SEL'SKOKHOZYAISTVENNAYA BIOLOGIYA
[AGRICULTURAL BIOLOGY], 2014, № 6, pp. 26-35 ISSN 313-4836 (Online)

UDC 636.5.034:636.018

doi: 10.15389/agrobiology.2014.6.26rus
doi: 10.15389/agrobiology.2014.6.26eng

PROBLEM OF EGG PRODUCTIVITY IN HENS AND ITS EARLY PREDICTION

A.L. SHTELE

K.A. Timiryazev Russian State Agrarian University, 49, ul. Timiryazevskaya, Moscow, 127550 Russia, e-mail alshtele@mail.ru
Received January 10, 2014

Abstract

The generalized processes of natural maturation of oocyte with egg yolk in the ovary, production of egg white and eggshell in the oviduct, as well as ovulation and laying cycle are under the genotype control. Besides, they are affected by the environment and regulated by neurohumoral (neurohormonal) system. All these factors determine ultimately the egg productivity in poultry. Thus, it is limited by time, required for the oocyte maturation and yolk synthesis, and also by the decreasing reproductive potency of hens and egg quality because of aging and/or influence of technological factors. Whatever it was, the observed phenotypic variability due to selection pressure and the applied intensive technologies in poultry indicates the physiological limits of productivity (i.e. egg-laying rate, egg weight and quality) to become wider in hens with intensive metabolism. In the modern egg hybrid crosses a daily ovulation occurs synchronously with a mature egg formation and laying during long productive usage. The egg laying chickens can be forecasted in the postembryonic ontogenesis by the number of large follicles which are maturing in the ovary, if 85-90 % egg productivity is reached within 5-6 weeks after the laying begins. The steady cycle of egg laying with small interval (1-2 days) is also of importance. Thus, the rapid formation of 5-6 follicles in the ovary coinciding with weekly maturation of the yolk in ovogenesis determines the biological potency of reproductive function in high-yield laying hens. The use of these parameters for assessing egg chicks and their offspring gives an opportunity to predict the high-producers in the early ontogenesis. It will speed up breeding to improve modern egg crosses, create new ones, and also to optimize the intensive technologies in poultry.

Keywords: egg productivity, chicken genome, oocyte, ovary, ovogenesis, egg-laying, integrity, concept, prediction.

Since 1950s due to long and intensive breeding and hybridization the annual egg productivity in hen crosses increased almost 2 times and amounts 320-330 in number and 60-65 g in an average weight compared to 55-60 g. The weight of shell and white of the eggs mostly increases, while the yolk weight in selected lines of egg crosses is stabilized at 16-17 g, being up to 18 g on average in hybrids (1). Hence, egg productivity almost reached the biological limits.

Complicated processes of natural maturation of oocyte with the yolk in the ovaries, the egg white and shell formation in the oviduct, ovulation and oviposition are genetically based, neurohumorally regulated and depend on the environment. Therefore, egg production is limited by the time of an oocyte maturation and the yolk formation, on one side, and a reduced productivity and egg quality upon hen aging and(or) because of used poultry technologies, on the other side.

Study of genome structure and functions in the hens with high egg production are being intensified resulting in developed and improved technologies for poultry breeding and commercial use. Thus, early prediction of egg production is essential.

Genetic bases for egg productivity and breeding. Selection and crossing based on advances in population genetics are the main approaches in poultry breeding. The high yielding egg hen hybrids is due to strict selection for desired traits in the lines and under crossing the matching lines. For long

time the occurring genetic diversity was enough to keep up the variability of polygene traits and increase hen productivity. The DNA technologies based on genetic polymorphism and multiple molecular markers allowing early forecasting are currently used (1).

Hen haploid genome sequencing showed 24 000 genes and more than 1×10^9 bp in polymorphic regions reflecting genetic diversity. SNPs (single nucleotide polymorphism) are basic at marker assisted selection (2). This approach is most effective in case the valuable traits are sex-linked. Early screening young cocks from the lines and related groups reduces the time required for selection over generations.

In hen genome above 3 million SNPs are reported allowing to locate the markers for polygenic quantitative traits (3) and to identify genes of structural proteins, multiple regulatory proteins and the markers being used in genome mapping and poultry breeding. A development of the chips for more than 600 000 nucleotide sequences identified in the commercial lines has been reported (4). Complete hen genome sequencing should simplify detecting polymorphic DNA regions, marking specific nucleotide sequences, and mapping structural genes and loci involved in the production control. Particularly, the cytogenetic mapping, linkage groups and polymorphic markers were basic in the last reported version of the hen integrated chromosome map, including 1889 loci of which 450 loci formed 50 linkage groups (5).

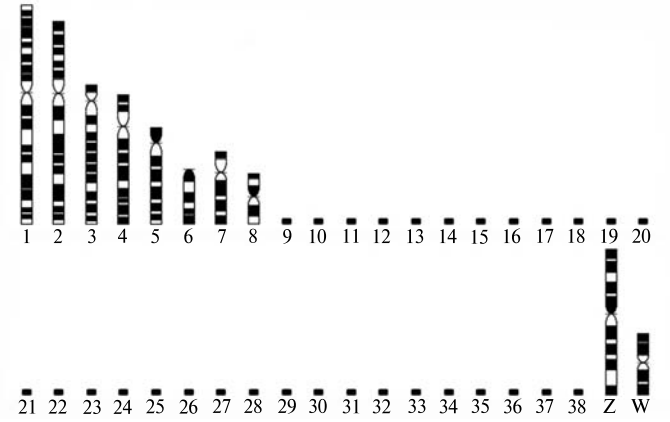

Fig. 1. The chicken (*Gallus gallus*) chromosome karyotype (a haploid set and two sex chromosomes) (38) (http://www.thearkdb.org).

Genomic QTLs screening revealed 29 loci on 5 of 8 described macro chromosomes, the chromosome 2, 3, 4, 5 and 8, and also on sex Z chromosome (Fig. 1). There were the loci contributing to body weight and egg size, feed conversion, etc. The 8 macro chromosomes and Z chromosome are 70 % of the chicken genome nucleotide sequences, and the rest 30 % sequences are the micro chromosomes. Gene activity and indirect evidence of an increased gene density in the micro chromosomes have also been shown (6).

Chicken Z or X chromosomes contain the genes affecting productivity. There are auto sex homozygotes different in color due to *K* and *k* alleles and in the rate of feathering due to *S* and *s* alleles, resulting in clear differences between the day-old chickens depending on their sex. Using dwarf gene (*dw*/*DW*) the maternal lines with reduced weight and increased egg productivity were developed and further involved into meat cross Hubbard ISA F15 breeding (7).

The alleles of restricted (*ro*) and normal (*RO*) ovulation located on Z chromosome are significant in view of egg productivity prediction. Sometimes the laying hens homozygous for *ro* are unable to ovulation of the oocyte with yolk because of a spot mutation and insufficient transport of lipoproteins from liver to follicles at yolk formation (8). Also the size of some bones in wings and legs as well as their mineral content are influenced by genes of restricted ovulation contributing the increase in weight compared to highly productive

poultry (9).

The Hy-Line International (USA) recently uses the genome marker assisted selection focused on the desired commercial traits and the early predicted productivity. The main valuable traits are the high lifelong productivity in hybrids during 80 weeks and more, tolerance to stresses and disease resistance (http://www.hyline.com).

Ovognesis in high-producing laying hens. Morphogenesis of ovaries and oviduct, development and maturation of oocyte, egg formation and time the hen reaches puberty and starts to produce eggs are related to ontogenetic periods. Due to breeding for past 60-70 years the age of the first oviposition in egg hens decreased 1.5 times from 6 months (26-27 weeks) to 4 months (17-18 weeks). However, bone strengths in wings and legs during post embyo development also lowered. The selection for strong bones together with limited feeding, and also the stabilization of 1.2-1.3 kg weight from the beginning to the end of hen commercial use are the countermeasures applied (10).

Some changes in the development of ovary function in hybrids occur at generative phase as observed in Loghmann Brown. The gonad rudiments are formed during 4 days, and from day 8 their differentiation into ovaries or testes begins. From day 11 the primordial germ cells turn into oogonia, and their number reaches several hundred thousands due to fast mitotic divisions. To day 19 most oogonia die, and just several differentiate into oocytes able to form follicles (11).

Until chick hatching the follicular stage prevails and results in formation of primary oocyte. In the ovary of 1 day hen there are 3500-4000 primary oocytes of 0.01-0.02 mm in diameter and 30-50 mg in total weight. The developing oocyte and the ovary interact via the follicle. Primary oocyte (with no yolk) contains the large nucleus with diploid chromosomal set tightly surrounded with vitelline membrane envelop (12, 13).

At vegetative phase the primary oocyte growth and development occur in the ovarian follicles until the mature oocyte ovulates into the oviduct. In turn, this phase is subdivided into several stages (Table 1). During 1-6 weeks the oocyte slightly increases in size due to cytoplasm accumulation, the latter being 0.5-1.5 mm in diameter, the germinal disc appears, and nucleus increases in size.

1. Phases of oogenesis in high-producing laying hens

Phase, stage	Object, organ	Time	Product
Generative phase (embryo period)	Embryo—one day old chick	8-21 days	Primordial germ cells — oogonia → oocytes
Vegetative phase (post embryo period)	Ovary	From 1 day to 17 weeks	Oocyte — primary oocyte → mature oocyte
Growth of oocyte	Ovary	From 1 day to 6 weeks	Oocyte with germinal disc and cytoplasm
Development of oocyte	Ovary	7-16 weeks	Oocyte with developing yolk as a single cell
Maturation of oocyte	Ovary	16-17 weeks	Mature oocyte with yolk
Ovulation	Ovary	About 30 minute	Gamete with haploid chromosomal set redy to fertilization
Laying period in hens	Ovary and oviducти	18-73 weeks and more	Primary oocytes at different staged in the course of rhythmic ovulation and oviposition)

The longest second phase of ovogenesis occurs from week 7 to week 16, when yolk mass increases due to blood transport of lipo- and glycoproteins, triglycerides, phospholipids, cholesterol and other biologically active substances from liver to the follicle and their accumulation.

Oocyte maturation occurs from week 16 to week 17. An accelerated yolk formation is subsequently completed in several large follicles within 1 week period. Fast yolk accumulation in the ovarian follicle takes 5 to 6 days, when pri-

mary oocyte turns into mature oocyte, or secondary oocyte, and ovulates into the oviduct. Breaking follicle envelope and ovulation itself take 15-30 minutes.

A mature oocyte (blastodisk) is located on yolk surface as a single cell surrounded by vitelline membrane. During diploid to haploid transformation the meiosis I is completed before ovulation, and meiosis II occurs after the ovulation in the oviduct resulting in a haploid gamete. Due to yolk it is provided with nutrients and the required bioactive substances. Each oocyte with yolk is subjected to long changes in hens from 1 day to 16-17 week age regardless of whether there was or was not the fertilization. After egg white and shell appear, the egg formation is completed.

Domestic hens are peculiar in their capability to produce eggs without fertilization. This is essential to determine the period of their productive use and biological limits of productivity both in cases the fertilized eggs used for incubation and unfertilized eggs used for food.

Current concept for egg formation. After ovulation, as the yolk is moving along the egg tube, the egg white and shell formation occur, resulting in egg laying. It takes about 22-24 hours, including 20 minutes in the infundibulum, 3 hours in the magnum to add albumen, 1 hour in the isthmus, and 18-19 hours in the utherus. Shell formation takes 17-18 hours, thus being second essential factor to restrict egg production in hens (14).

Earlier the maximal rate of transfer of nutrient from blood to follicle per its surface area was observed for 2.5 g oocytes (cited by 13). It could be considered the initial follicle in each set of fast maturating follicles. As the surface in each next follicle enlarges the rate of yolk formation increases because of increased follicle envelope.

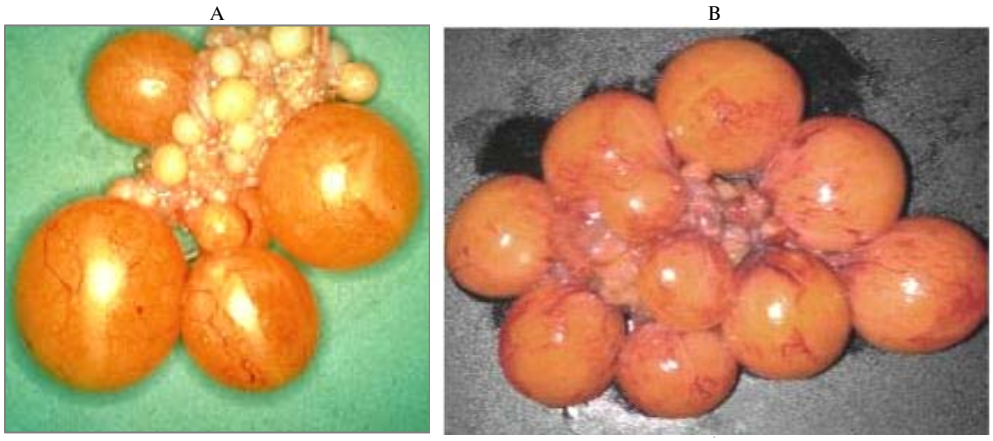

Fig. 2. Large follicle in ovaries of high-producing laying hens (A) **and hens with combination of meat and egg productivity (B) in White Plimutrok poultry (Cobb cross) (10).**

In high producing laying hens with more than 300 egg per year there is the first biggest follicle (Fig. 2, A), designated as the pre-ovulate one, with the rest ranged on their size and weight. In the photo the minimal number of follicles indicates the ovulation of the biggest follicle in the set occurred earlier. Yolk weight in hybrid hens is reported to be 18 g (15).

At relatively low egg production of 210-230 eggs, which are characteristic for the modern crossed with combination of meat and egg production and also for the maternal line of meat crosses, not less than 8-10 large follicles could occur simultaneously in the ovary. It leads to desynchronized ovulation and oviposition, especially during the second half of productive use, resulting in two yolk eggs of 75-80 g in weigh.

In ovary of White Plimutrok hens (see Fig. 2, B) none of three the largest follicles differed from each other in size, so each could be a pre-ovulate one. In such a case almost simultaneous ovulation of two follicles is possible leading to double yolk eggs and indicating desynchronized ovulation, laying and oviposition. Double yolk eggs also could be produced by young hens with still unstable cycle of egg laying. The eggs of changed shape or deviations in other morphometric parameters can indirectly indicate a desynchronized laying.

Laying cycle being individual for each hen is significant for high and sustainable productivity. The period of successively laid eggs defines the laying cycle. In high-producing hens there are long cycles of 50 to 80 days followed by 1-2 day interval. The frequency of repeated cycles with intervals determines the laying rhythm during time of productive use.

High producing hens are peculiar in ability to rapid accumulation of the nutrients and bioactive substances in 5-6 large successfully formed follicles at 6-7-day period of oocyte maturation. In the biggest one the yolk weight mostly increases 24 hours before the ovulation, with the follicle diameter of 2-35 mm in young hens and 40-42 mm in the adults. The follicle number in the ovary reflects the level of reproductive function and laying potency in poultry (16).

Egg white and shell formation is synchronized with the ovulation and laying cycle, determining time of egg formation under different follicle number in the ovary (Fig. 3). We suggest the coefficient of follicle growth as an indicator of its daily increase in weight. This coefficient is calculated from the difference in weigh gain (18.0-2.5 g) divided by the number of follicle in the ovary (see Fig. 3).

In case there are 5 follicle in the ovary the coefficient of growth is 3.10 thus being the highest, while for 6, 7, 8 and 9 follicles it is 2.58, 2.21, 1.94 and 1.92, respectively. So if in the ovary there are 5-6 follicles with maturing oocyte and yolk the growth coefficient is higher.

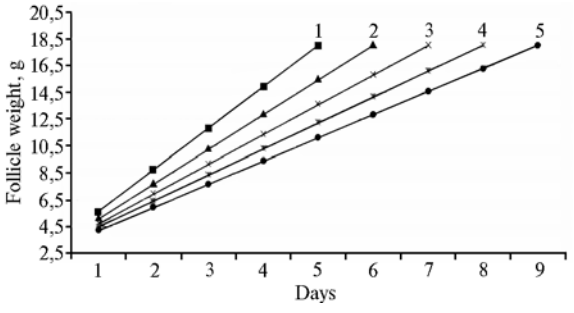

Fig. 3. Calculated time for the large follicle formation depending on their number in the ovary of laying hens: 1-5 — 5, 6, 7, 8 and 9 follicle, respectively.

Previously 7-9 and more large follicles per ovary considered appropriate and determining egg productivity in meat and egg producing breeds. However, it should be noted that the less number of successively maturing follicles is found, the faster ovulation occurs, resulting in higher egg productivity observed.

During ontogenesis the genetically determined, complicated and long processes of oocyte-yolk complex growth and maturation are mostly limiting for egg production. In high-producing poultry the biosynthetic activity and accumulation of yolk components in the large follicles are enough to provide their rapid formation and daily ovulation with corresponding rhythm of the oviposition. Laying 361 eggs for 364 days by a Leghorn hen probably is a biological limit of the egg productivity.

Forecasting egg production. Hybrid hens are accelerated in growing and start to lay eggs being 16-17 week-old. The earliness of maturity in a hen group is estimated at an average 5 % laying intensity, being determinative for further total egg number. Inherited laying rate at the beginning of oviposition is the factor mostly impacting egg production.

In laying hens the ovaries and oviduct, as well as other organs, have to function hard, especially at the beginning and on the top of oviposition. The nutrients and bioactive components of yolk, white and shell actively produced in liver are transferred to follicles, ovary and oviduct. The age of puberty also is an important factor. In high-producing egg hens the puberty is considered reached at 50 % laying rate achieved. In the crosses of the Hy-Line International (USA) this time has been decreased by almost 3 weeks over past 30 years (17). Accelerated growth and puberty are also peculiar to other egg crosses determining speedup of top productivity which is typical for hen hybrids (Table 2).

The weight from 1 day-old chicken until the end of laying period is the main controlled parameter indicating growth, development and physiological performance in hens. Breeding for increased egg production is effective due to weight optimization by limited feeding. In closed flocks the line breeding allows permanently lengthening the period of oviposition with keeping up the laying rate above 85 %.

2. The main parameters of egg productivity in Hy-Line International hen crosses (USA)

Parameter	1980	2002	2009
Age of 50 % productivity, days	161	145	143
Top laying rate, %	92	95	96
Survival, %	92	96	96-97
Total egg number per a hen	263	323	326
Weight of a 74 week-old hen, g	2470	2000	1980

During 2009-2010 international competition held in Czech Republic the Novogen Brown hens of Novogen S.A.A. (France) produced 351 eggs on average for 385 days at 91.2 % intensity (18). This level is almost the same as biologically limited (Table 3). Hereinabove we ranged these results with respect of total egg weight in kg as general commercial parameter of egg production.

3. Яичная продуктивость гибридных кур (55 нед, международные конкурсные испытания, Чехия, 2009-2010 годы)

Crosses	Laying rate per a hen		Average egg weight, g	Total egg weight, kg	Survival, %	Feed conversion ratio per 1 kg of total egg weight
	egg number	%				
Novogen Brown (Novogen S.A.A., France)	351,1	91,2	61,5	21,59	99	2,32
Hisex (Hendrix Poultry Breeder, Netherlands)	346,1	90,0	61,7	21,35	96	2,32
Lognmann (Loghmann Tierzucht GmbH, Germany)	338,9	88,0	62,5	21,18	99	2,34
isa Brown (ISA A Hendrix Genetics Company, Netherlands)	342,1	88,6	61,6	21,07	98	2,37
Hy-line (Hy-Line International, USA)	336,6	87,4	61,9	20,84	98	2,33
Super Nick (H&N International GmbH, Germany)	330,1	85,7	62,3	20,56	96	2,44
Tetra («Bábolna Tetra Kft., Hungary)	330,1	85,7	62,1	20,50	95	2,41
Bovans (ISA A Hendrix Genetics Company, Netherlands)	326,8	84,5	62,7	20,49	96	2,45

Thus, phenotypic changes due to selection and breeding show more wide physiological limits for egg productivity. High-producing layers are capable of producing a mature oocyte-yolk complex which ovulates with further egg white and shell formation and oviposition at daily cycle. The laying hens with high egg production can be forecasted in the postembryonic ontogenesis by the number of large follicles which are maturing in the ovary, if 85-90 % egg productivity is reached within 5-6 weeks after the laying begins. In case there are 5 to 6 large follicles in the ovary their maturation takes 6-7 days. Just a coincidence of these

parameters we consider the key determinative for the reproduction potency and early forecast of egg production in poultry.

REFERENCES

1. Tixier-Boichard M., Leenstra F., Flosk D.K., Hocking P.M., Weigend S. A century of poultry genetics. *World's Poult. Sci. J.*, 2012, 68(2): 307-322 (doi: 10.1017/S0043933912000360).
2. Masabanda J.S., Burt D.W., O'Brien P.C.M., Vignal A., Fillon V., Walsh P.S., Cox H., Tempest H.G., Smith J., Habermann F., Schmid M., Matsuda Y., Ferguson-Smith M.A., Crooijmans R.P.M.A., Groenen M.A.M., Griffin D.K. Molecular cytogenetic definition of the chicken genome: The first complete avian karyotype. *Genetics*, 2004, 166: 1367-1373 (doi: 10.1534/genetics.166.3.1367).
3. Wong G.K., Liu B., Wang J. et al. A genetic variation map for chicken with 2.8 million single-nucleotide polymorphisms. *Nature*, 2004, 432: 717-722 (doi: 10.1038/nature03156).
4. Shmutts M. Genomnaya selektsiya v plemennom razvedenii nesushek. *Materialy XVII Mezhdunarodnoi konferentsii VNAP «Innovatsionnye razrabotki i ikh osvoenie v promyshlennom ptitsevodstve»* [Proc. Int. Conf. «Innovations and their use in commercial poultry]. Sergiev Posad, 2012: 121-122.
5. Rodionov A.V. *Tsitogenetika domestitsirovannykh ptits: fizicheskie i geneticheskie karty khromosom i problema evolyutsii kariotipa. Avtoreferat doktorskoi dissertatsii* [Cytogenetics of domesticated birds: physical and genetic map of chromosomes and karyotype evolution. DSc Thesis]. St. Petersburg, 2001.
6. Sazanov A.A. *Molekulyarnaya organizatsiya genoma ptits* [Molecular structure of avian genome]. St. Petersburg, 2010.
7. *Plemennaya rabota v ptitsevodstve* /Pod redaktsiei V.I. Fisinina, Ya.S. Roitera [Breeding in poultry. V.I. Fisinin, Ya.S. Roiter (eds)]. Sergiev Posad, 2011.
8. Nimpf J., Schneider W.J. Receptor-mediated lipoprotein transport in laying hens. *J. Nutrit.*, 1991, 121: 1471-1474.
9. Kim W.K., Ford B.C., Mitchell A.D., Elkin R.G., Leach R.M. Comparative assessment of bone of wild-type, restricted ovulator, and out of production hens. *Br. Poult. Sci.*, 2004, 45: 463-470 (doi: 10.1080/00071660412331286172).
10. Shtele A.L. *Ptitsevodstvo*, 2011, 9: 19-24.
11. Khokhlov R.Yu. *Funktsional'naya morfologiya organov razmnozheniya kur v ontogeneze. Avtoreferat doktorskoi dissertatsii* [Functional morphology of reproductive organs during hen ontogenesis. DSc Thesis]. Ufa, 2009.
12. Krok G.S. *Mikroskopicheskoe stroenie organov sel'skokhozyaistvennykh ptits s osnovami embriologii* [Microstructure of organs and embryology in poultry]. Kiev, 1962.
13. Rol'nik V.V. *Biologiya embrional'nogo razvitiya ptits* [Biology of embryonic development in avians]. Moscow-Leningrad, 1968.
14. Shtele A.L. *Kurinoe yaitso: vchera, segodnya, zavtra* [Egg in hens: new peculiarities]. Moscow, 2004.
15. Tsarenko P., Vasil'eva L. *Zhivotnovodstvo Rossii*, 2009, 9: 21-22.
16. Shtele A.L. *Materialy XVII Mezhdunarodnoi konferentsii VNAP «Innovatsionnye razrabotki i ikh osvoenie v promyshlennom ptitsevodstve»* [Proc. XVII Int. Conf. «Innovations and their use in commercial poultry]. Sergiev Posad, 2012: 123-124.
17. Samokhina N., Kapustyan E. *Ptitsevodstvo*, 2012, 6: 15-16.
18. Gordeeva T. *Zhivotnovodstvo Rossii*, 2011, 10: 17-20.