Acta of Bioengineering and Biomechanics
Vol. 11, No. 3, 2009

Original Paper

Effect of diet on mechanical properties of horse's hair

MAŁGORZATA KANIA[1], DOROTA MIKOŁAJEWSKA[1], KRZYSZTOF MARYCZ[2], MAGDALENA KOBIELARZ[3,*]

[1] Interdepartmental Students' Science Group of Biomechanics, Wrocław University of Technology, Poland.
[2] Electron Microscope Laboratory, Wrocław University of Environmental and Life Sciences, Poland.
[3] Institute of Machine Design and Operation,
Faculty of Mechanical Engineering, Wrocław University of Technology, Poland.

The aim of this research was to assess the effect of diet supplementation with zinc and copper, in different chemical forms (organic and inorganic), on the mechanical properties of the hair of healthy English thoroughbred horses. Hairs were taken from 18 horses which had been fed with oats and hay for a period of 110 days. Twelve of the horses had been additionally given a daily dose of 700 g of high-quality 44-ingredients Fohlengold St-Hippolyt muesli made by Muhle Ebert Dilheim. Six of them had received the muesli-containing organic zinc and copper (OS), while the other six horses had received the muesli-containing inorganic zinc and copper (IS). The mechanical properties of the hairs before and after the supplementation period were tested in a Synergie 100 (MTS) testing machine. Each of the hairs was loaded at a constant rate of 20 mm/min until rupture. Young modulus (*E*), breaking stress (*Ru*) and yield point (*Rs*) of the particular hairs were determined. No significant changes in the mechanical parameters were observed in the reference group in which the horses were fed with only oats and hay for the whole experimental period of 110 days. The supplementation of the diet with inorganic zinc and copper resulted in an increase in the elasticity and diameter of the hairs and in a simultaneous reduction in their strength. Whereas organic zinc and copper caused an increase in the elasticity and strength of the hairs and a simultaneous reduction in their diameter. It has been shown that the organic form of the supplemented trace zinc and copper (mainly copper) elements has a beneficial effect on the mechanical properties of the hairs since it results in an increase in both their elasticity and strength.

Key words: *mechanical properties, hairs, horses, supplementation, elements, zinc, copper*

1. Introduction

Hair constitutes a cover protecting the body of animals. Hair is insoluble in water and chemically inactive [1]. It is highly hygroscopic, absorbing water at a very fast rate (reaching 75% of its maximum absorbing capacity in 4 minutes) [2]. Hair is characterized by high elasticity and tensile strength. Its modulus of elasticity is in a range of 2 GPa [3]÷ 3 GPa [4], [5] and its rupture strain ranges from ca 35% [4] to 50% [3]. The tensile strength of hair is usually in a range of 120 MPa [4]÷170 MPa [3], but it can be as high as 250 MPa [5] and is linked with the diphase nature of the hair's cortex [6]. As the hair is being stretched [6], α-keratin molecules turn into β-keratin while the matrix from gel turns into sol [7], [8].

Silicon [5], zinc and copper [9], [10] and chelated iron, potassium and zinc [11] are absorbed by hair. Also heavy metals (including lead and cadmium) present in industrial pollutants accumulate in hair [12]. The effect of these elements on the structure of hair and its appearance has been sufficiently described in the literature since all the changes in the appearance of hair cover, connected with the organism's nutritional state, fatigue and diseases, are used in animal health diagnostics [13]. Moreover, the accumulation of elements in hair changes its mechanical properties [9]. Hence the aim of this research was to quantitatively assess the effect of diet supplementation with zinc and copper, both of organic and inorganic origin,

* Corresponding author: Magdalena Kobielarz, Division of Biomedical Engineering and Experimental Mechanics, Faculty of Mechanical Engineering, Wrocław University of Technology, 7/9 Łukasiewicza Street, 50-371 Wrocław, Poland. E-mail: magdalena.kobielarz@pwr.wroc.pl
Received: March 28th, 2009
Accepted for publication: October 21st, 2009

on the mechanical properties of the hair of healthy animals. The mechanical properties of the hair are indispensable to mathematical modelling of the hair behaviour in different loading and environmental conditions [14].

2. Material and method

Hair samples were taken from 18 English thoroughbred horses randomly assigned to 3 dietary groups. Before supplementation the groups had not significantly statistically differed from each other with regard to the age and body mass of the individual horses. For a period of 110 days all the horses had been fed with oats and hay. Six of them had not received any supplements (MD), twelve horses had received additionally a daily dose of 700 g of high-quality 44-ingredients muesli made by Muhle Ebert Dilheim. Six of them had received the muesli containing organic zinc and copper (OS), while the other six horses had received the muesli containing inorganic zinc and copper (IS). The feed had been given three times a day. During the nutritional experiment the horses had stayed in box stalls with padded floors and with day turn out into a paddock.

Mechanical properties were tested for 36 hairs taken from each horse before and after the supplementation period. The hairs were taken from the horses' manes and were cut off close to the skin. Each time the diameter of the hair tested was determined under the AxioImager M1m (Zeiss) optical microscope that has magnification of 100× (figure 1).

Fig. 1. Way of determining hair's diameter from optical microscope image

A Synergie 100 (MTS) machine was used to test the mechanical properties of the hairs. Each of the hairs was uniaxially loaded until a rupture at a constant rate of 20 mm/min. The hairs were fixed in the testing machine by means of clamps. The initial length of the individual hairs was 20 mm.

Engineering strain (ε) was calculated from the equation:

$$\varepsilon = \frac{\Delta l}{l_0}, \tag{1}$$

where: l_0 (mm) – the initial length, Δl (mm) – the displacement.

Engineering stress (σ) was calculated as a ratio of the force acting at a given moment to the initial cross-sectional area of the hair:

$$\sigma = \frac{F}{A_0}, \tag{2}$$

where: F (N) – the instantaneous force value, A_0 (mm^2) – the initial cross-sectional area.

Young modulus (E), breaking stress (Ru) and yield point (Rs) for the particular hairs (figure 2) were determined from the stress–strain curve.

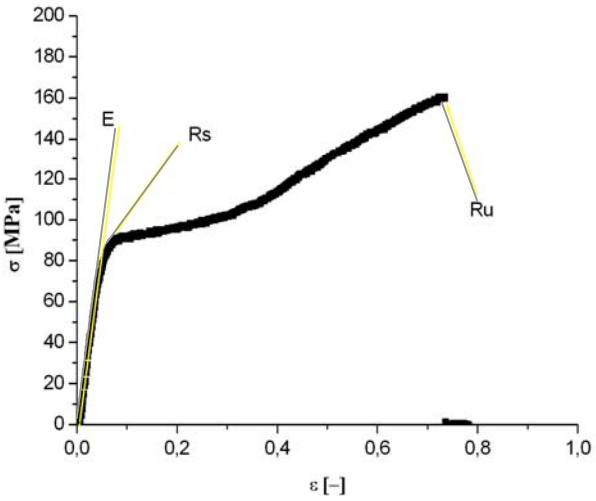

Fig. 2. Typical stress–strain curve with marked quantities being analyzed

All the results obtained were statistically handled (Statistica 8.0 package, StatSoft) and presented in the form of averages with standard deviations (X ± SD). Student's t-test for dependent samples was applied to analyze the data. The tests were carried out for a significance level (p) boundary value of 0.05. At this significance level the results obtained did not differ from each other (except for the diameters in group IS). In order to statistically distinguish the determined parameters in the particular nutritional groups, further analyses were made for $p \leq 0.1$.

3. Results

The mechanical properties and diameters determined for the individual horses representing the dif-

ferent nutritional groups had not statistically differed from each other (for $p = 0.05$ and $p = 0.1$) before the experiment, which justifies the random selection of horses for the particular nutritional groups.

A comparative analysis of the diameters (d) of the hairs before and after the supplementation period showed that their significant increase (by ca. 23%) took place in the horses receiving the inorganic supplements, whereas the organic supplements caused a reduction in the diameter by about 11%. In the case of the reference group, the diameter was found to increase by ca. 2.5% (figure 3).

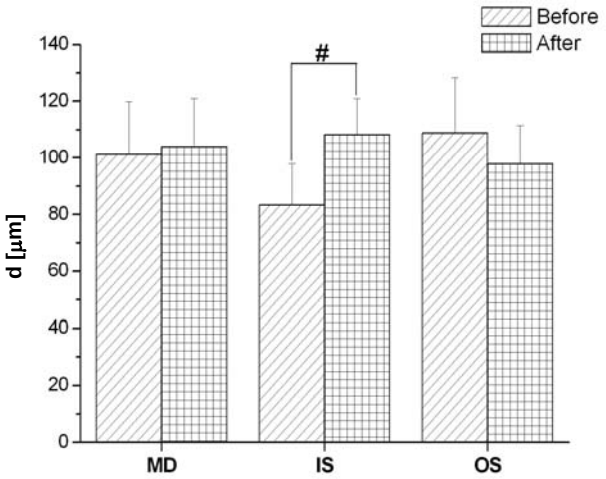

Fig. 3. Distribution of diameters d before and after diet supplementation for particular nutritional groups (# result statistically significant at level $p \leq 0.05$)

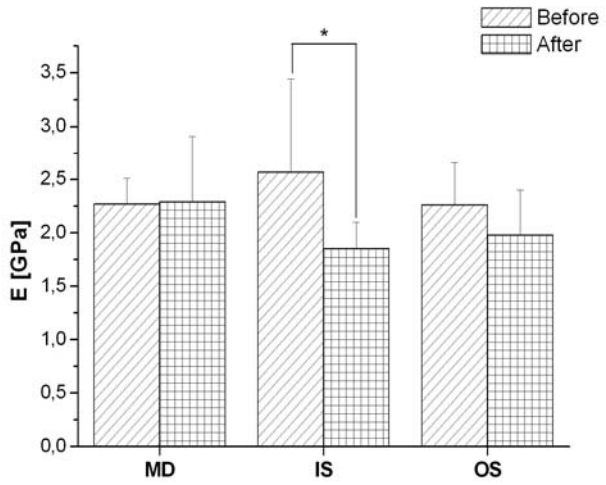

Fig. 4. Distribution of Young modulus (E) values for hairs from manes of horses in particular nutritional groups (* result statistically significant at level $p \leq 0.1$)

In the group of horses receiving the inorganic supplements, the Young modulus (E) decreased by over 39%. Also the supplementation of the diet with organic zinc and copper caused a decrease in the E modulus by about 14% for the average values. After the full supplementation period the monodiet was found to have no influence on the E modulus (the difference in the results amounted to merely 1%) (figure 4).

The breaking stress (Ru) value for the horse hairs after the supplementation period increased by over 35% for the organic dietary supplements and decreased on average by 8% for the inorganic dietary supplements. No significant change in the breaking stress value (a 5% increase) occurred in the reference group (figure 5).

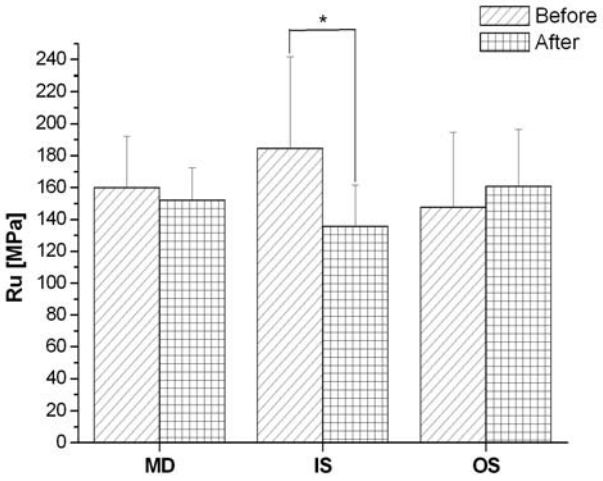

Fig. 5. Distribution of breaking stress (Ru) values for hairs from manes of horses before and after supplementation period (* result statistically significant at level $p \leq 0.1$)

After the supplementation period the yield point (Rs) for all of the horse hairs in all the nutritional groups decreased by: 27% for the inorganic dietary supplements, 5% for the organic dietary supplements and nearly 3% in the reference group (figure 6).

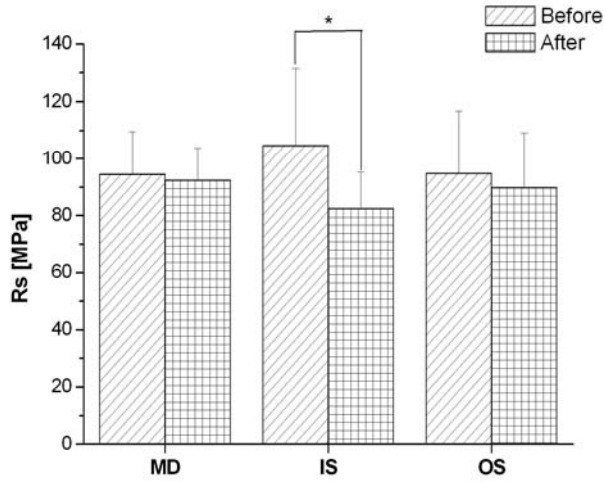

Fig. 6. Distribution of yield point (Rs) values for hairs from manes of horses before and after supplementation period (* result statistically significant at level $p \leq 0.1$)

For all the mechanical parameters analyzed only in the group of horses receiving the inorganic dietary supplements statistically significant differences in the quantities analyzed occurred at the significance level $p \leq 0.1$. As regards the diameter values, the differences in the group IS were observed at the significance level $p \leq 0.05$.

4. Discussion

Although the appearance of hair reflects the state of health of the organism [13], the qualitative description is insufficient and quantitative assessment of the effect of the particular diet components on the condition of animal hair cover should be made. The aim of the investigations was to quantitatively assess the mechanical properties of hair of English thoroughbred horses depending on their diet. The effects of two microelements, i.e. organic and inorganic zinc and copper, on the diameter and mechanical properties of hairs from horse manes were compared. No statistically significant changes in the diameters of the hairs and their mechanical properties were observed in the reference groups of horses fed with only oats and hay (a monodiet) for the full period (110 days) of the nutritional experiment. The supplementation of the diet with inorganic zinc and copper caused a statistically significant increase in the elasticity and diameter of the hairs while reducing their strength. Whereas the organic supplements which the horses had been given caused an increase in the elasticity and strength of the hairs while reducing their diameter, but the differences were not statistically significant. The absence of statistically significant differences in the mechanical properties in group OS might be due to the too short supplementation time (considering the absorption of the elements by the hair and their distribution in the structure of the hair) and also due to an insufficient number of horses in the particular dietary groups. However, the number of horses in the particular dietary groups was not lower in comparison with the numbers found in the literature on the subject. For instance, the investigations on the influence of environmental pollution [12] were carried out on 10 horses at the age of 4–14 years and 15 sheep at the age of 1–3 years. Merely 5 horses at the age of 8 made up the experimental group in the investigations on the effect of the chelation with glycine of copper, iron, potassium, manganese and zinc on the absorption of these elements by the animal organism [11]. The supplementation period of 110 days is sufficient for elements to accumulate in the hair's structure. An SEM-EDS elemental composition analysis carried out by MARYCZ et al. [10] showed an increase in copper and zinc concentration in horse hair after 110 days of diet supplementation and a beneficial effect of a diet enriched with zinc and copper on the quality of the hair cover. AMELING et al. [11] observed the absorption of iron, potassium and zinc by the animal organism after merely 47 days of administering 24-g daily doses of the supplement.

The distribution of the elements absorbed in the hair's structure is still unknown. One can assume that it varies along the length of the hair, being similar to the distribution of lipids in the hair's structure [15]. The amount of lipids in the hair sheath decreases as the distance from the hair root increases, causing a reduction in the hair's mechanical properties [15]. The distribution of elements in the hair's structure may have a similar character, but this requires further studies.

The results of our study on horse hair mechanical properties corroborate in general the results published by others researches. However, it should be noted that there are a lot data available for comparison. Reports on the mechanical properties of human and animal hair indicate that the properties vary for different species and testing conditions. The values of the Young modulus determined in this study are in the same range as those obtained by WICKETT et al. [5], SESHADRI et al. [4] and REBENFELD et al. [3]. Also the breaking stress and the yield point are in similar ranges to those reported by REBENFELD et al. [3]. The way and duration of storing hairs before testing have a significant influence on the values of their mechanical parameters. Long storing time from hair taking to testing adversely affects the measurement results, causing a reduction in the Young modulus and in plastic stress [16]. The absorption of water by hair reduces its tensile strength, elasticity modulus and yield point [16]. Whereas UV radiation has no effect on the mechanical properties of hair [17]. The effect of temperature, leading to a reduction in the elasticity modulus, the yield point and the breaking stress and simultaneously to an exponential increase in unit elongation, is significant [3]. For this reason all the measurements presented here were carried out within three days from hair taking, under replicable temperature (ca 21 °C) and humidity (ca 30%) conditions, preventing the test material from being exposed to high temperature, water or UV radiation during transport, storage and measurements.

The chemical form of the elements has a major influence on their absorption from the alimentary canal [10]. DOBRZAŃSKI et al. [18] analyzed the degree of copper, manganese, iron an zinc accumulation in the eggshells of

hen's eggs and feathers, depending on the chemical form of the administered (organic and inorganic) elements and found that bioaccumulation of organic copper in the structures tested was statistically higher than that of inorganic copper. But the chemical forms of iron, manganese and zinc had no significant effect on their content in the structures tested. LIU et al. [12] found that the pollution (inorganic) copper content in horse hair was not elevated to a statistically significant degree, whereas the inorganic zinc content was elevated to a statistically significant degree. This means that inorganic zinc and organic copper are absorbed by hair and become effectively incorporated into its structure. Therefore one can conclude that in the case of group OS it is mainly the organic copper that is the active element, while in group IS it is inorganic zinc. The results presented in this paper show that in group OS in comparison with the changes observed in group IS, where mainly inorganic zinc was accumulated by the hairs, an advantageous (from the functional point of view) change in the mechanical parameters occurred. The simultaneous increase in the elasticity and strength of the hairs in group OS after the supplementation period testifies to the beneficial influence of diet supplementation with organic copper and zinc (mainly copper) on the condition of the hair cover in horses.

References

[1] WOLFRAM L., *Human hair: A unique physicochemical composite*, Journal of the American Academy of Dermatology, 2003, 48(6), S106–S114.

[2] DAWBER R., *Hair: its structure and response to cosmetic preparation*, Clinics in Dermatology, 1996, 14(1), 105–112.

[3] REBENFELD L., WEIGMANN H., DANSIZER C., *Temperature dependence of the mechanical properties of human hair in relation to structure*, Journal of the Society of Cosmetic Chemists, 1966, 17, 525–538.

[4] SESHADRI I., BHUSHAN B., *In situ tensile deformation characterization of human hair with atomic force microscopy*, Acta Materialia, 2008, 56(4), 774–781.

[5] WICKETT R. et al., *Effect of oral intake of choline-stabilized orthosilicic acid on hair tensile strength and morphology in women with fine hair*, Archives of Dermatological Research, 2007, 299(10), 499–505.

[6] RUDALL K., *The biomolecular structure of hair keratin*, Progress in Biological Sciences in Relation to Dermatology, 1964, Cambridge University Press, London.

[7] DANILATOS G., FEUGHELMAN M., *The microfibril-matrix relationships in the mechanical properties of keratin fibers*, Textile Research Journal, 1980, 50(9), 568–574.

[8] FEUGHELMAN M., *The physical properties of alpha keratin fibers*, Journal of the Society of Cosmetic Chemists, 1982, 33, 385–406.

[9] PAGAN J., GEAR R., *Advances in equine nutrition*, Nottingham University Press, Thrumpton, 2004, 3.

[10] MARYCZ K. et al., *The correlation of elemental composition and morphological properties of the horses hair after 110 days of feeding with high quality commercial food enriched with Zn and Cu organic forms*, Electronic Journal of Polish Agricultural Universities, 2009, 12(3), #04.

[11] AMELIN M. et al., *Effect of chelated mineral supplementation on the absorption of Cu, Fe, K, Mn and Zn in horse hair*, Journal of Radioanalytical and Nuclear Chemistry, 2003, 258(2), 449–451.

[12] LIU Z., *Lead poisoning combined with cadmium in sheep and horses in the vicinity of non-ferrous metal smelters*, The Science of the Total Environment, 2003, 309(1–3), 117–126.

[13] KOBRYŃ H., KOBRYŃCZUK F., *Anatomia zwierząt*, PWN, Warszawa, 2006, tom 3.

[14] KRIVOVICHEV G., TREGOUBOV V., *Computer modelling of ciliary motility*, Acta of Bioengineering and Biomechanics, 2008, 10(3), 61–64.

[15] DUVEL L. et al., *Analysis of hair lipids and tensile properties as a function of distance from scalp*, International Journal of Cosmetic Science, 2005, 27(4), 193–197.

[16] THOZHUR S., CROCOMBE A., SMITH P., *Structural characteristics and mechanical behaviour of beard hair*, Journal of Materials Science, 2006, 41(4), 1109–1121.

[17] SANTOS-NOGUEIRA A., JOEKES I., *Hair color changes and protein damage caused by ultraviolet radiation*, Journal of Photochemistry and Photobiology B: Biology, 2004, 74(2–3), 109–117.

[18] DOBRZAŃSKI Z. et al., *Influence of organic forms of copper, manganese and iron on bioaccumulation of these metals and zinc in laying hens*, Journal of Elementology, 2008, 13(3), 309–319.