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EFFECT OF BRINE CONSTITUENTS ON THE CONTENT AND PROPERTIES OF WATER IN THE *PORCINE MUSCULUS LONGISSIMUS DORSI*

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Abstract. The capacity to bind water exerts a crucial influence on the quality of cured products manufactured from whole muscles and subjected to thermal treatment. The experimental material comprised the lumbar and thoracic parts of the *longissimus dorsi (musculus longissimus lumborum et musculus longissimus thoracis)* muscle of pigs. The aim of the performed experiments was to analyse the impact of different composition of brines which contained a specific quantity of salts of inorganic acids on the value of active acidity, water activity, water holding capacity and the way of water binding. It was found that both parts of raw *longissimus dorsi* muscle differed with regard to the pH value, water activity and molecular dynamics of bound water. The water holding capacity as well as the mutual relationships between the quantities of free and bound waters were identical. The type of the applied brine exerted some influence on the level of water holding capacity. The relative amount of free water in relation to bound water analysed on the basis of relaxation measurements was the highest when the mixture of sodium chloride and sodium triphosphate was applied. The mixture of chloride and sodium diphosphate reduced the relative content of free water in relation to bound water in comparison with the application of brine which contained only NaCl and increased it in comparison with the application of diphosphate. The presence of sodium chloride increased water activity, while the presence of phosphates decreased this parameter. The lumbar part of the examined muscle showed higher water activity. The application of the salt mixture did not change the value of water activity in comparison with NaCl alone for the lumbar part but increased water activity for the thoracic part of the muscle.

Keywords: low field NMR, water activity, water holding capacity

INTRODUCTION

The obtained desirable production results constitute a resultant of the quality of the meat raw material, its tissue structure as well as the type and quantity of the

employed functional additives. Sarcoplasm proteins dissolve in water and mild salt solutions but their impact on meat tenderness is only slight. The meat structure is made up of myofibrillar proteins in the amount of 55-60% and connective tissue proteins – about 2-6% in relation to the total protein content in meat (Pospiech *et al*. 2003). The introduction into muscles of components of curing mixtures, including sodium chloride and polyphosphates, increases their tenderness and reduces thermal drip from muscles during their thermal treatment (Mc Gee *et al*. 2003). The capacity to bind water exerts a decisive influence on the quality of cured products manufactured from whole muscles and subjected to thermal treatment (Uchman 1998). Sodium chloride enhances the solubility of muscle proteins, improves tissue water holding capacity and increases the ionic force of the environment (Xargaýo *et al.* 1998). Moreover, it affects the aroma, the texture and the shelf life of manufactured products (Rauusunen *et al*. 2005), and regulates water activity (Uchman 1998).

In meat industry, different technological additives and their mixtures characterised by different effects on raw material are employed. It was found that the application of a mixture of sodium chloride and lactic acid reduces the water holding capacity and water retention by meat (Medyński *et al*. 2000). On the other hand, meat marination in a mixture of lactic and citric acids results in pH reduction. In comparison with lactic acid, samples treated with citric acid retain water worse (Aktas *et al.* 2003). However, these macroscopic parameters do not allow studying the dynamic state of water. There is no doubt that the introduction of salt into the system affects the way of water binding as well as its mobility. The utilisation of techniques based on the NMR phenomenon makes it possible to analyse in detail the dynamic state of water on the sub-molecular level (Baranowska *et al.* 2006, Ruiz-Cabrera *et al.* 2004, Sorland *et al.* 2004).

The discussed article presents results of investigations concerned with water binding in the thoracic and lumbar parts of swine *longissimus dorsi* muscle using brines of different chemical composition. The aim of the undertaken investigation was to assess the impact of aqueous solutions of sodium chloride and phosphates and their combinations on the content and properties of water in both parts of the investigated muscle. The obtained results may allow optimisation of the curing process depending on the type of the muscle.

MATERIAL AND METHODS

The experimental material comprised the *longissimus dorsi* muscle of pigs, excised from carcasses 48 hours after slaughter. The following two parts of this muscle were investigated: the thoracic (*musculus longissimus thoracis*) and the lumbar (*musculus longissimus lumborum*).

After removing the epimysium from the muscles, they were ground twice through a mesh of 3 mm diameter and the obtained material was mixed thoroughly. Next, the obtained material was divided into portions treated as individual experimental samples. One of them was not subjected to any treatments and was treated as the control (S), and another one (W) was treated with clean deionised water. The remaining samples were treated with brines of different composition which contained specific quantities of inorganic salts. The employed salts were dissolved thoroughly in deionised water of 4-7°C temperature. The amount of the added salts was calculated in relation to the sum of muscle (1 part) and water (2 parts) parts. The following compounds were employed to prepare the brines: sodium chloride (NaCl) in the amount of 2%, tetrasodium diphosphate ($Na_2H_2P_2O_7 \cdot 6H_2O$) – 0.3% converted into P_2O_5 and 0.3% sodium triphosphate ($Na_5P_3O_{10}$) converted into P_2O_5. Each muscle and each sample were analysed in three replications. Sodium triphosphate usually constitutes 70-80% of all phosphates found in various curing mixtures (Uchman 1998). The employed compounds were converted into P_2O_5, among others, because each of the applied phosphates is characterised by a different solubility in water as well as different molecular weight. Samples of comminuted meat were shaken for 3 hours in shakers, together with solutions of the salts listed below and their mixtures:

- sodium chloride,
- tetrasodium diphosphate,
- sodium triphosphate,
- sodium chloride + tetrasodium diphosphate,
- sodium chloride + sodium triphosphate.

At termination of the shaking process, the obtained material was centrifuged in glass vessels for 5 minutes at 3000 rpm obtaining a supernatant and sediment. The ultimate material used for chemical and physical analyses and measurements was the muscular tissue sediment obtained after centrifugation. The pH value was determined using the Accumet-15 pH-meter with a combined electrode against three buffer standards. Water activity was measured with the assistance of Aquaspector-1 apparatus with 0.005 accuracy, after reaching the relative equilibrium humidity in the measuring chamber over the examined sample. At each stage of the experiment, the total water content in muscles was assessed employing the method of drying at the temperature of 105°C as well as the content of free water by Grau-Hamm method (Grau *et al*. 1957). The amount of sodium chloride was determined by the Mohr method using silver nitrate (PN-73/A/82112/Az1/ 2002) and the content of phosphates was estimated with the Quimociac reagent following dry mineralisation of muscle samples (PN-ISO 13730 /1999). The obtained results were converted into P_2O_5. Measurements of the spin-spin and spin-lattice relaxation times were carried out using the NMR spectrometer operating at the

frequency of 30 MHz using inversion-recovery pulse sequence (measurements of the spin-lattice relaxation times) (Fukishima *et al*. 1981) and series of CPMG pulses (measurements of the spin-spin relaxation times) (Carr *et al*. 1954, Meiboom *et al*. 1958).

The results obtained in the study were subjected to three-factorial analysis of variance. The significance of differences between means was determined for the level of $p \leq 0.05$ on the basis of the least significant difference (LSD).

RESULTS AND DISCUSSION

In this experiment, raw muscles (S) and the tissue sediment of muscles in which the brine solution (W) was replaced by deionised water were treated as control samples. Samples with the addition of individual brines were designated as follows: tissue sediment with the addition of sodium chloride – (N), with the addition of tetrasodium diphosphate – (P), with the addition of sodium triphosphate – (T), with the addition of the mixture of sodium chloride + tetrasodium diphosphate – (P+N) and with the addition of sodium chloride + sodium triphosphate – (T+N). Changes in the active acidity are presented in Figure 1.

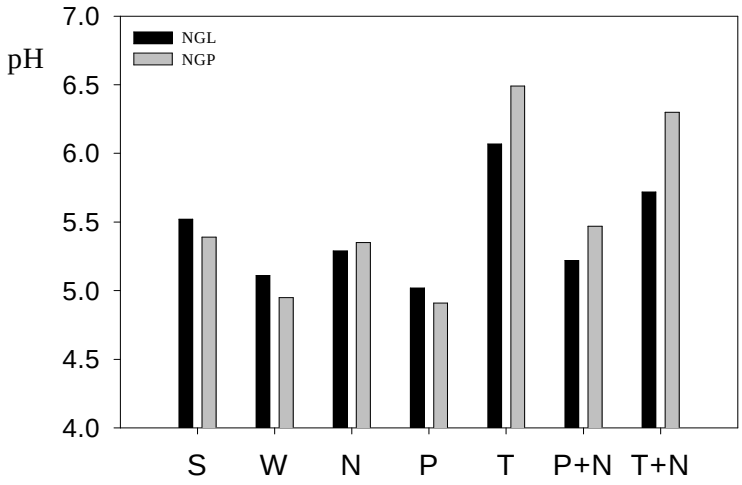

Fig. 1. Changes in active acidity in the examined muscle sediments (NGL – lumbar part of the muscle, NGP – thoracic part of the muscle)

The addition of clean water to the system causes increased acidity, whereas the inclusion of sodium chloride and triphosphate reduces the acidity of the systems (in comparison with the control sample W) and this effect is more apparent when

triphosphate is added. The introduction of diphosphate increases the acidity of muscle sediments. Significant acidity changes are observed following the application of mixtures of salts making up the brine. The acidity of the systems was reduced more by the mixture of diphosphate and sodium chloride than by the mixture of triphosphate and sodium chloride.

The content of sodium chloride and phosphates was determined in the examined muscle sediments. The results of assays are presented in Figures 2 and 3.

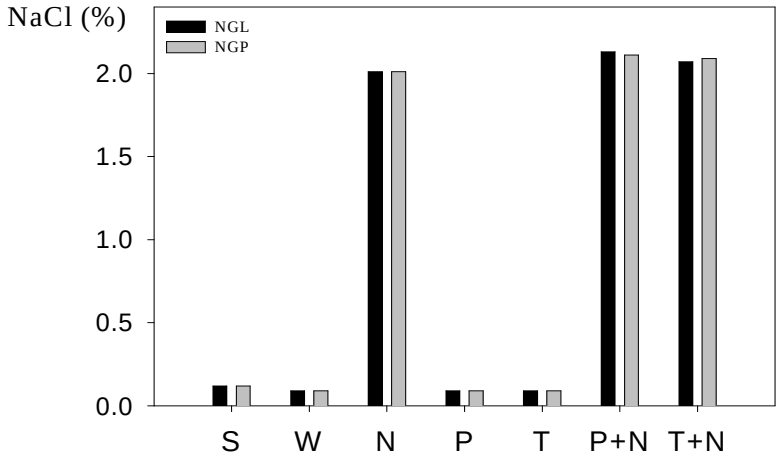

Fig. 2. Content of sodium chloride in the examined muscle sediments

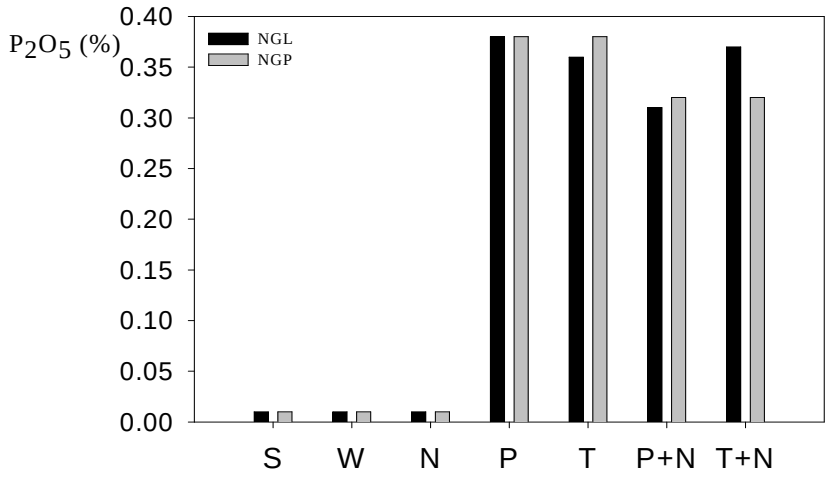

Fig. 3. Content of phosphates in the examined muscle sediments

In comparison with the control samples, increased quantities of sodium chloride were found only in the systems to which this salt was added. Similarly, elevated amounts of phosphates were recorded only in samples to which brines containing these compounds were added. The addition of sodium chloride to brines containing diphosphate and triphosphate reduced the content of phosphates.

In order to ascertain how the individual brines change the content of water in the muscle sediment, changes in the percentage proportion of free water (Ww) in the total water content (Wo) in the system were analysed (Fig. 4). Quantitatively, the value of this parameter is equal to the water holding capacity.

The value of this parameter is the same in both parts of the raw *longissimus dorsi* muscle. The application of the brine containing diphosphate does not cause changes in the water holding capacity in comparison with the sediment obtained after shaking the comminuted muscles with water. All the remaining brines reduce the content of free water in relation to the total water content. No significant changes were observed between systems containing sodium chloride, triphosphate and the mixture of both these salts. The water holding capacity of the sediment containing diphosphate and sodium chloride is low and comparable with the value determined for the raw muscles.

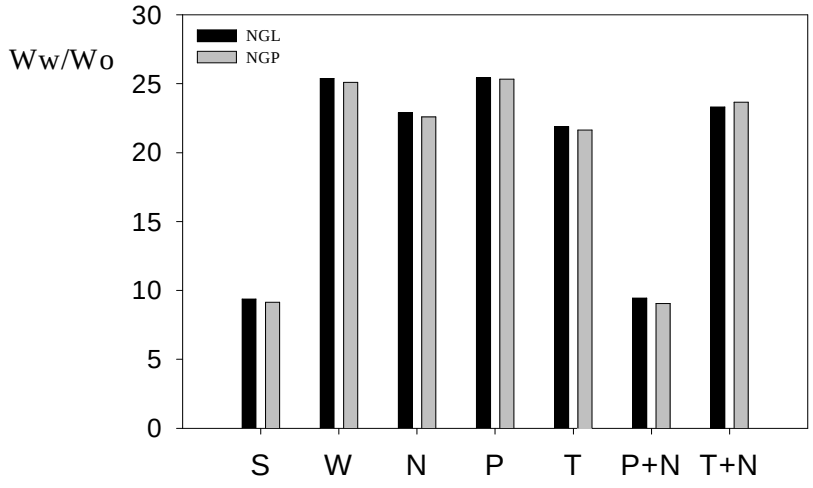

Fig. 4. Percentage proportion of free water in the total water content in the examined muscle sediments

Measurements of the water activity in the examined muscles revealed differences between the two parts of the muscle but these differences were only slight (Fig. 5).

In comparison with the system containing water, water activity is reduced following the addition of sodium chloride. Water activity increases after the addition

of diphosphates and triphosphates. Mixtures of sodium chloride and diphosphates or triphosphates reduce a_w in comparison with the brines containing only phosphates; however, in the thoracic part of the muscle these values are higher than in the treatments when brines containing only NaCl are applied.

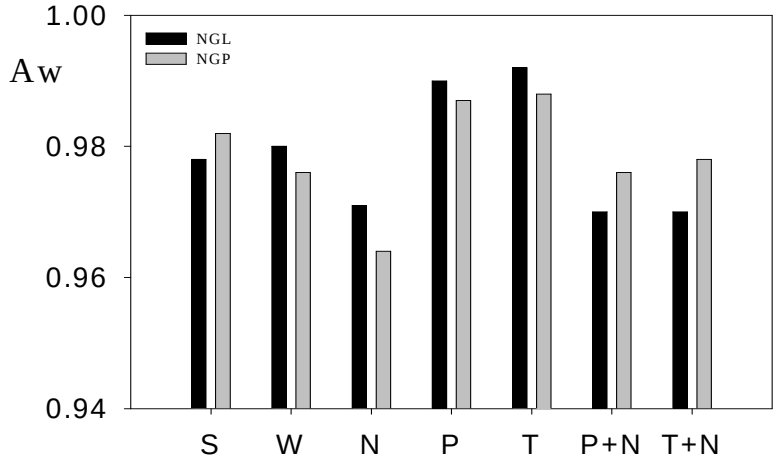

Fig. 5. Water activity in the examined muscle sediments

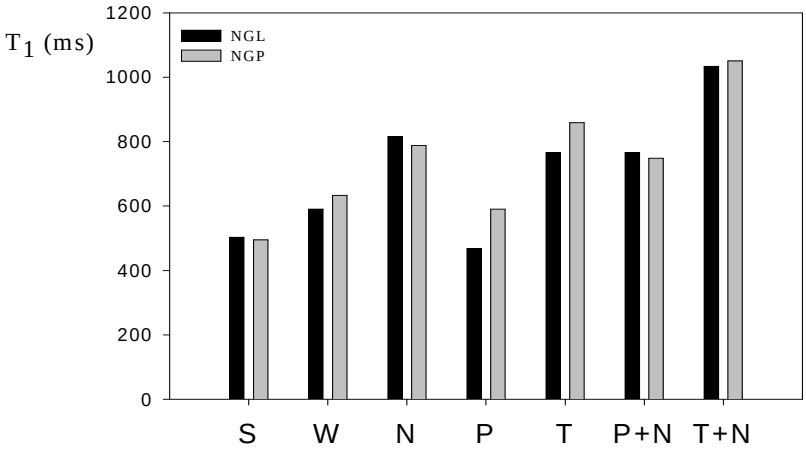

Fig. 6. Values of the spin-lattice relaxation times in the examined muscle sediments

In both parts of the analysed raw muscle, the quantity of free water in relation to bound water is the same (Fig. 6).

In comparison with the systems containing deionised water, the T_1 value is observed to decline only in the case of the application of the brine containing diphosphate. The lumbar part of the examined muscle contains more bound water. The addition of sodium chloride leads to increased quantities of free water in relation to bound water in the system. These values are identical in both parts of the examined muscle.

Figures 7 and 8 present values of the spin-spin relaxation times of the bound water fraction (T_{21}) and free water fraction (T_{22}) in the analysed systems.

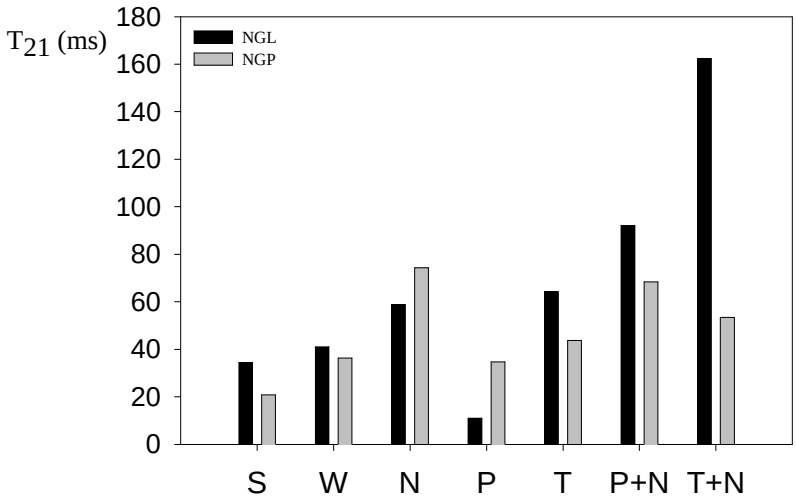

Fig. 7. Values of the short component spin-spin relaxation times in the examined muscle sediments

A significant impact of the brine on the molecular dynamics of bound water is observed. Furthermore, probably due to differences in the histological structure of the two parts of the muscle, differences in the T_{21} values in raw muscles were observed. Water is bound more strongly in the thoracic part of the muscle. Deionised water causes that the T_{21} values increase in both parts of the examined muscle. In comparison with the raw muscles, greater differences were found in the thoracic part of the muscle which may suggest worse water binding on protein molecules.

The free water dynamics (Fig. 8) is identical in both parts of the raw muscle. The T_{22} value increases after the addition of deionised water to the muscle. The brine containing only sodium chloride causes that the dynamics of both water fractions increases. Moreover, water is more mobile in the lumbar part of the examined muscle than in the thoracic part. Sodium diphosphate contained in the brine limits considerably the mobility of both water fractions in the lumbar part.

On the other hand, no changes in the T_{21} and T_{22} values are observed in the thoracic part of the muscle in comparison with samples containing deionised water, but sodium triphosphate introduced into the system causes that the water dynamics in the lumbar part of the muscle is higher than in the thoracic part. The mixture of sodium chloride and phosphates makes bound water more dynamic in the lumbar part of the examined muscle, while the dynamics of free water is limited in comparison with the second part of the muscle.

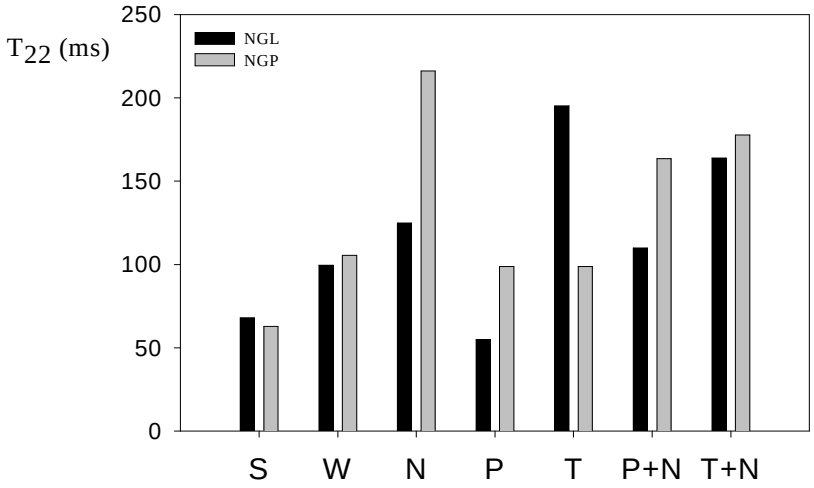

Fig. 8. Values of the long component spin-spin relaxation times in the examined muscle sediments

Data obtained from the relaxation studies reveal quantitative and qualitative changes in both water fractions following the addition of phosphate-containing brines. The application of sodium chloride fails to affect differences in the T_1 values in both parts of the muscle, although different dynamics is observed depending on the analysed part of the *longissimus dorsi* muscle. Similar effects are observed using the mixture of phosphates and sodium chloride.

The results discussed above indicate clearly that different structural parameters of the muscle fibres of both parts of the *longissimus dorsi* muscle exert some influence on changes in the way and quantity of water binding in the system. Macroscopic parameters, such as water holding capacity, do not expose these differences. Changes in the activity of water are observed but, due to the values of this parameter (changing from about 0.966 to about 0.987), it is difficult to analyse the changes in detail on the sub-molecular level only on the basis of these data.

CONCLUSIONS

1. Both parts of the raw *longissimus dorsi* muscle differ with regard to the acidity, water activity and the molecular dynamics of bound water. The water holding capacity as well as the relationships between the amount of free and bound water are the same.

2. The type of the applied brine affects the value of the water holding capacity. The mixture of sodium chloride and diphosphate reduces the water holding capacity to the level of raw muscles. No significant differences were found in the water holding capacity of the two parts of the examined muscle using sodium chloride, triphosphates and the mixture of these two salts.

3. The relative amount of free water in relation to bound water analysed on the basis of relaxation measurements is the highest when the mixture of sodium chloride and sodium triphosphate is applied. The mixture of sodium chloride and sodium diphosphate reduces the relative content of free water in relation to bound water in comparison with the case when the brine containing only NaCl is used and increases it in comparison with the application of diphosphate.

4. The presence of sodium chloride increases water activity, while that of phosphates reduces this parameter. The lumbar part of the examined muscle shows higher water activity. The application of a mixture of salts does not change the value of water activity in comparison with NaCl alone for the lumbar part, but increases the water activity for the thoracic part.

5. The above conclusions make it possible to optimise the choice and adjust the composition of the brine to the type of the cured muscle.

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WPŁYW SKŁADNIKÓW SOLANKI NA ZAWARTOŚĆ I WŁAŚCIWOŚCI WODY W MIĘŚNIU NAJDŁUŻSZYM GRZBIETU ŚWIŃ

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S t r e s z c z e n i e. Zdolność wiązania wody ma decydujący wpływ na jakość wyrobu peklowanego, wyprodukowanego z całych mięśni i poddanego obróbce cieplnej. Materiał doświadczalny stanowiły: część lędźwiowa i piersiowa mięśnia najdłuższego grzbietu świń. Analizowano wpływ solanek o zróżnicowanym składzie, które zawierały określoną ilość soli kwasów nieorganicznych na wartość kwasowości czynnej, aktywności wody, wodochłonność oraz sposób wiązania wody. Stwierdzono, że obie części surowego najdłuższego mięśnia grzbietu różnią się kwasowością, aktywnością wody i dynamiką molekularną wody związanej. Wodochłonność i wzajemne relacje między ilością wody wolnej i wody związanej są takie same. Rodzaj zastosowanej solanki ma wpływ na wartość wodochłonności. Względna ilość wody wolnej w stosunku do wody związanej analizowana na podstawie pomiarów relaksacyjnych jest największa przy zastosowaniu mieszaniny chlorku sodu i trójpolifosforanu. Mieszanina chlorku sodu i pirofosforanu obniża względną zawartość wody wolnej w stosunku do wody związanej w porównaniu do zasto-

sowania solanki zawierającej tylko NaCl i podwyższa w porównaniu do zastosowania pirofosforanu. Obecność chlorku sodu powoduje wzrost aktywności wody a fosforanów obniża ten parametr. Część lędźwiowa mięśnia wykazuje wyższą aktywność wody. Zastosowanie mieszaniny soli nie zmienia wartości aktywności wody w porównaniu do samego NaCl dla części lędźwiowej ale podwyższa aktywność wody dla części piersiowej.

S ł o w a k l u c z o w e: aktywność wody, wodochłonność, relaksacja NMR