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Electrochemical activation as a fat rendering technology

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Abstract:
Introduction. The existing methods of animal fat obtaining have certain disadvantages, hence fat extraction study highly is relevant. Electrochemically activated solutions are known to have a great potential for animal fat extraction. The present paper introduced a new advanced fat obtaining technology based on the principle of electrochemical activation.
Study objects and methods. The research featured ostrich fat obtained by wet rendering in water and in an electrochemically activated solution (catholyte) using various processing methods and technological parameters. Standard methods helped define the physical and chemical parameters of the obtained fat samples.
Results and discussion. The paper introduced a technological and hardware setup of an ostrich fat production line with the necessary equipment specifications. The research made it possible to define the optimal parameters for fat extraction: the salt concentration for the catholyte = 4 g/100 cm^3, voltage = 40–42 V, pH = 11, and redox potential of the catholyte = between –600 and –700 mV. During the fat processing, cell membranes in the electrolyte were destroyed, which inactivated the enzyme system. The obtained combination of physical and chemical factors resulted in ostrich fat of high quality. Fat extraction in an electrochemically activated solution (catholyte) catalyzed the process and increased the fat yield, regardless of the processing temperature. The fat yield exceeded 58% at 55°C and catholyte pH of 11.0. At 95–100°C and pH of 9.5–10.6, it exceeded 95%.
Conclusion. The new technology increased the fat yield, maintained its high quality, and reduced the processing cost. Therefore, the developed production line could be recommended for fat extraction of farm animals, depending on the intended use.

Keywords: Fatty acid, fats, raw material, electrolysis, catholyte, food production, water, solutions

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INTRODUCTION

Fat rendering technology should take into account the specific character of the technical solutions. Wet rendering produces a three-phase system, which includes fat, broth, and greaves. However, the process is slow and renders no fat at low processing temperatures. Dry rendering involves high temperatures and results in a two-phase system of greaves and fat. Chemical rendering is fast and highly productive, but acid or alkali treatment limits the intended use of the final product. Hydrolytic rendering destroys the protein component of fat with hot alkali. Unfortunately, the resulting fat is instable, and the greaves cannot be used for feed production. Hydromechanical and electric pulse methods are most effective for glue and gelatin production, as they destroy the connective tissue of the fat cell of tubular bones. Extraction methods based on organic solvents are extremely rare in the meat industry: not only are they fire-hazardous and labor-consuming, but they also require sophisticated equipment. It is fat rendering with electrochemically activated solutions that gives the most positive results [1]. The last decades have seen a growing scientific interest in the use of water as a potential source of unconventional chemical reactions [2–5].

Electrochemically activated solutions make various production processes less energy-, time-, and material-consuming [6]. Electrolysis of water has a number of advantages over mechanochemical, magnetic, and thermal activation methods [7]. Even at low concentrations, electrochemically activated solutions demonstrate properties similar to concentrated acid and alkaline solutions [8, 9]. Domestic and foreign research confirmed their effectiveness in various fields and resulted in a number of patents [10–18]. Some studies featured advanced production methods for electrolyzers and activated water with improved properties [19–22]. An efficient electrocatalyst possesses a number of certain properties. For instance, it has low hydrogen overpotential at industrial current densities with a constant potential value that remains stable over time. It has a good chemical and electrochemical resistance and is capable of a long-time service. In addition, an effective electrocatalyst does not emit harmful products during electrolysis [23–27].

The present analysis of modern scientific research in the field of animal fat extraction indicated the relevance of new technical solutions in this sphere.

The research objective was to create an ecologically safe fat rendering production line based on the principle of electrochemical activation. The study focused on intensifying the process of fat extraction and increasing the fat-water separation.

STUDY OBJECTS AND METHODS

Ostrich fat became a research object as a novel raw material resource. In addition, ostrich fat is rich in unsaturated fatty acids, easy to separate into fractions, and similar with traditional poultry fats in terms of physical and chemical properties. Ostrich fat has low melting and chilling points. For subcutaneous fat, the melting point is 33–35°C, and the chilling point is 25–27°C. For internal fat, the melting and chilling points are 30–32 and 21–23°C, respectively. As for the iodine value, ostrich fat surpasses that of other farm animals and is close to that of chicken: J_2 of subcutaneous fat is 56.6 ± 0.5 g/100 g; J_2 of internal fat is 61.7 ± 0.5 g/100 g. Table 1 illustrates a comparative analysis of the fatty acid composition of subcutaneous and internal ostrich fat.

Table 1 Fatty acid composition of ostrich fat, % of the total fatty acids

Fatty acids	Symbol	Subcutaneous fat	Internal fat
Myristic	C14:0	0.80	0.7
Myristooleic	C14:1	0.10	0.1
Pentodecanoic	C15:0	0.10	0.1
Palmitic	C16:0	28.70	28.3
Palmitoleic	C16:1	5.20	5.2
Margaric	C17:0	0.10	0.1
Cis-10-heptadecene	C17:1	0.10	0.1
Stearic	C18:0	7.15	8.7
Trans-elaidic	C18:1	0.40	0.1
Oleic	C18:1	37.00	38.5
Linoleic	C18:2	17.95	16.3
Arachidonic	C20:0	0.10	0.1
γ-Linolenic	C18:3	1.40	0.4
Eicosenoic	C20:1	0.60	0.6
Heneicosanoic	C21:0	–	–
Linolenic	C18:3	0.20	0.2
Eicosatrienoic	C20:3	0.10	0.1
Total saturated:		36.95	38.0
Total unsaturated, including:		63.05	62.0
monosaturated		43.40	44.8
polysaturated		19.65	17.2

The process of in-lab ostrich fat rendering started with preliminary grinding of the refined raw fat to a particle size of 0.5 mm. The wet rendering in water (control sample) and in an electrochemically activated solution, namely catholyte (experimental sample), was performed in an HM-220VM vacuum reactor (Japan – Taiwan). The equipment provided uniform heating and temperature control, as well as vacuum and fat mixing. The water was used at a ratio of 8:1 to the mass of raw materials and met the requirements of State Standard R 51232-98[1]. Extraction was carried out at 55, 75, and 100°C for 60 min. The stepwise thermal processing time was 20 min per stage.

Filtration was used to separate the raw materials into solid and liquid fractions. Vacuum under the filtering surface intensified the process. The fat was separated from the water-protein phase by centrifugation at 6.000 rpm/min for 5 min. The resulting fat with different melting points was dehydrated in a PE-8910 rotary evaporator (Russia) at a residual pressure of 2666.44 Pa. The remaining solid phase underwent subsequent melting at higher temperatures. The new technical approach appeared to have a number of advantages over the existing ones (Patent No. 2382072 RU, February 20, 2010). It proved to be less water- and time-consuming, produced less waste, and rendered fat with a controlled melting point.

The electrochemically activated solution was obtained in an electrolyzer by electrolyzing a 10% aqueous NaCl solution at the following modes: DC power = 0.5–0.6A, voltage = 40–42V, pH = 9–11, redox potential = –(400–700) mV, mass fraction of sodium chloride = 4 g/100 cm^3.

Table 2 describes the methods and modes of the fat rendering process.

The conditions and parameters of fat rendering were established both experimentally and by calculation using the Box-Wilson orthogonal central composite design, where each factor was fixed at five levels (–α, –1, 0, 1, +α). The number of design points equaled:

$$N = N_1 + 2n + N_0 \quad (1)$$

where: N_1 – number of points in complete factorial experiment $2n$; $2n$ – number of paired points on the coordinate axes; N_0 – number of experiments in the central design.

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[1] State Standard R 51232-98. Drinking water. General requirements for organization and quality control methods. Moscow: Standartinform; 2010. 21 p.

Table 2 Methods and modes of ostrich fat rendering

Fat	Rendering method	Processing details
Internal	Wet rendering in water, pH = 7–8 at various processing temperatures	The thermal treatment included several stages: at the first stage, the heating temperature reached 39°C, at the second – 55°C, at the third – 75°C, at the fourth – 100°C. The melting time was 20 min at each stage. Before each stage, the fat mass was mixed, and the fat was separated stepwise. The resulting fat fractions were pooled into one sample.
Subcutaneous		
Internal	Wet rendering in water, pH = 7–8	The raw fat was processed at 55°C with constant stirring.
Subcutaneous		
Internal	wet rendering in water, pH = 7–8	The raw fat was processed at 75°C with constant stirring.
Subcutaneous		
Internal	Wet rendering in water, pH = 7–8	The raw fat was processed at 100°C with constant stirring.
Subcutaneous		
Internal	Wet rendering in electrochemically activated solution (catholyte), pH = 9–11 at various processing temperatures	The thermal treatment included several stages: at the first stage, the heating temperature reached 39°C, at the second – 55°C, at the third – 75°C, at the fourth – 100°C. The melting time at each stage was 20 min. Before each stage, the fat mass was mixed, and the fat was separated stepwise. The resulting fat fractions were pooled into one sample.
Subcutaneous		
Internal	Wet rendering in electrochemically activated solution (catholyte), pH = 9–11	The raw fat was processed at 55°C with constant stirring.
Subcutaneous		
Internal	wet rendering in electrochemically activated solution (catholyte), pH = 9–11	The raw fat was processed at 75°C with constant stirring.
Subcutaneous		
Internal	Wet rendering in electrochemically activated solution (catholyte), pH = 9–11	The raw fat was processed at 100°C with constant stirring.
Subcutaneous		

The matrix rendered the following equation:

$$\hat{y} = b_0 + b_1\chi_1 + b_2\chi_2 + \ldots$$
$$+ b_k\chi_k + b_{12}\chi_1\chi_2 + b_{13}\chi_1\chi_3 + \ldots$$
$$+ b_{k-1}\chi_{k-1}\chi_k + b_{11}\chi_1^2 + \ldots + b_{kk}\chi_k^2 \qquad (2)$$

where b_0 – absolute term; x_1, $x_2 \ldots x_n$ – factors that determine the level of the performance parameter; b_1, $b_2 \ldots b_n$ – regression coefficients for factor indicators that describe the effect of each factor on the performance parameter in absolute terms.

The melting time $X_1(Z_1)$, the pH of the electroactivated medium $X_2(Z_2)$, and the processing temperature of the raw fat $X_3(Z_3)$ were selected as primary factors. The response function was the output of rendered ostrich fat (Y_3). The significance of the coefficients of the mathematical model was established based on the Student's criteria. The tabulated value of the Student's test $t_p(f)$ for $P = 0.05$ and the number of degrees of freedom $f = 3$ was 3.18. The adequacy of the regression equation was controlled by calculating the error square and the error mean square. The Fisher criterion was determined using the Table as $F_{1-p} = (f_1, f_2)$. The equation was adequate if the resulting F-ratio was less than the tabular $F < F_{1-p}$. (f_1, f_2) for the selected significance level ($P = 0.05$) and the numbers of degrees of freedom.

Gas chromatography helped define the fatty acid composition of ostrich fat. The methyl ester extraction and chromatography were based on State Standard 32150-2013[II] under the following conditions: gas chromatograph – Kristall 5000.2, chromatographic column – Omegawax-320 (30 m×0.32 mm×0.50 μm), carrier gas – nitrogen, evaporator gas pressure – 85 kPa, split ratio – 1:40, and evaporator temperature – 250°C. The temperature of the column thermostat was programmed as follows: it was maintained at 120°C for 9 min, and then it was brought up to 210°C at 3°C/min, where it stayed the same for 30–40 min.

The data processing was conducted as follows. The mass fraction of fatty acids was calculated as the ratio of the chromatographic peak area of a particular fatty acid to the sum of all peak areas in the chromatogram. The experiment did not take into account the corrections for the detector sensitivity to the particular fatty acid. It also left out the difference in the molecular weight of the methyl ester and that of the fatty acid itself. The reason was that these corrections are significant only for short-chain fatty acids with the number of carbon atoms between C4 and C10.

The mass fraction of water and volatile substances was determined according to the methods described in State Standard R 50456-92 (ISO 662-80)[III]. The iodine

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[II] State Standard 32150-2013. Food eggs and foodstuffs of processed poultry eggs. Method for determination of fatty acid composition. Moscow: Standartinform; 2019. 13 p.

[III] State Standard R 50456-92 (ISO 662-80). Animal and vegetable fats and oils. Determination of moisture and volatile matter content. Moscow: Standartinform; 2008. 6 p.

Table 3 Physicochemical indicators of ostrich fat obtained by electrochemical activation

Rendering type	Processing temperature, °C	Fat	Acid number, mg KOH/g	Peroxide number, mmol of active oxygen per kg	Anisidine number	Viscosity at melting point, kPA×s
In tap water, pH = 7–8	39, 55, 75, 100	Internal	3.00	8.0	4.9	1.03*
		Subcutaneous	2.70	7.7	4.1	1.53*
	55	Internal	2.50	5.4	4.0	0.82
		Subcutaneous	2.40	6.9	4.1	0.85
	75	Internal	2.60	6.9	5.5	0.75
		Subcutaneous	2.30	7.0	4.2	0.78
	100	Internal	2.20	5.5	5.0	0.55
		Subcutaneous	1.30	5.3	4.0	0.60
In electrochemically activated solution (catholyte), pH = 11	39, 55, 75, 100	Internal	3.00	8.0	4.9	1.25*
		Subcutaneous	2.70	7.7	4.1	1.75*
	55	Internal	0.20	1.8	2.0	0.73
		Subcutaneous	0.21	2.0	2.1	0.80
	75	Internal	0.20	2.9	2.2	0.75
		Subcutaneous	0.19	2.2	2.0	0.81
	100	Internal	1.05	4.8	2.9	0.45
		Subcutaneous	0.90	4.6	2.5	0.56

* The viscosity of the combined ostrich fat fraction was determined at 39°C

number was calculated according to State Standard R ISO 3961-2010[IV]. The melting and chilling points were based on State Standard 32189-2013[V]. The control of acid and peroxide numbers was based on State Standard R ISO 27107-2010[VI]. The peroxide number was determined using the potentiometric method according to the end point. The density was measured according to State Standard 18329-2014 (ISO 1675:1985)[VII]. The anisidine number was measured by the optical density of the test solution after its reaction with an acetic acid solution of para-anisidine according to State Standard 31756-2012 (ISO 6885:2006)[VIII]. A rotary digital viscometer was used to determine fat viscosity as specified in State Standard 1929-87[IX]. The experiments were done in triplicates and processed statistically.

RESULTS AND DISCUSSION

The safety and intended use of the product depend on the physicochemical indicators of the rendered fats that are regulated by technical documentation and standards.

The physicochemical indicators of the quality of ostrich fat clearly showed the advantage of the proposed method (Table 3). The fat rendered using the experimental technology had low acid, peroxide, and anisidine values. Processing raw materials in an electrochemically activated solution inactivated the enzyme system (lipase, phospholipase) even at low temperatures (39 and 55°C). The catholyte mechanism proved to be effective, as it lowered and, in some cases, prevented the hydrolytic processes of triacylglycerols. Wet rendering in tap water demonstrated the opposite tendency. The acid numbers revealed a significant amount of free fatty acids and peroxide compounds in the rendered fat. Unlike the experimental technology, water rendering resulted in a characteristic smell.

Fat viscosity is known to affect the rate of heat transfer, separation, and settling. Therefore, this indicator was considered significant for the new technology and equipment. Table 3 shows that internal fat had a lower viscosity than subcutaneous fat, which was due to its unsaturation degree and an increase in the number of double bonds. According to A.V. Gorbatov, liquid products have no ultimate shear stress, and the flow occurs at any minimum shear stress [28]. After cooling, the ostrich fat did not lose all its viscosity. In contrast, pork fat develops a solid crystallization framework at temperatures below 27°C and loses its viscosity.

Table 4 demonstrates that the effectiveness of the experimental technology was fully confirmed by the yield.

[IV] State Standard R ISO 3961-2010. Animal and vegetable fats and oils. Determination of iodine value. Moscow: Standartinform; 2019. 12 p.

[V] State Standard 32189-2013. Margarines, cooking fats, fats for confectionery, baking and dairy industry. Sampling rules and methods of control. Moscow: Standartinform; 2014. 36 p.

[VI] State Standard R ISO 27107-2010. Animal and vegetable fats and oils. Determination of peroxide value by potentiometric end-point determination. Moscow: Standartinform; 2011. 16 p.

[VII] State Standard 18329-2014 (ISO 1675:1985). Liquid resins and plasticizers. Methods for determination of density. Moscow: Standartinform; 2015. 12 p.

[VIII] State Standard 31756-2012 (ISO 6885:2006). Animal and vegetable fats and oils. Determination of anisidine value. Moscow: Standartinform; 2014. 13 p.

[IX] State Standard 1929-87. Petroleum products. Methods of test for determination of dynamic viscosity by rotary viscosimeter. Mooscow: Izdatel′stvo standartov; 2002. 7 p.

Table 4 Fat yield at various processing methods

Rendering method	Processing temperature, °C	Fat	Fat yield, %
In tap water, pH = 7–8	39, 55, 75, 100	Internal	45.0–48.0*
		Subcutaneous	
	55	Internal	50.0–55.0
		Subcutaneous	
	75	Internal	65.0–70.0
		Subcutaneous	
	100	Internal	82.0–87.0
		Subcutaneous	
In electrochemically activated solution (catholyte), pH = 11	39, 55, 75, 100	Internal	55.0–58.0*
		Subcutaneous	
	55	Internal	68.0–72.0
		Subcutaneous	
	75	Internal	80.0–85.0
		Subcutaneous	
	100	Internal	91.0–95.0
		Subcutaneous	

* The viscosity of the combined ostrich fat fraction was determined at 39°C

Electrochemical activation method produced a significantly higher yield than wet rendering in water (Table 4). Second-order orthogonal designs helped establish the effect of technological parameters on fat yield. Table 5 shows the levels of fat extraction factors, while Table 6 demonstrates the matrix of the experiment. Mathematical model 2^k took into account both the number of star points on the coordinate axes of the factor space and points in the center design. Star shoulder α indicated the distance from the center design to the star point.

Table 5 Variation of factors for fat rendering in electrochemically activated liquid (catholyte)

Factors	–α (–1.21)	Z_j^{min}	Z_{j0}	Z_j^{max}	+α (+1.21)
Time, min (Z_1)	25	30	45	60	65
pH (Z_2)	7.5	8	9	10	10.5
Temperature, °C (Z_3)	50	55	75	95	100

The dependence of the output on the set parameters is given as a regression equation (Eqs. (3) and (4)).

$$Y = 81.96 + 3.481\chi_1 + 2.89\chi_2 + 3.17\chi_3 + \\ + 0.67\chi_1\chi_2 + 0.613\chi_1\chi_3 + 0.27\chi_2\chi_3 - \\ - 0.32\chi_1\chi_2\chi_3 - 0.985X_1^2 - 1.26\chi_2^2 - 0.728\chi_3^2 \quad (3)$$

After checking the coefficients of the equation, only nine proved significant. Therefore, the final equation was as follows:

$$Y = 81.96 + 3.481\chi_1 + 2.89\chi_2 + \\ + 3.17\chi_3 + 0.67\chi_1\chi_2 + 0.613\chi_1\chi_3 - \\ -0.985X_1^2 - 1.26\chi_2^2 - 0.728\chi_3^2 \quad (4)$$

The Fisher's criterion calculated $F = (f_1, f_2) = (6; 3) = 7.39$ proved the obtained Eq. (4) to be adequate for experiment ($S_{reprod.} = 0.207$, $S_{resid.} = 1.53$), as condition $F < F_{1-p}$, (f_1, f_2); $7.39 < 8.94$ holds at $P = 0.05$.

The obtained equation made it possible to establish an equidirectional positive effect of temperature, rendering time, and catholyte pH on fat yield. In addition, the cross impact of the hydrogen index and the processing temperature was insignificant, while the joint action mechanism of "processing time – catholyte pH" and "processing time – melting temperature" proved

Table 6 Second-order orthogonal design for ostrich fat rendering ($k = 3$, $n_0 = 1$)

Experiment number	Factors in a dimensionless coordinate system			Full-scale factors			Y_1, %	Y_{calc}, %	$(Y_1–Y_{calc})^2$
	X_1	X_2	X_3	Z_1, min	Z_2	Z_3, °C			
1	+1.00	+1.00	+1.00	60	10.0	95	88.9	89.80	0.830
2	–1.00	+1.00	+1.00	30	10.0	95	80.3	80.30	0
3	–1.00	–1.00	+1.00	30	8.0	95	74.2	75.80	2.690
4	–1.00	–1.00	–1.00	30	8.0	55	70.0	70.70	0.530
5	+1.00	–1.00	+1.00	60	8.0	95	81.5	82.70	1.420
6	+1.00	–1.00	–1.00	60	8.0	55	74.3	75.10	0.680
7	+1.00	+1.00	–1.00	60	10.0	55	83.1	82.20	0.730
8	–1.00	+1.00	–1.00	30	10.0	55	75.6	75.20	0.160
9	+1.21	0	0	65	9.0	75	84.1	84.70	0.360
10	–1.21	0	0	25	9.0	75	75.5	76.30	0.640
11	0	+1.21	0	45	10.5	75	83.6	83.60	0
12	0	–1.21	0	45	7.5	75	75.7	76.60	0.810
13	0	0	+1.21	45	9.0	100	85.3	84.70	0.360
14	0	0	–1.21	45	9.0	50	76.5	77.10	0.360
15	0	0	0	45	9.0	95	82.0	81.96	0.002

Extra experiments in the center design $Y_1 = 81.0$; $Y_2 = 81.9$; $Y_3 = 81.5$; Z_1 – rendering time, min.; Z_2 – pH value (pH), Z_3 – temperature, °C to be insignificant. Nevertheless, a significant increase in the abovementioned factors would have a negative effect. Thus, simulating the technological conditions of fat extraction in an electrochemically activated liquid could control the properties of the raw material and its productivity. The identified dependencies were taken into account in order to improve the technological conditions of fat extraction (Fig. 2).

The experimental data made it possible to build a technological line for ostrich fat rendering [29]. It owed its innovative character to a higher fat yield and a more efficient fat extraction process based on electrochemical activation.

Figures 1 and 2 illustrate the sequence of technological operations and hardware design of the fat production line. Table 7 contains the necessary equipment specification.

The ostrich fat production line with the specified properties operated as follows [29]. Raw fat was loaded into the receiving funnel of the AVZh-400 centrifugal machine for primary grinding to 5–6 mm. Simultaneously, hot water (70°C) was added info the grinder in the amount of 20% of the raw material mass (Table 7, *1*). After that, the raw material was fed into the IN-20 worm inactivator (*2*), where it was treated with both indirect and direct heating steam under a pressure of ≤ 0.3 MPa. The electrochemically activated solution (catholyte) flowed in a ratio of 4:1 to the raw material mass through the pipeline that connected the inner working area of the inactivator with the catholyte tank (*19*). Unlike the traditional wet rendering, the fat was watered in an electrolyte (catholyte). A prefabricated 10% aqueous solution of sodium chloride (*25*) was poured into the electrolyzer (*21*), which was connected

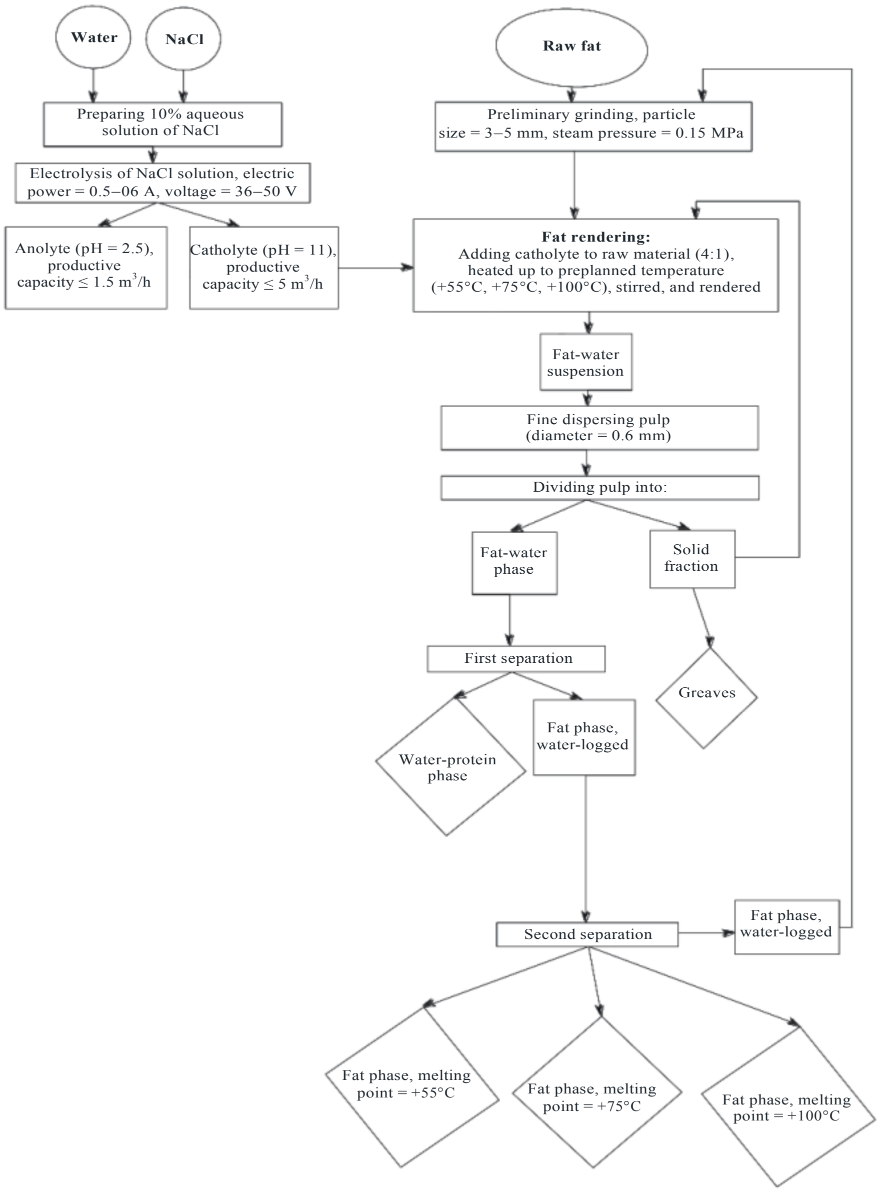

Figure 1 Technological scheme of ostrich fat production

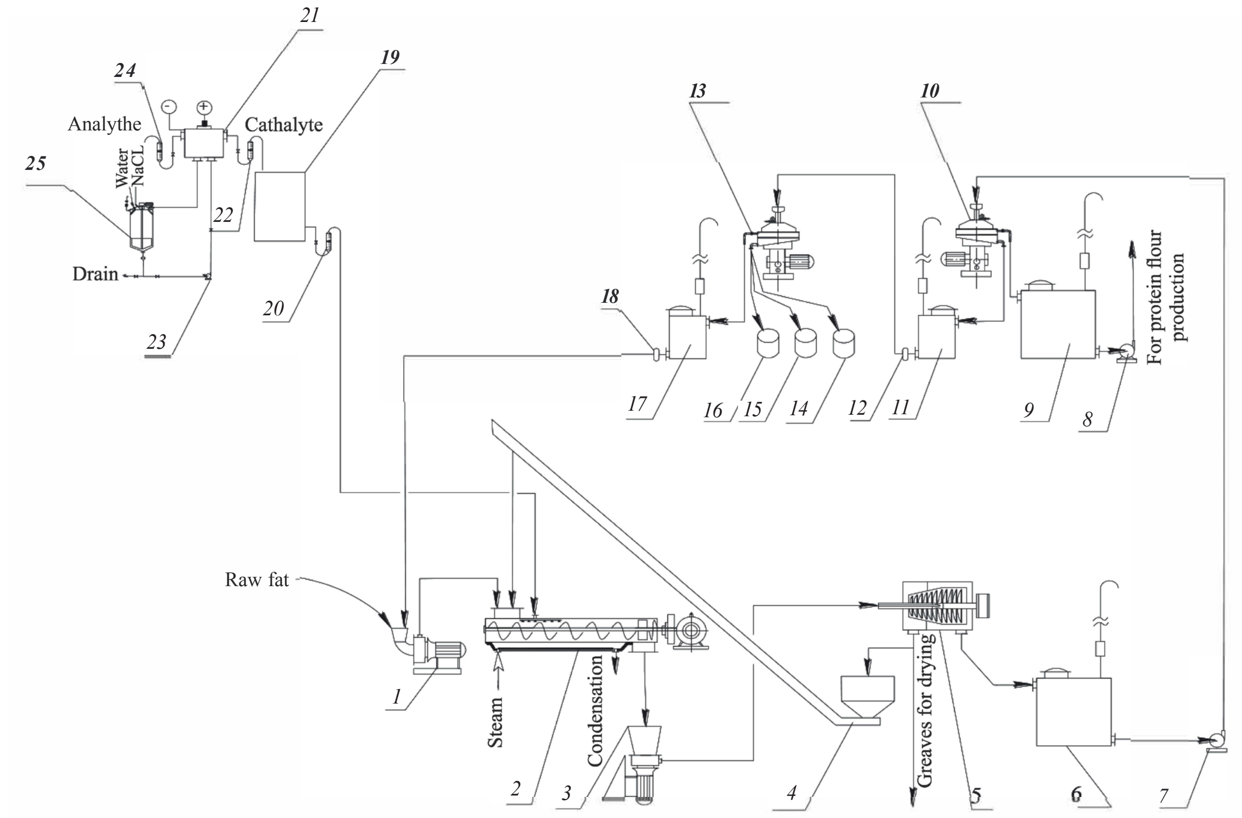

Figure 2 Ostrich fat production line [29]. *1* – device for primary grinding of raw fat; *2* – worm inactivator IN-20; *3* – disintegrator; *4* – hopper with a helix lift; *5* – pulp separation device; *6*, *17* – vertical free-flow tank for collecting fat-water fraction; *7*, *8*, *12*, *18*, *23* – pump; *9* – vertical free-flow tank for collecting water-protein fraction; *10* – the first separator of the fat-water fraction; *13* – the second separator; *14*, *15*, *16* – tanks for collecting fat fractions with a predetermined melting point; *19* – tank for electrochemically activated solution; *20*, *22*, *24* – flowrator; *21* – device for obtaining electrochemically activated solution (electrolyzer); *25* – tank for NaCL solution

to the catholyte tank (*19*). To increase the rendering, the medium for electrochemical activation was applied precisely during the relaxation period. At that stage, its activity and technological properties were at their maximum. The screw rotation frequency was 60 rpm. To sum it up, the raw material was ground and heated with direct heating steam to a predetermined temperature, depending on the melting point of fat rendering.

The obtained combination of mechanical and physicochemical factors made it possible to intensify fat extraction without losing in the yield and quality of fat. The essence of this phenomenon lied in the unipolar processing of sodium chloride solution in the cathode chamber of the electrolyzer. As a result, the solution acquired a metastable state with unique relaxing physicochemical properties. The structural components of the interionic energy interaction underwent a significant change. The active concentration of ions changed because the activity coefficients had changed, not the concentration. The electrolyte is known to reach stable values over a period of time that ranges from minutes to hundreds of hours [27].

The technology made it possible to increase the fat yield without high temperatures or chemicals. Cell membranes were destroyed despite the low processing temperatures.

After that, the processed raw fat was fed to an extra disintegrator (*3*) to obtain a finely ground pulp suspension (particle size = 0.6 mm). The centrifugal force of the ABZh-245 machine pumped the ground fat to the height of 3 m.

At pressure of 0.3 atm, the suspension was fed by gravity to an extra device (Table 7, *5*) in order to separate the pulp into a fat-water fraction and greaves. The fat-water fraction entered the first FCA fat separator (*10*) via the first collection vessel (*6*) through the pipeline and pump (*7*). There it was continuously separated into water-protein glue and fat-water fraction.

The first separation concentrated and purified the fat-water suspension. It entered the rotating drum at the rotation speed of 5,000 min^{-1} and dispersed into thin layers between the conical trays. Under the centrifugal force, protein and other solid particles moved along the bottom surface of the trays and were thrown into the sludge space. Partial sludge discharge occurred at specified time intervals in the operating mode. The processing time depended on the concentration of solid

Table 7 List and technical sepcifications of ostrich fat production equipment

Item	Equipment	Number	Specifications
1	Centrifugal machine AVZh-400	1	Q = 1000 kg/h; N = 15 kW, steam pressure = 0.15 MPa, hole diameter = 30 mm, number of holes = 6, rotor speed = 24.3 s^{-1}, rotor diameter = 310/400 mm. Overall dimensions: 1300 × 400 × 900 mm
2	Worm inactivator IN-20	1	Q = 30 t/s, indirect steam temperature = 120–1,40°C, heating steam consumption = 100 kg/h, steam pressure = ≤ 0.3 MPa, number of nozzles = 12, installed power = 0.75 kW. Overall dimensions: 400 × 600 × 6400 mm
3	ABZh – 245 machine	1	Q = 1,500 kg/h, N = 14 kW, steam pressure = 0.15 MPa, hole diameter = 6 mm, number of holes = 152, rotor speed = 24.3 s^{-1}, rotor diameter = 230/245 mm. Overall dimensions: 1300 × 400 × 900 mm
4	Hopper with a helix lift VK-160 4286– TL –HC–75/187	1	Hopper volume V = 0.25 m^3, length = 4286 mm, lift height = 7000 mm, N = 2.5 kW
5	Centrifuge NOGSh-325	2	Fat-water suspension production = 2.5 t/h, N = 7 kW; inner rotor diameter = 325 mm, inner rotor length = 540 mm, discharge radius = 140 mm, revolutions per minute (max.) = 3500, relative number of screw revolutions per minute = 23.5, power consumption per 1 ton of raw fat = 2.22 kW. Overall dimensions: 520 × 1456 × 1600 mm
6, 9	Vertical free-flow tank BT(B)-0.1-0.0-V	1	V = 0.25 m^3; diameter D = 600 mm, height H = 900 mm, weight = 80 kg
7, 8	Pump X 50-32-125a	2	Q = 10.5 m^3/h, H = 14 m, N = 4.0 kW. Chemical; horizontal overhang pump, with casing support; diameter of the inlet branch pipe = 50 mm, diameter of the outlet branch pipe = 32 mm; nominal wheel diameter = 125 mm
10	Fat separator FTsA	1	Productivity = 1500 cm^3/h; power = 15 kW. Overall dimensions: 1800 × 990 × 1320 mm
11, 17	Vertical free-flow tank BT(B)-0.1-0.0-V	1	V = 0.125 m^3; diameter = 400 mm, height = 1000 mm; weight = 61 kg
12, 18	Pump NSh 10-M-3 L U1	2	Productivity = 0.8 m^3/h, N = 1.1 kW, temperature t = 80°C, pressure = 125 atm
13	Fat separator FSTSP-1	1	Productivity = 1000 cm^3/h, power = 7.5 kW. Overall dimensions: 1440 × 1080 × 1210 mm
14, 15, 16	Vertical free-flow tank BT(B)-0.1-0.0-V	3	V = 0.10 m^3, diameter D = 400 mm, height = 800 mm, mass = 56 kg
19	Tank for electrochemically activated solution (catholyte)		Stainless steel – AISI 304 (08X18H10); volume = 2.5 m^3
20, 22, 24	Electrocontact flowrator SWK	3	Q = 0.05–0.1 dm^3/min, 13–24 dm^3/min; t_{max} = 100°C, p_{max} = 250 bar, material – stainless steel, accuracy ± 4%
21	Electrolyzer for obtaining electrochemically activated solution	1	Volume V = 1.25 m^3, power intake N = 0.75 kVt; current strength = 40 Vt, catholyte productivity (pH = 11) = ≤ 5 m^3/h; anolyte productivity (pH = 2.5) = 1.5 m^3
23	Pump TsNS 4/30	1	Feed rate = 1.6 m^3/h, flow pressure = 20 m, power = 1.1 kVt, temperature ≤ 150°C, for corrosive liquid pumping
25	Tank for NaCL solution	1	Stainless steel – AISI 304 (08X18H10). Number of mixers – 1; rotation = 60 rpm; N = 1.75 kVt. Overall dimensions: 1650 × 1650 × 2820 mm

particles in the raw material. The average processing temperature in the separators directly depended on the preset melting temperature in the inactivator; the processing time was 5 sec. The water-protein fraction entered the tank (*9*) via the first outlet of the separator with the help of a pressure disc along the pipeline under a pressure of 0.3 MPa. The mass fraction of the waste water from the first separator was about 70%.

Through the second outlet, the remaining fat-water fraction was fed into the second tank (*11*). After that, it went through the second separator (FSTsP-1) with a one-millimeter inter-plate gap for further separation (*13*), resulting in the target product with a preset melting point (*14*, *15*, *16*).

To reduce fat loss, the remaining fat-water phase returned into the machine for primary grinding of raw fat after the second separation (*1*). From there, it went into the IN-20 worm inactivator for processing (*2*), together with a new batch of raw fat.

The designed line was sustainable and provided not only complete fat rendering, but also its fractionation depending on the melting temperature. A stepwise approach to the processing of raw materials with a gradual increase in temperature made it possible to

Table 8 Quality indicators of the ostrich subcutaneous fat obtained according to the developed technology

Indicator	Fractions of ostrich fat with melting point of:		
	≤ 55°C	≤ 75°C	100°C
Color	Light yellow	Light yellow	Opaque white with a yellow tint
Smell	Characteristic, typical of this type of fat	Characteristic, typical of this type of fat	Characteristic, typical of this type of fat with no signs of greasing or rancidity
Texture	Liquid	Liquid	Ointment-like, with allowable heterogeneous structure (creaming)
Moisture content, %, ≤	0.8	0.8	0.8
Acid number, mg KOH/g, ≤	3.5	3.5	3.5
Peroxide number, mole of active oxygen/kg, ≤	7.0	7.0	7.0
Viscosity, at 24°C, kPa·s	≤ 0.7	0.70–0.85	1.25–1.75
Density ρ_{20}^{24}, kg/m^3	861–865	881–892	898–910

control the process and process the various types of animal and poultry fats. The new technical solution returned the fat-water phase and suspension through a helical conveyor (*4*), which was connected to the centrifuge (*5*), back to the inactivator (Fig. 2).

The new production line provided a closed technological cycle that minimized the loss of valuable fat product low temperature rendering.

Table 8 demonstrates the technical result of the production line.

CONCLUSION

Electrochemically activated solution introduced in the process of fat rendering made it possible to adjust its properties depending on the intended use of the final product. The developed method of fat rendering and the new sustainable fat production line produced high quality fat and increased the yield of the product compared to the traditional wet rendering in water. The method was based on an inexpensive and safe sodium chloride reagent, which reduced costs and losses in the technological cycle. As a result, the new technology increased the productivity of fat extraction and the degree of fat-water fraction separation. The developed fat production line based on electrochemical activation can be recommended for farm animal fat rendering depending on the intended use.

CONTRIBUTION

All the authors are equally responsible for the obtained research results and the manuscript.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest related to the publication of this article.

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