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STUDY OF THE INFLUENCE OF PLANT-BASED COMPONENTS ON THE PHYSICOCHEMICAL AND ORGANOLEPTIC PROPERTIES OF MEAT PRODUCT

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The aim of the work was to study the complex of humic-fulvic acids, calamus rhizome and pumpkin seed cake as antioxidants on physicochemical and organoleptic parameters of meat product.The methodology included the application of a factorial experiment design with varying concentrations of plant components, wet salting, heat treatment and evaluation of quality parameters. The results showed that the addition of humic-fulvic acids and calamus rhizome reduced pH and TBA, pumpkin seed cake reduced cooking loss and improved organoleptic properties. The most balanced indicators were recorded in the sample with 3 % of calamus and 0.7 % of humic-fulvic acids: pH - 5.57; TBA - 0.43 mg MDA/kg; Cookloss - 17.01 %; organoleptic score - 4.92. The plant components can be effectively used as antioxidants and acid regulators contributing to the improvement of stability, quality and consumer characteristics of meat products.

Keywords: horse meat, meat roulade, humic-fulvic acids, calamus rhizome, pumpkin seed cake, functional meat product.

ИССЛЕДОВАНИЕ ВЛИЯНИЯ РАСТИТЕЛЬНЫХ КОМПОНЕНТОВ НА ФИЗИКО-ХИМИЧЕСКИЕ И ОРГАНОЛЕПТИЧЕСКИЕ СВОЙСТВА МЯСНОГО ПРОДУКТА

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Целью работы было изучение комплекса гуминовых и фульвовых кислот, корневища аира и жмыха тыквенных семечек в качестве антиоксидантов на физико-химические и органолептические показатели продукта из конины. Методология включала применение факторного экспериментального плана с варьированием концентраций растительных компонентов, мокрый посол, термическую обработку и оценку показателей качества. Результаты показали, что добавление гуминовых и фульвовых кислот и корневище аира снижало показательрН и ТВА, а тыквенный жмых уменьшал потери при тепловой обработке и улучшал органолептические свойства. Наиболее сбалансированные показатели были зафиксированы в образце с 3 % аира и 0,7 % гуминовых и фульвовых кислот: рН - 5,57; ТВА - 0,43 мг MDA/кг; потери при варке - 17,01 %; органолептическая оценка - 4,92. Исследование показало, что растительные компоненты могут эффективно использоваться в качестве антиоксидантов, способствующих улучшению стабильности, качества и потребительских характеристик мясных продуктов из конины.

Ключевые слова: конина, мясной рулет, гуминовые и фульвовые кислоты, корневище аира, жмых тыквенных семечек, функциональный мясной продукт.

ӨСІМДІК ТЕКТІ КОМПОНЕНТТЕРДІҢ ЕТ ӨНІМІНІҢ ФИЗИКА-ХИМИЯЛЫҚ ЖӘНЕ ОРГАНОЛЕПТИКАЛЫҚ ҚАСИЕТТЕРІНЕ ӘСЕРІН ЗЕРТТЕУ

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Зерттеу жұмысы мақсаты - гуминді және фульвон қышқылдары кешенінің, аир тамыр сабағы мен асқабақ дәні күнжарасының жылқы еті негізіндегі ет өнімінің физика-химиялық және органолептикалық көрсеткіштеріне антиоксидант ретінде әсерін зерттеу болды. Зерттеу әдістемесі өсімдік текті компоненттердің әртүрлі концентрацияларымен факторлық эксперименттік жоспарды қолдануды, дымқыл тұздауды, термиялық өңдеуді және сапа көрсеткіштерін бағалауды қамтыды. Зерттеу нәтижелері гуминді-фульвон қышқылдары мен аир тамыр сабағының қосылуы pH және ТВА көрсеткіштерін төмендететінін көрсетті, ал асқабақ дәні күнжарасы жылумен өңдеу кезіндегі шығынды азайтып, органолептикалық қасиеттерін жақсартты. Ең оңтайлы нәтижелер 3 % аир мен 0,7 % гуминді-фульвон қышқылдары қосылған үлгіде тіркелді: pH - 5,57; ТВА - 0,43 мг MDA/кг; пісіру кезіндегі шығын - 17,01 %; органолептикалық бағалау – 4,92. Зерттеу нәтижелері өсімдік текті компоненттерді жылқы етінен жасалған ет өнімдерінің тұрақтылығын, сапасын және тұтынушылық сипаттамаларын жақсартуға бағытталған тиімді антиоксиданттар ретінде пайдалануға болатынын көрсетті.

Түйін сөздер: жылқы еті, ет рулеті, гуминді-фульвон қышқылдары, аир тамыр сабағы, асқабақ дәні күнжарасы, функционалды ет өнімі.

Introduction. In the conditions of modern food industry increasing attention is paid to the development of functional meat products using natural components with biologically active properties. In this regard, promising directions are the inclusion in the formulation of meat products of plant raw materials with antioxidant, immunostimulating and antimicrobial activity. Such components include acorus calamus rhizome, pumpkin seed cake, as well as a complex of humic and fulvic acids.

Acorus calamus rhizome is a valuable source of biologically active substances, including essential oils (α-asarone, β-asarone), phenolic compounds and glycosides with pronounced antioxidant, antimicrobial and anti-inflammatory activity. Studies by scientist Evdokimov and his colleagues have shown that the addition of calamus extracts to meat products helps to reduce microbial contamination and increase shelf life by inhibiting lipid oxidation [1]. In addition, calamus components have a positive effect on digestion by modulating intestinal microflora and have a carminative effect.

Pumpkin seed cake (Cucurbita pepo L.) is a rich source of dietary fibre (up to 15-20%), proteins (about 30%), polyunsaturated fatty acids, especially linoleic acid, as well as tocopherols and phytosterols. It also contains phenolic compounds with high antioxidant activity that protect lipids from oxidation in meat matrices. A study by scientist Leichtweis and colleagues showed that the use of pumpkin seed cake in meat products helps to increase the overall antioxidant activity, improve the texture and nutritional value of the product [2]. In addition, it reduces the glycemic index and improves the lipid profile of the final product.

Complex of humic and fulvic acids is a bioactive mixture of humic acids, fulvic acids and humins. These substances have a high complexing ability, binding metal ions and improving their bioavailability, which contributes to the trace element enrichment of the meat product. According to studies in recent years, the addition of humic-fulvic acids to poultry diets or meat products contributes to a decrease in lipid oxidation, an increase in the activity of antioxidant enzymes (catalase, glutathione peroxidase) and a decrease in the activity of lipoxygenases [3,4].

In a study by Simakova and her colleagues, scientists emphasize that humic substances can perform a preserving function, increasing the shelf life of poultry meat without the addition of synthetic antioxidants [5]. In the study of the scientist Mao,

it was found to improve the immune status of animals and increase meat productivity, which makes humic-fulvic acids a promising additive for use in the technology of functional meat products [6].

The aim of the present work is to study the effect of humic-fulvic acid complex and calamus rhizome on physicochemical and organoleptic parameters of meat product.

Materials and methods. For the investigation of the impact of plant components on the quality attributes of meat products, horse meat-based roll (roulade) samples were prepared at the Educational and Scientific Center of Meat Processing of the Almaty Technological University.

The following components of plant origin were purchased for the experiment:

- calamus Rhizome - dried crushed raw material with a specific aroma and bitter-spicy flavor;

- complex of humic and fulvic acids ‘T8 Tayga Stone’ - a natural concentrated product containing active humic and fulvic acids with antioxidant properties;

- pumpkin seed cake is a secondary plant product after oil pressing, characterized by a high content of dietary fibre, minerals and antioxidants.

The selection of Acorus calamus rhizome and the complex of humic-fulvic acids was based on their known functional properties, including the potential ability to lower the pH and reduce the thiobarbituric acid (TBA) value, thereby slowing lipid oxidation processes. Additionally, the humic-fulvic acids were expected to contribute to meat tenderness by modifying muscle tissue structure. Pumpkin seed cake was utilized to enhance the sensory profile-specifically flavor and aroma-while simultaneously acting as a barrier coating, thus reducing moisture loss during thermal treatment.

For the study, horse meat was purchased from the local market, which was visually characterised by signs of increased pH, which was confirmed by organoleptic indicators (dark red colour, dry and hard surface and reduced elasticity) indicating possible changes as a result of storage. After acquisition, the meat was subjected to technological operations: cutting, deboning. Next, the meat was cut into 200 g pieces with a weight of about 1 cm thick and prepared for the wet salting process.

A brine base including 1.5 litres of water, 75 g table salt and 0.3 g sodium nitrite was made to prepare the brine. Portions of meat were placed in a specially purchased plastic dish (GN1/6 polypropylene/Schneider/Germany) and poured 100 ml of the prepared brine base. Then, humic-fulvic acid complex and, previously brewed in hot water and cooled to room temperature, calamus rhizome (100 ml) were introduced into the brine. The amount of plant-based components was calculated according to the experimental matrix as a percentage of the meat weight (200 g). The total volume of brine for each sample was 200 ml.

The brining process was carried out at 2 ± 2°C and lasted 24 hours.

After completion of the salting process, the meat samples were removed from the brine and further prepared for heat treatment. The pumpkin seed cake was ground to powder using a nano-crusher (Grindomix GM 200, Retsch, Germany) to obtain a homogeneous fine structure. Then, water was gradually added to the obtained powder, mixing thoroughly until a homogeneous paste-like consistency was achieved, which was convenient for application to the surface of meat.

The obtained paste from pumpkin seeds evenly covered the surface of each meat sample in the amount of 5% of the weight of meat raw material, after which the products were formed in the form of rolls. The prepared rolls were hermetically wrapped in thin aluminium foil and placed in a heat chamber (UK-3\1M100, Techtron+, Russia). Heat treatment was carried out at 110°C until the temperature in centre of the roll reached 78°C, which was monitored using a thermometer with a probe.

After completion of thermal treatment, the rolls were cooled to room temperature (20±2°C) in air. Then the finished samples were placed in storage at refrigerator temperature (2±2°C) until the organoleptic evaluation and laboratory tests aimed at studying the effect of plant components on the quality parameters of the meat product.

Laboratory analyses of the final products were conducted at the accredited testing laboratory “Food Safety” of Almaty Technological University (Certificate accreditation No.KZ. T.02.E1158).

Thiobarbituric acid number (TBA) was determined according to GOST R 55810-2013. The method is based on spectrophotometric measurement of the intensity of colouration arising from the interaction of fat oxidation products with thiobarbituric acid, which allows to assess the degree of oxidative damage of the fat component of meat.

The pH value was determined by potentiometric method. The essence of the method is the direct measurement of hydrogen ion activity using a glass electrode potentiometer, which allows to quickly and accurately determine the acidity of the meat sample under study.

The mass loss of meat samples was calculated from the sample weight values before heat treatment, and the sample weight values after heat treatment. The mass loss reflected the weight of the sample after heat treatment (B) as a percentage of the weight of the sample before heat treatment (A), as shown by the equation below:

$$Cookloss\ (\%) = \left[\frac{A-B}{A}\right] ?100$$

The organoleptic evaluation of the meat product was carried out in accordance with GOST 9959-2015 “Meat and meat products. General requirements for organoleptic evaluation.”The analysis involved 10 employees and master’ s degree students of the Department of Food Technology of Almaty Technological University (Kazakhstan), who are already familiar with the criteria for assessing organoleptic characteristics of products. Participation in the analysis was voluntary and participants provided verbal consent for the sensory evaluation. The assessment took place in a well-ventilated room with adequate lighting and no distractions. Food samples were evenly sliced and chilled to 20°C±2°C, then placed in labeled white plastic plates. For sensory tests, participants used warm water to cleanse the palate between samples to eliminate the influence of the previous evaluation on the next sample. The results of the coded samples were presented as a sensory scale from 0 to 5 points, where 1 point denotes the lowest score and 5 points denotes the highest score. This method involves the systematic assessment of sensory characteristics such as appearance, color, smell, texture, and taste.The overall score was calculated as the arithmetic mean of these five parameters.

This study was carried out using the Black Box method. X_1 - mass fraction of Acorus calamus rhizome (1%, 3%, 5%) and X_2 - mass fraction of humic-fulvic acid complex (0.3%, 0.5%, 0.7%) were selected as variable factors of the experiment. To investigate the effect of these factors on pH and thiobarbituric acid (TBA) values, a second-order fractional-factorial experimental design was applied to obtain reliable results with a limited number of experimental points. From the total number of variants, only samples corresponding to key combinations of variables were physically analyzed. The remaining values were interpolated on the basis of the constructed regression equations reflecting the dependence of the studied indicators on the levels $X_1$and X_2.

All experiments were performed at least three times ($n \geq 3$). Results are presented as «mean±standard deviation» (M±SD).

Values obtained by calculation using multiple regression equations are marked with an asterisk in the tables and graphs to distinguish between measured and modelled data.

The values of meat loss weight after heat treatment and organoleptic characteristics were determined using a full factorial experiment.

Results and discussion. Following the completion of laboratory analyses and the calculation of values using the regression equation, an experimental matrix was constructed containing all values of the resulting factors. (Table 1).

Table 1 - Matrix of factorial experiment with the values of resulting quality indicators of the meat product

Name of samples	X1	X2	Y1	Y2	Y3	Y4
	Calamus Rhizome,%	HF Acidconc.,%	pH	TBA,mg MDA/kg	Cookloss,%	Organoleptic score, points
Sample 1	1	0,3	6,38±0,52	0,55±0,03	18,89±0,14	4,46±0,39
Sample 2	1	0,5	6,36±0,54	0,52*±0,03	25,58±0,15	4,58±0,35
Sample 3	1	0,7	6,34±0,56	0,48±0,03	16,51±0,13	4,65±0,36
Sample 4	3	0,3	5,58*±0,49	0,49*±0,03	19,63±0,13	4,79±0,37
Sample 5	3	0,5	5,82±0,45	0,50±0,03	21,5±0,12	4,84±0,35
Sample 6	3	0,7	5,57*±0,42	0,43±0,03	17,01±0,13	4,92±0,34
Sample 7	5	0,3	4,67±0,38	0,41±0,03	16,82±0,15	4,16±0,38
Sample 8	5	0,5	4,74*±0,36	0,38*±0,03	13,86±0,13	4,25±0,41
Sample 9	5	0,7	4,68±0,31	0,33±0,02	14,42±0,12	4,37±0,37
Control sample	0	0	6,58±0,56	0,39±0,02	33±0,21	3,91±0,35
Note: * - values calculated using the regression equation						

Surface Plot of Y_1(pH) against X_1(Calamus Rhizome) and X_2(HF Acid conc.) is shown in Figure 1.

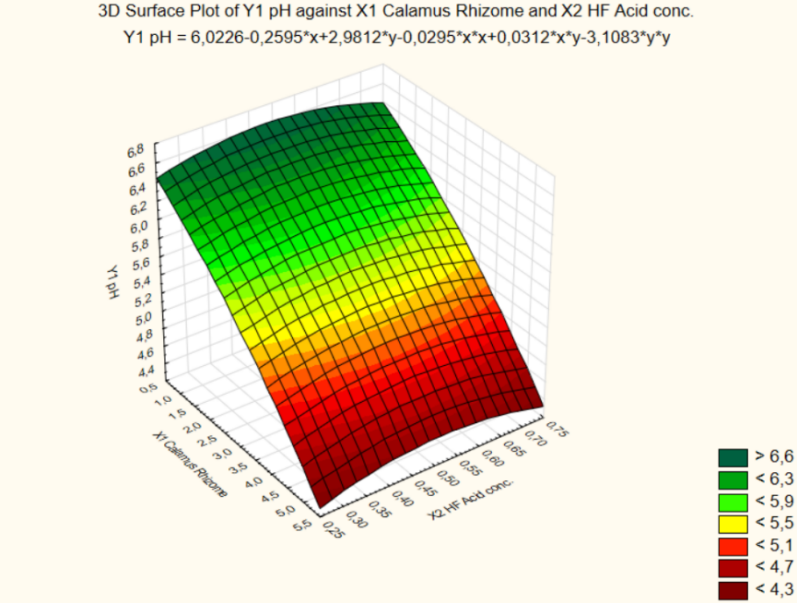


Fig.1 - 3D Surface Plot of Y_1(pH) against X_1(Calamus Rhizome) and X_2(HF Acid conc.)

The regression equation for Y_1(pH) as a function of X_1 (Calamus Rhizome) and X_2 (HF Acid conc.):

$Y_1(pH) = 6,7469-0,3417X_1 + 0,3698X_2 - 0,0229X^2_1 + 0,1088X_1X_2 - 0,7985X^2_2$

Regression model performance metrics:R^2 = 0,9732; R^2_adj = 0,9334;MS_e = 0,0516;

The response surface analysis (Figure 1) shows that the value of Y_1 (pH) decreases systematically with increasing levels of factors X_1 (Calamus Rhizome) and X_2 (HF Acid concentration). The maximum pH value (6,58) is observed at zero values of the factors, i.e. in the control sample. The minimum pH values (4,68) were recorded at maximum additive dosages of X_1 = 5% and X_2 = 0.7% ($p<0,05$).

As the doses of both X_1 and X_2 increase, a stable and progressive decrease in pH value is observed. And the greatest dynamics of decrease is fixed at simultaneous increase of both factors. This indicates a synergistic effect of plant components aimed at acidification of the medium. In the technological context, this can be a positive factor, since a controlled decrease in pH improves the stability of the product and affects its structural and mechanical properties.

Surface Plot of Y_2(TBA) against X_1(Calamus Rhizome) and X_2(HF Acid conc.) is shown in Figure 2.

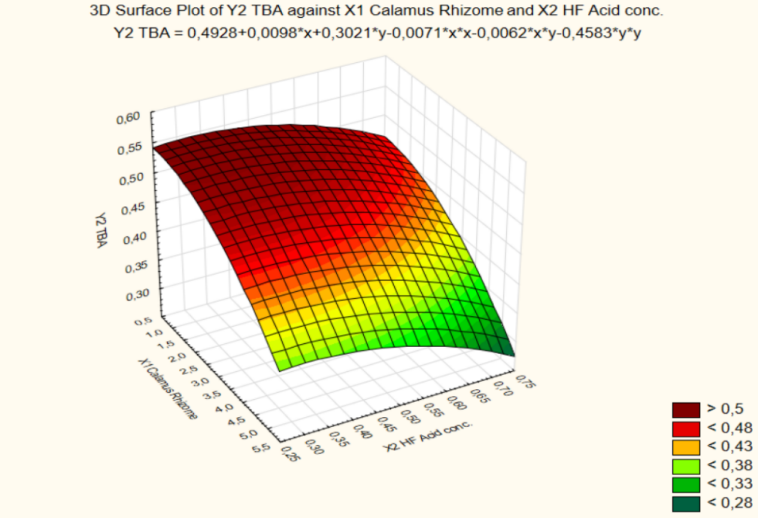


Fig.2 - 3D Surface Plot of Y_2(TBA) against X_1(Calamus Rhizome) and X_2(HF Acid conc.)

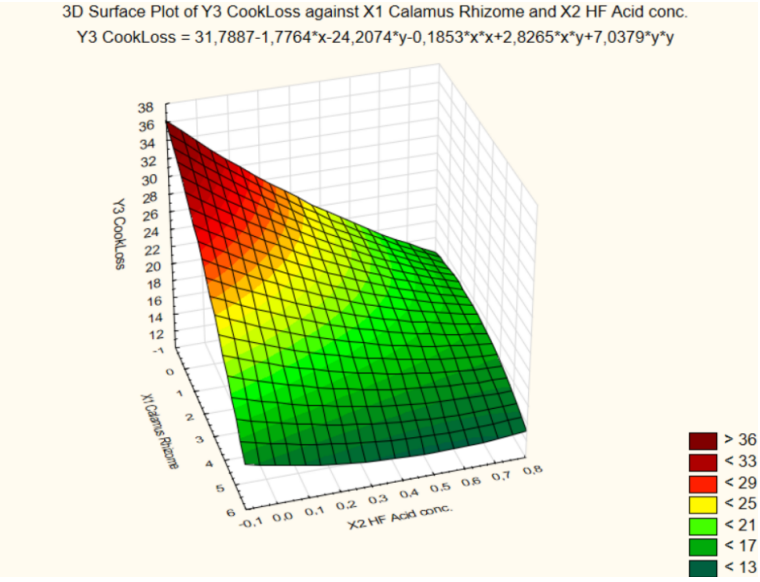


Fig.3 - 3D Surface Plot of Y_3(CookLoss) against X_1(Calamus Rhizome) and X_2(HF Acid conc.)

The regression equation for Y_2(TBA) as a function of X_1 (Calamus Rhizome) and X_2 (HF Acid conc.):

Y_2 (TBA) = 0,3945 + 0,021X_1 + 0,6567X_2 - 0,008X^2_1 - 0,0168X_1X_2 - 0,772X^2_2

Regression model performance metrics:R^2 = 0,9434; R^2_adj = 0,9116;MS_e = 0,0484;

Response surface analysis (Figure 2) demonstrates that the Y_2 value (TBA) decreases with increasing concentrations of X_1 (Calamus Rhizome) and X_2 (HF Acid conc.). According to the experimental matrix data, the maximum value of TBA is 0,55 mg MDA/kg and it was recorded in sample 1 at minimum levels of factors (X_1 = 1%, X_2 = 0.3%). The minimum TBA value of 0,33 mg MDA/kg is observed in sample 9 at maximum values of X_1 = 5% and X_2 = 0.7% ($p<0,05$).

The response surface has a steady downward profile reflecting a progressive decrease in lipid oxidation rate as the concentrations of plant components increase. The most pronounced decrease of Y_2 values is observed at simultaneous increase of both factors, which indicates their combined influence on the TBA indicator.

Surface Plot of Y_3(CookLoss) against X_1(Calamus Rhizome) and X_2(HF Acid conc.) is shown in Figure 3.

The regression equation for Y_3(CookLoss) as a function of X_1 (Calamus Rhizome) and X_2 (HF Acid conc.):

Y_3(CookLoss) = 31,7887 - 1,7764X_1 - 24,2074X_2 - 0,1853X^2_1 + 2,8265X_1X_2 + 7,0379X^2_2

Regression model performance metrics:R^2 = 0,9816; R^2_adj = 0,9636;MS_e = 0,0476;

The analysis of the response surface reflecting the dependence of the mass loss index after heat treatment (Y_3, Cookloss) on the concentrations of calamus rhizome (X_1) and humic-fulvic acid complex (X_2) shows a clear tendency to decrease the values of Y_3 with increasing levels of the studied factors. The maximum weight loss was recorded in the control sample (X_1 = 0%, X_2 = 0%) and was 33.00%, indicating significant moisture loss in the absence of vegetable additives. The minimum Cookloss value was observed at the maximum levels of both factors, X_1 = 5% and X_2 = 0.5-0.7%, and was 13.42-13.86% (samples 8 and 9) ($p<0,05$).

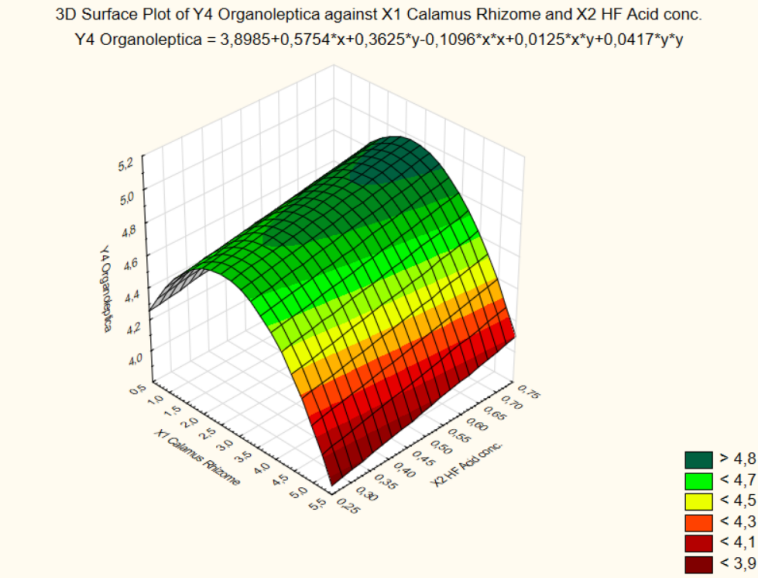


Fig.4 - 3D Surface Plot of Y_4(Organoleptic) against X_1(Calamus Rhizome) and X_2(HF Acid conc.)

The response surface is characterised by a uniform decrease in mass loss as the dosages of both X_1 and X_2 increase. A particularly pronounced decrease is observed in the region of

high concentrations of humic-fulvic acids, which confirms their contribution to moisture retention in the structure of the meat product. The model shows a stable negative relationship between the level of vegetable additives and weight loss, indicating an improvement in the moisture retention capacity of the meat semi-finished product when they are used.

Surface Plot of Y_4(Organoleptic) against X_1(Calamus Rhizome) and X_2(HF Acid conc.) is shown in Figure 4.

The regression equation for Y_4(Organoleptic) as a function of X_1 (Calamus Rhizome) and X_2 (HF Acid conc.):

Y_4 (Organoleptic) = 3,9095 + 0,5742X_1 + 0,3228X_2 - 0,1095X^2_1 + 0,0137X_1X_2+ 0,0768X^2_2

Regression model performance metrics:R^2 = 0,9524; R^2_adj = 0,9126;MS_e = 0,0541;

Analysis of the response surface (Figure 4) illustrating the dependence of organoleptic score (Y_4) on the concentrations of aira rhizome (X_1) and humic-fulvic acids (X_2) showed the presence of a clearly defined optimum. The maximum value of Y_4 was 4,92 points and was observed in sample 6 at X_1 = 3% and X_2 = 0.7%. The minimum value of organoleptic evaluation, 3,91 points, was recorded in the control sample (X_1 = 0%, X_2 = 0%) where there were no plant additives ($p<0,05$).

The response surface has a dome-shape, indicating the presence of a region of optimal values of the factors. At low levels of X_1 and X_2, the meat was characterised by a tough consistency and poor flavour, which is reflected in a low consumer evaluation. On the contrary, at excessive dosages of vegetable components (in particular, X_1 = 5%), a sour and bitter flavour was observed, caused by the saturation of the product with biologically active compounds, which also reduced the overall perception. The highest organoleptic indices corresponded to medium levels of factors. At these ratios, the product was characterised by a balanced flavour, moderate textural tenderness and harmonious aroma.

The joint decrease in pH and TBARS achieved by combining the HFA complex with Acorus calamus rhizome is consistent with two complementary chemical levers – polyprotic acid donation and transition-metal chelation. Humic/fulvic matrices are rich in carboxyl and phenolic sites that both release H (lowering pH and shifting buffers) and sequester Fe^{2} /Fe^{3} , Cu^{2} , curbing metal-catalysed initiation of lipid peroxidation [7-9]. Likewise, Klein O.I. et al. systematically demonstrated that humic materials display peroxyl-radical scavenging linked to their phenolic/carboxyl functionality, supporting the dual proton-donor/chelator role [10].

From the perspective of oxidation control, TBARS reduction follows the canonical pathway in which iron catalysis governs initiation and propagation in muscle lipids. In technologically similar emulsion systems, Jittrepotch N. et al. showed that the chelator EDTA suppresses non-heme-iron-catalysed oxidation in sausages, highlighting that metal control alone can substantially depress TBARS. HFA in research provides a natural chelation platform with added acidity to modulate the matrix environment [11]. Consistently, the review by Bellucci E.R.B. et al. collates multiple meat-product studies where phenolic extracts lower TBARS via radical scavenging and partial metal binding, a mode that parallels the HFA + calamus pairing [12].

The acidifying effect observed is attributable to the polyprotic nature of humic/fulvic structures (multiple pK_a domains) and the phenolic pool in calamus. Proton release reduces the effective buffer capacity of the meat system and can reposition protein solubility relative to the myofibrillar isoelectric region-mechanistic features consistent with the spectroscopy-guided view of humic reactivity [13]. In parallel, Parki A. et al. documented that *A. calamus* essential oil compositions vary seasonally yet retain pronounced radical-quenching potential, aligning with our use of calamus as a phenolic proton source and antioxidant partner to HFA [14].

Regarding the pumpkin seed cake, our findings reflect the well-known trade-off between matrix-level water binding and PUFA enrichment. The cake’s dietary fibres and proteins create capillary and gel-type binding sites that limit thermal drip,

which rationalises the cooking-loss decrease. At the same time, the high linoleic (ω-6) fraction heightens the oxidative liability unless antioxidant protection is present [15]. Likewise, Öztürk & Turhan reported that pumpkin seed kernel flour used in beef meatballs improved cooking yield but altered TBARS dynamics during storage due to PUFA enrichment [16]. Similarly, Gadekar Y.P. et al. summarised that 3% pumpkin seed flour can replace fat and improve yield while necessitating oxidation management-a balance we achieve here by coupling the cake with HFA + calamus [17].

The additional TBARS decrease when calamus accompanies HFA is credibly ascribed to polyphenolic radical quenching that complements HFA chelation [18]. In concordance, Dinev T. et al. showed strong antioxidant capacity for methanolic *A. calamus* extracts, and clinical-pharmacognosy summaries note potent DPPH and β-carotene/linoleate antioxidant activity for calamus essential oil-evidence that translates to meat systems where lipid-radical propagation drives TBARS accumulation. Thus, our dual-mode intervention (chelation + radical quenching) mirrors the combined strategies that outperform single-mode antioxidants in comminuted meats [19].

On sensory and yield, the net improvement at moderate calamus levels is consistent with phenolic–protein network effects and matrix water immobilisation: modest phenolic inputs can tighten the heat-set network without introducing off-notes, while the cake's fibres/proteins supply structural water binding that offsets the pH-induced shift toward lower WHC. Likewise, de Melo F.A.B. et al. reported that pumpkin-derived solids enhance yield in burger systems at practical inclusion levels, provided that oxidation is actively managed—a condition satisfied in our design by the HFA + calamus synergy [20].

Based on data from technological regulatory documents for meat products, quality parameter limits were established to ensure an optimal balance between safety, stability, and organoleptic characteristics. In particular, the optimal pH range was determined to be 5.6–6.0, which provides both safety and acceptable texture. The threshold value for TBA should not exceed 0.5 mg MDA/kg, as higher values indicate the development of oxidative processes. Cook loss should be minimized, as it directly affects the juiciness and yield of the final product. Conversely, the organoleptic score should approach the maximum level, reflecting the flavor, aroma, and texture perceived by consumers. According to the combined assessment of all four parameters, the best result was obtained for Sample 6, which contained 3% Acorus calamus rhizome and 0.7% humic-fulvic acid complex: pH - 5.57, TBA - 0.43 mg MDA/kg, cook loss - 17.01%, and organoleptic score - 4.92, making it the optimal formulation in terms of the qualitative characteristics of the meat product.

Conclusion. The results of this study clearly demonstrate the high effectiveness of plant-based components-acorus calamus rhizome, a humic-fulvic acid complex, and pumpkin seed press cake—in the production of meat products. It was established that the addition of the humic-fulvic acid complex and Acorus calamus rhizome enables controlled reduction of pH and TBA due to their acidic, chelating, and antioxidant properties, thereby strengthening oxidative and physicochemical stability of the product.The pumpkin seed press cake exhibited functional and technological properties as a moisture-retaining matrix, significantly reducing mass loss and improving flavor and aroma characteristics.

Based on the integrated analysis of all measured parameters and considering the established technological limits, the sample containing 3% Acorus calamus rhizome and 0.7% of the humic-fulvic acid complex, with the following values: pH - 5.57, TBA - 0.43 mg MDA/kg, cook loss - 17.01%, and organoleptic score - 4.92 was identified as the optimal formulation.

For a comprehensive assessment of the functionality of the studied plant components, further research is needed to investigate the stability of the meat product during storage, including the dynamics of changes in acid, peroxide, and thiobarbituric values over time. The current findings confirm the antioxidant potential of Acorus calamus rhizome and the humic-fulvic acid complex, justifying their application as natural inhibitors of oxidative processes in meat products.

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