doi:10.1017/S0043933919000618

Factors affecting chick quality in Poland

J. PAWŁOWSKA[1]* and E. SOSNÓWKA-CZAJKA[2]

[1]Department of Production Systems and Environment; [2]Department of Poultry Breeding; National Research Institute of Animal Production, Kraków, Poland
***Corresponding author: joanna.pawlowska@izoo.krakow.pl**

Global poultry production has increased rapidly over the last 50 years and is now the most-consumed meat species in the world. The consumption of poultry in Poland accounts for almost 40% of the total meat consumption and averages 30 kg per person. Being the most flourishing sector of agriculture, poultry production faces many challenges from increasing competition (high quality products and lower prices for consumers). The profitability of poultry breeding and rearing is determined by the production of healthy and well-developed chicks, and the value of hatching eggs is closely linked to genetic line, flock age, layer housing conditions and parent flock nutrition, as well as incubation and pre- and post-hatching management. The qualitative assessment of newly hatched chicks must be based on clear and objective methods regarding health status of the flock and performance of the birds. It is essential that modern poultry production pays particular attention to these factors to achieve a high percentage of hatchability and the production of chicks which fully express their genetic potential under intensive production systems.

Keywords: chick quality; pre-incubation factors; chick length; chick weight; scoring methods

Introduction

Poultry production is one of the most flourishing and dynamically developing sectors of Polish agriculture. Domestic production distinguishes itself from the other European countries due to expansion into foreign markets. Between the years 2010-2017, poultry meat production in Poland has been estimated to have increased by as much as 75% and its consumption accounted for almost 40% of total meat consumption and averaged 30 kg per person (Poultry and Eggs Market, 2017). These has led to the conclusion that poultry producers must address the production of hatching eggs to meet the needs of domestic supply and increased exports. According to Statistics Poland (2018), in 2017 the number of hatched chicks for commercial broiler flocks was 1104.8 million birds. Taking into account the above factors, obtaining high quality chicks is crucial for increasing the economic efficiency of broiler production.

The growth rate of broilers has increased considerably since the 1950s due to genetic

© World's Poultry Science Association 2019
World's Poultry Science Journal, Vol. 75, December 2019
Received for publication July 16, 2019
Accepted for publication September 9, 2019

https://doi.org/10.1017/S0043933919000618 Published online by Cambridge University Press

selection and the duration of growing time has been reduced by 60% over the course of several decades (Afsarian *et al.,* 2016). The rapid genetic improvement of chickens in meat yield parameters has influenced embryonic development and metabolism of birds, as well as the characteristics of newly hatched chicks (Hulet and Meijerhof, 2001). Druyan (2010) endeavoured to compare genetic lines of broilers and layers, and their effects on chick embryo development. This author observed that chicks originating from Ross and Cobb strains hatched 24 h earlier than Lohmann chicks, and were characterised by higher oxygen consumption during incubation, and higher post-hatching body weight. This suggested that genetic selection shaped chick embryo development and its metabolic traits.

The profitability of poultry production depends largely on healthy and well-developed chicks, and the value of hatching eggs is determined by many factors, such as genetic line, flock age, layer housing conditions and parental nutrition, as well as the incubation process and the pre- and post-hatching management. Therefore, modern poultry production has to pay attention to these factors to achieve a high percentage of hatchability and the production of chicks which fully express their genetic potential under intensive production systems. This review aims to investigate those factors influencing chick quality.

Assessment of day-old chicks

Day-old chicks are the end-product of the hatchery and form the starting material for commercial production of eggs and meat. With regard to economic aspects, the main purpose of a hatchery is to achieve a high percentage of hatchability, while the quality and health of newly hatched birds determine performance outcomes to slaughter. According to Tona *et al.* (2005) it is generally believed that high hatchability is associated with high quality of chicks, and maximisation of hatching success translates into optimal quality of day-old chicks. The lack of explicit parameters to describe chick quality has led many researchers to create and standardise their own scales (Boerjan, 2002; Tona *et al.,* 2003). In analogy with the Apgar score for the assessment of newborn infants, the Pasgar score has been developed as an objective measure for day-old chick quality. High-quality chicks receive a maximum score of 10 points. Another quality indicator is the Tona score, which is based on information collected from farms and hatcheries, whereby Belgian researchers defined the criteria for qualitative chick scoring based on parameters such as activity, outward appearance and yolk sac resorption. These characteristics are assessed according to their importance on a scale of 0 to 100. The sum of the scores for all characteristics is used as a tool for assessing the quality of day-old chicks (Tona *et al.,* 2003).

Another quality indicator is chick length, which is measured from the tip of the beak to the tip of the middle toe (Mukhtar *et al.,* 2013). The authors of numerous publications have observed a positive correlation between the length of newly hatched chicks and final body weight of broilers (Wolanski *et al.,* 2007; Molenaar *et al.,* 2008; Petek *et al.,* 2008). Although the weight of newly hatched chicks is often used as a determinant of their quality, authors differ regarding its relationship with final slaughter weight (Vieira and Moran, 1999; Tona *et al.,* 2003; Wolanski *et al.,* 2003). Meijerhof (2009) concluded that the weight of day-old chicks is of limited value as a quality indicator, and highlighted a positive correlation between the weight of hen eggs and the weight of chicks. In turn, in newly hatched chicks, body weight has been correlated with the remaining yolk sac. The above information suggested that increased amounts of yolk in the chick's body cavity provide evidence of poor utilisation. In addition, weak embryos, which are deemed to be

https://doi.org/10.1017/S0043933919000618 Published online by Cambridge University Press

hatchery waste, do not completely absorb the yolk sac (Özlü *et al.,* 2018). It follows that chick body weight is not an optimal indicator for the quality of newly hatched chicks and their slaughter potential. In this situation, measurement of yolk free body mass (YFBM) is seen as a reliable qualitative method. YFBM is calculated by subtracting the residual yolk from the chick body weight. High values of YFBM suggests a better development of the chick. Under hatchery conditions, however, this method has limited practical application because a large number of chicks have to be killed to determine the yolk free body mass. In the case of visual appraisal, an interesting concept has been introduced by Petek *et al.* (2010), who chose chick feather colour as an indicator of quality. Because feather pigmentation comes from the yolk, they concluded that more yellow feathers may be indicative of maximal yolk uptake, which translates into day-old chick quality. However, because the number of studies that test this hypothesis is small, this assertion cannot be conclusively confirmed.

Breed

Commercial strains of broilers (two paternal strains and two maternal strains) have been developed to achieve high meat performance These strains must show good muscling and high reproductive parameters. In response to genetic selection, the body weight of current meat breeds has increased over 30 years by 400%, while feed conversion has improved by 50% (Buzala and Janicki, 2016). At the same time, commonly used breeds exhibit significant productive differences, and commercial strains, which are the basis for production of poultry, are not uniform. Sterling *et al.* (2006) showed higher body weight and better feed conversion ratios in Cobb compared to Ross broilers. This difference was supported by Hristakieva *et al.* (2014), who reported that the body weight of newly hatched chicks was higher for Cobb compared to the Ross line. The data on final body weight of the chickens confirmed a continuing trend. Comparative analyses from commercial strains of broilers are quite common, and, to date, have focussed on production results and meat quality (Farran *et al.,* 2000; Rahimi *et al.,* 2006; Kosarachukwu *et al.,* 2010; Dozier and Gehring, 2014), rearing conditions and housing systems (Altan *et al.,* 2000; Arruda *et al.,* 2016; Bergmann *et al.,* 2017), feeding of birds (Heck, *et al.*, 2004; Sterling *et al.,* 2006), incubation and hatchability (Suarez *et al.,* 1997; Abudabos, 2010). Publications by Tona *et al.* (2004; 2010) are among the few to provide a comprehensive analysis of embryonic development and to compare physiological parameters of embryos and the quality of chicks from different commercial lines of broilers.

According to Nangsuay *et al.* (2015), intensive genetic selection in modern broiler lines (Cobb 500 and Ross 308) has influenced the post-hatching development of chicks and stage of incubation. The intense metabolic processes that occur in the avian embryo generate heat. The combination of this heat emission with the temperature of the incubation environment influences the embryo's body heat, which is reflected as eggshell temperature. In turn, this property may affect embryo development, chick quality, as well as future growth performance (Molenaar *et al.,* 2011). During incubation, Ross 308 embryos used 13.9 kJ more energy than Cobb 500, and the efficiency of converting energy to yolk free body mass was approximately 7.6% lower compared to Cobb 500 (Nangsuay *et al.,* 2015). The discrepancies observed between these lines were determined by different metabolic strategies during the period of limited gas exchange at incubation.

https://doi.org/10.1017/S0043933919000618 Published online by Cambridge University Press

Broiler breeder nutrition

Rearing broiler parent stock is a key step in production. Good flock management can guarantee a high percentage of fertile eggs for producing healthy and strong day-old chicks. Over the last few decades, a major problem in parent farms has been the decline in the number of fertile eggs, especially during the second laying period (van Emous *et al.,* 2015). According to Yassin *et al.* (2008), this phenomenon may be triggered by poor management of the flock (genetic origin, bird health, egg quality and flock age). Another key factor is to provide animals with sufficient feed nutrients. A well-balanced diet is a major determining factor for rearing efficiency of parent flocks and for shaping production traits during lay and the production of high-quality eggs.

Eggs have a relatively stable composition and contain all the nutrients needed for embryonic development. Unlike vitamins and minerals, the energy and protein composition of eggs does not change due to the nutrition of layers at the parent farm (Whitehead *et al.,* 1985). Moraes *et al.* (2011) investigated the effect of dietary protein and energy in broiler breeder flocks on dressing percentage in the offspring. They fed three different energy levels (2950, 2800 or 2650 ME kcal/kg) combined with two protein levels (14 or 16%) and found that the low energy to high protein ratio diet increased breast yield of the offspring.

The observations made to date showed that dietary protein concentration in a breeder flock contributes significantly to progeny performance (Chang *et al.,* 2016). To determine the effect of protein content in broiler breeder diets on the development of chickens, van Emous *et al.* (2015) used an arrangement of treatments with three dietary protein levels (high, medium, and low protein) and two growth strains (fast and slow growing chickens). The offspring of fast-growing breeders had a higher body weight at 34 days of age than those from slow-growing strains. The low protein diet had a positive effect on breast meat yield in male broilers, while that of female broilers was not affected. In referring to Lopez and Leeson (1995), the data showed that a very low protein diet for broiler breeders considerably reduced egg weight and the body weight of newly hatched chicks, but had no significant effect on the body weight and carcass quality in broilers.

Normal chick embryo development is determined by the mineral (macro- and microelements) content of the layer diet on the parent farm. According to Chang *et al.* (2016), development and quality of day-old chicks are affected by vitamins D and E, selenium, zinc and magnesium. The content of cholecalciferol (vitamin D_3) in the layer diet is positively correlated to the levels of vitamin D_3 and 25-OH D_3 in the hen's egg yolk (Mattila *et al.,* 1999). Vitamin D_3 is converted to the active form 25-OH-D_3 and 1,25-OH-D_3 through metabolic pathways in the liver and kidneys, respectively. The optimum deposition of vitamin 25-OH-D_3 in the layer diet may increase Ca absorption from the intestine, thus improving eggshell quality. Furthermore, increased content of this vitamin has a beneficial effect on hatchability and improves chick quality (Saunders-Blades and Korver, 2015). The findings of Atencio *et al.* (2005) suggested that supplementation of 2,000 or 4,000 IU vitamin D_3/kg to parent flock diets will increase the final body weight of the offspring in relation to unsupplemented chickens, while the incidence of tibial dyschondroplasia will be lower in the offspring. Saunders-Blades and Korver (2015) determined the effect of vitamin D in broiler breeder diets on innate immune resistance in the offspring and concluded that supplementing with 25-OH-D_3 increased hatchability and innate immunity to *E. coli* in broiler chicks.

In poultry production, vitamin E is added to the diet in a natural or synthetic form, mainly as α-tocopherol, and, along with selenium, represents an important antioxidant. According to Driver *et al.* (2006), chickens may synthesise inadequate vitamin E levels and its concentration in the body depends on the diet. By modifying the composition of

https://doi.org/10.1017/S0043933919000618 Published online by Cambridge University Press

the broiler breeder hen diets, it is possible to increase the amounts of both vitamin E and selenium in eggs (Payne, *et al.,* 2005; Mohiti-Asli *et al.*, 2008). Day-old chicks from hens supplemented with vitamin E at 60 IU/kg feed, were characterised by considerably higher antibody titre compared to the control group and the group fed at 20 IU (Andi *et al.,* 2006) According to the same authors, increased transfer of maternal antibodies to progeny translates into a stronger humoral response of day-old chicks and greater immunity to disease. Urso *et al.* (2015) used a broiler breeder flock to determine the effect of vitamin E and selenium in the diet of hens on the quality of hatched chicks. Hens aged 47 weeks old fed L-selenomethionine (0.4 mg/kg) and 120 mg vitamin E/kg feed produced heavier eggs than the less supplemented groups. The applied rations had no statistically significant effect on the body weight of newly hatched chicks. In the case of selenium, Pappas *et al.* (2006) observed that chicks hatched from hens fed diets with 0.5 mg/kg of organic Se, showed a higher tissue Se concentration compared to the unsupplemented group.

Flock age

Egg quality changes with the age of the hens, which may result in lower hatchability and poorer quality chicks. Chang *et al.* (2016) stated that egg composition might be affected by age of hen, as is the yolk to eggshell ratio. Chicks hatched from older flocks are characterised by higher body weight compared to chicks from younger flocks. This correlation applied to the entire broiler rearing period (Tona *et al.,* 2004). Yolk sac nutrient reserves were higher in chicks hatched from the older flock. This relationship was confirmed by Ulmer-Franco *et al.* (2010), who reported that Cobb 500 hatching eggs from a flock aged 59 weeks had a higher yolk percentage compared to the eggs from a 29-week-old flock. Polish researchers observed that hatching parameters varied according to parent flock age (Nowaczewski *et al.,* 2016). When analysing egg weight changes with regard to hen age, these authors observed the weight of hatching eggs to differ between flocks aged 26-30 and 46-64 weeks. Older hens laid 11.3 g heavier eggs than youngest hens. In view of the above experiments, another important study by Ramaphala and Mbajiorgu (2013) demonstrated that the coefficient of correlation between the weight of hatching eggs and the weight of chicks was positive (r=0.995).

Flock age determines traits related to egg content and eggshell quality. Hatching eggs from young flocks are characterised by better albumen quality and stronger eggshells (İpek and Sözcü, 2013). In turn, stronger eggshell reduces oxygen transfer to the developing embryo, which may slower embryo growth and metabolism (Lourens *et al.,* 2006). Older flocks exhibited a higher percentage of abnormalities in newly hatched chicks (Boerjan, 2002). Layer age determines egg hatchability, and the results of Abudabos (2010) suggested that eggs from older Ross hens are characterised by lower hatchability compared to eggs from young hens. The lowest hatchability (70.4%) was obtained from eggs laid by the oldest hens. The average hatchability increased to 85.2% for the younger group of the same strain. It follows from the studies cited above that hatching value of eggs is determined by hen age, which determines egg weight and embryo development.

Storage of eggs

Storage of hatching eggs is a common practice in poultry production, especially in large commercial flocks. However, stored eggs are exposed to many factors affecting the

https://doi.org/10.1017/S0043933919000618 Published online by Cambridge University Press

quality of chicks (Goliomytis *et al.,* 2015). During storage, hatching eggs undergo changes in the form of water and carbon dioxide losses as well as an increase in albumen pH (Decuypere *et al.,* 2001; Silversides and Scott, 2001). Prolonged egg storage periods extend the time for incubation and chick hatching. This situation increases the time newly hatched chicks remain in the incubator and delays their access to water and feed (Tona *et al.,* 2003). According to Khan *et al.* (2014), storage of hatching eggs prior to incubation has no significant effect on hatchability if this period does not exceed eight days. Nevertheless, extending this period beyond seven days after fertilisation reduces hatchability parameters (Fasenko *et al.,* 2001). Goliomytis *et al.* (2015) observed that, after four-day storage of eggs, hatchability was around 85%. When this period was extended to 16 days, hatchability decreased to 80%. In the context of prolonged egg storage, an increased percentage of early dead embryos was observed. For eggs from Rhode Island Red hens (RIR), nine days storage of hatching eggs was found to be associated with increased embryonic mortality between one and seven days of incubation (48.3%; Khan *et al.,* 2014). A similar phenomenon was reported by Petek and Dikmen (2006) for broilers. Higher mortality was characteristic for embryos from eggs stored for 15 days (12.3%) compared to eggs stored for five days, for which early embryonic mortality was 5.1%. These authors stated that development of embryos from eggs stored for a prolonged time (over five days) may not start immediately after placement of the eggs in the incubator or the development stage is slower in the initial incubation period. Prolonged storage of eggs is detrimental to the incubation process and hatchability, and according to Reijrink *et al.* (2010), early use of 'fresh' eggs for incubation (less than four days) increases mortality in chicks.

Incubation and post-hatching period

Technological advances over several decades have improved avian egg incubation techniques. Modern, fully automatic incubators permit precise setting of hatching parameters for different poultry species. According to Udawaththa *et al.* (2018), whether the embryo develops normally or not depends on incubation conditions. Heat produced during incubation is a critical element in initiating the embryonic development of the bird. Small changes in artificial incubation temperature may have a significant impact on embryo development, and later on chick quality and carcass dressing percentage (Lourens and Van Middelkoop, 2000). The optimum temperature in the setter should range from 37.6 to 38.0°C (Molenaar *et al.*, 2011). It can be concluded from the results of many studies that fluctuations in incubation temperature affect the development of muscles (Clark *et al.,* 2017), internal organs (Leksrisompong *et al.,* 2007), skeletal bones (Shim and Pesti, 2011), and the quality of day-old chicks (Molenaar *et al.,* 2011).

Hulet *et al.* (2007) studied the effect of low (37.5°C), moderate (38.6°C) and high (39.7°C) temperatures on body weight of chicks. Chicks from the group exposed to high temperatures exhibited higher body weight (43.1 g) compared to the middle (42.2 g) and low temperature (41.1 g) groups. A reverse trend was noted towards the end of rearing. The highest body weight was observed in broilers from the group exposed to moderate temperatures, and lowest in the high temperature group (2.263 kg *vs*. 2.166 kg). An interesting concept was introduced by Tzschentke (2008), who concluded that chicks exposed to high temperature towards the end of incubation can be better adapted to unfavourable environments (*e.g.* high temperatures) later in the fattening period.

It is common in hatcheries to hold early hatchlings until all chicks in the baskets have emerged. This practice causes the earliest hatched chicks have no access to feed and

https://doi.org/10.1017/S0043933919000618 Published online by Cambridge University Press

water for a relatively long time. This situation may be prolonged by other organisational activities, such as sexing, vaccination or transport to the farm. It is known that long-term feed withdrawal may suppress the digestive tract from developing, which impairs the absorption of nutrients and translates directly into weight gains of the chickens (Uni *et al.*, 2005). Delayed post-hatch feeding was the subject of a study by Shinde Tamboli *et al.* (2017), in which one-day-old chicks had access to feed within 6, 12, 24 and 36 h of hatching. The authors concluded that post-hatch feed deprivation for the first 24 h did not affect growth performance but improved immune response in slow growing broiler females. However, these parameters were adversely affected when chicks were feed-deprived for more than 36 h.

In ovo feeding

Chick quality can be influenced by using *in ovo* feeding to embryos (Pawłowska, 2015). This method is described within the US Patent (6.592.878) of Uni and Ferket (2003). *In ovo* feeding involves the administration of nutritive supplements into the embryonic amnion at 17-18 days of incubation. Supplementation at this stage of development allows the chick to ingest the amniotic fluid together with the solution and to absorb it in the intestines. This manipulation has proved effective in several studies which used *in ovo* injection of carbohydrates (Tako *et al.,* 2004; Uni *et al.,* 2005; Bhanja *et al.,* 2008; Zhai *et al.,* 2011), amino acids (Bhanja *et al.,* 2005; Kadam *et al.,* 2008; Shafey *et al.,* 2014) and vitamins (Nowaczewski *et al.,* 2012; Gonzales *et al.,* 2013; Salary *et al.,* 2014; Gholami *et al.,* 2015). The studies cited above indicated that the injection of active substances into the egg has a beneficial effect on biochemical processes and the development of the chick embryo, hatchability and quality of newly hatched chicks.

Conclusions

In summary, poultry production efficiency is closely linked to the biological quality of chicks, which includes various characteristics that determine the performance potential of day-old chicks. In recent years, breeding value of poultry has increased as new commercial lines were developed, and so the environmental, health and nutritional requirements have become more demanding. These changes have an effect on different stages of high-quality chick production. Broiler breeder farms choosing optimum commercial lines for the production of broiler chicks, and continuous breeding work brings with it changes in the nutritional and environmental demands in the management of parent flocks. Selection of optimum diets has an effect on layer health and the quality of hatching eggs, and on the quality of the chicks. Opinions vary in the literature and in breeding practices regarding the thermal-humidity conditions required at different stages of incubation and the effect of various modifications on embryonic and postembryonic development. The assessment and selection of newly hatched chicks in poultry hatcheries has to be refined. The literature provided a clear conclusion that production of high-quality chicks requires further research concerning breeding work, nutrition and management of pedigree flocks, principles of hatching egg storage and incubation and the assessment of chick quality. The research concerning *in ovo* supplementation of embryos is promising but requires further investigation.

https://doi.org/10.1017/S0043933919000618 Published online by Cambridge University Press

References

ABUDABOS, A. (2010) The effect of broiler breeder strain and parent flock age on hatchability and fertile hatchability. *International Journal of Poultry Science* **9**: 231-235.

AFSARIAN, O., SHAHIR, M.H., AKHLAGHI, A., LOTFOLAHIAN, H., HOSEINI, A. and LOURENS, A. (2016) Periodical low eggshell temperatures during incubation and post hatch dietary arginine supplementation: Effects on performance and cold tolerance acquisition in broilers. *Poultry Science* **95**: 2427-2434.

ALTAN, O., OĞUZ, A., PABUÇCUOĞLU, A. and KONYALIOĞLU, S. (2000) Effects of heat stress on growth, some blood variables and lipid oxidation in broilers exposed to high temperature at an early age. *British Poultry Science* **41**: 489-493.

ANDI, M.A., SHIVAZAD, M., POURBAKSH, S.A., AFSHAR, M., ROKNI, H., SHIRI, N.E., MOHAMMADI, A. and SALAHI, Z. (2006) Effects of vitamin e in broiler breeder diet on hatchability, egg quality and breeder and day old chick immunity. *Pakistan Journal of Biological Sciences* **9**: 789-794.

ARRUDA, J.N.T., MENDES, A.S., GUIRRO, E.C.B.P., SCHNEIDER, M., SIKORSKI, R.R., SAUSEN, L., DIAS, E.R. and BONAMIGO, D.V. (2016) Live performance, carcass yield, and welfare of broilers of different genetic strains reared at different housing densities. *Brazilian Journal of Poultry Science* **18**: 141-152.

ATENCIO, A., EDWARDS, H.M. (Jr) and PESTI, G.M. (2005) Effects of vitamin D3 dietary supplementation of broiler breeder hens on the performance and bone abnormalities of the progeny. *Poultry Science* **84**: 1058-1068.

BERGMANN, S., SCHWARZER, A., WILUTZKY, K., LOUTON, H., BACHMEIER, J. and SCHMIDT, P. (2017) Behavior as welfare indicator for the rearing of broilers in an enriched husbandry environment - A field study. *Journal of Veterinary Behavior* **19**: 90-101.

BHANJA, S.K. and MANDAL, A.B.(2005) Effect of in ovo injection of critical amino acids on pre- and post-hatch growth, immunocompetence and development of digestive organs in broiler chickens. *Asian-Australasian Journal of Animal Sciences* **18**: 524-531.

BHANJA, S.K., MANDAL, A.B., AGARWAL, S.K. and MAJUMDAR, S. (2008) Effect of in ovo glucose injection on the post-hatch growth, digestive organ development and blood biochemical profiles in broiler chickens. *Indian Journal of Animal Sciences* **78**: 869-872.

BOERJAN, M. (2002) Programs for single stage incubation and chick quality. *Poultry and Avian Biology Reviews* **13**: 237-238.

BUZALA, M. and JANICKI, B. (2016) Review: Effects of different growth rates in broiler breeder and layer hens on some productive traits. *Poultry Science* **95**: 2151-2159.

CHANG, A., HALLEY, J. and SILVA, M. (2016) Can feeding the broiler breeder improve chick quality and offspring performance? *Animal Production Science* **56**: 1254-1262.

CLARK, D.L., WALTER, K.G. and VELLEMAN, S.G. (2017) Incubation temperature and time of hatch impact broiler muscle growth and morphology. *Poultry Science* **96**: 4085-4095.

DECUYPERE, E., TONA, K., GRUGGEMAN, V. and BAMELIS, F. (2001) The day-old chick: A crucial hinge between breeders and broilers. *World's Poultry Science Journal* **57**:128-139.

DOZIER, W.A. and GEHRING, C.K. (2014) Growth performance of Hubbard × Cobb 500 and Ross × Ross 708 male broilers fed diets varying in apparent metabolizable energy from 14 to 28 days of age. *Journal of Applied Poultry Research* **23**: 494-500.

DRIVER, J.P., ATENCIO, A., PESTI, G.M., EDWARDS, H.M. (Jr) and BAKALLI, R.I. (2006) The effects of maternal dietary vitamin D3 suplementation on performance and tibial dyschondroplasia of broiler chicks. *Poultry Science* **85**: 39-47.

DRUYAN, S. (2010) The effects of genetic line (broilers vs. layers) on embryo development. *Poultry Science* **89**:1457-67.

FARRAN, M.T., KHALIL, R.F., UWAYJAN, M.G. and ASHKARIAN, V.M. (2000) Performance and carcass quality of commercial broiler strains. *Journal of Applied Poultry Research* **15**: 190-197.

FASENKO, G., ROBINSON, F., WHELAN, A., KREMENIUK, K. and WALKER, J. (2001) Prestorage incubation of long-term stored broiler breeder eggs: 1. Effects on hatchability. *Poultry Science* **80**:1406-1411.

GHOLAMI, J., QOTBI, A.A.A., SEIDAVI, A., MELUZZI, A., TAVANIELLO, S. and MAIORANO, G. (2015) Effects of in ovo administration of betaine and choline on hatchability results, growth and carcass characteristics and immune response of broiler chickens. *Italian Journal of Animal Science* **14**: 187-192.

GOLIOMYTIS, M., TSIPOUZIAN, T. and HAGER-THEODORIDES, A. (2015) Effects of egg storage on hatchability, chick quality, performance and immunocompetence parameters of broiler chickens. *Poultry Science* **94**: 2257-2265.

GONZALES, E., CRUZ, C.P., LEANDRO, N.S.M., STRINGHINI, J.H. and BRITO, A.B. (2013) In ovo supplementation of 25(OH)D to broiler embryos. *Brazilian Journal of Poultry Science* **15**: 199-202.

https://doi.org/10.1017/S0043933919000618 Published online by Cambridge University Press

HECK, A., ONAGBESAN, O., TONA, K., METAYER, S., PUTTERFLAM, J., JEGO, Y., TREVIDY, J. J, DECUYPERE, E., WILLIAMS, J., PICARD, M. and BRUGGEMAN, V. (2004) Effects of ad libitum feeding on performance of different strains of broiler breeders. *British Poultry Science* **45**: 695-703.

HRISTAKIEVA, P., MINCHEVA, N., OBLAKOVA, M., LALEV, M. and IVANOVA, I. (2014) Effect of genotype on production traits in broiler chickens. *Slovak Journal of Animal Science* **47**: 19-24.

HULET, R., GLADYS, R., HILL, D., MEIJERHOF, R. and EL-SHIEKH, T. (2007) Influence of egg shell embryonic temperature and broiler breeder flock age on posthatch growth performance and carcass characteristics. *Poultry Science* **86**: 408-412.

HULET, R.M. and MEIJERHOF, R. (2001) Multi- or single-stage incubation for high-meat yielding broiler strains. *Proceedings of Southern Poultry Science and Southern Conference of Avian Diseases*, Atlanta, pp. 35.

İPEK, A. and SÖZCÜ, A. (2013) Broiler chick quality and scoring methods. *Journal of Agricultural Faculty of Uludag University* **27**: 131-137.

KADAM, D.M.M., BHANJA, S., MANDAL, A., THAKUR, R., VASAN, P. and BHATTACHARYYA, A. (2008) Effect of in ovo threonine supplementation on early growth, immunological responses and digestive enzyme activities in broiler chickens. *British Poultry Science* **49**: 736-741.

KHAN, M.J.A., KHAN, S.H., BUKHSH, A. and AMIN, M. (2014) The effects of storage time on egg quality and hatchability characteristics of Rhode Island Red (RIR) hens. *Veterinarski Arhiv* **84**: 291-303.

KOSARACHUKWU, C.O., IHESHIULOR, O.O.M., OMEDE, A. and OGBUEWU, P.I. (2010) Effect of strain on growth, carcass characteristics and meat quality of broilers reared for 12 weeks. *New York Science Journal* **3**: 112-116.

LEKSRISOMPONG, N., ROMERO-SANCHEZ, H., PLUMSTEAD, P.W., BRANNAN, K.E. and BRAKE, J. (2007) Broiler incubation. 1. Effect of elevated temperature during late incubation on body weight and organs of chicks. *Poultry Science* **86**: 2685-2691.

LOPEZ, G. and LEESON, S. (1995) Response of broiler breeders to low-protein diets. 2. Offspring performance. *Poultry Science* **74**: 696-701.

LOURENS, A. and VAN MIDDELKOOP, J.H. (2000) Embryo temperature affects hatchability and grow-out performance of broilers. *Avian and Poultry Biology Reviews Impact* **11**: 299-301.

LOURENS, A., MOLENAAR, R., VAN DEN BRAND, H.E., HEETKAMP, M.J.W., MEIJERHOF, R. and KEMP, A. (2006) Effect of egg size on heat production and the transition of energy from egg to hatchling. *Poultry Science* **85**: 770-776.

MATTILA, P., LEHIKOINEN, K., KIISKINEN, T. and PIIRONEN, V. (1999) Cholecalciferol and 25-hydroxycholecalciferol content of chicken egg yolk as affected by the cholecalciferol content of feed. *Journal of Agricultural and Food Chemistry* **47**: 4089-4092.

MEIJERHOF, R. (2009) The influence of incubation on chick quality and broiler performance. *Proceedings of the 20th Australian Poultry Science Symposium*, Sydney, pp. 167-170.

MOHITI-ASLI, M., SHARIATMADARI, F., LOTFOLLAHIAN, H. and MAZUJI, M.T. (2008) Effects of supplementing layer hen diets with selenium and vitamin E on egg quality, lipid oxidation and fatty acid composition during storage. *Canadian Journal of Animal Science* **88**: 475-483.

MOLENAAR, R., HULET, R., MEIJERHOF, R., MAATJENS, C.M., KEMP, B. and VAN DEN BRAND, H. (2011) High eggshell temperatures during incubation decrease growth performance and increase the incidence of ascites in broiler chickens. *Poultry Science* **90**: 624-632.

MOLENAAR, R., REIJRINK, I.A.M., MEIJERHOF, R. and VAN DEN BRAND, H. (2008) Relationship between hatchling length and weight on later productive performance in broilers. *World's Poultry Science Journal* **64**: 599-604.

MORAES, T.G.V., PISHNAMAZI, A., MBA, E.T., RENEMA, R.A. and ZUIDHOF, M.J. (2011) Effect of maternal energy and protein on broiler carcass yield. *Poultry Science* **90 (Suppl. 1)**: 102-103 (Abstr.).

MUKHTAR, N., KHAN, S.H. and ANJUM, M.S. (2013) Hatchling length is a potential chick quality parameter in meat type chickens. *World's Poultry Science Journal* **69**: 889-896.

NANGSUAY, A., MEIJERHOF, R., VAN DEN ANKER, I., HEETKAMP, M.J., KEMP, B. and VAN DEN BRAND, H. (2015) Development and nutrient metabolism of embryos from two modern broiler strains. *Poultry Science* **94**: 2546-2554.

NOWACZEWSKI, S., BABUSZKIEWICZ, M. and KACZMAREK, S. (2016) Effect of broiler breeders' age on eggshell temperature, embryo viability and hatchability parameters. *Annals of Animal Science* **16**: 235-243.

NOWACZEWSKI, S., KONTECKA, H. and KRYSTYNIAK, S. (2012) Effect of in ovo injection of vitamin C during incubation on hatchability of chickens and ducks. *Folia Biologica* **60**: 93-97.

ÖZLÜ, S., SHIRANJANG, R., ELIBOL, O. and BRAKE, J. (2018) Effect of hatching time on yolk sac percentage and broiler live performance. *Brazilian Journal of Poultry Science* **20**: 231-236.

PAPPAS, A.C., ACAMOVIC, T., SURAI, P.F. and MCDEVITT, R.M. (2006) Maternal organo-selenium compounds and polyunsaturated fatty acids affect progeny performance and levels of selenium and docosahexaenoic acid in the chick tissues. *Poultry Science* **85**: 1610-1620.

https://doi.org/10.1017/S0043933919000618 Published online by Cambridge University Press

PAWŁOWSKA, J. (2015) Application of in ovo technology to improve efficiency of poultry production. *Wiadomości Zootechniczne* **3**: 158-162 [in Polish].

PAYNE, R.L., LAVERGNE, T.K. and SOUTHERN, L.L. (2005) Effect of inorganic versus organic selenium on hen production and egg selenium concentration. *Poultry Science* **84**: 232-237.

PETEK, M. and DIKMEN, S. (2006) The effects of prestorage incubation and length of storage of broiler breeder eggs on hatchability and subsequent growth performance of progeny *Czech Journal of Animal Science* **51**: 73-77.

PETEK, M., ORMAN, A., DIKMEN, S. and ALPAY, F. (2008) Relations between day-old chick length and body weight in broiler. *Uludag University Journal of the Faculty of Veterinary Medicine* **27**: 25-28.

PETEK, M., ORMAN, A., DIKMEN, S. and ALPAY, F. (2010) Physical chick parameters and effects on growth performance in broiler. *Archives Animal Breeding* **53**: 108-115.

POULTRY AND EGGS MARKET (RYNEK DROBIU I JAJ - STAN I PERSPEKTYWY) (2017) Jadwiga Seremak-Bulge (red.), Warszawa [in Polish].

RAHIMI, S.H., ESMAEILZADEH, L. and KARIMI TORSHIZI, M.A. (2006) Comparison of growth performance of six commercial broiler hybrids in Iran. *Iranian Journal of Veterinary Research* **7**: 38-44.

RAMAPHALA, N.O. and MBAJIORGU, C.A. (2013) Effect of egg weight on hatchability and chick hatch-weigh of Cobb 500 broiler chickens. *Asian Journal of Animal and Veterinary Advances* **8**: 885-892.

REIJRINK, I., BERGHMANS, D., MEIJERHOF, R., KEMP, B. and VAN DEN BRAND, H. (2010) Influence of prestorage incubation on embryonic development, hatchability, and chick quality. *Poultry Science* **88**: 2649-2660.

SALARY, J., SAHEBI-ALA, F., KALANTAR, M., REZA, H. and MATIN, H. (2014) In ovo injection of vitamin E on post-hatch immunological parameters and broiler chicken performance. *Asian Pacific Journal of Tropical Biomedicine* **4**: 616-619.

SAUNDERS-BLADES, J.L. and KORVER, D.R. (2015) Effect of hen age and maternal vitamin D source on performance, hatchability, bone mineral density, and progeny in vitro early innate immune function. *Poultry Science* **94**: 1233-1246.

SHAFEY, T.M., MAHMOUD, A.H., ALSOBAYEL, A.A. and ABOUHEIF, M.A. (2014) Effects of in ovo administration of amino acids on hatchability and performance of meat chickens. *South African Journal of Animal Science* **44**: 123-130.

SHIM, M.Y. and PESTI, G.M. (2011) Effects of incubation temperature on the bone development of broilers. *Poultry Science* **90**: 1867-1877.

SHINDE TAMBOLI, A.S., AKSHAT GOEL, MANISH MEHRA, ROKADE, J.J., PRAGYA BHADAURIA, YADAV, A.S., MAJUMDAR, S. and BHANJA, S.K. (2017) Delayed post-hatch feeding affects the performance and immunocompetence differently in male and female broiler chickens. *Journal of Applied Animal Research* **46**: 306-313.

SILVERSIDES, F. and SCOTT, T. (2001) Effect of storage and layer age on quality of eggs from two lines of hens. *Poultry Science* **80**:1240-1245.

STATISTICS POLAND (2018) *Farm animals in 2017*. Warsaw, Poland.

STERLING, K.G., PESTI, G.M. and BAKALLI, R.I. (2006) Performance of different broiler genotypes fed diets with varying levels of dietary crude protein and lysine. *Poultry Science* **85**: 1045-1054.

SUAREZ, M.E., WILSON, H.R., MATHER, F.B., WILCOX, C.J. and MC PHERSON, B.N. (1997) Effect of strain and age of the broiler breeder female on incubation time and chick weight. *Poultry Science* **76**: 1029-1036.

TAKO, E., FERKET, P.R. and UNI, Z. (2004) Effects of in ovo feeding of carbohydrates and β-hydroxy-β-methylbutyrate on the development of chicken intestine. *Poultry Science* **83**: 2023-2028.

TONA, K., BAMELIS, F., DE KETELAERE, B., BRUGGEMAN, V., MORAES, V.M.B., BUYSE, J., ONAGBESAN, O. and DECUYPERE, E. (2003) Effects of egg storage time on spread of hatch, chick quality, and chick juvenile growth. *Poultry Science* **82**: 736-741.

TONA, K., BRUGGEMAN, V., ONAGBESAN, O., BAMELIS, F., GBEASSOR, M., MERTENS, K. and DECUYPERE, E. (2005) Day-old chick quality: relationship to hatching egg quality, adequate incubation practice and prediction of broiler performance. *Avian and Poultry Biology Reviews* **16**: 109-119.

TONA, K., ONAGBESAN, O.M., JEGO, Y., KAMERS, B., DECUYPERE, E. and BRUGGEMAN, V. (2004) Comparison of embryo physiological parameters during incubation, chick quality, and growth performance of three lines of broiler breeders differing in genetic composition and growth rate. *Poultry Science* **83**: 507-513.

TONA, K., ONAGBESAN, O.M., KAMERS, B., EVERAERT, N., BRUGGEMAN, V. and DECUYPERE, E. (2010) Comparison of Cobb and Ross strains in embryo physiology and chick juvenile growth. *Poultry Science* **89**: 1677-1683.

TZSCHENTKE, B. (2008) Monitoring the development of thermoregulation in poultry embryos and its influence by incubation temperature. *Computers and Electronics in Agriculture* **64**: 61-71.

https://doi.org/10.1017/S0043933919000618 Published online by Cambridge University Press

UDAWATHTHA, M.T., ADIKARI, A.M.J.B. and GAMLATH, G.A.S.N. (2018) Effect of multi-stage incubator types on hatchability and chick quality of broiler chicken. *Wayamba Journal of Animal Science* **10**: 1737-1742.

ULMER-FRANCO, A.M., FASENKO, G.M. and O'DEA CHRISTOPHER, E.E. (2010) Hatching egg characteristics, chick quality, and broiler performance at 2 breeder flock ages and from 3 egg weights. *Poultry Science* **89**: 2735-2742.

UNI, Z. and FERKET, P.R. (2003) Enhancement of development of oviparous species by in ovo feeding. US Patent 6.592.878. North Carolina State University, Raleigh, NC; and Yissum Research Development Company of the Hebrew University of Jerusalem, Jerusalem (Israel).

UNI, Z., FERKET, P.R., TAKO, E. and KEDAR, O. (2005) In ovo feeding improves energy status of late-term chicken embryo. *Poultry Science* **84**: 764-770.

URSO, U.R.A., DAHLKE, F., MAIORKA, A., BUENO, I.J.M.A., SCHNEIDER, F., SUREK, D. and ROCHA, C. (2015) Vitamin E and selenium in broiler breeder diets: Effect on live performance, hatching process, and chick quality. *Poultry Science* **94**: 976-983.

VAN EMOUS, R.A., KWAKKEL, R.P., VAN KRIMPEN, M.M., VAN DEN BRAND, H. and HENDRIKS, W.H. (2015) Effects of growth patterns and dietary protein levels during rearing of broiler breeders on fertility, hatchability, embryonic mortality, and offspring performance. *Poultry Science* **94**: 681-691.

VIEIRA, S.L. and MORAN, E.T. (Jr) (1999) Effects of egg of origin and chick post-hatch nutrition on broiler live performance and meat yields. *World's Poultry Science Journal* **55**: 125-142.

WHITEHEAD, C.C., PEARSON, R.A. and HERRON, K.M. (1985) Biotin requirements of broiler breeders fed diets of different protein content and effect of insufficient biotin on the viability of progeny. *British Poultry Science* **26**: 73-82.

WOLANSKI, N.J., LUITEN, E., MEIJERHOF, R. and VEREIJKEN, A.L.J. (2003) Yolk utilisation and chick length as parameters for embryo development. *Avian Poultry Biology Review* **15**: 233-234.

WOLANSKI, N.J., RENEMA, R.A., ROBINSON, F.E., CARNEY, V.L. and FANCHER, B.I. (2007) Relationships among egg characteristics, chick measurements, and early growth traits in ten broiler breeder strains. *Poultry Science* **86**: 1784-1792.

YASSIN, H., VELTHUIS, A.G.J., BOERJAN, M., VAN RIEL, J.W. and HUIRNE, R.B.M. (2008) Field study on broiler eggs hatchability. *Poultry Science* **87**: 2408-2417.

ZHAI, W., ROWE, D.E. and PEEBLES, E.D. (2011) Effects of commercial in ovo injection of carbohydrates on broiler embryogenesis. *Poultry Science* **90**: 1295-1301.

https://doi.org/10.1017/S0043933919000618 Published online by Cambridge University Press

https://doi.org/10.1017/S0043933919000618 Published online by Cambridge University Press