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# PRODUCTIVE LONGEVITY OF ANIMALS, METHODS OF ITS PREDICTION AND EXTENSION

(review)

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## Abstract

Lengthening the terms of the productive use of animals is the most important problem in the cultivation of dairy and dairy and beef cattle, pig breeding and other branches of animal husbandry. The aim of this work was to review the influence of various genotypic and paratypic factors on life expectancy, productive longevity of farm animals, as well as analysis of studies to find modern ways of predicting and prolonging them. It was shown that with an increase in milk yield for lactation from 2500-3000 kg to 10000 kg of milk, the duration of productive use of cows decreases from 7-9 to 2-3 lactations, which increases the cost of milk production (I.I. Klimenok et al., 2001; J.R. Wright et al., 2016 et al.). An increase in milk productivity is accompanied by a decrease in reproductive function: the service period is prolonged, animal fertility decreases due to stress resulting from activation of the lactational dominant (A.I. Abilov et al., 2013; Y.S. Schuermann et al., 2016, etc.) To improve reproductive functions, duration of use, it is recommended to use special mineral-vitamin supplements (L.V. Romanenko et al., 2014; B. Close, 2007). Animal welfare is considered as an indicator of the stability of the system and is considered economically profitable (P.A. Oltenacu et al., 2010; L.V. Efimova et al., 2017). The duration of the productive use of sows, depending on the number of farrowing during use, fertility, survival of piglets and other factors is 3-4 farrowing instead of 4.5 in accordance with the accepted norm, which also affects economic indicators (M.D. Hoge et al., 2011). The indicators of heritability of signs of longevity in cattle and pigs are given (L. Canario et al., 2006), various feeding methods, breeding techniques, including the use of genetic markers to lengthen the economic use of animals. (C.N. Lopes et al., 2011; A.I. Sironen et al., 2010 et al.). Molecular markers related to the reproductive characteristics and duration of use of animals are given, which should also be used in genomic selection (N.S. Yudin et al., 2015; Q. Zhang et al., 2017). The theoretical provisions on the causes of aging, the influence of various stressors arising as a result of peroxide and antioxidant processes in the body are considered (E.S. Bauer, 1935; V.L. Voeikov, 2002).The role of reactive oxygen species, free radicals, and antioxidants of different nature on the reproductive function and viability of animals under stressful effects of different strengths is discussed (D.D. Boler et al., 2012; M. Sajeda Eidan, 2016). Thus, to increase the duration of the use and longevity of farm animals, combined with high productivity and adaptability to various, including adverse environmental factors, methods should be used that add up to several positions. It is necessary to develop and use proper feeding techniques that optimize the energy balance during all periods of the reproductive cycle, create favorable conditions for keeping animals, providing for exposure to certain stimulating factors that increase the biophysical potential of the body, affecting the functioning of biochemical systems. One should use the latest methods for predicting the level of free-radical oxidation of animal tissue lipids, which affect the manifestation of oestrus, oocyte and sperm viability, and the use of antioxidants with feed additives to balance oxidative and antioxidative processes. One more approach is to create herds (breeds, types) of animals with a high genetic potential for productivity and stress resistance using the most effective selection methods, genetic markers, genetic and mathematical models, and genetic engineering methods.

Keywords: productive longevity, milk yield, stress, reproductive function, heritability, genetic markers, free radicals

With the intensification of animal husbandry, especially commercial farming technologies, animals do not lack close interaction with the natural environment. They do not receive microelements directly from the soil, insolation from the sun, and are subjected to the additional stress because of overcrowding and machineries. As a result, there is a reduction in life expectancy and economic use of livestock. Lengthening the productive life of animals is becoming a major problem in dairy and meat cattle breeding, pig breeding and other livestock industries.

The purpose of this review was to describe the influence of various genotypic and paratypic factors on life expectancy and productive longevity, as well as to carry out an analysis of studies to predict and search for modern ways to prolong them in farm animals.

In the 1990s, the productive longevity of the Siberian breed of black-and-white cows (3,736-4,122 kg milk yield per lactation, 15,500-17,600 kg life-time milk yield) when mating with Holstein bulls was 4.1-4.5 calvings [1]. With the increase in the milk yield of the first-calf cows, the time of their use in dairy herds even increased from 81.6 months for cows with milk yield of 2,501-3,000 kg to 105.6 months for cows with milk yield of 4,501-5,000 kg. The best in the duration of economic use in the Kholmogory breed were first-calf cows with milk productivity of at least 3,501-4,500 kg. They were used in dairy herds for at least 94.8-104.4 months [2].

In recent years, with the increase in animal productivity in many farms of the Russian Federation, the duration of the use of cows has begun to decrease to 2-3 lactations [3]. According to Strizhakov [4], the period of use is up to three calvings for cows with the productivity of 5,000-7,000 kg, and two calvings for cows with milk yield from 9,000 to 10,000 kg. As per Wright et al. [5], the use of cows in the USA equals 2.8 lactations. According to Hare et al. [6], this indicator is 2.8 for Holstein cows, 2.9 for Ayrshires, 2.4 for Guernsey cows, and 3.2 for Jersey cows. The average survival of cows to the 2nd calving is 73%, to the 3rd calving — 50%, to the 4th calving — 32%, from the 5th to the 8th calving — 19%, 10%, 5%, and 2%, respectively [6]. From Holstein-Friesian replacement heifers selected at 1 month of age at English dairy farms, 11% do not live up to the 1st calving. Of calving animals, 19% are rejected during the 1st lactation period, and 24% during the 2nd lactation period. Only 55% of replacement heifers successfully complete the 3rd lactation [7].

Fedoseeva et al. [8] believe that the main task of breeding highly productive animals should be not so much an increase in the milk yield as the creation of optimal conditions to realize existing genetic potential of milk productivity and especially the increase in productive longevity. The analysis of the productivity of Holsteinized cows of the Kholmogory breed has shown that productive longevity is only 3.3-3.8 calvings at the average annual milk yield of 7,400-7,800 kg. According to the authors, this indicator is influenced by many factors, the most important of which are stress, physical inactivity, nutritional imbalance, decreased adaptive abilities of the body, leading to impaired reproductive function and the birth of weak offspring.

In the last century, Shteiman [9], the outstanding breeder and the author of the Kostroma cattle breed paid special attention to the lengthening of use of highly productive cows. He believed that this provides an increase in the number of outstanding offspring and significantly reduce the cost of all products. At the Karavaevo breeding farm, some cows lived until they were 19-22 years old, their life-time milk yield was 98-103 tons. The Poslushnitsa II cow gave 14,115 kg of milk for 300 days of the 6th lactation with a fat content of 3.92%. Its daily ration with the maximum daily milk yield (61 kg of milk) consisted of concentrated (58%), succulent (35%) and rough (7%) feeds. Opytnitsa, the record-holder cow, lived 19 years. Shteiman believed that the maximum milk yield for lactation could be reached if the cow was well-prepared during the dry period due to accumulation of necessary nutrients [9, p. 98]. This contributes to a more uniform coverage of the costs of milk production and allows avoiding excessive stress of cows throughout lactation.

The main causes of cow culling at present are infertility, abortions, mastitis, difficult calving, and the birth of small or dead calves [10-13]. Infertility is especially common among animals that produced more than 11,000 kg of milk during the first calving [14]. If the living conditions at the first calving do not correspond to high milk production, then the productive life is reduced, and the number of calvings decreases. As per Jaśkowski et al. [15], the high genetic potential of milk production in cows affects their fertility. They have a longer service period, a shorter estrus cycle and fewer chances of ovulation after calving. Oocytes of cows with a high genetic potential form a smaller number of blastocysts than in cows with an average potential. This leads to infertility and postpartum disorders.

Calving, in which animals need help or surgery, increases the risk of culling by 18% compared to that without assistance. The increased complexity of calving has a greater effect on culling in the first lactation than in subsequent ones. Difficult calving, mainly the first one, increases the cost of depreciation of the herd by 10% compared to the easy one [10]. There is a statistically significant relationship between the temperament and functional longevity of cows [16]. The very nervous (stress-sensitive) Holstein, Ayrshire and Jersey Canadian cows were 26%, 23% and 46% more prone to culling than very calm (stress-resistant) cows. The probability of culling very hard-milking cows of these breeds was 36%, 33% and 28% higher than average-hard-milking ones.

Recently, in order to increase the longevity of animals, special attention has been paid to some exterior parameters. Positive effects of posterior limb positioning, hoof angle and movement on life expectancy were found. Cows with a better structure of legs and hoofs are more likely to have long productive uses. Groups of cows with the highest and lowest scores for pelvic limbs differed in the duration of economic use by 931 days [17]. In the work of Zavadilová et al. [18], cows with crescent legs had lower longevity than cows with more straight legs.

Selection for plentiful milk production and elongation of lactation, causing activation of the lactational dominant, leads to stress in animals [19]. With an increase in milk productivity, the sexual dominant temporarily fades away, the duration of the service period increases, the effectiveness of artificial insemination decreases, and the duration of productive use decreases [3]. So, according to Sharkaeva et al. [20], in imported selection cows with a milk yield of 8,271 kg for the 1st lactation, the service period was 194.6 days compared to 114.9 days in Black-and-White cows with a milk yield of 5,688 kg. Moreover, the survival rate of imported cows before the 3rd lactation was only 38.6% versus 54.5% of cows of local selection. Schuermann et al. [21] consider longevity to be a key component of sustainable dairy farming. Highly productive dairy cows often suffer from ovarian dysfunction and infertility, resulting in reduced reproductive and productive lifespan. The authors attribute sterility to metabolic stress during the transition period (from the 3rd to the 12th week after calving), when there is an increase in cholesterol, triglycerides, total bile acids and a decrease in the concentration of glucose and glutathione compared to the period before calving.

With an increase in milk yield, animal welfare as a whole and the fertility of offspring decreases, problems with legs and metabolism appear, and life expectancy decreases. Many scientists consider the well-being of animals to be an economically advantageous condition, which is an indicator of the sustainable husbandry with the high quality of products [22]. In the investigation of Efimova et al. [23] conducted on a large population the correlation coefficients between milk yield and reproductive ability in highly productive Holstein cows with loose housing on a deep non-replaceable bedding (milk yield 7,081 kg) were negative ($r$ from –0.39 to –0.69 in daughters of different bulls; the level of statistical significance from $p < 0.05$ to $p < 0.001$). For cows that were kept loose in boxes, with a milk yield of 6,762 kg, these coefficients turned out to be positive, although insignificant ($r$ from 0.01 to 0.25). That is, the content in the boxes, apparently, provided the animals with better well-being due to less exposure to stress and other environmental factors [23]. Studies conducted by Koketsu [24] indicate that achieving longevity and high reproductive ability of animals in breeding herds do not contradict each other. These indicators can be improved simultaneously.

Romanenko et al. [25] and Volgina et al. [26] proved that in order to realize the genetic potential of the milk productivity of cows with a milk yield of about 9,000 kg and above, it is necessary to optimize energy, protein, carbohydrate, and mineral-vitamin nutrition. To optimize energy supply during the stall period, they recommend increasing the amount of high-energy feed in the first phase of lactation. This contributes to a better realization of the genetic potential of cows for milk production in the following months.

During the early postpartum period, tissues of highly productive dairy cows undergo extensive catabolism due to the negative balance of nutrients. During this period, nutrients are distributed both in favor of lactation and to ensure the viability of the animal. However, metabolic disorders often lead to diseases that dramatically decrease the productive, reproductive abilities and the immune status [27]. The inadequate intake of nutrients and changes in feeding increase the risk of inflammation of the uterus. The strategy of manipulating health in the prenatal and postpartum periods should be aimed at minimizing the negative balance of nutrients, improving homeostasis and immunity through an appropriate diet. Supplements of unsaturated fatty acids of the n-3 and n-6 families usually improve fertility if they do not interfere with the metabolism of rumen microorganisms.

The use of mineral feeds that regulate the acid-base ratio, especially calcium, has a significant effect on the state of health, reproductive function, cow productivity and milk quality [28]. In the first weeks after calving, when the feed intake of the main feeds is reduced, the amount of calcium consumed is not enough for the cow. Feeding dry cows with special additives that create acidic conditions solves the problems of improving reproduction, increasing productivity during the lactation period, and reducing the cost of veterinary drugs. Vitamin E plays a vital role in calcium metabolism, bone formation and the incorporation of this element into the skeleton. Calcium salts of polyunsaturated fatty acids are used in beef cattle breeding to increase the reproductive ability of cows [29].

Negative consequences for the reproductive function and the duration of the productive use of animals are also observed in pig breeding with an increase in the milk production of sows due to the large size of the litter, which leads to excessive mobilization of body reserves during lactation. Life expectancy and productive use of sows are also becoming an economic problem, especially with high productivity. These indicators depend on the age at the first farrowing, the number of farrowing during the period of use, the length of the period between weaning and hunting, multiple fertility, the number of stillborn piglets and piglets born during the sow's life, growth rate and survival of suckling pigs. The higher the fertility, the lower the number of stillborn piglets and the higher the nest weight at 21 days of age, the less likely they are to be culled [30].

In pig breeding, there is a special attitude toward the preparation of dams in the dry period and during gestation, so that the sow has enough milk to feed the piglets while maintaining its continued use. In the conditions of pig farms, it is customary to receive 4.5 farrowing from the dam during the period of use. However, this is not always achieved, although 11-12 farrowings are obtained from some dams. The most common causes of culling sows, as in dairy cattle breeding, are reproductive problems (40-51%), leg problems (23-29%) and mortality (15-19%) [31]. Experiments have shown that the selection of pigs from highly productive and adapted dams, who survived 5 or more farrowing, and boars kept without a walk for at least 2 years, can be effective only if the animals for several months before insemination had motions [32]. The feeding and keeping conditions affect the fatness of pigs during the first farrowing, which, in turn, affects the condition of the body, leg strength and longevity. These indicators are improved when pigs are grown on floor coverings and bedding, which contribute to the development of healthy legs, and diets that limit the loss of live weight during lactation [33].

The main limiting factor in sow multiple pregnancy is embryonic loss during the first 2-3 weeks of gestation [34]. The reproductive quality of sows is largely dependent on the protein and lysine content of the diet. Low consumption of these substances weakens the development of follicles, reduces their ability to support oocyte maturation, becomes the main reason for sows to drop out due to agalactia, and leads to a decrease in milk production due to insufficient accumulation of nutrients in the body. During pregnancy, sows need significant amounts of minerals (Ca, P, Fe, Zn, Mn, Se, etc.) that are involved in the construction of embryo bones and milk synthesis. Close [35] believes that the content of these minerals in the diet should be increased at each subsequent gestation by 5%. To improve the economic performance of pig farming, it is necessary to reduce the time between weaning and hunting. This period, and at the same time, the duration of the entire productive use of sows is influenced by such factors as the timing and duration of ovulation, the correct determination of hunting and insemination techniques, seed quality, embryo mortality, fatness, and the immune status [36]. The period from weaning to insemination determines the multi-fetal pregnancy of sows. It was revealed that the multiplicity and weight of the nest of piglets during weaning, as well as the interval between weaning and hunting are higher in sows with later puberty (223-226 versus 185 days).

The selection of animals using statistical methods is not effective enough due to low heritability, relatively late manifestation of a trait or its manifestation only under the influence of certain factors, the presence of hidden carriers of undesirable traits, diseases. The heritability rate of survival in Holstein-Friesian heifers and cows in the UK, according to Pritchard et al. [37], amounted to 0.01-0.06. The heritability of the duration of the economic use of beef cows is small ($h^2 = 0.14$); therefore, it is believed that genetic improvement in longevity is difficult [38]. The coefficient of inheritance of life expectancy and reproductive traits in pigs varies from 0.14 to 0.17 [39]. For the heritability of the interval between weaning and the first hunt in sows after farrowing, this indicator is 0.17-0.18. The inheritance coefficient of the total number of piglets in the nest, live-born piglets, and the number of stillborn piglets is 0.10, 0.08 and 0.19, respectively [40)]

The modern science allows breeding not only through the estimation of the breeding value by statistical methods, but also at the genomic level. Animal genetics and breeding are developed on the basis of population genetics, from estimation of selection indices and the creation of complex genetic prediction systems to the development of accurate genome management systems. Based on the information received, it is possible to conduct genetic selection and control specific genotypes at an early stage of the animal's life [41]. From determining the Estimated Breeding Value using the best linear unbiased prediction method (BLUP), based on the interaction of the genotype and the environment (heritability estimate), one can pass to marker-assisted selection (MAS) for certain genes, controlling economically useful traits, regardless of the degree of their inheritance.

Thus, the *DGAT1* gene located on the chromosome 14 (BTA14) [42] was identified as a genetic marker of the duration of the productive life of cattle, fat content, and milk productivity. Crossbred cows have single nucleotide polymorphisms (SNPs), associated with reproductive longevity, on chromosomes 4, 5, 15, and 19, which can be used to increase the life span of animals [43]. When identifying genomic regions in North American dairy cattle, the results of previous studies were confirmed and new sites were discovered that were associated with longevity, lactation resistance, reproductive function, and profit [44]. Zhang et al. [45] identified two important genomic regions located on chromosomes 6 (META-CHR6-88MB) and 18 (META-CHR18-58MB) which are associated with longevity. The *NPFFR2* was previously identified as a candidate gene for resistance to mastitis, the META-CHR18-58MB marker is associated with calving difficulties. The relationship of polymorphic DNA variants with milk productivity in cattle is discussed in detail by Yudin et al. [46].

About 30,000 genes were found for pigs [47] that can be used in genomic selection. It is particularly effective for signs that appear in the late stages of ontogenesis (life expectancy) or have low inheritance (reproductive capacity), as well as for resistance to disease and stress [41, 48]. At present, candidate genes associated with the reproductive characteristics of pigs (*ESR* and *PRLR*) [49], characteristics of the structure of legs, and life length of the sow [50-52] are of particular importance. Genetic markers have been found to improve milk production indicators that are associated with the reproductive qualities and life length of sows [53].

It was found that the duration of use of sows largely depends on several genes that affect these processes. Thus, the genetic markers of carnitine O-palmitoyltransferase (*CPT1A*) and C-C chemokine receptor (*CCR7*) were significantly ($p < 0.05$) associated with at least one reproductive trait. These results indicate that molecular markers should be considered for use in breeding in order to improve the duration of use of sows [54, 55].

It can be assumed that genomic selection for the life span and economic use of animals, as well as for productivity, will be more effective. In this case, the genome is tested using chips (matrices) for a large number of single nucleotide markers, the SNPs, covering the entire genome and associated with a quantitative trait locus (QTL), which makes it possible to determine the genotypes with the desired manifestation of productive traits and evaluate the breeding characteristics of the animal. Genomic selection allows decoding the genotype already at birth and selecting the best animals for breeding, which increases the accuracy and reliability of the evaluation of breeding pigs, significantly accelerates the selection process.

The search and use in the selection of markers of nuclear and mitochondrial DNA are becoming revolutionary. However, it should be borne in mind that genetic markers can indicate the location of certain genetic factors associated with longevity or productivity in animal chromosomes, be a means of early prediction of productivity and accelerated selection, but do not reveal the biochemical and biophysical processes that occur in the body during their phenotypic manifestation or interaction with each other. To a large extent, their manifestation depends on environmental factors, including various stressful irritations.

Theories of aging of organisms are divided into two types, i.e. genetic and free radical [56]. The aging process is a variable, stochastic and pleiotropic phenomenon which is regulated by various environmental and genetic factors [57]. The activity of the telomerase enzyme decreases in aging cells, which causes the shortening of the telomere end sites of chromosomes and does not ensure the preservation of DNA properties in successive generations of cell divisions [58]. Telomere shortening occurs in all somatic cells of the body in many diseases [59]. According to the free-radical theory of aging, the so-called free radicals appear in the process of life activity in the cytoplasm; they play a key role in the reproductive function of mammals, in the development of follicles, in the process of maturation of oocytes and sperm cells, their capacitation. The appearance of radicals depends on many factors, including the composition of the feed [60], the housing conditions, and the genetic characteristics of the animals [61]. In experiments on mice, it was shown that the oxidative process, which is observed in the blood serum, ovaries, and eggs and is caused by animal stresses, significantly affects the development of oocytes [62]. Spermatozoa, characterized by an extremely high rate of metabolism, produce particularly large amounts of free radicals [63, 64]. There are specific enzyme absorbers of reactive oxygen species, the glutathione peroxidase, catalase, superoxide dismutase (65], which convert active oxygen species into harmless molecules and play a huge role in the development of follicles and the maturation of oocytes [61, 65, 66]. Catalase has been tested by scientists to improve the quality of semen during freezing [66, 67]. A leading role in the molecular mechanisms of antioxidant protection and bringing the concentration of free radicals to the physiological norm belongs to thiol compounds that have SH-groups, showing high reactivity [68, 69]. Certain relationships between catalase and SH-groups in the blood lead to an improvement in sperm capacitation and thereby to better fertilization of the eggs [70, 71].

The latest ideas about the peculiarities of the processes involving free-radicals and the generation of electron-excited states in ontogenesis are based on the principles of theoretical biology formulated in the 1930s by Bauer [72]. According to them, the living system extracts substances and energy from the environment due to the higher thermodynamic (biophysical) potential. This requires a certain external impulse (signal), i.e. a stress stimulus within the physiological norm [59]. The animals, especially from reproductive groups, should not only be in favorable conditions, but also have systematic optimal loads to mobilize neuroendocrine systems. Experiments and practice have shown a positive effect of forced movement on the health and sperm production of producers, on the development of young animals, the productivity and viability of breeding stock.

Thus, to increase the longevity of farm animal use combined with high productivity and adaptability to various, including adverse, factors, a set of techniques should be applied. First, favorable feeding and housing conditions are mandatory. Nevertheless, certain stress factors at physiologically acceptable levels are also necessary to stimulate biochemical functions and production of reactive oxygen species, which causes electronically excited states in cells and thus increases the biophysical potential. Second, it is necessary to create herds (breeds, types) of animals with high genetic productivity potential using the most effective breeding methods, genetic markers and engineering, genetic and mathematical models.

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