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Article

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INFLUENCE OF ELECTROCHEMICALLY ACTIVATED WATER ON THE PHYSICAL PROPERTIES AND RHEOLOGICAL INDICATORS OF MEAT PATES

The object of research is the physical properties and rheological indicators of meat pates with corn starch suspensions prepared with activated water. Among the components of the composition of drinking water and food products, there are many substances with particularly inherent biological activity. The biological activity of water is caused by increased electronic or proton activity. Today, various ways of changing properties of water are known, but the most promising reagent-free method is the electrochemical activation of water. As a result of electrochemical treatment of water with an electric current, its electrochemical characteristics change. As a result, electrochemically activated aqueous solutions (catholyte/anolyte) are obtained; the water is saturated with oxygen, accelerates the removal of metabolic waste and promotes the most complete assimilation of nutrients.

The research was aimed at determining the influence of activated water in the composition of starch suspensions on the physical properties and rheological indicators of meat pates with their content. Activated water affects the pH value of pates, which in the meat industry indicates the freshness and quality of meat raw materials and products made from them. Before pasteurization, the pH value for all samples was practically identical. That is, at the initial stage, activated water does not affect the acidity of pates. In the process of storage, the concentration of (H^+) ions increases in pates, and the pH shifts to the acidic side. Water activity indicators of pates with starch suspensions on activated water gravitate towards the indicators of pates more than to the indicators of starch, the range for which is within 0.280–0.400. The dependence of the change in shear stress on the relaxation time of pates showed that regardless of the dosage of the starch suspension, the values of the shear stress of the samples on the catholyte in the time range 0–300 s are significantly higher than the values of the samples on the anolyte and tap water. This is explained by the ability of these samples, having acquired the necessary structure, to be less exposed to the external influence of deformation and to keep the structure more intact. The creep curves of all samples testify about the trimodal nature of the classical experimental creep curve. Thus, the electrochemical activation of water modifies the properties of corn starch and significantly affects the rheological indicators of meat pates containing it.

The obtained results can be used in the development of recipes for meat pates and their production at enterprises.

Keywords: *electrochemically activated water, anolyte, catholyte, starch suspension, rheological indicators, meat pate.*

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1. Introduction

There are many substances with a particularly inherent biological activity among the components of the composition of drinking water and food products. Biological activity means the ability to bioregulate the physiological processes of life, the ability to supply the body with the necessary macro- and microelements, natural vitamins, enzymes, amino acids, etc. [1].

The biological activity of water is caused by increased electronic or proton activity, since water is a quantum-mechanical system consisting of free and associated water phases [2, 3]. The association of charged dipole water molecules in clusters is carried out due to hydrogen bonds between different electric poles of neighboring water molecules [4]. Nowadays various ways of changing the properties of water are known – chemical, biochemical, physical and others. However, the most promising reagent-free method is the electrochemical activation of water.

Water with temporarily changed physical and chemical properties with an unchanged chemical elemental composition before and after the activation process is a substance in a thermodynamically unbalanced state. This substance has an excess of internal potential energy, which gradually dissipates or rapidly decreases in the process of various physical and chemical interactions, causing its abnormal activity.

As a result of electrochemical treatment of water using an electric current, its electrochemical characteristics change. In this case electrochemically activated aqueous solutions (catholith/anolyte) are obtained; the water is saturated with oxygen, accelerates the removal of metabolic

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waste and promotes the most complete assimilation of nutrients [5].

The electrical conductivity and ionization of water is explained by three types of electric charge transfer mechanisms: covalent charge transfer (Faraday's law – this law does not take into account the presence of a supramolecular structure in water. Only a separate dipole of water is taken into account). Relay charge transfer – a solvated proton loses its solvate (hydrate) shell and then it is transferred under the action of an electric field surrounded by amorphous water molecules to the next location, where a new solvate (hydrate) shell is formed around it. Crocket charge transfer – spatial charge transfer with a «plus» sign of a proton takes place with the participation of associated molecular complexes (water clusters). This mechanism is more often recognized in studies in biological water media [6].

When considering the mechanism of proton mobility in associated water, it is assumed that the thermally activated deformation of the oxygen framework of structural associates of water makes a significant contribution to the electronic excitation energy of water molecules that are part of typical ring associates of water (pentameters and hexamers). Such a deformation is capable of covering large fragments of aggregates of water molecules, since the compression of one structural ring is accompanied by the expansion of neighboring ones, and vice versa.

Molecular hydrogen has great potential for prophylactic and therapeutic applications in many diseases due to its great efficiency and novel concept. It was proven that the simplest, most practical and most effective method of hydrogen obtaining is its obtaining with water. Hydrogen dissolved in water is a convenient and safe method of its introduction into the body [7].

Hydrogen water is able to selectively suppress the most toxic free radicals (hydroxyl radical and peroxynitrite), which are harmful to cells and tissues of the human body. Hydroxyl radical is not long-lived (the life time in the cell is about 7–10 s) and highly reactive compound, capable of oxidizing protein and lipid molecules, especially unsaturated membrane lipids, which can cause changes in the properties of cell membranes. In addition, the hydroxyl radical induces bond breaks in the DNA molecule, which leads to irreversible damage to the genetic apparatus [8].

Molecular hydrogen has various positive effects: antioxidant, anti-inflammatory, anti-apoptotic, anti-allergic, and it also stimulates energy metabolism [9].

The mechanism of the positive effect of hydrogen on the human body is related to its unique properties:

1. H_2 quickly transforms particularly toxic hydroxyl radicals found in the body into water. It easily penetrates inside cells and effectively neutralizes cytotoxic oxygen radicals, protecting proteins, DNA and RNA from damage.

2. H_2 supports the activity of the body's own antioxidants, activates and regulates the action of additional antioxidant enzymes, such as glutathione, superoxide dismutase, catalase, etc., as well as protein substances that are part of the cell's defense systems. H_2 perform signaling functions that promote intercellular communication, cell metabolism, and gene expression.

3. Hydrated formations of water molecules around hydrogen molecules form the smallest water clusters, the presence of which helps to overcome cell dehydration and transport vitamins and minerals to the cell.

4. The biological value of drinking water is an unconditional fact as a result of numerous medical and biological studies. The main reason for the acquisition of hydrogen-enriched water with antioxidant and immunomodulatory properties is the formation of a reducing electron-donating state in water, which is the key to its health-improving properties [10].

The health effect of electrochemically activated water is interesting for the scientific community. Research is being conducted on the effectiveness of using electrochemical treatment of water to improve the quality of products based on it, in particular for the production of beer, milk whey, dough kneading, etc. [11, 12].

Significant therapeutic advantages of molecular hydrogen and hydrogen-enriched water in comparison with other known antioxidants are the following:

– high regenerative potential;
– lack of influence on the physiological parameters of the blood (temperature, pressure, pH, O_2 etc.);
– a complex mechanism of influence;
– the ability to activate the body's own endogenous antioxidants – vitamins and enzymes (synergistic effect);
– selectivity of action (hydrogen neutralizes mainly cytotoxic radicals, without affecting less active signaling molecules, which are also active forms of oxygen, but perform physiologically useful functions and are necessary for normal metabolism).

The small size of the molecules allows them to penetrate through the hematoencephalic barrier and biological membranes (including mitochondria, where hydrogen suppresses cytotoxic free radicals at the site of their formation, and the nucleus, where hydrogen prevents the oxidative destruction of DNA) [13]. Such water is characterized by a low level of side effects, even with high concentrations of hydrogen, due to the absence of byproducts, unlike other known antioxidants. Hydrogen, interacting with the hydroxyl radical, forms a neutral water molecule, and no chain reactions or side chemical compounds are formed [14].

One of the main branches of the food industry is meat branch. Methods for preserving animal meat in a cooled state using activated water (anolyte, catholyte) are being studied. Before cooling, meat is sequentially treated with catholyte with pH=11–13 and a redox potential (RP) of 600/800 mV and then with anolyte with pH=1.5–3 and RP of 800–1200 mV with an active chlorine content of 0.05–0.10 %. Catholyte and anolyte were obtained from an aqueous solution of magnesium chloride 0.5–1 %, with a specific energy consumption of 1000–1500 Kl/l. In this case, the anolyte is passed through a catalyst or a sorbent, for example, activated carbon or manganese oxide carbon. This invention makes it possible to increase the effectiveness of the anolyte by increasing the shelf life of meat while simultaneously reducing energy consumption, to obtain preservatives for meat, which will make it possible to expand the raw material base [15], along with other methods of increasing the functional and technological indicators of raw materials for meat products [16, 17].

Meat pates are in wide demand among consumers. The composition of the recipe includes components that are able to provide the necessary structure of the product. Starch products have gained popularity as structure formers and emulsifiers.

Corn starch is used to regulate the structural and mechanical properties of pates in the meat industry. The ability to hydrate and swell allows to change the viscosity of starch suspension. Phospholipids in starch granules can be complexed with amylose, which prevents water binding, resulting in lower swelling power and low viscosity at high temperatures.

In starches with a high amylose content, the amylose-lipid complex and low amylopectin content cause very low swelling capacity and low viscosity even at high temperatures. In contrast, high amylopectin content is involved in higher swelling capacity and higher viscosity at low temperatures [18].

Due to the high water-absorbing capacity of starch, the viscosity of pates increases and proper structure formation is ensured. In this process, the water used to prepare starch suspensions plays an important role.

Improvement of existing methods of water activation and study of new ones will contribute to the solution of the problems of imparting beneficial properties directly to water and products containing it, at the same time contributing to the regulation of sensory and physicochemical indicators of these products. In particular, solving the problems of water preparation and determining the parameters of this process to ensure the structuring of food systems is relevant.

Therefore, *the aim of the research* was to determine the effect of activated water in the composition of starch suspensions on the physical properties and rheological indicators of pates with their content.

2. Materials and Methods

2.1. Preparation of samples. Electrochemically activated water obtained by the electrochemical method was used for the research. To obtain electrochemically activated water, tap water was used (supplier – JSC «Kyivvodokanal», Ukraine), which was characterized by RP=+224, pH=6. For activation, tap water is passed through a laboratory diaphragm electrolyser. Two experimental samples of activated water were obtained with different set parameters of RP: catholyte (RP=–542±20, pH=10) and anolyte (RP=+767±15, pH=3).

Corn starch suspensions were prepared in a ratio of corn starch:water – 1:10 using catholyte and anolyte at a temperature of t=23±2 °C (the temperature at which starch modification begins). The suspensions were kept for 2 hours to ensure starch hydration. Pates were prepared from chicken liver and meat, bread, a mixture of vegetables – onions and carrots, eggs and milk. Suspension of corn starch in different quantities were added to the recipe. In the production of pates, traditional technological modes of production of pasteurized canned pates were used [19].

Samples of pates with suspensions of corn starch prepared using tap water were control samples.

2.2. pH of pates. Active acidity was determined at a product temperature of 20±2 °C. About 40 cm^3 of pate was put into a clean, dry glass, the electrodes were immersed into it, and after 10–15 s the numerical indicators were taken on the scale of the device.

2.3. Water activity of pates. Water activity in pates was determined using a HygroLab-2 water activity analyzer (Rotronic, Switzerland) at room temperature in the measurement range of 0–1 a_w (0–100 % relative humidity).

The studied sample is put into a container and placed in a measuring chamber. The water activity sensor is installed on the top. The measurement cycle lasts 3–5 minutes, after which the value of water activity and temperature for each sample is indicated on the display [20].

2.4. Rheological indicators of pates. Rheological indicators were determined using a Kinexus Pro+ rheometer (Malvern Instruments Ltd., Great Britain). The used geometry was a circular plate with a diameter of 40 mm (PU40 SR5040 SS:PL61 ST), fixed on a vertical shaft. The prepared sample was placed on the lower platform; the shaft with the plate was lowered to a gap of 1 mm. The relaxation characteristics of pates were determined by the dependence of shear stress and shear strain on relaxation time. The study was conducted for 300 seconds [21].

3. Results and Discussion

One of the important indicators of product quality in the food industry is the acidity/alkalinity (pH) of the food medium. The pH indicator in the meat industry indicates the freshness and quality of raw meat and products from it.

The analysis of studied pates (Table 1) before pasteurization showed an almost identical pH indicator for all samples. That is, at the initial stage, activated water does not affect the acidity of pates.

After pasteurization, the samples with starch suspensions on activated water with both 2 % and 5 % starch had a slightly lower pH value compared to the control samples. High temperatures in the process of pasteurization destroy myoglobin, causing the release of iron, which can increase the pro-oxidant potential of pates [22]. On the other hand, the destruction of tissues leads to the release of pro-oxidants naturally present in raw meat. Water activation affects these processes but not insignificantly.

In the process of storage the concentration of (H^+) ions increases in pates, and the pH shifts to the acidic side. This indicates that muscle proteins in liver pate are susceptible to oxidative reactions, which lead to a pH shift towards an acidic medium [23]. The pH indicators of all pate samples are almost the same, regardless of the production of starch suspensions using activated water or tap water.

Pates are short-term storage products. In particular, the water activity indicator is used to predict the shelf life of food products. The value of the water activity index (a_w) in food products also affects the sensory indicators, microbiological stability, and the manufacturing process.

The activity of water characterizes its ability to participate in physical, chemical and biochemical reactions. The activity of water in the bound state is lower than in the free state.

The indicators of water activity of pates with starch suspensions on activated water (Table 2) tend to the indicators of pates more than to the indicators of starch, the range for which is within 0.280–0.400 [24].

Table 1

Indicator of acidity of pates medium

Sample	Before pasteurization	After pasteurization	After pasteurization (21 days after depressurizing the package)
Control sample with 2 % starch	6.5	6.7	6.3
Sample with 2 % starch on anolyte	6.6	6.65	6.4
Sample with 2 % starch on catholyte	5.65	6.6	6.3
Control sample with 5 % starch	6.6	6.72	6.4
Sample with 5 % starch on anolyte	6.6	6.55	6.3
Sample with 5 % starch on catholyte	6.6	6.65	6.3

Table 2

Water activity index of pates with starch suspensions prepared on activated water

Sample	Control sample with 2 % starch	Sample with 2 % starch on anolyte	Sample with 2 % starch on catholyte	Control sample with 5 % starch	Sample with 5 % starch on anolyte	Sample with 5 % starch on catholyte
Before pasteurization	0.970	0.969	0.980	0.960	0.962	0.984
After pasteurization	0.971	0.950	0.970	0.972	0.970	0.973
After pasteurization (21 days after depressurizing the package)	0.963	0.960	0.972	0.970	0.971	0.969

The water activity of pates with a starch suspension prepared on the anolyte practically does not change before pasteurization, compared to the control sample, but on the catholyte it increases to a greater extent with an increase in the starch content in the suspension: by 1 % and 2.5 % at 2 % and 5 % of starch.

After pasteurization, a significant change in the indicator was observed. In the sample on anolyte and 2 % starch, a_w decreased significantly – by 2.2 %, and this indicator remained unchanged for the control sample. Raw pates contain a large amount of available water, which explains the short shelf life of these products. In addition, this fraction of water is weakly bound to the solid food matrix [25]. Activated water in the process of heat treatment of raw pates affects the process of modification of protein and carbohydrate structures, thereby reducing a_w by inducing the formation of water molecular clusters [26]. This should have a positive effect on their microbiological stability [27, 28].

For the sample on catholyte, a_w reached a similar value as for the control sample. In general, compared to the values before pasteurization, samples of pates on anolyte and catholyte had lower values of the studied parameter.

In the pate sample with 5 % starch in suspension, the trend was different. Values for samples on tap water and anolyte increased, and on catholyte – decreased, compared to the values of pates before pasteurization. However, all pates had approximately the same water activity indicators.

After 21 days, a_w values slightly increased compared to the values immediately after pasteurization. This is explained by the fact that during the storage process, an increase in water activity was observed in the samples, which is probably related to the process of proteolysis. However, the changes were not significant [29].

During the technological process of making pates, a mechanical force is applied to the sample. It is important to know how quickly the sample reacts to the application of an external force. Relaxation time describes this indicator.

The yield strength is an estimate of the rheology index of pate products, which indicates the resistance to the movement of the braking force between the particles of the raw material in the product [30]. Studies of the dependence of the change in shear stress (σ) on the relaxation time (τ) of pates with different dosages of corn starch suspensions on tap water (control sample), catholyte on anolyte (Fig. 1) showed that the nature of the curves is more influenced by the used water than the amount of starch suspensions. Suspensions have a relaxation time scale similar to viscoelastic fluids, but they do not behave like viscoelastic fluids [31].

Regardless of the starch suspension dosage, the values of shear stress (σ) of the samples on the catholyte in the time range of 0–300 s are significantly higher than the values of the samples on the anolyte and tap water. At the initial moment, the values of the yield strength of all samples reach their maximum value. The stress reached a maximum at τ=72–73 s and then entered the relaxation stage, then slowed down to gradually approach a fixed value, which is consistent with the recovery characteristics of the structure [32].

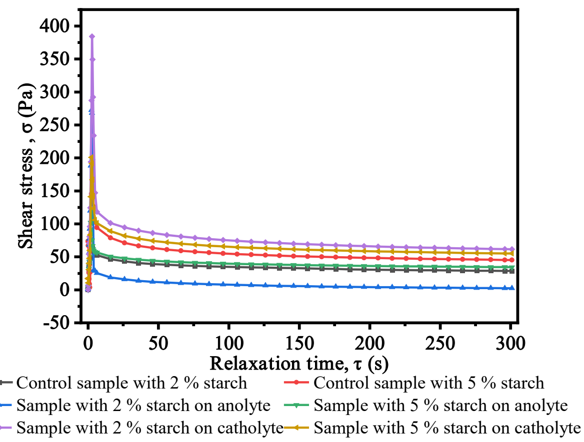

Fig. 1. The dependence of the change in the shear stress on the relaxation time of pate samples with different dosages of corn starch suspensions prepared on water with different RP indicators

As the relaxation time (τ) increases, the values gradually decrease, stabilizing after 150 s of relaxation. At the final stage, the shear stress (σ) of the sample on the anolyte with 2 % starch in the suspension practically reaches zero. This testifies to the ability of this sample, having acquired the necessary structure, to be less exposed to the external influence of deformation and to keep the structure more intact [33].

Water not only plays a role in the formation of the pate structure, but also provides the necessary reaction medium [34].

As can be seen from Fig. 1, the curves of the samples on the anolyte are located below, and the catholyte, interacting with the starch granules in the suspension, prevents the improvement of the increasing speed of the yield point of the pates.

The creep curves (curves of deformation versus time at a constant applied differential voltage) of all samples indicate the trimodal character of the classical experimental creep curve, i. e., three phases of creep are observed – primary, secondary, and tertiary (Fig. 2) [35].

Samples of pates with starch suspensions on tap water and catholyte have practically the same values throughout the experiment. Samples with anolyte are significantly different. At the same time, the amount of starch in the suspension is important: with 5 %, the shear deformation (Y^*) is greater (up to 11 %), with 2 % is less (up to 8 %). The nonlinear effect is observed only in the first stage up to 75 s of relaxation. At the same time, the samples were deformed at very slow speeds. As the relaxation time (τ)

increased, the deformation did not increase. This fact indicates that the shear deformation (Y^*) of the samples does not depend on time, but on the available stress. In the sample containing 5 % starch in the suspension prepared on the anolyte, this dependence is different. For this sample, the factorial character of the relaxation process is observed, that is, the dependence of the shear strain (Y^*) on the relaxation time to a greater extent than on the stress, since this indicator stops changing after 175 s of relaxation [36].

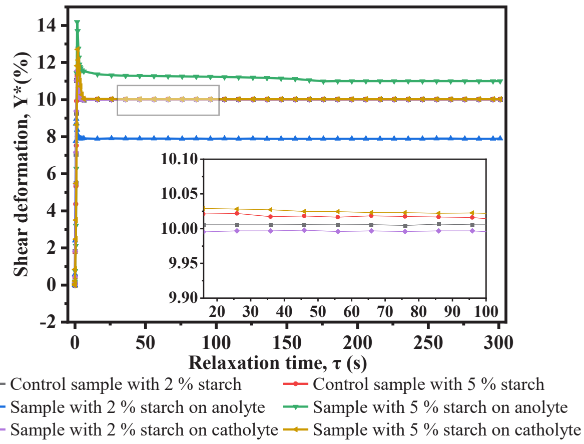

Fig. 2. The dependence of the change in the shear strain on the relaxation time of pate samples with different dosages of corn starch suspensions prepared in water with different RP indicators

On the basis of the conducted research, it was established that the electrochemical activation of water modifies the properties of corn starch and significantly affects the rheological indicators of meat pates containing it. In particular, the speed of reaction of pate samples changes to the application of an external force, which occurs during the technological process of their production. Activated water in the composition of corn starch suspensions practically does not affect the change in the active acidity of pates and has a negligible effect on the activity of water in the samples.

The obtained results can be used in the development of recipes for meat pates and their production at enterprises.

There were no significant restrictions when conducting research, however, the influence of martial law conditions took place due to the impossibility of conducting research during an air raid, which delayed the timing of their conduct and processing of results. Also, the temporary lack of electricity prevented the planning of experiments.

When conducting further research, it is advisable to determine the influence of activated water on other rheological parameters of pates, in particular, viscosity characteristics, as well as on the redistribution of moisture bond forms in products.

4. Conclusions

1. Activated water affects the pH value of pates, which in the meat industry indicates the freshness and quality of meat raw materials and products made from them. Before pasteurization, the pH value for all samples was practically identical. That is, at the initial stage, activated water does not affect the acidity of pates. In the process of storage of pates, the concentration of (H+) ions increases, and the pH shifts to the acidic side.

2. The water activity indices of pates with starch suspensions on activated water tend towards those of pates more than those of starch, the range for which is within 0.280–0.400.

3. The dependence of the change in shear stress on the relaxation time of pates showed that the nature of the curves is more influenced by the used water than the amount of starch suspension. Regardless of the dosage of the starch suspension, the shear stress values of the samples on the catholyte in the time range of 0–300 s are significantly higher than the values of the samples on the anolyte and tap water.

4. The creep curves (curves of deformation versus time at a constant applied differential voltage) of all samples indicate the trimodal nature of the classical experimental creep curve, i. e. three phases of creep are observed – primary, secondary and tertiary.

5. Thus, the electrochemical activation of water modifies the properties of corn starch and significantly affects the rheological indicators of meat pates containing it.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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The study was performed without financial support.

Data availability

The manuscript has no associated data.

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