Physico-chemical and rheological properties of meat pates with corn starch suspensions prepared on electrochemically activated water

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Abstract

Introduction. The aim of the study was to determine the influence of electrochemically activated water application on the rheological properties of corn starch suspensions and pates prepared with them.

Materials and methods. Corn starch suspensions were prepared on artesian water, which was activated by electrochemical treatment on a diaphragm electrolyzer. Physico-chemical characteristics of electrochemically activated water were determined using a Palintest 7500 photometer. Morphological studies of starch granules were carried out by scanning electron microscopy, and granulometric composition was determined by laser diffraction method. The rheological indicatorss of starch suspensions and pates were studied using a Kinexus Pro+ rheometer.

Results and discussion. The physico-chemical characteristics of electrochemically activated water except pH met the requirements of the European Parliament and Council Directive on the quality of water intended for human consumption. The water absorption capacity of starch when preparing its suspensions on a catholyte (obtained by passing a direct electric current through water in the cathode chamber of an electrolyzer) decreased by 26%, and when prepared on an anolyte (obtained in the process of water oxidation reactions on the anode) increased by 18%. The moisture holding capacity of hydrated starch decreased by 10% when using catholyte, and increased by 36% when using anolyte. Electrochemically activated water had a significant effect on the rheological characteristics of starch suspensions: with an increase in the percentage of complex shear strain, the shear stress increased proportionally for samples of suspensions made on electrochemically activated water. The viscoelastic properties of starch suspensions prepared using electrochemically activated water both at 25 °C and at 68 °C tended towards an ideally elastic gel, that is, they had more elastic structure than the control samples. Under the action of shear deformation, the elastic properties were lost, while the suspensions acquired viscosity (phase angle values increased). The maximum value of the moisture binding capacity of pates was observed when using a starch suspension prepared on anolyte. The best values of rheological characteristics of pates were obtained when using starch suspension with 2% starch prepared on anolyte.

Conclusions. Electrochemically activated water had a significant effect on the physicochemical and rheological properties of semi-finished products, in particular corn starch suspensions, and pates prepared with them, and contributed to better structuring of the studied food systems.

Introduction

Water is a part of any raw material used in food industry. It is often the main component of a food product and determines its properties. Electrochemical treatment of water to give it new valuable for preparation of food qualities belongs to new environmentally friendly technologies (Ivanov et al., 2021).

When a direct electric current is passing in the cathode chamber of the electrolyzer, water is saturated with products of electrochemical reactions such as hydroxide ions, hydrogen, metal hydroxides, which are formed from water-soluble salts, resulting in activated water, defined as a catholyte (Figure 1).

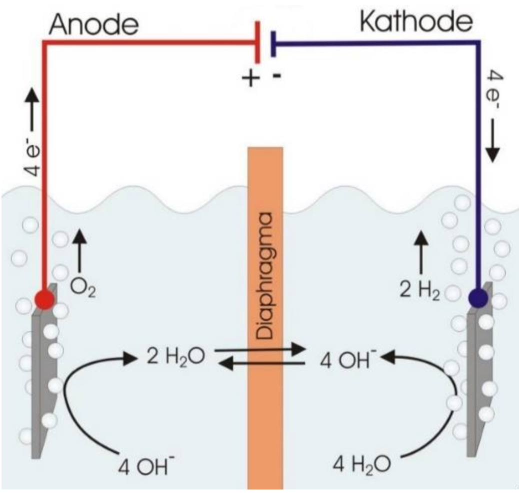


Figure 1. Scheme for the process of electrochemical activation of water

At the anode, water is oxidized with subsequent release of oxygen and chlorine gas, and the resulting liquid is called anolyte (Jiang et al., 2021). The catholyte, which consists of negatively charged OH^- ions and H_2 molecular hydrogen formed in the electrolysis process, received a negative potential. Anolyte is obtained in the process of electrolysis near the positive electrode, the anode, where oxidants are accumulated, and as a result a positive oxidation-reduction potential (ORP) is formed. These are primarily positively charged ions (cations) of hydrogen H^+, as well as hypochlorous acid HClO, oxygen O_2, and hydrogen peroxide H_2O_2 (Wulan and Notodarmojo, 2020).

Redox reactions are the basis of life on Earth (Scheibe et al., 2011). Water is responsible for redox processes, as the main solvent (in the chemical sense) and as the main structural element of the body (in the biological sense). The redox potential of the internal medium of a healthy person is always below zero and ranged from -90 to -225 mV (Matsiyevska, 2017), but for industrially purified artesian water – from +100 to +400 mV. Such differences in the ORP of water means that the activity of electrons in the internal medium of the human body is much higher than the activity of electrons in artesian water. To use water rationally in exchange processes of the body, it must be conditioned according to ORP values, which are achieved by applying electrochemical activation technologies (Goncharuk et al., 2010).

In food products, water is used not only for adding to the recipe in its pure form, but also for the preparation of semi-finished products, such as starch suspensions. Starch is a part of the most food products; in addition, it is widely applied as an emulsifier. Starch could be in native or modified forms. Native starch is obtained in the process of wet grinding of grain, and modified starches are obtained from native starch by chemical or physical methods. Starch in its native form has certain limitations compared to modified starch: the lower the hydration level, lower thermal stability, lower shear resistance, and higher retrogradation rate (Dru et al., 2018; Kaur et al., 2019).

During the preparation of food products, starches are subjected to mechanical action, as a result of which their rheological characteristics change, which have a significant impact on the quality of the finished product, in particular on its structural and mechanical properties, such as consistency, water-retaining and moisture-binding capacity (Montes et al., 2022).

To modify corn starch, its suspension is treated with heat, which means heating the suspension before the start of gelatinization. As an environmentally friendly modification method, this method attracts much attention because it involves only water and heat without the use of chemical reagents (Guo et al., 2020). Compared to native starch, heat-treated starch is better for use in the recipes of hard-to-digest foods, namely meat and pasta products, and canned food (Chung et al., 2009).

Meat pates are popular, widely demanded products, the formulation of which includes corn starch to regulate their structural and mechanical properties (Song and Jane, 2000).

Electrochemical water treatment is used to convert water into a metastable excited state. This technology is one of the most accessible methods, which is based on a unipolar electrochemical effect on water (Li et al., 2023).

The use of electrochemically activated water (anolyte or catholyte) to prepare suspension of thermally modified starch can change its rheological properties, which will allow it to regulate the quality of food products.

The aim of the present study was to determine the influence of electrochemically activated water on the rheological characteristics of corn starch suspensions and pates prepared with them.

Materials and methods

Obtaining electrochemically activated water

Electrochemically activated water was obtained using diaphragm electrolyzer by electrochemical treatment of artesian water with initial characteristics of pH 6 and ORP +224 mV. After setting the operating mode of the electrolyzer, two experimental water samples were obtained: catholyte with ORP -542±20, pH 10 and anolyte with ORP +767±15, pH 3. The required amount of water consumption was set at the level of 18 l/h.

Determination of physico-chemical characteristics of electrochemically activated water

Samples of waste were taken from containers that were previously washed with the same water to minimize the error. Physical and chemical parameters were determined using the Palintest 7500 photometer. Test tubes with a volume of 10 ml were filled with a water sample and Palintest water test tablets were added for each type of element: Mg, Fe, Mn, Cl, F, Al, K, NO_2, NO_3, PO_4, and SiO_2. After that, it was left at room temperature for a certain time to fully develop color. Results were recorded on the photometer display (Al-Mahrabi et al., 2021).

Determination of pH. Determination of pH of water was carried out using an I-160MI ionometer by potentiometric method of measurement. Water was added to a clean, dry glass up to the mark of 40 cm^3, the electrodes were immersed in it, and after 10-15 s the indicators were taken on the scale of the device (Lahav et al., 2001).

Determination of redox potential. Redox potential was measured using an Oakton ORP Tester 10 (Cole-Parmer, UK). The principle of the method was based on measuring the potential difference on two electrodes (Pt-electrode and a reference electrode with a double Ag/AgCl connection). Resolution was ±1 mV with accuracy ±2 mV. The electrode was placed in a fixed position with the sample above the bottom of the container. The output signal was established within 5 minutes (Tantra et al., 2012).

Determination of electrical conductivity. The electrical conductivity of water was measured by inducing a small alternating current through a precise volume of the studied liquid. Readings were recorded with a measuring device (Mccleskey et al., 2011).

Preparation of starch suspensions

Corn starch produced by AS GROUP, LLC (Ukraine) was used for the research.

Suspensions were prepared in the ratio of corn starch: water as 1:10 at water temperature t = 23±2 ºC (the temperature at which starch modification began) and kept for 2 hours to ensure starch hydration. The control was a sample of starch suspension on artesian water.

Water absorption capacity of starch

To determine the water absorption capacity (WAC), 0.5 g of starch was dispersed in 50 ml of distilled water and left for 30 min at room temperature in pre-weighed centrifuge tubes. The obtained suspension was centrifuged for 30 min at 3500 rpm. The upper layer with water was removed and dried for 25 min at a temperature of 50 ºC to remove excess moisture. Then it was re-weighed.

WAC was expressed in %, which was determined by the formula:

$$WAC = [(W2 - W1)/Ws]\cdot 100,$$

where W1 is the weight of the test tube with a dry sample;
W2 is the weight of the sample with the tube after centrifugation;
Ws is the weight of the sample.

Moisture retaining capacity of starch

To determine the moisture retaining capacity (MRC), 0.5 g of starch was dispersed in 50 ml of distilled water and left for 30 minutes at room temperature in a heat-resistant glass. The suspension was subjected to heat treatment with constant stirring for 30 min to a temperature in the center of 95±2 ºC, cooled to a temperature of 10±2 ºC, placed in pre-weighed centrifuge tubes and centrifuged for 30 min at 3500 rpm. The upper layer with water was removed and dried for 25 min at a temperature of 50 ºC to remove excess moisture and re-weighed.

MRC was expressed in %, which was determined by the formula:

$$MRC = [(W2 – W1)/Ws]\cdot 100,$$

where W1 is the weight of the test tube with a dry sample;
W2 is the weight of the sample with the tube after centrifugation;
Ws is the weight of the sample.

Determination of morphology and granulometric composition of starch grains

Morphology and surface relief of starch granules were studied by scanning electron microscopy using a Tescan MIRA 3 LMU microscope (Niamat et al., 2019). The sample was applied to a conductive carbon substrate and coated with a 30 nm layer of gold using a PECS 682 precision sputtering system. When measuring, an area with a field of view of 1.5 mm was selected.

The study of the dispersed composition of starch powder was carried out using a laser particle size analyzer (Bettersizer 2600; Dandong Baxter Instrument Co., Ltd., China) in the dry dispersion mode, using the laser diffraction method (Changgao et al., 2022).

Determination of rheological indicators of starch suspensions

Determination of the rheological indicators of corn starch suspensions was carried out on a Kinexus Pro+ rheometer. Starch Paddle Plastic 2 Blade geometry was used – a coaxial cylinder with a paddle stirrer (PC34 SL0007 SS) mounted on a vertical shaft. Suspensions were analyzed at the temperature at which the modification of starch began – 25 ºC, and at the temperature of gelatinization of corn starch – 68 ºC. The suspension was placed in a cylinder to a height of 70 mm; the stirrer was lowered and brought to a temperature of 25 ºC. The complex shear stress (σ), shear viscosity (η), phase angle (ϭ) was determined depending on the change in the complex shear strain with its gradual increase (0 – 100%). Each step was maintained until a steady state was reached in a minimum time. Similarly, the experiment was conducted after heating the suspension to 68 ºC (Alvarez et al., 2015).

Preparation of meat pates

Onions and carrots were peeled and sent for grinding; the liver was washed with cold water and cut into pieces, blanched at a temperature of 98-100 ºC for 15-30 minutes, cooled; wheat flour bread was soaked in milk; chicken eggs were washed, the starch suspension was prepared in a starch:water ratio of 1:10.

The prepared raw materials were loaded into a mixer and crushed until a homogeneous mass was obtained. Pates were packaged in glass jars, which were loaded into equipment for pasteurization. After that, they were cooled and labeled.

Determination of rheological characteristics of meat pates

Determination of the rheological characteristics of pates was carried out on a Kinexus Pro+ rheometer (Malvern Instruments Ltd., Great Britain). The geometry used 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 complex shear stress (σ), shear viscosity (η), phase angle (ϭ) was determined depending on the change in the complex shear strain with its gradual increase (0 – 100%). Each step was maintained until a steady state was reached in a minimum time (Marynin et al., 2023).

Determination of the moisture binding capacity of meat pate

To determine the moisture binding capacity of pates, the moisture content in the product was previously determined. Moisture content was determined by drying 5 g sample to constant weight at a temperature of 105 ºC. The moisture binding capacity relative to the moisture content (MBCm) and to the weight of the sample (MBCs) was determined by pressing 0.30 g of minced meat and calculating the ratio of the area of the wet spot to the weight of the minced meat or moisture in the sample (Strashynskiy et al., 2016).

The size of the wet spot (external) was calculated by the difference between the total area of the spot and the area of the spot formed by minced meat. It was experimentally established that one cm^2 of the area of a wet filter spot corresponded to 8.4 mg of moisture.

The mass fraction of bound moisture in the samples was calculated by the formulas:

$$MBCs = (M - 8.4S) \cdot 100/m_0$$
$$MBCm = (M - 8.4S) \cdot 100/M$$

where M is the total weight of moisture in the sample, mg;
S is the wet spot area, mg;
m_0 is the weight of minced meat, mg.

Statistical analysis

All experiments were performed in three replicates. Results were shown as mean ± standard deviation. Statistical analysis was performed using the XLstat software (version 2020).

Results and discussion

Physico-chemical characteristics of electrochemically activated water

Physico-chemical characteristics of water, as a component of food products, were important from the point of view of its safety and quality. The determined characteristics were compared with norms for artesian water (The Drinking Water Directive, 2020) (Table 1).

Electrical conductivity was determined as a measure of electrolytic properties of water. In the catholyte, the value was higher by 19.1% than in the control, in the anolyte it was lower by 17.0%. These data correlated with water hardness values: in the unfiltered catholyte obtained after passing artesian water through the electrolyzer, both hardness and electrical conductivity were higher than for the control. This is explained by the presence of Ca^{2+} and Mg^{2+} salt ions, which have the ability to conduct an electric current. The level of total hardness of the water samples correlated with the obtained data on the content of calcium and magnesium, which, together with other minerals were present in both artesian and electrochemically activated water (Table 2).

Table 1

Physico-chemical characteristics of water

Characteristics	Type of water		
	Artesian	Catholyte	Anolyte
pH	7.34±0.1	10.15±0.1	3.16±0.1
Total hardness, mmol/l	2.42±0.1	Unfiltered – 4.02±0.1 Filtered – 2.12±0.1	2.06±0.1
Total alkalinity, mmol/l	4.6±0.1	4.7±0.1	4.0±0.1
Electrical conductivity, µS/cm	470±1.1	560±10	390±10
RP, mV	246±10	-562±20	767±15

Table 2

Content of mineral substances in water

Mineral substances	Content of mineral substances, mg/l, in water		
	Artesian	Catholyte	Anolyte
Calcium (Ca)	56.40±0.1	Unfiltered – 113.60±0.1 Filtered – 37.60±0.1	45.60±0.1
Magnesium (Mg)	24.0±0.1	28.0±0.1	22.0±0.1
Total iron (Fe)	0.02±0.0001	Not found	0.01±0.00001
Manganese (Mn)	0.001±0.00001	Not found	0.002±0.00001
Chlorine (Cl)	17.5±0.1	1.7±0.001	15.5±0.1
Fluorine (F)	0.24±0.001	0.19±0.0001	0.38±0.0001
Aluminum (Al)	0.16±0.001	0.097±0.0001	0.16±0.0001
Potassium (K)	3.2±0.01	6.8±0.1	2.3±0.01

The content of total iron in the electrochemically activated water decreased: in the anolyte by 50%, and it was not detected in the catholyte. Since the content of Ca^{2+} and Mg^{2+} salt ions in the anolyte was lower than in the control, its electrical conductivity was also lower (Table 1).

The content of oxides in the studied water samples is given in Table 3.

Table 3

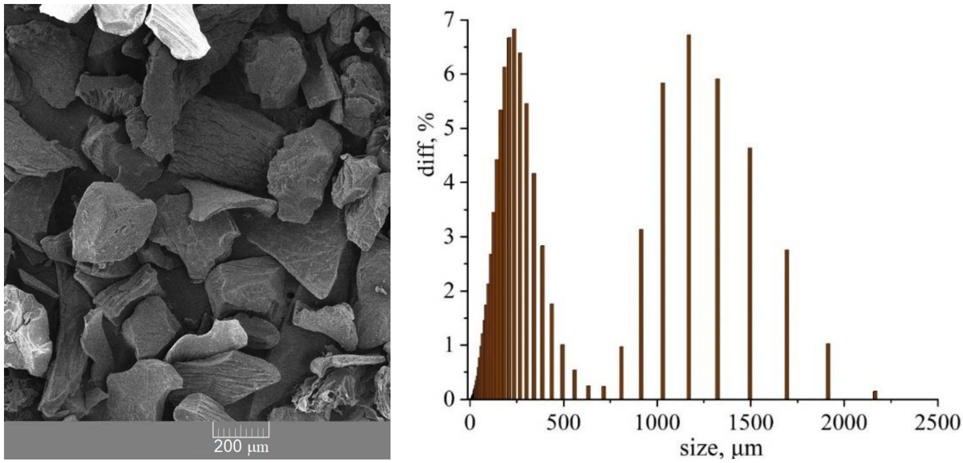
The content of oxides in water

Oxides	The content of oxides in water, mg/l		
	Artesian	Catholyte	Anolyte
Nitrites (NO_2^-)	0.02±0.0001	0.017±0.0001	0.007±0.0001
Nitrates (NO_3^-)	2.79±0.01	1.16±0.01	3.34±0.01
Phosphates (PO_4^{3-})	0.09±0.0001	0.05±0.0001	0.15±0.0001
Silicon (SiO_2^-)	12.25±0.1	13.0±0.1	16.0±0.1

The content of nitrites in water after its electrochemical treatment decreased significantly, namely by 15% in catholyte and 65% in anolyte compared to artesian water. The content of sulfates in the anolyte was lower by 33.3%, and no sulfates were detected in the catholyte. Chloride content in catholyte was significantly lower than in artesian water – by 90.3%, and in anolyte by 11.4%. This was because inorganic compounds, including toxic ones (nitrites and sulfates), underwent cathodic and anodic oxidative destruction, and strong inorganic oxidants, including chlorine, were inactivated during chemical reactions (Lu and Zhang, 2022).

Electrochemically activated water with acidic (anolyte) and reducing (catholyte) properties will have a positive effect on the rheological indicators of the semi-finished products with it. When using water for the preparation of starch suspensions and their subsequent use in the formulation of food products, it was important to determine the morphological features and relief of the surface of starch grains.

In the study of starch by scanning electron microscopy, lamellar large and rounded small grains with a porous surface were found in the form of granules of various shapes and sizes (Figure 2a), which was confirmed by the distribution of particles obtained by laser diffraction (Figure 2b).



a b

Figure 2. Scanning electron microscopy of corn starch granules and particle size distribution

To characterize the size distribution of particles, the values D10, D50 and D90 were used, which were equivalent volume diameters at 10%, 50% and 90% of the total volume, respectively.

The analysis of the obtained results of particle size distribution indicated the polydispersity of the system and the wide distance between the D10 and D90 points (Table 4).

Table 4

Particle size distribution

Sample	D10, µm	D50, µm	D90, µm	Specific surface area SSA, m^2/kg
Corn starch	102±5	270±5	1364±8	11.22±1

Note: Each value is the mean of triplicate measurements ± SD.

Depending on the type of water used, hydrated starch will have different functional and technological properties. So, when using activated water for the preparation of starch suspensions in the case of catholyte, the water-absorbing capacity of starch decreases by 26%, and when prepared on anolyte, it increases by 18%. Therefore, when using anolyte, the amount of added water in the formulation for the manufacture of products with starch suspensions should be increased (Figure 3).

When using catholyte to obtain a suspension of starch, the water-holding capacity of starch is reduced by 10%, and anolyte is increased by 36%. Such changes are explained by different acidity of aqueous media, and the salts present in catholyte prevent its absorption of catholyte by starch granules (Han et al., 2009).

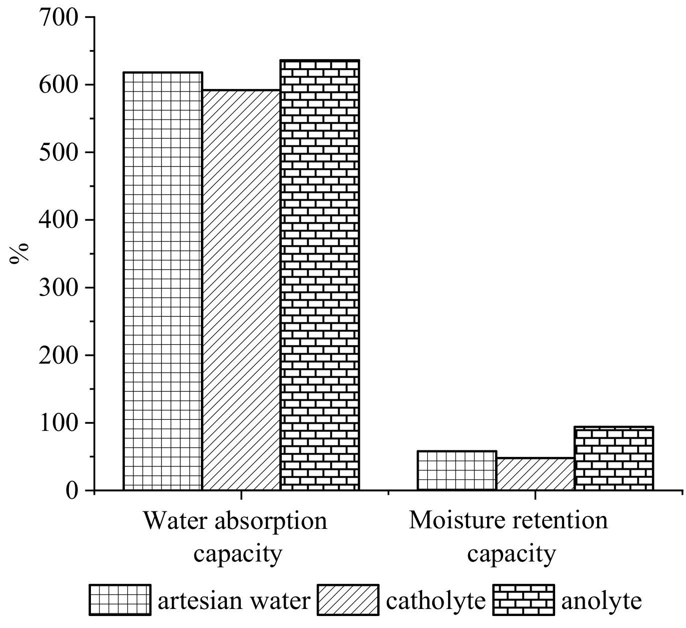


Figure 3. Functional and technological properties of hydrated starch depending on the water used

The use of electrochemically activated water can be effective in controlling the structure-forming and thickening properties of starch. During the technological processes of manufacturing food products, mechanical work is applied (transactions of mixing, molding), as a result of which the structure of starch grains is deformed. The effect of electrochemically activated water (catholyte and anolyte) on the change in the rheological characteristics of corn starch suspensions at different temperatures was determined.

The dependence of the change in the complex shear stress (σ) of corn starch suspensions on the complex shear strain (Y) is shown in Figure 4. It was found that with an increase in the percentage of shear strain, the shear stress increased proportionally for all samples. Moreover, for the suspension of corn starch on the catholyte at 25 ºC, this change was the most rapid (0–2.5 Pa), somewhat less on the anolyte (0–2 Pa), and in the control with artesian water – 0–1 Pa.

When the temperature of gelatinization (68°C) was reached, the change in the complex shear stress were much lower, but the trend of the change remained: the least rapid increase in the complex shear stress was observed for the control – 0–0.4 Pa, for suspensions on the catholyte and anolyte, this indicator was slightly higher, however practically coincided in the entire range of action of shear deformation – 0–0.6 Pa and 0–0.7 Pa, respectively.

The change in the viscous properties of the starch suspension estimated by the index of complex shear viscosity during deformation is shown in Figure 5.

It was established that the complex shear viscosity of all samples decreased in the entire range of deformation influences. The initial values for the samples on the catholyte and anolyte at 25 ºC and at 68 ºC were higher than the corresponding values of these parameters for the control sample. Moreover, this tendency was observed in the entire range of deformations, because viscous properties were manifested to a greater extent in the case of preparation of starch suspension on electrochemically activated water. This was explained by the fact that the nature of the contact of hydrophilic groups changed, namely, the contact zone between swollen starch granules decreased, which provided more opportunities for starch to bind water molecules (Chen et al., 2020; Chen et al., 2018).

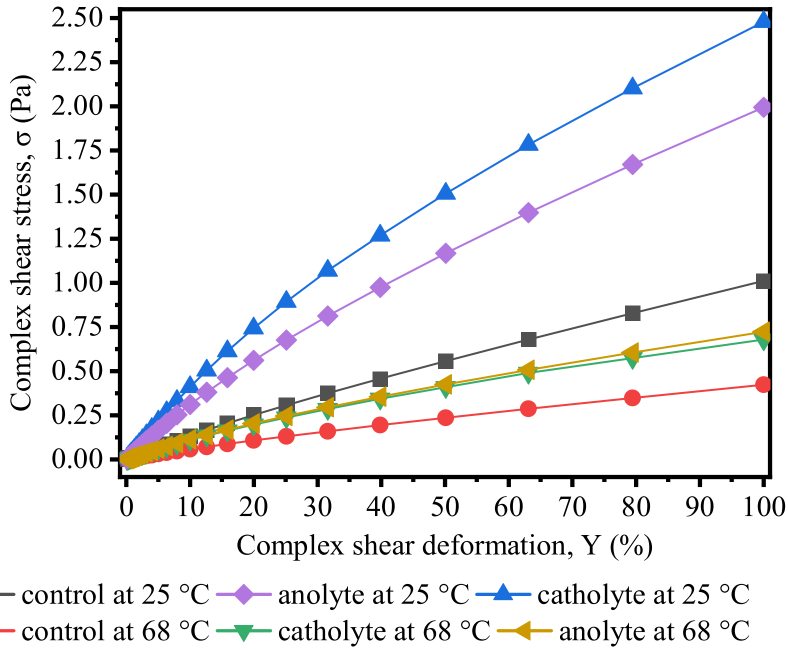


Figure 4. Dependence of the change in the complex shear stress (σ) of corn starch suspensions at temperatures of 25 ºC and 68 ºC, prepared with electrochemically activated water, on the complex shear strain (Y)

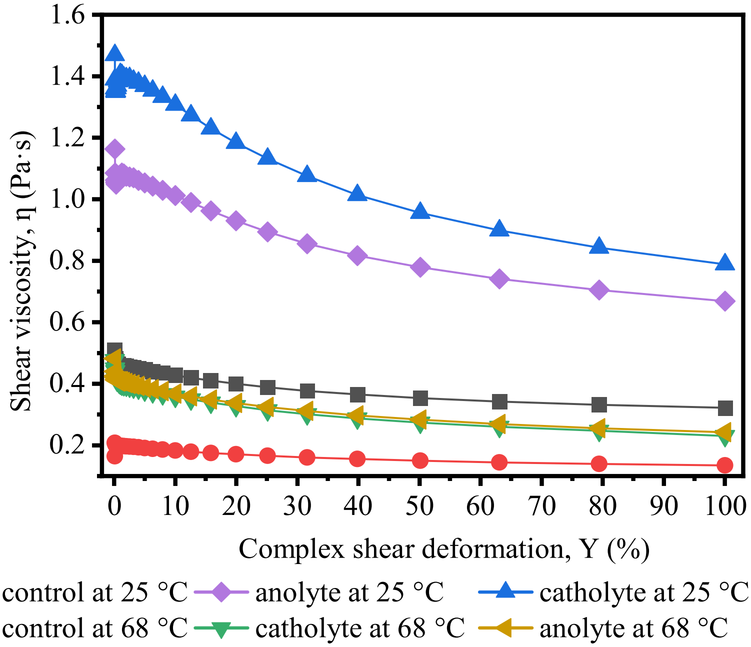


Figure 5. Dependence of shear viscosity of corn starch suspensions at temperatures of 25 ºC and 68 ºC, prepared with electrochemically activated water, on the complex shear strain (Y)

To characterize the effect of electrochemically activated water on the viscoelastic properties of starch suspensions, the change in the phase angle was determined, which is the angle between the light incident on the object and the reflected light (Figure 6).

The phase angle of the suspension on the catholyte at 25 ºC is lower than on the anolyte and with artesian water: 29.13º, 34.28º and 51.29º, respectively, in the absence of deformation. At the temperature of pasteurization, the sample with artesian water also had the highest value - 55.46º, but the values of the phase angle of the samples on the catholyte and anolyte coincided - 39.05º, and this trend was observed in the entire range of deformation influence. The values of the phase angle of the suspensions on the catholyte and anolyte both at 25 ºC and at 68 ºC tended to 0 (ideally elastic gel), that is, they had more elastic structure than the control samples. At the same time, with the effect of shear deformation, the elastic properties were lost, while the suspensions acquired viscosity (phase angle values increased).

Changes in functional and technological and rheological indicators of starch suspensions when using electrochemically activated water should affect the properties of pates with their content, in particular, functional and rheological indicators.

Determination of the moisture binding capacity of the pates in relation to the weight of the sample (MBCs) and the weight of moisture in the sample (MBCm) showed that the anolyte had greater influence on the studied indicators (Table 5).

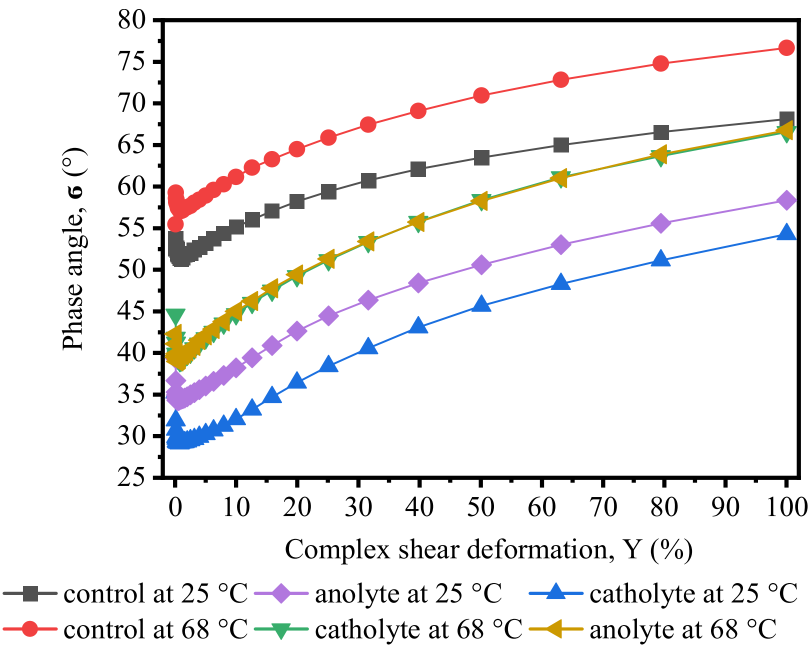


Figure 6. Dependence of the phase angle during the study of suspensions of corn starch at temperatures of 25 °C and 68 °C, prepared with electrochemically activated water, on the complex shear deformation

Table 5

Moisture binding capacity (MBC) of the pates

Moisture binding capacity	Type of water used		
	Artesian	Catholyte	Anolyte
2% corn			
MBCs before pasteurization, %	67.61	70.02	100
MBCs after pasteurization, %	66.95	68.66	100
MBCs after 21 days after pasteurization, %	58.65	62.28	93.79
MBCm before pasteurization, %	96.29	96.12	100
MBCm after pasteurization, %	96.59	94.33	100
MBCm after 21 days after pasteurization, %	90.95	91.45	96.47
5% corn			
MBCs before pasteurization, %	70.59	87.57	86.25
MBCs after pasteurization, %	86.36	90.00	73.71
MBCs after 21 days after pasteurization, %	70.88	83.10	71.27
MBCm before pasteurization, %	73.83	88.80	96.70
MBCm after pasteurization, %	98.76	90.00	96.85
MBCm after 21 days after pasteurization, %	94.90	94.67	96.06

With the content of 2% starch in the suspension on the anolyte and catholyte, the MBCs of the pates increased by 32.39% and 2.41% before pasteurization, compared to the control, and by 33.05% and 1.71% after pasteurization. When using anolyte, this indicator reached a maximum value of 100%. Electrochemically activated water helped to increase the hydrophilic properties of starch granules and slowed down their reduction over time (Akua et al., 2022). An increase in the proportion of starch helped to increase the moisture binding capacity of the pates in relation to the weight of the sample.

In the samples of pates with 2% starch in the suspension on the anolyte, the moisture binding capacity of the pate in relation to the mass of moisture in the sample increased by 3.71% before pasteurization, compared to the control, the catholyte almost did not affect the value of this indicator. After pasteurization of pate on the anolyte, the moisture binding capacity in relation to the mass of moisture in the sample reached 100%, on the catholyte it decreased by 2.26% compared to the control.

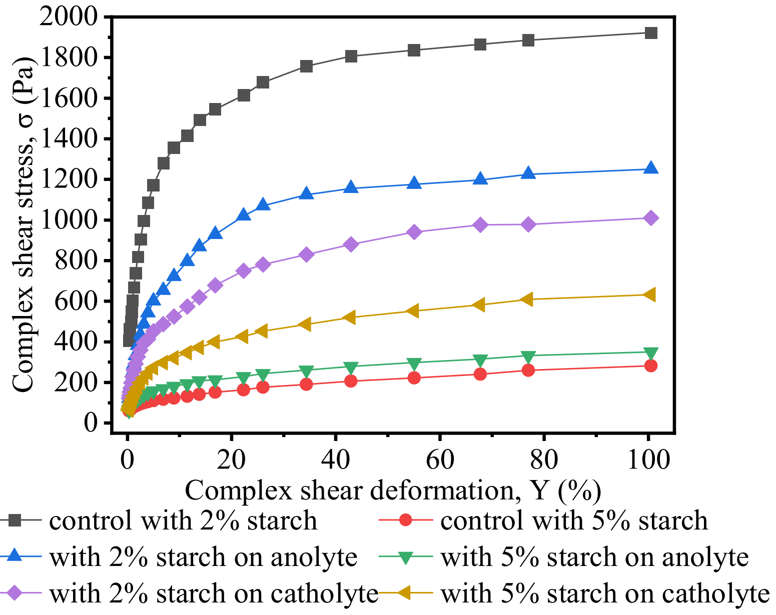
In the process of storage, MBCs and MBCm decreased in all samples. However, in pates with electrochemically activated water, the percentage of reduction was lower, compared to the control, which indicated better moisture binding and preservation of the texture of the products.

When starch suspension was used in the production of pates, the food system was partially distorted. Studies of the dependence of the change in the complex shear stress of pates with a suspension of corn starch on the complex shear deformation showed that with an increase in the percentage of deformation, the shear stress increased proportionally for all samples (Figure 7). Moreover, for samples with the suspension with 2% starch, this change was the most rapid in the control – 33–1623 Pa, somewhat less in the anolyte – 21–1156 Pa, and in the catholyte – 18–946 Pa.

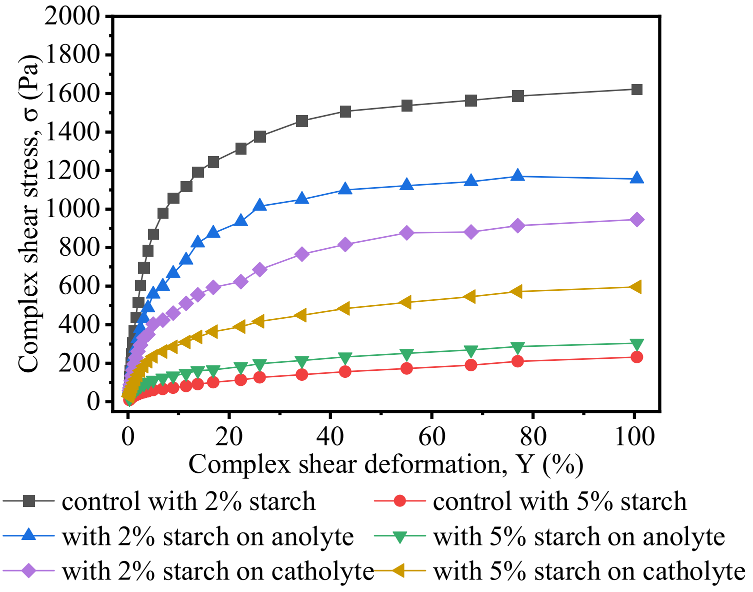
With an increase in the concentration of corn starch in the suspension, the values of the complex shear stress of the pates was significantly lower and the trend changed: the least rapid increase in the complex shear stress was observed for the control – 3–232 Pa, for pates with suspensions on the anolyte and catholyte this indicator was slightly higher – 5–305 Pa and 8–596 Pa respectively. The nature of the curves of these samples tended to samples of pure starch. However, the values of shear stress in the same strain range for pate samples were much larger: in the range of 3–1623 Pa compared to 0–2.5 Pa for samples of starch suspensions. This was explained by a change in the structure of the studied systems, namely an increase in viscosity and density (Amann-Winkel et al., 2013). In the process of storage, the complex shear stress decreased in all samples, which was explained by the fact that the pate structure became less strong over time and broke down faster at smaller deformations.

The change in the viscous properties of pates was determined by the index of shear viscosity during the deformation process (Figure 8).

Shear viscosity of all samples decreased in the entire range of deformation influences. The initial values for samples of pates with 2% starch in suspension were higher than the corresponding values of these parameters for pates with 5% starch in suspension: on artesian water, anolyte and catholyte – 5290 Pa·s, 3316 Pa·s and 2925 Pa·s, respectively compared to 472 Pa·s, 878 Pa·s and 1409 Pa·s for samples with 5%. In samples with 2% starch, the control had the highest values of shear viscosity in the entire range of deformations. Moreover, the systems did not stabilize until the end of the deformation influences both with suspensions on artesian and electrochemically activated water. This was due to the fact that with a low starch content, suspensions couldn't provide a stable pate viscosity, despite their strength (Montes et al., 2022). However, in this case, electrochemically activated water affected to a greater extent the nature of the contact of hydrophilic groups, which provided more opportunities for starch to bind water molecules.



a



b

Figure 7. The dependence of the change in the complex shear stress of pates with different concentrations of corn starch in the suspension prepared with electrochemically activated water on the complex shear strain:
a – after pasteurization; *b*– after 21 days after pasteurization

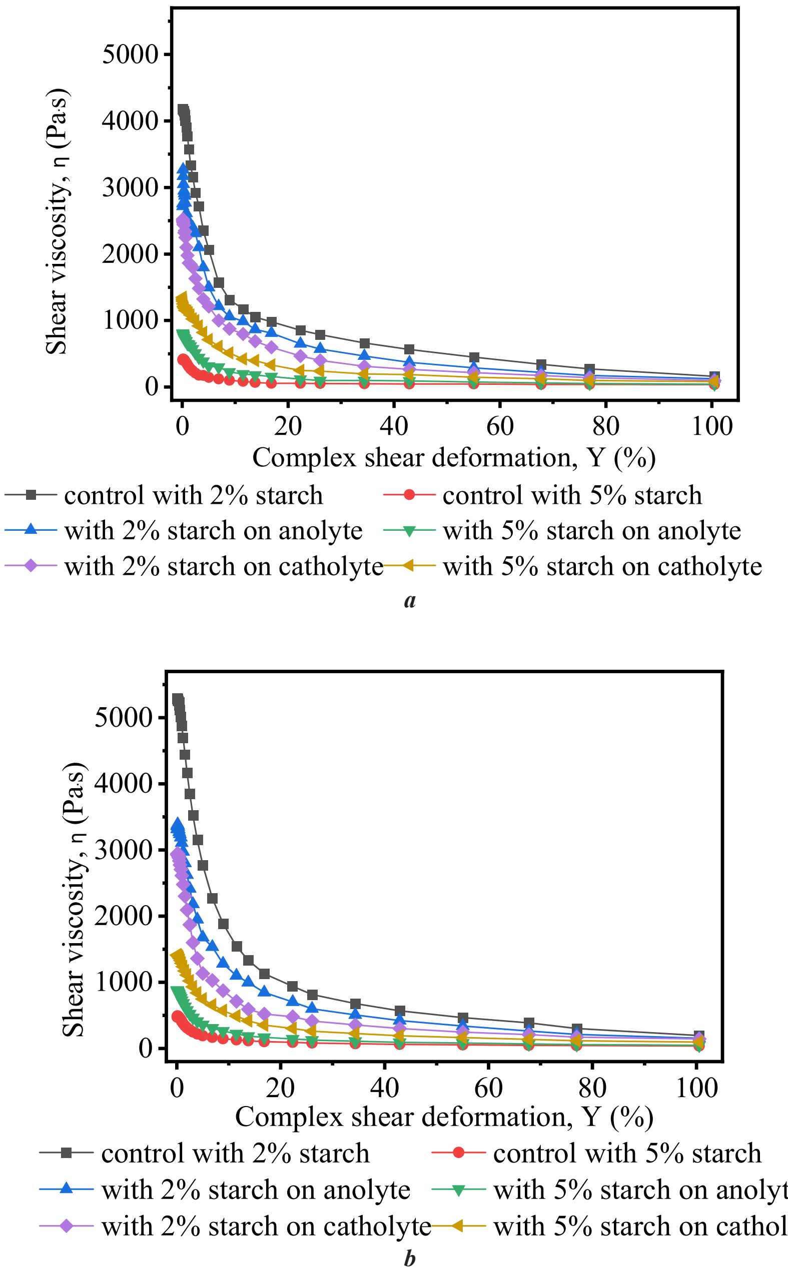
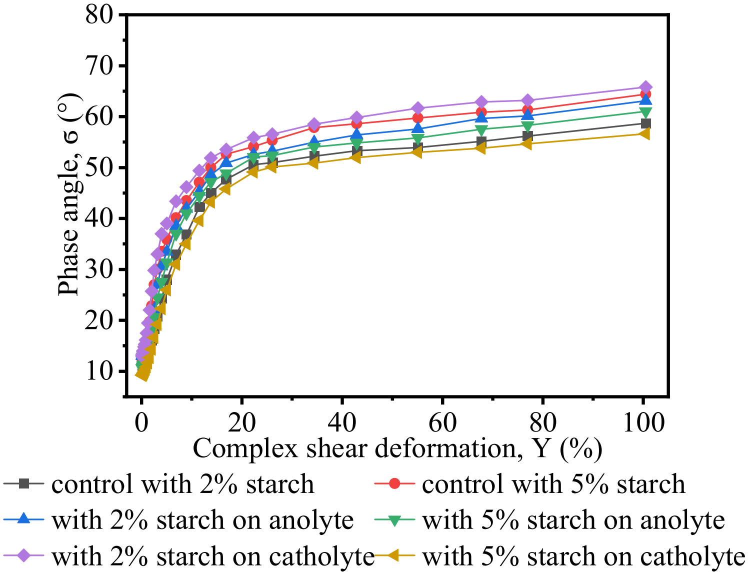


Figure 8. The dependence of the change in the shear viscosity of pates with different concentrations of corn starch in the suspension prepared with electrochemically activated water on the complex shear strain:
a – after pasteurization; *b*– after 21 days after pasteurization



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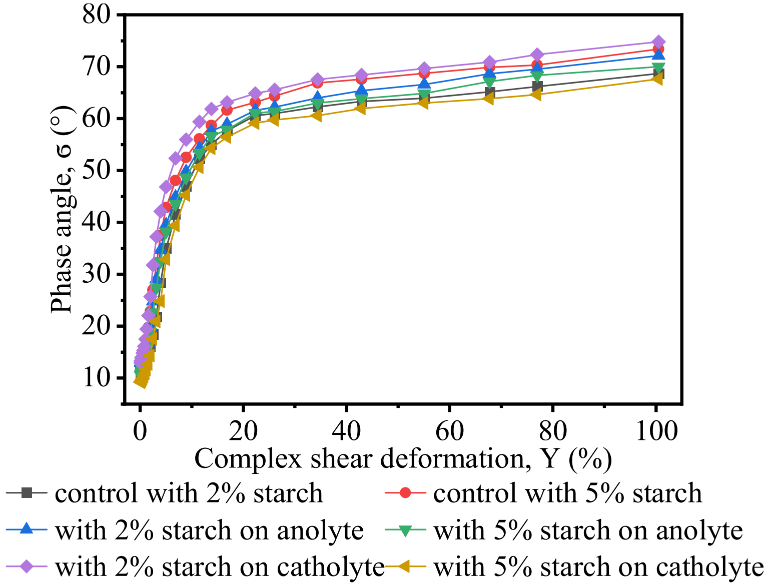

b

Figure 8. The dependence of the change in the phase angle duting pates investigation with different concentrations of corn starch in the suspension prepared with electrochemically activated water on the complex shear strain:
a – after pasteurization; *b*– after 21 days after pasteurization

In samples of pates with a suspension with 5% starch, the trend was opposite: the lowest values of shear viscosity over the entire range of deformation were in the control sample, slightly higher with suspensions on the anolyte and catholyte. However, the change of the investigated parameter was not as rapid as for samples with 2% starch. This was explained by the lower strength of the system (Boonkor et al., 2022). Pates acquired a stable viscosity after 80% deformation, both with artesian and with electrochemically activated water. In the process of storage, the shear viscosity increased in all samples, which correlated with the change values of this indicator depending on the change in the shear rate and was explained by the decrease in the strength of the pate system over time.

To characterize the effect of electrochemically activated water on the viscoelastic properties of pates and their internal structure, the change in the phase angle was determined, which was the angle between the light falling on the object and the light reflected from it (Figure 9). The curves of changes in the phase angle of pate samples were completely different in nature from the curves of pure suspensions, which indicated the influence of the formulation components on this indicator and the influence of electrochemically activated water on the structure of the pates.

The internal structure of the pate samples changed under the influence of electrochemically activated water on the starch suspension included in their composition, as evidenced by the phase angle parameters, because the changes were followed (that is, the phase angle/shear deformation curves of different dough samples did not match) (Cristiano et al., 2019).

In the absence of deformation, the phase angle of all samples was practically the same and was about 10º. Pates with a suspension with 5% starch prepared on catholyte and anolyte had a lower phase angle than the control sample in the entire range of deformations and tended to 0, that is, they provided a more elastic structure to the pates than the control sample. However, under the action of shear deformation, the elastic properties were lost, while the suspensions acquired viscosity (phase angle values increased) (Maurice, 2019).

Samples of pates with 2% starch prepared on catholyte and anolyte had a higher phase angle than the control sample, which indicated that this amount of starch when interacting with electrochemically activated water due to the much higher strength of the starch system was not able to ensure the elasticity of the minced meat system and helped to increase their viscosity. In the process of storage, the phase angle increased for all samples, which was explained by the increase in the viscosity of the pates and the loss of elasticity at smaller deformations.

Conclusions

1. Physico-chemical indicators of the quality of electrochemically activated water, except pH, met the requirements of regulatory documentation for potable artesian water.
2. When starch suspensions were prepared on the catholyte, the water absorption capacity of starch was slightly reduced by 26%, and when prepared on the anolyte, it increased by 18%. The values of moisture retention capacity changed similarly: in the case of catholyte, it decreased by 10%, and in the case of anolyte, it increased by 36%.
3. Electrochemically activated water had a significant effect on the rheological indicators of starch suspensions. As the percentage of complex shear strain increased, the shear stress increased proportionally for all samples on electrochemically activated water. Moreover, for the suspension on the catholyte at 25 ºC, this change

was the most rapid (0–2.5 Pa), somewhat less on the anolyte (0–2 Pa), with artesian water (control) – 0–1 Pa. The shear viscosity of all samples decreased in the entire range of deformation influences. The effect of electrochemically activated water on the viscoelastic properties of starch suspensions showed that they tended to 0 (perfectly elastic gel) at 25 ºC and at 68 ºC, that is, they had more elastic structure than the control samples. At the same time, with the effect of shear deformation, the elastic properties were lost, while the suspensions acquired viscosity (phase angle values increased).

4. The moisture binding capacity of pates was maximum when preparing starch suspension on the anolyte. The best values of the rheological indicators of pates were obtained when the starch suspension prepared on the anolyte with 2% corn starch was added to the recipe.

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