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The Study of Impedance, Thermal Insulation and Breaking Strength of Uniform and Mixed Wool

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Wool belongs to the fibres of animal origin, obtained from sheep, lamas, alpacas, Kashmiri and Angora goats, camels, guanacos and rabbits. It was one of the first fibres used in the production of clothing. In recent years, in addition to the use in the textile industry, its therapeutic properties have been appreciated and found application in the acoustic industry (soundproofing) and construction (thermal insulation) (Ballagh, 1996; Niżnikowski, 2011; Kaczmarska et al. 2001; Wiley et al., 2005).

The specific properties of wool and the physical and chemical characteristics associated with it, such as: fire resistance, breaking strength, hygroscopicity and thermal insulation make it a valuable product of animal origin (Wiley et al., 2005). In the 90s of the 20th century the impact of wool on the human body was also researched. It was indicated then that wool acted as a condenser, keeping the system charged electrically, which has a beneficial effect on the human body (Callahan and Kornberg, 1993). These features are related to its properties as a dielectric, i.e. a material with poor conductivity. It may be a result of low concentration or low mobility of electric charges or both factors at the same time (Jha et al., 2011). As a result, it is possible to use the research of electric properties of wool in order to determine the changes occurring in it, including the determination of its quality.

The study of electrical characteristics has become more and more commonly used in recent years because with a small amount of work it allows to determine changes occurring at the molecular level. This method is used, among others, in assessing the quality of food products and in assessing soils - replacing traditional methods which are often time-consuming and requiring more work. The research is based on the difference in the behaviour of the tested material in the electromagnetic field, which is described by the level of resistance (impedance - the level at which the material conducts the current) or dielectric properties of the material (Samouëlian et al., 2005; Bancalari et al., 2016).

The purpose of the research was to determine the impedance of two types of wool to determine changes in its resistance after washing and in the breed distinction. The examination of electrical characteristics was compared with the heat protection and breaking stress tests.

Material and methods

Research material

The samples were collected from the Zoological Garden in Wroclaw (Wrzosowka sheep - as mixed wool) and from the Agricultural Experimental Station in Swojec owned by the University of Life Sciences in Wroclaw (Olkuska sheep - as uniform wool). The animal shearing was held in May with an annual (12-month) wool recovery. For the measurements of electrical and heat-protective characteristics, samples of greasy wool were collected from 5 animals (females of two to three years of age) from each of the breeds, converged by weight, and after testing - washed and tested again. In order to determine the breaking strength, 15 hair pieces were taken from each individual (of which from Wrzosowka sheep at the ratio of 1:1:1, i.e. 5 hair pieces from each type).The test wool was washed with soap of the following composition: Sodium Tallowate, Sodium Cocoate, Sodium Chloride, Aqua, Glycerin, Tetrasodium Etidronate, Sodium Hydroxide. The weight of the samples was as follows: electrical properties 0.35 g (+/- 0.02 g), heat protection 0.52 g (+/- 0.015 g).

Testing electrical characteristics. The samples were tested using the High Impedance Analyser - Atlas 0441 by Atlas Solich in the Laboratory of Agricultural Engineering at the University of Life Sciences in Wroclaw. The device frequency range was from 10 Hz to 1 MHz. The samples were placed between the copper electrodes in a 3.9 mm thick chamber with the internal diameter of 38 mm, made of plastic. The measurements were taken at the constant temperature of 25°C and 70% humidity and were repeated twice.

Testing heat protection and breaking strength. The study was carried out in the Laboratory of Skin and Hair Coverage of the Institute of Animal Breeding of the University of Life Sciences in Wroclaw using apparatus for the evaluation of materials subjected to thermal radiation, heat protection (WPC) and the equipment for measuring the breaking stress (N) by Matest. The measurements were repeated twice. The breaking strength was calculated according to the formula:

1. $N = (Fn \times 10^4) / (n \times d^2 \times 9.81)$

where: *N* - breaking stress (kg / mm^2),
Fn - breaking force (cN),
d - diameter of the hair cross-section (μm), while heat protection, i.e. the heat transfer index (WPC) according to the formula:
$WPC=GSC_p/GSC_0$
Where: GSC_0 - thermal flux density impeding through the sample ($kW/^2$),
GSC_0 - thermal flux density directed to sample (kW/m^2).

*Elaboration of results***.** In order to determine the effect of washing on the results obtained in the impedance and heat protection tests, the Wilcoxon pairs order test ($P \leq 0.05$) was used while the results of the breaking stress were developed using the Mann-Whitney U test. All the statistical analyses were performed using the STATISTICA ver. 13.1.

The results and their discussion

The impedance test (Ω) of wool samples were performed in the frequency range from 10 Hz to 1 MHz. At lower frequencies, wool samples were characterised by abrupt changes in the values of the characteristics whereas at a frequency of current flow above 64 kHz the progress was linear with a downward tendency. Impedance is a generalisation of electrical resistance; the higher it is, the lower the conductivity of the material, i.e. its resistance is higher.

Significant impedance strokes with noticeable differences due to the type of wool can be observed at the initial frequency, i.e. 10 Hz (Fig. 1). The highest impedance at this frequency is observed with respect to wool of the Olkuska sheep (300 MΩ, while for the washed wool of Wrzosowka sheep it amounts to 80 MΩ). The wool, both washed and greasy, from Olkuska sheep, was characterised by impedance strokes at the frequencies of 20, 40 and 80 Hz, while the wool of Wrzosowka sheep at frequencies of 16, 40 and 98 Hz (Fig. 2), followed by a linear decrease in the impedance value. Similar strokes and linear decrease were observed in washed wool.

The heat-protective test, i.e. determining the heat transfer through the tested material, did not show any significant differences in the two types of wool ($P \geq 0.05$). The heat transfer index for uniform greasy wool was 1.17 and 1.42 for mixed wool. The breaking strength, however, showed differences between the uniform and mixed wool (Tab. 2) as the uniform wool was characterised by about 4 times higher value than mixed wool. The results of the breaking stress, however, did not show any differences between the washed and greasy wool.

The impedance tests revealed significant statistical differences ($P \leq 0.05$) between the washed and greasy wool both form uniform and mixed wool. The largest differences between the washed and greasy wool were shown in Olkuska sheep ($P = 0.000019$, while for the washed and greasy wool of Wrzosowka sheep - $P = 0.000073$). The washed wool at Olkuska sheep is characterised by a higher impedance than greasy wool, and significant differences are visible at 20 Hz frequencies (respectively: 189 MΩ, 35 MΩ), 40 Hz (respectively: 120 MΩ, 34 MΩ), 80 Hz (respectively: 80 MΩ, 31 MΩ). The higher impedance for Wrzosowka sheep wool is observed at 20 Hz frequencies (respectively: 81 MΩ, 29 MΩ), 40 Hz (respectively: 74 MΩ, 33 MΩ), and in the range from 130 to 260 Hz (respectively, in the ranges: 44–28 MΩ, 27–20 MΩ). At frequencies above 32 kHz there is a linear decrease in the impedance value in all tested samples.

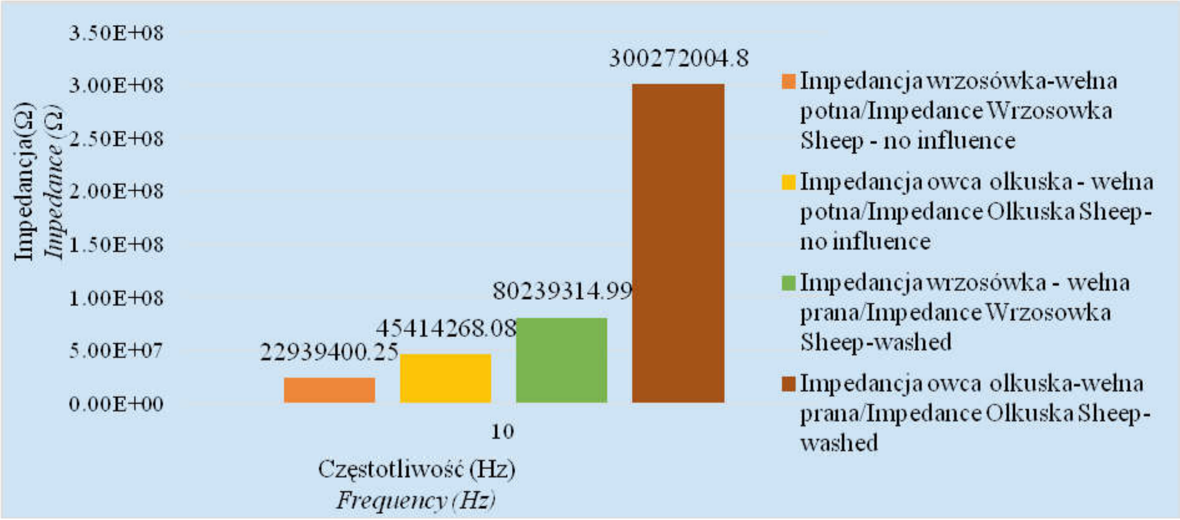

Fig.1. Impedance (Ω) of wool at frequency of 10 Hz

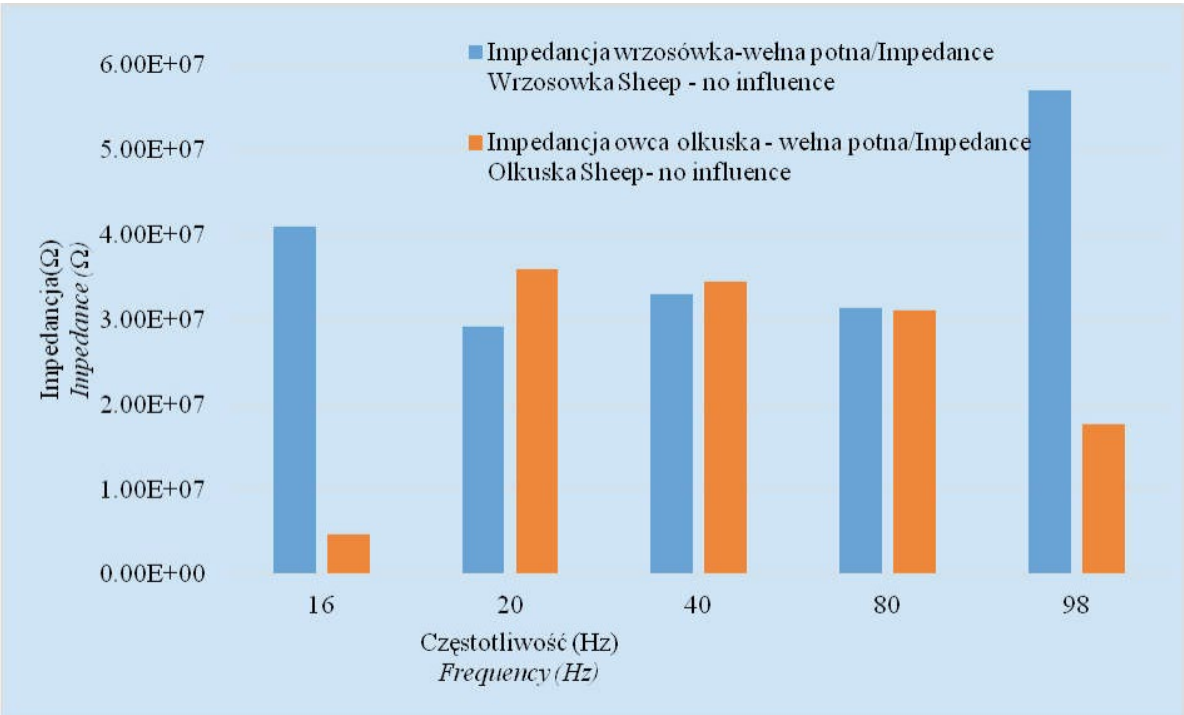

Fig. 2. Impedance (Ω)) of wool from Olkuska and Wrzosowka sheep at frequency of 16, 20, 40, 80 and 98 Hz

Table 1. Heat transfer coefficient of greasy and washed wool

Type	*Greasy wool*	*Washed wool*
Wrzosowka sheep	1,42 a	0,71 b
Olkuska sheep	1,17 a	0,502 b

Table 2. Results of tensile strength of greasy and washed wool (kg/mm²)

Type	*Wrzosowka sheep*	*Olkuska sheep*
Greasy wool	1,54 a	6,54 b
Washed wool	1,52 a	6,39 b

The results of the impedance test showed significant differences between the washed and greasy wool, which is reflected in the thermal permeability test but has not been demonstrated in the breaking strength test. The washing significantly reduced the thermal permeability index (tab. 1), the impedance level increased along with the decrease in thermal transmission.

The impedance phenomenon is commonly used in the assessment of microbiological quality of food products as well as in the examination of agricultural materials because it determines changes at the molecular level (Bancalari et al., 2016, Jha et al., 2011). An additional advantage of this method is the non-destructive effect on the material being tested. The obtained results of the electrical characteristics research are influenced by external factors and the structure of the material under study (Jha et al., 2011).

Individual hair types are characterised by different levels of filling by keratin. Hair is built in 90-95% from "hard" α-keratin. It fills the inside of the hair in varying degrees, which makes it possible to differentiate various anatomic types of hair, and different types of wool due to their occurrence in the cover. Depending on the degree of filling, the hair types differ in thickness, hygroscopicity, strength, elasticity and resistance to mechanical factors. Demonstrating the difference in wool types between the studied animals is related to the diverse structure of the keratin that fills it, which also affects the differences in break stress, the value of which it has a significant impact (Cardamone et al., 2009; Safari et al., 2007; McKittrick et al., 2012). Demonstrating inter-breed differences through electrical features was confirmed in the own study by the breaking strength. However, it was not confirmed by the thermal permeability test, which was probably related to a similar level of thermal insulation of each type of wool.

The level of thermal permeability changed after washing, which was also demonstrated in the impedance level test. It was found that with the decrease in thermal permeability, i.e. the increase in thermal insulation, the resistance of the tested types of wool also increased. The variability in the impedance level resulted in the case of washing up of the grease layer and increasing the electrical conductivity of the sweat, which in 90% consists of water and salts and organic acids (Jaber et al., 2012). The upper layer of the hair is covered with a hydrophobic epicuticle and made of proteins and lipids that reduce electrical conductivity (Kurzepa, 2014; Koehn et al., 2010). This was probably the factor influencing the increase of test resistance in the tested materials.The application of the impedance test reveals both the differences between the types of wool and the effect of washing on wool. Therefore, when studying the electrical properties of wool, it is possible to develop a faster method in the future and reduce the workload to determine its quality and changes under the influence of various factors.

Conclusions

1. The comparison of impedance (Ω) revealed differences in the behaviour in the electromagnetic field of two types of wool - uniform and mixed wool.

1. In the heat-protection test, there were no differences between the washed and greasy wool.

2. The wool impedance test revealed a significant effect of washing ($P < 0.05$) on the wool of Olkuska sheep and Wrzosowka sheep. The washed wool was characterised by higher resistance than the greasy wool. However, no changes have been found in the testing of breaking stress.

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STUDY OF IMPEDANCE, THERMAL INSULATION AND BREAKING STRENGTH OF UNIFORM AND MIXED WOOL

Summary

The study of electrical characteristics allows determining changes at the molecular level. Application of this method to determine changes in the coat may in the future accelerate the tests compared to traditional methods. The study was conducted to determine the differences between two types of wool: uniform and mixed. Electrical parameters (impedance (Ω)) were compared in terms of different types of wool and washing effect. In order to confirm the results, a heat resistance test and a wool stretch test were carried out for each of the studied groups. The impedance (Ω) of wool samples was studied in the frequency range from 10 Hz to 1 MHz. Differences in the impedance of the samples showed differences between homogeneous and mixed wool, which was confirmed by the tensile strength test ($P < 0.05$). On the other hand, the thermal insulation test did not reveal any significant differences between the types of wool. However, it showed a significant impact on wool washing, as well as the study of electrical characteristics. In this case, however, the break stress test showed no difference between washed and greasy wool (no influence). Washed wool was characterized by lower heat resistance, related to the decrease in impedance. The electrical characteristics show the variability of wool types and the impact of its treatment. Further research in the future will allow developing a faster and less labor-intensive method of determining the quality of the coat and the changes taking place under the influence of various factors.

Key words: electrical characteristics, impedance, heat transfer index, breaking strength, wool