The effect of duration of the productive use on the element status of Holstein cows

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Abstract. The article presents data on the elemental status of highly productive Holstein cows in terms of duration of productive use. The elemental status was studied on the composition of animal hair. Elemental analysis of samples was carried out by AES-ICP and MS-ICP. It has been established that the first lactation cows differed in minimal concentrations of As, Hg, Cd, Sr wool. With an increase in toxic elements with aging, an increase in zinc levels in the fourth lactation cows was recorded. A significant correlation was found between the sum of toxic elements (As, Hg, Sr, Cd) and concentrations of Cu ($r = -0.57$), Mn ($r = 0.49$), Se ($r = 0.68$) and Zn ($r = -0.56$) in wool. An assessment of the elemental status of cows in relation to the boundaries of the “physiological norm” revealed an increase in the number of deviations with an increase in the productive use ifrom 2 to 11.

1. Introduction

Effective development of the milk industry is impossible without constant monitoring of the physiological state of dairy cows [1], including mineral metabolism. The importance of monitoring of the intensity of mineral metabolism is determined by the influence of chemical elements on hormones [2], enzymes [3], the immune system [4], antioxidant defense mechanisms [5,6], and health [7,8].

To assess the level of chemical elements in the body, elemental analysis of various biological materials, including hair, was carried out [9]. Hair is a non-invasive and informative biological material; therefore, this study aims to identify and correct elements, assess biogeochemical provinces, etc. [10, 11]

However, the elemental status of animals and humans is highly mobile and determined by the influence of a number of factors, including a genotype, a gender, pregnancy and lactation, a level of productivity and an age [12,13].

Existing data show that the age has a significant impact on the content of trace elements in various biological substrates [14,15]. However, the data obtained are rather scattered and contradictory.

In this regard, the purpose of this study is to assess the elemental status of highly productive Holstein cows due to the duration of productive use, as well as the interpretation of the results obtained within the “physiological norm”.

2. Materials and methods

2.1 Object

Experiments were conducted on Holstein cows with a live weight of 510–540 kg. The lactation stage was 35-55 days after calving. Milk productivity was 38-51 l/day. Experimental studies were carried out...
in accordance with the instructions and recommendations of the Order of the Ministry of Health of the USSR of July 27, 1978 No. 701 “On Amendments to the Order of the Ministry of Health of the USSR of 12.08.77 No. 755” and “The Guide for Care and Use of Laboratory Animals” (National Academy Press, Washington, DC 1996). Efforts were made to minimize the suffering of animals and reduce the number of samples used.

2.2 The scheme of the experiment
The experimental part of the work was carried out in 2017 in CJSC Gatchinskoye of Leningrad Region. Animals (n = 64) were divided into 4 groups depending on the duration of productive use: first lactation (n = 16; age - 2.7 years), second lactation (n = 16; age - 3.6 years), third lactation (n = 16; age - 4.5 years), fourth lactation (n = 16; age - 5.4 years).

2.3 Sampling and analysis of wool samples
Wool samples were taken from the top of withers [16] using stainless steel scissors. Elemental analysis of samples was carried out by AES-ICP and MS-ICP methods. The results were compared with the “physiological norm” established within the 25 and 75 centiles for cows of Leningrad region (n=148): Ca (915-2386); K (3122-4154); Mg (318-664); Na (2196-3124); P (228-290); Co (0.0330.055); Cr (0.088-0.144); Cu (8.05-9.48); Fe (100.1-171.1); I (10.13-19.57); Mn (3.52-6.50); Se (0.158-1.14); Zn (116.1-141.1); B (3.41-10.90); Li (0.049-0.071); Ni (0.158-0.222); Si (6.29-11.48); V (0.0160.027); Al (2.06-4.41); As (0.029-0.05); Cd (0.0031-0.0052); Hg (0.0021-0.0061); Pb (0.046-0.142); Sn (0.015-0.05); Sr (1.83-3.69).

2.4 Statistical analysis
The significance of differences was checked using the Mann-Whitney U-test. The level of significance (P) was taken to be less than or equal to 0.05. The correlation coefficients were calculated by Spearman (Kc). For data processing, the software package Statistica 10.0 (StatSoft, Inc., USA) was used. The tables show the average values of indicators (M) and their standard deviations (± STD).

3. Results
The elemental composition of wool depending on the duration of productive use is presented in Table 1.

First lactation cows had minimal concentrations of As, Hg, Cd, Sr wool. With aging, an increase in the zinc level of fourth lactation cows was recorded (P ≤ 0.01). The concentration of Cu decreased (P ≤ 0.05).

Assessment of the elemental status of cows in relation to the boundaries of the “physiological norm” revealed an increase in the number of deviations with aging (Fig. 1, 2, 3, 4). If for first lactation sowed deviations from the norm only in two elements (Fe, Sn), fourth lactation cows had deviations in 11 elements (Ca, Cu, I, B, Li, Ni, As, Cd, Hg, Sn ).
Table 1. The concentration of chemical elements in hair taken from withers of Holstein cows in terms of lactation (µg/g)

| Element | I              | II             | III            | VI             |
|---------|----------------|----------------|----------------|----------------|
|         | Lactation      | Macroelements  |                |                |
| Ca      | 1761±952.2     | 1529±537.5     | 1982±794.8     | 2522±143.1     |
| K       | 3758±1004      | 3477±934.3     | 3325±702.9     | 4018±473.5     |
| Mg      | 514.2±233.7    | 460.2±146.7    | 550.7±203.9    | 617.3±124.3    |
| Na      | 3071±1487      | 2462±485.3     | 2146±638.6     | 2568±544.2     |
| P       | 258.9±42.77    | 251.2±60.22    | 273.5±50.66    | 238.7±34.3     |
| Co      | 0.047±0.019    | 0.043±0.016    | 0.042±0.015    | 0.037±0.008    |
| Cr      | 0.135±0.072    | 0.106±0.040    | 0.107±0.028    | 0.134±0.096    |
| Cu      | 8.83±0.916     | 8.71±1.39      | 8.94±0.488     | 7.43±0.668*    |
| Fe      | 227.9±264.0    | 148.9±71.70    | 152.7±55.20    | 169.8±20.56    |
| I       | 17.78±11.32    | 14.35±5.44     | 10.02±6.04     | 9.70±6.40      |
| Mn      | 5.16±2.76      | 5.15±1.85      | 5.23±2.20      | 5.48±1.12      |
| Se      | 0.990±0.284    | 0.807±0.126    | 0.962±0.209    | 0.895±0.030    |
| Zn      | 124.1±15.04    | 128.4±15.89    | 119.1±3.62     | 144.1±17.55**  |
| B       | 7.06±4.40      | 6.92±4.35      | 7.73±3.37      | 13.17±3.99*    |
| Li      | 0.059±0.014    | 0.059±0.007    | 0.054±0.017    | 0.075±0.007*   |
| Ni      | 0.22±0.127     | 0.176±0.026    | 0.192±0.052    | 0.326±0.240    |
| Si      | 8.06±3.36      | 9.62±3.59      | 10.50±2.97     | 10.08±4.99     |
| V       | 0.020±0.009    | 0.020±0.006    | 0.020±0.008    | 0.026±0.009    |
|         | Conditionally vital microelements |               |                |                |
| Al      | 4.13±2.96      | 2.88±1.54      | 3.37±1.21      | 2.72±1.87      |
| As      | 0.034±0.006    | 0.042±0.014*   | 0.042±0.011*   | 0.048±0.014*   |
| Cd      | 0.003±0.002    | 0.003±0.002    | 0.005±0.002*   | 0.007±0.002**  |
| Hg      | 0.004±0.002    | 0.008±0.004**  | 0.007±0.006    | 0.007±0.005    |
| Pb      | 0.118±0.068    | 0.063±0.042    | 0.050±0.025*   | 0.063±0.045    |
| Sn      | 0.043±0.069    | 0.021±0.013    | 0.030±0.024    | 0.114±0.169    |
| Sr      | 2.03±1.64      | 2.46±0.558     | 2.63±1.01      | 3.58±0.297     |

* P ≤ 0.05; ** P ≤ 0.01 - compared to group I
Figure 1. The frequency of deviations of the elemental composition of wither wool of first lactation Holstein cows.

Figure 2. The frequency of deviations of the elemental composition of wither wool of second lactation Holstein cows.
The calculation of the Spearman's rank correlation coefficients for animals of the experimental groups revealed a significant correlation between the amount of moles of toxic elements growing with the number of lactations (As, Hg, Sr, Cd) Cu, Mn, Se and Zn concentrations in wool (Table 2).

**Table 2.** The coefficients of correlation of the sum of moles of toxic elements (mmol/kg) and the concentration of essential elements (µg / g) in wither wool of Holstein cows

| Elements                  | Co  | Cr  | Cu  | Fe  | I   | Mn  | Se  | Zn  |
|---------------------------|-----|-----|-----|-----|-----|-----|-----|-----|
| Toxic microelements (As, Hg, Sr, Cd) | 0.23| 0.19| -0.57*| 0.23| 0.22| 0.49*| 0.68*| -0.56*|
4. Discussion
With aging the concentration of As, Hg, Sr, and Cd increases. An increase in toxic trace elements in cows is due to external exposure and accumulation of metals in the body. This hypothesis is supported by studies showing the age dependence of heavy metals in the hair of residents of large cities [15]. In our experiment, lead and tin content in the wool of third lactation cows decreased in. This fact is consistent with the research by LopezAlonso et al. (2003) [17] who found that cows do not accumulate toxic elements with age.

It was revealed that against the background of increasing concentrations of toxic elements (As, Hg, Sr and Cd), an increase in the exchange pool of their antagonist – zinc – was identified. The data on the age dynamics of zinc are very diverse and contradictory [15, 18]. Within the framework of the existing concept developed for humans [19], an increase in the level of zinc above the 75th percentile in the fourth lactation cows may indicate a zinc deficiency.

An increase in the zinc exchange pool in the fourth lactation cows was accompanied by a decrease in the copper concentration in animal wool below 25 centiles. This indicates depletion of reserves of the animal and development of hypoelementosis in copper, which fits well with the previously known antagonistic relationship between copper and zinc [20]. An example of this interaction is a change in the elemental status of alcohol-addicted persons [21].

It can be assumed that the high milk productivity of cows (38-51 l/day) contributed to the depletion of iodine. The concentration of the latter in wool decreased below 25 centiles in third and fourth lactation cows. One more cause of this phenomenon is a "pressure" of an increasing pool of toxic elements on its metabolism [22]. This may be due to the accumulation of cadmium which can cause oxidative stress and mitochondrial thyroid dysfunction [23, 24].

5. Conclusion
An increase in the duration of productive use of dairy cows is associated with changes in the concentrations of chemical elements and toxic elements in wool. A better understanding of age-related changes in the elemental status of an organism can improve reproductive abilities and productive longevity of dairy cows.

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References
[1] Donat K, Siebert W, Menzer E and Söllner-Donat S 2016 Long-term trends in the metabolic profile test results in German Holstein dairy herds in Thuringia, Germany Tierarztl. Prax. Ausg. G. Grosstiere. Nutztiere 44(2) 73–82 doi: 10.15653/TPG-150948. Epub 2016 Mar 21.
[2] Hansen S L, Ashwell M S, Moeser A J, Fry R S, Knutson M D and Spears J W 2010 High dietary iron reduces transporters involved in iron and manganese metabolism and increases intestinal permeability in calves J. Dairy Sci. 93(2) 656–65
[3] Guyot H and Rollin F 2007 The diagnosis of selenium and iodine deficiencies in cattle Ann. Med. Vet. 151 166–91
[4] Mittag J, Behrends T, Hoefig C S, Vennström B and Schomburg L 2010 Thyroid hormones regulate selenoprotein expression and selenium status in mice PLoSOne 5 129–31 doi: 10.1371/journal.pone.0012931.
[5] Zhao X J et al 2015 Oxidative stress and imbalance of mineral metabolism contribute to lameness in dairy cows Biol. Trace Element Res. 164(1) 43–9 doi: 10.1007/s12011-014-0207-1.
[6] Tangpong J and Saturug S 2010 Alleviation of lead poisoning in the brain with aqueous leaf extract of the Thunbergialaurifolia (Linn.) Toxicol. Lett. 198 83–8 doi: 10.1016/j.toxlet.2010.04.031

[7] Kalashnikov V, Zajcev A, Atroschenko M, Kalinkova L, Kalashnikova T, Miroshnikov S, Frolov A and Zav'yalov O 2018 The content of essential and toxic elements in the hair of the mane of the trotter horses depending on their speed Environmental Sci. and Pollut. Res. 25(22) 21961–7

[8] Wang H, Jiang Y, Tian C, Pan R, Dang F, Feng J, Li M, Zhang Y, Li H and Man C 2018 Determination of the transfer of lead and chromium from feed to raw milk in Holstein cows Food Addit. Contam. Part A. Chem. Anal. Control. Expo. Risk. Assess. 35(10) 1990–9 doi: 10.1080/19440049.2018.1496279. Epub 2018 Sep 5.

[9] Pieper L, Schmidt F, Müller A E and Staufenbiel R 2017 Zinc concentrations in different sample media from dairy cows and establishment of reference values Tierarztl. Prax. Ausg. G. Grosstiere. Nutztiere. 45(4) 213–8 doi: 10.15653/TPG-160741. Epub 2017 May 8. German

[10] Miroshnikov S A, Zavyalov O A, Frolov A N, Bolodurina I P, Kalashnikov V V, Grabeklis A R, Tinkov A A and Skalny A V 2017 The Reference Intervals of Hair Trace Element Content in Hereford Cows and Heifers (Bos taurus) Biological Trace Element Res. 180 56–62

[11] Siwińska N, Žak A, Slowikowska M, Kubiai K, Jaworski Z and Niedzwiedź A 2018 Morphology and elemental analysis of free range and stabled Polish Konik horses hair using Energy-dispersive X-ray spectroscopy (EDS) Pol. J. Vet. Sci. 21(1) 65–72 doi: 10.24425/119023

[12] Długaszek M and Kopczyński K 2014 Correlations between elements in the fur of wild animals Bull. Environ. Contam. Toxicol. 93(1) 25–30 doi: 10.1007/s00128-014-1260-3. Epub 2014 Mar 26

[13] Cygan-Szczygelińska D, Stanek M, Giemratowska E and Janicki B 2014 Impact of breeding region and season on the content of some trace elements and heavy metals in the hair of cows Folia Biol. 62(3) 163–9

[14] Alonso M L, Benedito J L, Miranda M, Castillo C, Hernández J and Shore R F 2003 Mercury concentrations in cattle from NW Spain Sci. Total Environ. 302 93–100

[15] Skalnaya M G, Tinkov A A, Demidov V A, Serebryansky E P, Nikonorov A A and Skalny A V 2016 Age-related differences in hair trace elements: a cross-sectional study in Orenburg, Russia Ann. Hum. Biol. 43(5) 438–44 http://dx.doi.org/10.3109/03014460.2015.1071424

[16] Miroshnikov S, Kharamanov A Zavyalov O., Frolov A, Duskaev G, Bolodurina I and Arapova O 2015. Method of sampling beef cattle hair for assessment of elemental profile Pakistan J. of Nutrition 14(9) 632–6

[17] Alonso M L, Benedito J L, Miranda M, Castillo C, Hernández J and Shore R F 2003 Mercury concentrations in cattle from NW Spain Sci. Total Environ. 302 93–100

[18] Hong S R, Lee S M, Lim N R, Chung H W and Ahn H S 2009 Association between hair mineral and age, BMI and nutrient intakes among Korean female adults Nutr. Res. Pract. 3(3) 212–9 Retrieved from: http://dx.doi. org/10.4162/nrp.2009.3.3.212

[19] Skalnaya M G, Demidov V A and Skalny A V 2003 About the limits of physiological (normal) content of Ca, Mg, P, Fe, Zn and Cu in human hair Trace Elements in Medicine 4(2) 5–10

[20] Bremner B I and Beattie J H 1995 Copper and zinc metabolism in health and disease: speciation and interaction Proc. of the Nutrition Society 54 489–99

[21] Skalny A V, Skalnaya M G, Grabeklis A R, Skalnaya A A and Tinkov A A 2018 Zinc deficiency as a mediator of toxic effects of alcohol abuse Eur J Nutr. 57(7) 2313–22 doi: 10.1007/s00394-017-1584-y. Epub 2017 Nov 24

[22] Barysheva E S 2018 Experimental Simulation of the Effects of Essential and Toxic Trace Elements on Thyroid Function Bull. Exp. Biol. Med. 164(4) 439–41 doi: 10.1007/s10517-018-4007-z. Epub 2018 Mar 2

[23] Chung S M, Moon J S, Yoon J S, Won K C and Lee H W 2019 Sex-specific effects of blood cadmium on thyroid hormones and thyroid function status: Korean nationwide cross-sectional...
study J. Trace Elem. Med. Biol. 53 55–61 doi: 10.1016/j.jtemb.2019.02.003. Epub 2019 Feb 12

[24] Jancic S A and Stosic B Z 2014 Cadmium effects on the thyroid gland Vitam. Horm. 94 391–425