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ROLE OF CHROMIUM (III) IN THE NUTRITION OF PIGS AND CATTLE

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The results of our studies and the data of modern literature regarding the biological role of Cr(III) compounds in conditions of their application in the nutrition for pigs and cattle are discussed. The metabolic impact of Cr(III), coming from different sources – mineral and organic compounds, obtained by chemical synthesis or a nanotechnological method (chromium citrate), as well as in the form of biocomplexes from the cultural medium of *Saccharomyces cerevisiae* yeasts was analyzed. The metabolic connection between the impact of Cr(III) and the biosynthesis of some hormones – insulin, cortisol – as well as the sensitivity of some tissues and organs to the effect of chromium compounds was studied. A considerable part of the review material was dedicated to the metabolic effect of Cr(III) compounds on the reproductive function of pigs and cattle and their impact on the viability of the offspring and gametes of animals. The data about the stimulating effect of Cr(III) on the growth and development of the organism of piglets and calves, meat and milk performance of these species of animals are discussed. The relevance of dosing Cr(III) in the nutrition of pigs and cattle is highlighted.

Keywords: chromium, pigs, cattle, nutrition, nanobiotechnology.

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In modern conditions of animal production, involving the use of specialized breeds, usually high productivity and improved reproductive function of animals is mainly achieved via their adequate nutrition. However, it is necessary to consider the level of providing the animals with metabolic energy, nutrients and biologically active substances, since the excess or shortage of the mentioned substances leads to metabolic disorders or decrease in the productivity. It is especially important to provide a regular intake of essential microelements, required for normal life activity, into the organism. It is common knowledge that high biological activity of microelements is related to their participation in the synthesis of vitamins, hormones, to the role of activators and structural units in the molecules of the enzymatic systems. Trivalent chromium (Cr(III)) is one of vital and essential elements for animals, as it participates in the regulation of carbohydrate, lipid, and protein exchanges in the organism of animals [1]. However, this microelement is not standardized in Ukraine. Due to insufficient intake of chromium, the organism of animals has metabolic disorders, the symptoms of which are similar to those, observed for diabetes and cardiovascular diseases of humans [2]. It is also known that Cr(III) activates enzymes and stabilizes proteins and nucleic acids, promotes the growth and regeneration of tissues, improves immunity, and impacts the blood formation processes [1].

Natural feedstuffs, used to feed farm animals, contain 1,000–3,000 μg Cr/kg of feedstuffs. Here the changes in the glucose metabolism are observed in the organism of animals, when only 200 μg Cr/kg of the ratio are added, i.e. much less compared to its content in natural feedstuffs. This is conditioned by insufficient consumption of chromium from natural feedstuffs and its intensive removal from the organism in stressful conditions [3].

The concentration of Cr(III) in the tissues of animals decreases considerably with age: in some tissues – during the period of intensive growth, while in others – during critical physiological periods. In the conditions of intensive growth of animals, there is chromium deficiency in their organism, which leads to metabolic disorders. The homeostasis of Cr(III) in the organism of animals is considerably impacted by stress factors, stimulating its removal [3]. Technological stresses are potentially scheduled in animal production − re-grouping of animals, transporting, prophylactic immunization, the change in ratio, *etc*. – which condition the deficiency in Cr(III) in their organism. The deficiency in Cr(III) takes place in case of the high glycemic index of the ratio, lactation, infections, and physical injuries of animals.

As for pigs, glucose usually penetrates the organism with the feedstuffs. The mixed pig feed contains 60–85 % of cereal grain, which mostly contains carbohydrates in the form of starch – the source of glucose for pigs. Thus, the impact of the additives of Cr(III) to the ratio of pigs on glucose metabolism in their organism and the sensitivity of the cells to insulin was studied [4]. The increased level of glucose decreased in the blood of pigs, fed with 200 µg Cr/kg of the feed in the form of chromium picolinate. Here the animals had an evident increase in the sensitivity of tissues to insulin, and the sowing pigs – in their reproductive ability. Using experiments on piglets, other researchers demonstrated chromium-induced changes in the glucose level and the insulin response at the impact of chromium picolinate and propionate. Following the results of many studies, since 1990 chromium is added to the ratio of pigs in the USA.

The studies, conducted at the Institute of Animal Biology, NAAS, using 30–90-day-old White Large piglets, established that the addition of chromium chloride in the amount of 250 µg Cr/kg of mixed feed leads to the increase in insulin concentration in the blood of animals [6]. It is known that a biologically active form of chromium – chromodulin – acts as a part of insulin signal transduction system, as it bonds to the insulin receptor, supports its active conformation, stimulates the receptor-kinase activity and amplifies the hormone signal [1]. The increase in insulin concentration and enhancing its effect on the impact of chromium leads to the decrease in glucose concentration via the activation of processes of glucose use in cells [6].

It was determined that while feeding piglets with the inorganic form of chromium chloride in the amount of 250 µg Cr/kg of the feed, there is a decrease in the concentration of lipid hydroperoxides, TCA-active products of peroxide oxidation of lipids in blood along with the increase in the activity of the enzymes of the antioxidant system – superoxide dismutase, catalase, and glutathione peroxidase [6].

The Institute also had another study on the impact of the organic compound of chromium (250 µg/kg) in the form of naturally synthesized biocomplexes, which are a part of the cultural medium of *Saccharomyces cerevisiae* yeasts, previously incubated with different chromium compounds – Cr^{6+} and Cr^{3+} [7]. It was determined that the introduction of the cultural liquid, containing chromium biocomplexes, into the ratio of piglets affects the protein exchange processes in their blood, resulting in the increased concentrations of the total protein in the blood of animals of both experimental groups. This is conditioned by the fact that Cr(III) enhances the effect of insulin, which, in its turn, stimulates the protein anabolism in the cells. In addition, the animals of both experimental groups demonstrate the decrease in the content of urea and glucose in the blood, the increase in the activity of the enzymes of lactate dehydrogenase, catalase, and glutathione peroxidase, and the content of reduced glutathione in blood erythrocytes. Therefore, the results obtained give grounds for the assumption on the use of products of yeasts activity, rich in biocomplexes with chromium, as sources of Cr(III) in the ratio of pigs.

The positive effect of chromium picolinate additives on the organism sensitivity to insulin was also demonstrated in finishing pigs [8]. Here the impact of Cr(III) additives to the ratio of pigs on the regulatory effect of the growth hormone was revealed. It was demonstrated that porcine somatotropin increases the level of glucose and insulin in the blood of pigs, whereas chromium normalizes their concentration in blood.

Our studies revealed that the addition of 400 µg Cr/kg in the form of chromium chloride in the ratio of finishing pigs leads to the intensification in the glycolytic way of transforming glucose in the organism of five-month-old piglets, the stimulation of antioxidant protection – the increase in the activity of the enzymes of superoxide dismutase, catalase, glutathione peroxidase, the concentration of reduced glutathione, vitamin E, and insulin [9], the increase in the content of C_{20} – C_{22}-polyunsaturated fatty acids in blood plasma [10].

There are data about the increase in the efficiency of insulin effect at the addition of chromium picolinate to the ratios of periparturient sows and weaned piglets in order to mitigate the negative effect of the weaning stress and etiologic factors [11]. The stress, conditioned by the weaning of piglets, prevents their formation of active immunity, which leads to the decrease in their organism resistance. Therefore, there are active studies on the impact of chromium on the organism of piglets during their being weaned from the reproducing sows. For instance, the mixed feed for piglets was added chromium picolinate in the amount of 200, 400, and 800 μg/kg for seven weeks [12]. The piglets were immunized two and five weeks after weaning. It turned out that the addition of 400 μg Cr/kg of the feed led to the increase in the gain in the first four weeks after weaning. The titers of antigen-specific antibodies increased in the blood of piglets along with the amount of IgG six weeks after weaning, and the amount of IgM – during the whole period of studies. There is also an observed tendency to the activation of phytohemagglutinin-induced blastogenesis process of mononuclear cells of peripheral blood at the beginning of the weaning period.

The studies, conducted at our Institute using reproducing sows, fed with the mixed feed with the addition of chromium chloride in the amount of 300 μg Cr/kg of the feed, established the increase in chromium content in their milk and enhancing of the haematopoietic function of the organism and their immunobiological reactivity in the first month of young piglets [13]. It was determined that at the age of 5 and 20 days the concentration of immune complexes, circulating in the blood of the experimental group piglets increases 1.4-fold compared to the control. In addition, there is a tendency to the increase in phagocyte activity of neutrophils and the complementary activity of the blood serum of the experimental group piglets under the impact of chromium, compared to the animals in the control group.

Our experiments demonstrated that the introduction of the organic compound of chromium citrate, synthesized by the nanotechnological method, into the ratio of reproducing sows in the amount of 0.5 μg Cr/kg of the bodyweight leads to the increase in the content of total protein in their blood on the 5th and 20th day after the farrowing. The impact of chromium citrate in the amount of 2 μg Cr/kg of the bodyweight leads to the increase in the level of total protein both in the blood of the sows on the 5th day after the farrowing, and in their 20-day-old piglets [6].

The works of other authors demonstrated that the impact of chromium leads to the efficiency of feed consumption in pigs. In addition, the introduction of chromium picolinate to the ratio of pigs leads to the 20 % enlargement of the thickness of the muscle layer and the 25 % decrease in the fat layer in the area of the 10th rib [14].

Chromium also affects the reproductive function of pigs. Pregnancy is a physiological stress for reproducing sows as in this condition they may develop the impairment of the control over the level of glucose, which is restored after the birth of piglets. Frequent farrowing is a reason of the decrease in the chromium content in the organism, so reproducing sows need some time to restore its supply. The studies, conducted in the Netherlands, demonstrated that the level of glucose in the blood of sows is high after consuming feeds at the end of pregnancy and does not get stabilized after farrowing. In these conditions, there is a high mortality rate of piglets during first seven days after their birth [15].

The generalized results of experiments using 48,000 sows and over a million of their piglets confirm the direct impact of chromium on the reproductive function of pigs [16]. There is an evident increase in the number of piglets, born (0.22 piglets/farrowing), the number of alive piglets (0.37 piglets/farrowing), and the decrease in the stillborn piglets (0.05 piglet/farrowing) and mummified fetuses (0.10 piglet/farrowing).

The work, performed at the Institute, confirms that the addition of 300 μg/kg chromium chloride to the feed of sows leads to the 10.3 % increase in the number of piglets at birth. The weight of the litter of the experimental five-day-old piglets increased by 15.9 %, and their average gains – by 6.2 %. The weight of the litter of 20-day-old piglets increased by 29.9 %, and the average gains – by 10.8 %. The survival of experimental 20-day-old piglets increased by 12.3 % and amounted to 96.5 % [6].

It is believed that the addition of chromium to the ratio restores the tissue sensitivity of sows to insulin. At the same time, insulin enhances the effect of luteinizing hormone and stimulates ovulation in sows [17]. This is in agreement with the results of studies, conducted in Brazil, according to which the addition of 200 μg Cr/kg of the feed in the form of chromium picolinate to the ratio of sows increased the number of ovarian follicles in the ovaries (up to 17.1 against 16.5 in the control), accelerated the growth and development of viable embryos in the middle of the gestation period (14.0 against 12.7) and stimulated the survival of embryos (81.9 against 77.0 %) [18]. It was demonstrated that the amount of follicular estradiol and progesterone in the blood of sows after their first farrowing increases after the insulin injection during five days after weaning [19]. Other researchers state that the additional introduction of chromium picolinate in the ratio of pregnant sows causes the increase in the level of oxytocin and progesterone in blood [11].

The dependence between the level of glucose in blood and the reproductive function in pigs is well-known, but the impact of insulin on the reproductive function in pigs has been recently discovered [20]. It is believed that the addition of Cr(III) to the ratio of pigs affects the metabolic effects of insulin/glucose and stimulates their impact on reproduction [18]. Chromium increases the fertility of reproducing sows. At the same time, the impact of the addition of Cr(III) to the ratio of sows on the metabolism in the organism of piglets is yet to be studied in fine detail. Generally, pigs have a positive response to the addition of chromium to the ratio, as the reproductive ability of reproducing sows, the resistance, and intensity of growth of piglets are the main factors, determining the profitability of pig production.

The necessity of dosing chromium for cattle was established by the US National Scientific Board with the consideration of the fact that feeds, used for farm animals, contain the sufficient amount of Cr(III). However, the studies on cattle and other species of animals in 15 recent years demonstrated that the addition of Cr(III) to the ratio affects metabolic processes and productivity. At present, chromium propionate in the amount of up to 0.50 mg Cr/kg of dry ratio substance is allowed as the source of Cr(III) in the USA as an additive to the feeds. The works of some authors demonstrate that the addition of chromium propionate in the doses of 0.47, 0.94, and 1.42 mg Cr/kg of dry feed substance to the ratio of heifers affects glucose metabolism. The concentration of glucose in the blood of heifers of experimental groups was lower than that in the blood of control animals. It was proven that the need of heifers for Cr(III) in the growth period does not exceed 0.47 mg/kg of dry feed substance [21].

It was confirmed that Cr(III) affects the sensitivity of tissues to insulin in cows during the lactation period, as the resistance to insulin increases at the end of pregnancy and lasts during the early lactation period both in dairy [22], and meat breeds [23].

The scientists of our Institute revealed that the introduction of chromium citrate (30 μg Cr/kg of dry feed substance) to the ratio of cows in combination with selenium citrate (25 μg Se/kg of dry feed substance) promotes the increase in the activity of antioxidant enzymes, the increase in the concentration of retinol and α-tocopherol, and the decrease in the formation of the products of peroxide oxidation of lipids. The content of retinol and α-tocopherol in the milk of cows increases, and the milk yield increases by 2.8–9.3 % as well [24].

It is known that the period, starting with the 21st day prior to the delivery till the 21st day after the delivery, is metabolically critical for highly productive dairy cows. Most experiments involving the introduction of Cr(III) to the ratio of dairy cows have been conducted during this period. It was established that the introduction of 0, 0.03, 0.06, and 0.12 mg of chromium methionate per 1 kg of bodyweight to the ratio of cows leads to the increase in the feed consumption and the amount of milk, fat, and lactose during this critical period [25]. There are also some data [26] proving that the addition of chromium methionate in the dose of 0.08 mg per 1 kg of bodyweight to the ratio of cows during critical periods leads to the increased consumption of feeds, containing barley as a source of grain, contrary to the ones with corn.

It was determined that the addition of chromium-containing yeasts (4 mg Cr/day) in the middle of the lactation period of cows in heat stress conditions increase feed consumption by 1.6 kg and milk yield – by 3.3 kg per day [27]. The addition of chromium picolinate for milkers in heat stress conditions during early lactation also leads to the increased consumption of feeds and the milk yield [28].

The addition of Cr(III) to the ratio of cows may also improve the functioning of the immune system and reproduction. For instance, the addition of chromium (0.5 mg per 1 kg of dry feed substance) in the form of a chelate with aminoacid activates the concanavalin A-induced process of the blastogenesis of lymphocytes in cows [29]. Chromium addition prevents the decrease in this reaction, observed in control cows during the second week of pregnancy. The addition of 5 mg Cr/day to the ratio of cows led to the increase in the process of the formation of antibodies in the organism after the introduction of tetanus toxoid to dairy cows [30].

The works of other authors demonstrated that after the addition of chromium methionate (in the doses from 0 to 6.25 mg/day) to the ratio of dairy cows there was a decrease in the concentration of unesterified fatty acids (0.60 against 0.68 mmol/l) in blood from day 7 to day 10 of pregnancy and the increase in their mating during the first 28 days after the delivery (50.0 against 39.2 % in the control) [31].

The works of the scientists from the Institute of Animal Biology demonstrated that while feeding pedigree bulls with chromium chloride for two months in combination with selenium methionate, there was improvement in quality indices of sperm and its resistance along with the increase in the activity of succinate dehydrogenase and cytochrome of c-oxidase, the content of total protein and γ-globulin fraction by 18.3 % on the 90th day of the studies [32].

It was established that feeding bulls with chromium chloride, chromium methionate, and chromium nicotinate for three months during the preweaning period promotes the increase in the intensity of bodyweight gain by 4.1, 6.3, and 6.6 % respectively [33].

There was considerable interest to chromium due to experimental confirmation of its positive impact on the physiological condition of calves in stressful conditions. In particular, it was established that the addition of Cr(III) to the ratio of calves decreases the frequency of diseases during transportation, which occur due to transporting stress [34]. The stress induces the increase in the concentration of cortisol in the blood of calves, which is known to inhibit the immune function. The introduction of chromium to the ratio of calves after the stress leads to the decrease in the concentration of cortisol in their blood serum [34]. It was demonstrated that the addition of Cr(III)to the ratio of calves in the dose of 200, 500, or 1,000 μg/kg in the form of yeasts led to the increase in their gain by 29 %, the feed digestibility – by 15 %, and the content of cortisol in blood serum decreased linearly along with the increase in chromium dose [34].

CONCLUSIONS

The generalization of the literature data and the results of our own work indicate the urgency of using chromium compounds in the nutrition of pigs and cattle. The recommendations of scientists from Europe, the USA, and Canada, as well as the recent conclusions of experimental studies of Ukrainian authors testify to the fact that chromium is an essential microelement for humans and animals. However, the issue of using chromium compounds in the nutrition of farm animals requires further studies. The dosing of chromium for specific species of farm animals has not been stipulated in the domestic nutrition system yet. However, low toxicity of chromium compounds and high metabolic and productive effects for animals of most species opens a perspective of the approval for the use of tested compounds of Cr(III) in the nutrition of productive animals.

The analysis of the presented data allows for a conclusion that farm animals are capable of responding to chromium addition to the ratio by changes in metabolism and productivity. Chromium has a positive effect on the growth, development of fetus of both pigs and cattle and stimulates the metabolism of glucose and insulin. Thus, the addition of Cr(III) to the ratio of animals is experimentally proven. However, the determination of a need of farm animals for chromium requires the consideration of its low availability in the feeds as well as increased removal of Cr(III) from the organism, including the one due to the stress. It should also be considered that the content of Cr(III) in the organism of animals decreases considerably with age, during pregnancy and lactation.

Therefore, the expansion of experimental studies with the purpose of the further study of metabolic effects of the compounds of Cr(III) in the organism of pigs, cattle and other species of animals is urgent and scientifically grounded.

Роль хрому (ІІІ) в живленні свиней та великої рогатої худоби

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Обговорюються результати власних досліджень і дані сучасної літератури щодо біологічної ролі сполук Cr(III) за умов їхнього використання у живленні свиней і великої рогатої худоби (ВРХ). Проаналізовано метаболічний вплив Cr(III), що надходить із різних джерел – мінеральних та органічних сполук, отриманих хімічним синтезом або нанобіотехнологічним методом (цитрату хрому), а також у вигляді біокомплексів, які містяться в культуральному середовищі дріжджів *Saccharomyces cerevisiae.* Досліджено метаболічний зв'язок дії сполук Cr(III) з біосинтезом окремих гормонів – інсуліну, кортизолу, а також чутливість окремих тканин і органів до дії сполук хрому. Значну частину оглядового матеріалу присвячено метаболічному впливу сполук Cr(III) на репродуктивну функцію свиней і ВРХ та їхньої дії на життєздатність приплоду і гамет тварин. Обговорюються дані щодо стимулюючого впливу Cr(III) на ріст і розвиток організму поросят і телят, м'ясну і молочну продуктивність цих видів тварин. Підкреслено важливість нормування Cr(III) у раціонах свиней і ВРХ.

Ключові слова: хром, свині, велика рогата худоба, живлення, нанобіотехнологія.

Роль хрома (III) в питании свиней и крупного рогатого скота

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Обсуждаются результаты собственных исследований и данные современной литературы о биологической роли соединений Cr(III) при условии их использования в питании свиней и крупного рогатого скота (КРС). Проанализировано метаболическое влияние Cr(III), поступающего из разных источников − минеральных и органических соединений, полученных химическим синтезом или нанобиотехнологическим методом (цитрат хрома), а также в виде биокомплексов, содержащихся в культуральной среде дрожжей *Saccharomyces cerevisiae*. Исследована метаболическая связь действия соединений Cr(III) с биосинтезом отдельных гормонов − инсулина, кортизола, а также чувствительность отдельных тканей и органов к действию соединений хрома. Значительная часть обзорного материала посвящена метаболическому влиянию соединений Cr(III) на репродуктивную функцию свиней и КРС, их воздействию на жизнеспособность приплода и гамет животных. Обсуждаются данные о стимулирующем влиянии Cr(III) на рост и развитие организма поросят и телят, мясную и молочную продуктивность этих видов животных. Подчеркнута важность нормирования Cr(III) в рационах свиней и КРС.

Ключевые слова: хром, свиньи, крупный рогатый скот, питание, нанобиотехнология.

REFERENCES

1. *Pechova A, Pavlata L.* Chromium as an essential nutrient: a review. *Veterinarni Medicina*. 2007;**52**(1):1–18.
2. *Cefalu WT, Hu FB.* Role of chromium in human health and in diabetes. *Diabetes Care*. 2004;**27**(11):2741–51.
3. *Vincent JB.* The nutritional biochemistry of chromium (III). Amsterdam, Elsevier Sci. 2007;277 p.
4. *Van de Ligt CP, Lindemann MD, Cromwell GL.* Assessment of chromium tripicolinate supplementation and dietary protein level on growth, carcass, and blood criteria in growing pigs. *J Anim Sci*. 2002;**80**(9): 2412−9.
5. *Matthews JO, Southern LL, Fernandez JM, Pontif JE, Bidner TD, Odgaard RL.* Effect of chromium picolinate and chromium propionate on glucose and insulin kinetics of growing barrows and on growth and carcass traits of growing-finishing barrows. *J Anim Sci*. 2001; **79**(8):2172−8.
6. Iskra *RJa, Vlizlo VV, Fedoruk RS, Antoniak GL.* Chromium in nutrition animals. Kyiv, Agricultural science. 2014;312 p.
7. *Iskra RYa, Gonchar MV, Nechay HI, Maksymovych IYa*. Metabolic indices of piglets blood at feeding of cultural liquid of the yeast *Saccharomyces cerevisiae* containing chromium biocomplexes. *Biotechnology.* 2011;**4**(4): 50–8.
8. *Peres LM, Bridi AM, de Silva CA, Andreo N, Barata CCP, Dário JGN.* Effect of supplementing finishing pigs with different sources of chromium on performance and meat quality. *R Bras Zootec.*2014;**43**(7): 369−75.
9. *Iskra RYa.* Characteristic features in the organism of piglets metabolism at addition non-organic chromium compound to their ration. *Scientific Messenger of Lviv National University of Veterinary Medicine and Biotechnologies named after S. Z. Gzhytskyj*. 2010; **12**(12(44)):78–80.
10. *Iskra RYa.* Insulin and lipid content in blood plasma of pigs at an increase of chromium level in their diet. *The animal biology*. 2009;**11**(1−2):175–8.
11. *Lindemann MD, Carter SD, Chiba LI, Dove CR, LeMieux FM, Southern LL.* A regional evaluation of chromium tripcolinate supplementation of diets fed to reproducing sows. *J Anim Sci*. 2004;**82**(10):2972−7.
12. *Guikinglung Pamei, Tensingh Gnanaraj P, Sivakumar T, Thilak Pon Jawahar K, Muthuramalingam T, Pothiappan P*. Influence of dietary supplementation of chromium on the carcass traits of crossbred pigs. *J Adv Vet Anim Res.* 2014;**1**(3):125–9.
13. *Iskra RJa.* Hemopoesis and immunological features of the organism of piglets at conditions of feeding chromium to sows. *Experimental and Clinical Physiology and Biochemistry.* 2010;(1(49)):46–50.
14. *Mooney KW, Cromwell GL.* Effects of dietary chromium picolinate supplementation on growth, carcass characteristics, and accretion rates of carcass tissues in growing-finishing swine. *J Anim Sci.* 1995;**73**(11): 3351–7.
15. *Kemp B, Soede NM, Vesseur PC, Helmond FA, Spoorenberg JH, Frankena K.* Glucose tolerance of pregnant sows is related to postnatal pig mortality. *J Anim Sci*. 1996;**74**(4):879–85.
16. *Hagen CD, Lindemann MD, Purser KW.* Effect of dietary chromium tripicolinate on productivity of sows under commercial conditions. *Swine Health Prod*. 2000;**8**(2):59–63.
17. *Fries HCC, Souza LP, Faccin JEG, Reckziegel MV, Hernig L, Marimon BT, Bernardi ML, Wentz I, Bortolozzo FP.* Induction and synchronization of ovulation in sows using a Gonadotropin-releasing Hormone Analog (Lecirelin). *Anim Reprod*. 2010;**7**(4):362–6.
18. *Kumar P, Sait SF*. Luteinizing hormone and its dilemma in ovulation induction. *J Hum Reprod Sci*. 2011;**4**(1): 2–7.
19. *Bortolozzo FP, Pinheiro Machado I., Wentz I, Nagae R, Penz AM*. Effect of chromium picolinate on swine

reproduction. I. Influence on number of ovulations, number of viable embryos and embryo survival. *Proc of the 15th Int Pig Veterinary Soc Congr*. (5–9 July 1998, Birmingham, England). Birmingham. 1998;79.

20. *Kuhn G, Kanitz E, Tuchscherer M, Nürnberg G, Hartung M, Ender K, Rehfeldt C.* Growth and carcass quality of offspring in response to porcine somatotropin (pST) treatment of sows during early pregnancy. *Livest Sci*. 2004;**85**(2–3):103–12.
21. *Spears JW*. Chromium supplementation in cattle diets. *21st Annual Florida Ruminant Nutrition Symp.* University of Florida. 2010;143–55.
22. *Sano H, Narahara S, Kondo T, Takahashi A, Terashima Y.* Insulin responsiveness to glucose and tissue responsiveness to insulin during lactation in dairy cows. *Domest Anim Endocrinol*. 1993;**10**(3):191–7.
23. *Sano H, Nakai M, Kondo T, Terashima Y*. Insulin responsiveness to glucose and tissue responsiveness to insulin in lactating, pregnant, and nonpregnant, nonlactating beef cows. *J Anim Sci*. 1991;**69**(3):1122–7.
24. *Khomyn MM., Fedoruk RS.* Antioxidant profile of organism and biological value of milk of cows in the first months of lactation under feeding by chromium and selenium citrate. *The animal biology*. 2013;**15**(2):140–8.
25. *Hayirli A, Bremmer DR, Bertics SJ, Socha MT, Grummer RR.* Effect of chromium supplementation on production and metabolic parameters in periparturient dairy cows. *J Dairy Sci*. 2001;**84**(5):1218–30.
26. *Sadri H, Ghorbani GR, Rahmani HR, Samie AH, Khorvash M, Bruckmaier RM*. Chromium supplementation and substitution of barley grain with corn: Effects on performance and lactation in periparturient dairy cows. *J Dairy Sci*. 2009;**92**(11):5411–8.
27. *Al-Saiady MY, Al-Shaikh MA, Al-Mufarrej SI, Al-Showeimi TA, Mogawer HH, Dirrar A.* Effect of chelated chromium supplementation on lactation performance and blood parameters of Holstein cows under heat stress. *Anim Feed Sci Technol*. 2004;**117**(3–4):223–33.
28. *AnQiang L, ZhiSheng W, AnGuo Z.* Effect of chromium picolinate supplementation on early lactation performance, rectal temperatures, respiration rates and plasma biochemical response of Holstein cows under heat stress. *Pakistan J Nutr*. 2009;**8**(7):940–5.
29. *Burton JL, Mallard BA, Mowat DN*. Effects of supplemental chromium on immune responses of periparturient and early lactation dairy cows. *J Anim Sci*. 1993;**71**(6):1532–9.
30. *Faldyna M, Pechova A, Krejci J.* Chromium supplementation enhances antibody response to vaccination with tetanus toxoid in cattle. *J Vet Med B Infect Dis Vet Public Health*. 2003;**50**(7):326–31.
31. *Bryan MA, Socha MT, Tomlinson DJ.* Supplementing intensively grazed late-gestation and early-lactation dairy cattle with chromium. *J Dairy Sci*. 2004; **87**(12): 4269–77.
32. *Koleschuk OI., Fedoruk RS.* The protein composition and quality of the semen of bulls-sires during the use of the compounds of selenium, chromium, and vitamin E. *Scientific and Technical Bulletin Institute of Animal Biology of NAAS* and *State Scientific-Research Control Institute of Veterinary Medicinal Products and Feed Additives*. 2009;**10**(3):252–7.
33. *Khomyn MM.* Indicators of antioxidant protection of the bull organism and weight gain at feeding different chromium forms. *Scientific and Technical Bulletin Institute of Animal Biology of NAAS* and S*tate Scientific-Research Control Institute of Veterinary Medicinal Products and Feed Additives.* 2010;**11**(1):76–81.
34. *Soltan MA*. Effect of dietary chromium supplementation on productive and reproductive performance of early lactating dairy cows under heat stress. *J Anim Physiol Anim Nutr (Berl).* 2010;**94**(2):264–72.