “After oviposition, the

blastoderm has initiated differentiation into the three embryonic germinal layers: ectoderm, mesoderm, and endoderm. An embryo that has developed these layers is described as entering the gastrulation stage of development. Embryos that are in an early gastrulation stage do not hatch as well as those that are in a more advanced stage of gastrulation", (Bourassa et al., 2003). The mentioned study used two holding temperature groups of 66°F and 74°F for a set of eggs that were all collected on the same day. Once arriving at the hatchery, several eggs were separated from each trial group and placed in 48 hours of incubation without any additional storage days. The separated eggs were then broken open and embryonic development was determined (Bourassa et al., 2003). Development was the same for both temperature groups and the subsequent hatchability was comparable (Bourassa et al., 2003). Increasing holding temperatures did not depress hatchability. In comparison to other studies on hatchability, it appears that storage length and hen age also plays a huge role that cannot be ignored. More research is needed to determine if the elevated storage temperature alone would likely increase hatchability; therefore, future studies may investigate the effect of elevated storage times with different age hens and various holding times.

The two situations described above, elevated environmental temperatures followed by cold storage and increased, consistent storage temperatures prior to incubation, have led to the study of variably timed incubation periods during extended storage as a method for increased hatchability. Dymond et al. (2013) echoed what other research has explained, that cool storage up to 7 days is regarded as common practice and is not thought to influence hatchability. However, it is thoroughly documented that prolonged storage will decrease hatchability (Fasenko et al., 2001a; Tona et al., 2004) and increase incubation times (Reijrink at al., 2010). Extended storage time is thought to induce embryonic stress and cause cell death along with developmental

delays (Dymond et al., 2013). To prevent this decrease in hatching egg quality, there has been early research into exposing eggs to incubation conditions before storage (Kosin, 1956; Kan et al., 1962; Coleman and Siegel, 1966), although this poses another logistical challenge as pointed out by Dymond et al. (2013). Eggs are often stored at the farm prior to being shipped to the hatchery, therefore incubation prior to any storage is not feasible in most operations. In this 2013 study, three treatment groups were developed, and three different trials were conducted. All treatment groups were stored for 4 days postoviposition, where the control was set for incubation just after 4 days of storage. The second group did not receive any incubation treatment but was stored for 21 days. The third group was exposed to multiple short periods of incubation (4-hour treatments), at 37.5°C (99.5°F), over the course of a 21-day storage (Dymond et al., 2013). Three trials were performed where the third treatment group had slightly different days of short period incubation exposure. During the third trial there was an additional treatment administered where 6- or 12-hour incubation was administered after 4 days of storage, followed by 21 days of storage with no short periods of incubation (Dymond et al., 2013). The control eggs with only 4 days of storage immediately followed by incubation had the highest hatchability in this experiment. The treatment group stored for 21 days with no incubation treatments had a sharp decline in hatchability to 71%. The treatment group exposed to short periods of incubation did not hatch at the rate of the control eggs, but the hatchability was improved to 84% when compared to those stored for 21 days without any incubation treatment. The group of eggs exposed to the 6- or 12- hour incubation followed by 21 days of storage saw the lowest hatchability rates at 58% and 35 % respectively. Based on research performed by Fasenko et al. (2001b), the treatment of 6 hours of incubation followed by storage was expected to have an

increase in hatchability. A storage period followed by a heat treatment has shown the best results for increasing hatchability depressed by long storage.

A similar experiment performed by Gucbilmez et al. (2013) studied the effects of incubation heating during storage, but slightly different treatment temperatures, storage times, and treatment durations were used when compared to Dymond et al. (2013). Various hen ages were used in this experiment, which was an important factor in determining the success of each treatment. Gucbilmez et al. (2013) did however agree with the findings of other researchers, showing that heat treatments without any prior storage was not beneficial to hatchability (Meir and Ar, 1998; Fasenko et al., 2001b; Dymond et al. (2013).

Both described experiments found that periodic heat treatment applied to eggs which were in storage for an extended period increased hatchability. The multiple treatments applied by Dymond et al. (2013) may call for too much labor and intensive management at the hatchery. The treatments applied by Gucbilmez et al. (2013) yielded results that may provide useful for hatchery workers, although the factor of hen age was a big variable in these experiments and may call for further research before adoption of these practices by commercial hatcheries. Initial storage at the farm will be necessary, but there may be room for improvements at the hatchery to designate a group of eggs to storage and short incubation periods. Elevated storage temperatures at the farm in conjunction with a treatment of short periods of incubation during storage may provide a useful management tool when the egg supply grows too large for the hatchery.

Egg storage length and hen age

Previous studies have considered the effects of increased storage length of broiler breeder eggs, and many experiments are commonly performed in conjunction with hen age (Benton and

Brake 1996; Reis et al., 1997; Tona et al., 2004). Albumen characteristics, which change over the length of storage, are different at oviposition depending on the age of the breeder hen that laid the egg (Tona et al., 2004). It is difficult to look at storage length or hen age as independent factors because the internal qualities that would change are in the same realm of research. In many large scale commercial situations, the storage length on the farm is going to depend on a set "pick up" schedule, not the changing age of the breeder hens. Thus, knowing how storage and hen age affects the egg quality and that eggs hatchability may however, allow hatchery workers to prioritize when eggs are set in the incubator once they have been received at the hatchery. Observations of changed egg quality from egg storage displayed in previous research will be discussed, as well as hen age when it is a contributing factor.

It has been stated that changing albumen quality is a major contributor to the changing hatchability over the prolonged storage of an egg (Brake et al., 1997). Lapão et al. (1999) determined that longer storage times decreased the viability of hatching eggs in all flock ages, with eggs from all flock ages having a similar pH after 4 days of storage. Brake et al. (1997) explains the sequence of events an egg undergoes internally during post-ovipositional storage. The inner and outer membrane structures change to prevent bacterial penetration, along with the liquefaction of the albumen which allows for gaseous diffusion and the liberation of nutrients to the developing embryo (Brake et al., 1997). Albumen height and pH are often the factors assessed when determining albumen quality. These factors are discussed throughout hatchability literature when assessing the effects of both egg storage and breeder hen age. After a few days of storage, the liquefaction process is complete and an alkaline plateau of about 9 is reached in the albumen (Stern, 1991). The time that is takes the albumen to undergo the described transformation is variable and will change among flocks based on genetics, environment, and

nutrients (Brake et al., 1997). Albumen viscosity degradation, which is measured by albumen height is associated with increased pH (Stern, 1991). Short term storage is needed to allow these changes to happen in younger flocks (Asmundson and MacIlriath, 1948), but excessive storage will allow the albumen to degrade beyond what is useful for the viability of the developing embryo (Lapão et al., 1999). This explanation is supported by the prior research of Benton and Brake (1996) who describe the changing function of the albumen from a protection role to a nutrient supply role. The albumen height is a relative measure of albumen viscosity (Benton and Brake, 1996). Fresh eggs that are set for incubation begin with a higher albumin height, which would mean the albumen has a higher viscosity at setting and may not allow for necessary oxygen to reach the embryo resulting in early death (Benton and Brake, 1996). These less developed characteristics would be more pronounced in eggs from younger flocks (Lapão et al., 1999). The stated practices on egg storage are further explored by another study which investigated egg storage length in conjunction with breeder hen age and found that eggs from older flocks are ready for incubation just after oviposition, but eggs from younger flocks' hatch reasonably well when they are stored for a short period of time before being set for incubation (Reis et al., 1997). The age of the hen and storage length has been proven to affect the hatchability of broiler breeder eggs by multiple researchers (Benton and Brake, 1996; Reis et al., 1997; Lapão et al., 1999; Tona et al., 2004; Yassin et al., 2008). Overall, eggs from younger breeders should be stored before eggs from older breeders. This information does not suggest that eggs from older hens should not be used, but rather that management at the hatchery needs to use these findings when determining which eggs to set in the incubator. Information available to those working in the poultry breeding industry gives a lot of insight into the effects of egg storage and how to best manage the results with varying amounts of storage time.

Conclusion

The information in this literature review gives a summary of the factors (or areas) that are associated with the increase or decrease in hatchability of broiler breeders. Some of the factors could be implemented by flock advisors, breeder managers, and company executives when determining daily practices on the farm or when determining best practices throughout the company. There are many other factors that extend off the farm and into hatchery management practices. Ultimately, there is no magic answer to the hatchability issues that have risen within the parent broiler breeder industry. It is evident in this review that many factors are intertwined, and one single experiment has many other factors (or confounders) that may be impacting hatchability outcomes. Suggestions for future research and industry attention include:

1) Management of male birds to help with best performance for the breeder operations.
2) For the inclusion of practical practices (heat treatments) in the hatchery that actively plan for ways to increase or maintain the hatchability of eggs when long-term storage is inevitable.
3) The potential for new housing (enrichments) designs that increase bird mating behavior and relieves stress when sexual maturity is reached at different times for males and females.
4) Increased storage temperatures at the farm to reduce possible egg sweating and promote a uniform stage of embryo development.

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