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SUBSTANTIATION OF THE DAIRY-PLANT ADDITIVES TECHNOLOGY FOR USE IN FUNCTIONAL PRODUCTS

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Abstract. A promising area of modern research is the combination of raw materials of animal and plant origin, which allows the production of food products with a balanced composition. The chemical composition of the ultrafiltrate of whey from cottage cheese was modified by extracting biologically active substances from the leaf part of the yacon plant (*Smallanthus sonchifolius*), which belongs to the Asteraceae family. The yacon leaves were subjected to a series of preparatory procedures prior to use. This entailed a drying process that resulted in a mass fraction of dry matter ranging from 97–98%, followed by grinding to a particle size of 1–2 mm. The rational technological modes of obtaining a dairy-plant enrichment additive by extracting yacon substances with ultrafiltrate whey from cottage cheese have been scientifically substantiated. The ratio of solid to liquid phases (hydromodule) is 1:10, the pH of the extractant is 1.9–2.0 at an extraction temperature of 45±2°C for τ = 65–70 min. This process enables the extraction of dry matter at a rate of 2.4 g d.m./100 g of extract. The extraction process involved the separation of the extract from the pulp through a centrifugal separation technique at an angular velocity of 4000 rpm for a duration of 10–15 minutes. Subsequently, the extract was purified by means of membrane filtration. Thereafter, 27–30 g of calcium carbonate ($CaCO_3$) was added to 1 l of extract, which was then incubated for 8–15 min. This process enabled the complete conversion of citric acid contained within the extract to the organic form of calcium citrate. The resulting mass is then subjected to a drying process via spray drying, with the objective of achieving a moisture content of 4.5±0.2%. The additive is characterised by its organoleptic properties, which include a fine powder consistency (lumps may be present, which crumble easily under mechanical action) and a colour range from white to light yellow. It is also notable for its neutral taste, accompanied by a pleasant coffee flavour. The milk and vegetable enrichment additive contains 95.5±1.8% solids, 1.47±0.05% protein, 50.0±1.4% carbohydrates, 0.6±0.01% lipids, 1.05±0.05% phenolic substances, 1.18±0.05% tannins, and 41.2±1.2% ash (including 31.0±1.2% calcium citrate containing 6.5±0.3% calcium). The utilisation of the developed additive in the technologies of a number of health foods and beverages engenders a unique product and service experience for consumers, attracting those who value non-standard, healthy lifestyle and innovative approaches.

Keywords: dairy-plant enrichment additive, whey from cottage cheese, yacon, extraction, chemical composition, calcium, health-improving properties.

Introduction. Formulation of the problem

A significant contemporary domain within the agro-industrial complex pertains to the implementation of priorities in the realm of healthy nutrition. This encompasses the development and implementation of safe food products, the maximisation of the biological properties of raw materials and components that contribute to the preservation and enhancement of national health [1].

On the one hand, the absence of macro- and micronutrients in the diet, and on the other hand, the substandard quality of food products and the dearth of resource-saving technologies call for the formulation of novel scientific and practical approaches to optimise the utilisation of dairy protein, carbohydrate and vegetable raw materials in food production.

It is evident that considerable attention is paid by researchers to the use of secondary raw materials in the field of food technologies. These materials are capable of performing several functions simultaneously, including the enhancement of the nutritional and biological value of the product, the improvement of consumer properties, the stabilisation of quality, and the extension of shelf life. One such type of recycled raw material is whey, a by-product of the manufacturing process of hard and cottage cheeses.

Whey is a complex biological object that has found application in modern food production technologies. The characteristics of whey that make it a versatile ingredient in food production include its ability to be preserved, its low concentration of solids, its heterogeneity with pronounced selectivity in molecular weight and size, its ionic strength, and the presence of specific aromatic components that are transferred to the final products during processing. However, its use in non-dairy food products requires additional modification of properties [2].

The prevailing perspective on the issue is substantiated by nutritional monitoring, which has facilitated the identification of the discrepancy between the deterministic requirements for the level of consumption of physiologically valuable nutrients in food and their actual state.

Analysis of recent research and publications

The analysis of the current state of production and utilisation of whey from cottage cheese has led to the conclusion that there is a necessity to enhance its processing as an alternative resource of animal raw materials for further use for food purposes.

The process of whey processing is hindered by the unstable physical and chemical properties of the raw material, as well as the low concentration of solids. It is evident that a considerable number of food systems do not permit the utilisation of whey in substantial quantities. Consequently, the process of separating whey nutritional ingredients, particularly the extraction of ultrafiltrate, assumes significant importance.

A promising area of modern research is the combination of raw materials of animal and plant origin, which allows for the production of food products with a balanced composition. A review of the extant literature [3] reveals that the relevant components can be divided into three groups: fruit and berry, vegetable, and wild-growing raw materials. The utilisation of these components in food products has been demonstrated to enhance their organoleptic properties, while concurrently ensuring the provision of essential nutrients that contribute to a balanced product [4]. The implementation of this approach is contingent upon the coordination of the scientific, technical, and economic dimensions. It is evident that a number of methodologies can be distinguished from contemporary approaches to the production of new products.

One such method involves the incorporation of fruit and berry fillers into whey, a by-product of the manufacturing process of hard and cottage cheeses. The whey is then subjected to a process of nanofiltration, a technique that involves the concentration of the liquid to yield a new variety of high-quality beverages. These beverages are characterised by a balanced protein and carbohydrate composition, making them suitable for use as health foods. In addition, they possess pleasant organoleptic properties, which is a key attribute in the development of functional foods [5].

The development of geriatric drinks based on whey with vegetable fillers (carrot, pumpkin) and bacterial sourdough is gaining popularity, which provides a high organoleptic and probiotic effect of the finished drinks [6].

A plethora of studies on the use of whey from cottage cheese to produce extracts based on stevia (Stevia rebaudiana Bertoni) leaves has been conducted. The proposed method involves the replacement of sugar in fermented milk products [7].

However, the implementation of promising areas of industrial whey processing and the production of full-fledged functional products based on it is complicated by the specific taste and smell, which are important quality indicators.

However, there is a paucity of information regarding the substances responsible for the specific taste and smell of whey. In addressing the challenge of optimising specific organoleptic properties and expanding the application of whey in food production, research in the domain of whey taste and odour chemistry holds significant practical importance. The establishment of the nature and mechanism of formation of flavour and osmotic substances, along with their sensory and metric analysis, will facilitate the selection of ingredients capable of masking unpleasant whey tones. This, in turn, will enable the development of new product formulations with improved organoleptic properties, as well as the assessment of the dynamics of change and the prediction of quality during storage.

In order to eliminate and mask the undesirable organoleptic properties of whey from cottage cheese, it is advisable to use ultrafiltrate and additional components with pronounced and predictable quality indicators.

Ultrafiltrate is characterised by higher biological and colloidal stability than native whey. The efficiency of extraction with ultrafiltrate is increased by increasing the ionic strength of the solution, which contains a significant amount of carbohydrates and minerals. Furthermore, lactose, which constitutes approximately 70% of the dry matter in the ultrafiltrate, is an active reducing sugar that exhibits weak acidic properties and high chemical activity. Furthermore, the presence of lactose in whey has been demonstrated to increase osmotic pressure, thereby facilitating the extraction of substances from plant materials. It has been established that lactose, a constituent of the ultrafiltrate, possesses the capacity to absorb aromatic substances [8]. This property enables the optimal retention of light and medium-lived osmophoretic compounds within the resulting extract. The osmophoretic components of yacon, which are transferred to the extract, improve the specific serum odour of the ultrafiltrate due to their sorption by lactose.

The decision was taken to utilise the leaf part of the yacon plant (Smallanthus sonchifolius), which belongs to the Asteraceae family, as an additional component to modify the properties of whey from cottage cheese.

It has been established that yacon leaves are a source of essential amino acids, such as lysine (5.96 μg/mg), isoleucine (2.59 μg/mg), leucine (1.40 μg/mg) arginine (2.58 mcg/mg), valine (2.06 mcg/mg), histidine (1.82 mcg/mg), methionine (0.3 mcg/mg), threonine (3.04 mcg/mg), phenylalanine (2.84 mcg/mg). Essential amino acids are represented by alanine (3.08 μg/mg), aspartic and glutamic acids (5.00 μg/mg and 3.49 μg/mg), glycine (2.67 μg/mg), proline (2.05 μg/mg), serine (5, 17 μg/mg), tyrosine (1.43 μg/mg), cystine (10.29 μg/mg) are known chemical precursors of flavour, which further justifies the feasibility of using this plant material [9].

The beneficial properties of yacon are attributed to the fructan inulin, which, according to the extant literature, has the ability to reduce blood sugar levels [10,11]. The dry matter of yacon leaves is predominantly constituted of inulin, with a concomitant abundance of fructose, glucose, sucrose, vitamins and minerals [12].

In his works, D. Q. Dou and co-authors have demonstrated that the fructosan content in yacon ranges from 36–45% [13].

The antioxidant properties of yacon are determined by the presence of selenium, chlorogenic and caffeic acids, as well as a number of phenolic compounds [14].

Yan et al. [15] have established the presence of chlorogenic acid and tryptophan amino acid in the aerial organs of yacon by means of nuclear magnetic resonance (NMR) and mass spectrometry. The authors of the study hypothesise that the root tubers of the plant in question possess antioxidant properties.

Delgado, G. T. C. et al. demonstrated that biologically active substances found in yacon can reduce cholesterol and triglyceride levels [16].

It has been demonstrated by the scientific community that the biologically active substances present in yacon have the capacity to reduce blood sugar levels, enhance metabolic processes within the body, influence the function of the gastrointestinal tract, and exert an antisclerotic effect. The combination of hypoglycemic and antioxidant effects of yacon is the basis for recommending this plant as a basis for the creation of functional food products [17].

The data from the information and patent search, as well as the literature review, can be synthesised as follows: the use of ultrafiltrate as an extractant allows for the combination of the valuable properties of whey from cottage cheese, which has previously been shown to be the basis of therapeutic and preventive food products, and the deficient nutrients contained in yacon leaves.

The following areas of research are considered to be of priority: the development of methods for the modification of whey's chemical composition through the addition of plant materials, and the development of new technological solutions for the production of safe functional foods.

The purpose of the study is to provide scientific validation for the technology of an enrichment dairy-plant additive (EDPA) for utilisation in functional products.

In order to achieve this objective, it is necessary to solve the following **tasks**:

- to analyse the current scientific trends in the utilisation of whey and vegetable raw materials;
- using experimental studies and mathematical modelling, to establish rational modes of extraction of plant raw materials (prepared yacon leaves) with whey ultrafiltrate from cottage cheese;
- to analyse the organoleptic quality indicators and chemical composition of the developed EDPA;
- to substantiate the feasibility of using the developed EDPA in functional products.

Research materials and methods

The materials of the study were samples of a dairy-plant enrichment additive, which had been obtained by extracting prepared yacon leaves. The utilisation of whey ultrafiltrate from cottage cheese as an extractant was proposed on the basis of previous studies [18]. This process enables the extraction of additional extractive substances from the prepared yacon leaves and the enrichment of the extract with valuable whey components. Whey ultrafiltrate was supplied by Kharkiv Dairy Plant LLC. It is evident that, according to organoleptic characteristics, whey ultrafiltrate is a homogeneous, transparent liquid that exhibits a yellowish hue. The physicochemical parameters of the ultrafiltrate are as follows: titrated acidity (75–85°T); active acidity (pH=4.5–4.6); density (1017–1018 kg/m3); and dry matter content (5.0–5.2%).

The raw material of yacon leaves was provided by the Educational and Scientific Production Centre Experimental Field «Dokuchaevske». The plant material exhibited a spear-shaped green stem with anthocyanin spots in the upper part. The leaves are characterised by their substantial size, with blades measuring up to 32 cm in length and 22 cm in width. Their serrated edges are notable for their unevenness, and the leaves exhibit a distinctive colouration, with a dark green hue on the upper surface and a lighter green shade on the lower surface. The aroma is mild, reminiscent of young sunflower seeds. The experience evokes a sense of ambivalence, characterised by a simultaneous sense of sweetness and bitterness. The subject of this study was yacon leaves, which were subjected to preliminary preparation, involving drying to a mass fraction of dry matter of 97–98% and grinding to a particle size of 1 to 2 mm.

The flavour, colour, and aroma of the dairy-plant enrichment supplement were determined using the sensory profile method (flavour spectrum method) in accordance with DSTU ISO 6658:2005. The 'consensus method' was utilised to describe the prototypes, with the objective being to obtain a unanimous description of the flavour of the product. The characteristics were identified using both descriptive and associative terms.

The intensity of perception of each characteristic was determined by the commission on the following scale: Zero denotes absence; one indicates only recognition or threshold; two signifies weak intensity; three, moderate; four, strong; and five, very strong. The presence and intensity of the residual aftertaste was also identified.

The subsequent stage of the study involved the determination of the overall impression of the supplement, with consideration given to the adequacy of the perceived characteristics, their intensity, and the identifiable background flavour. The overall score is determined on a three-point scale: The initial evaluation yielded a rating of one for the first item, indicating a substandard outcome. The subsequent evaluation yielded a rating of two, indicating an average outcome. The final evaluation yielded a rating of three, indicating a satisfactory outcome.

The chemical composition was studied in accordance with the following methodology. Firstly, dry matter was determined by the gravimetric method, which consists in drying the sample at a temperature of 95–100°C to a constant weight. Secondly, protein was analysed by the Kjeldahl method (DSTU ISO 8968-1:200). Thirdly, carbohydrates were analysed by the permanganate method (according to Bertrand) (DSTU 5059: In 2008, the fat content was analysed using the extraction-weight method (according to Soxhlet) (DSTU ISO 1443:2005); the ash content was determined gravimetrically (DSTU ISO 5984-2004) after burning the sample in a muffle furnace at 500–600°C; and the calcium content was determined by the traditional method, which involved charring the sample, transferring calcium salts to a soluble state, and subsequently titrating them trilometrically (DSTU ISO 12081:2004).

In order to ascertain the rational modes of extraction of the prepared yacon leaves with whey ultrafiltrate from cottage cheese and to generalise the results obtained, the methods of planning multifactorial experiments were used [19,20,21]. The experimental results are to be processed, along with all the necessary calculations [19,20].

Results of the research and their discussion

The scientific concept of the work is to substantiate the approaches and principles of obtaining a dairy-plant enrichment additive by modifying the chemical composition of whey from cottage cheese through the use of plant materials. This will ensure the optimal utilisation of valuable nutrients in the production of fortified foods.

In order to ensure the rational use of whey from cottage cheese, the chemical composition of whey was modified by extracting substances from yacon leaves, which forms the basis for the production of an enrichment dairy-plant additive (EDPA).

The utilisation of whey as an extractant of plant leaf nutrients has been previously documented [22]. The utilisation of ultrafiltrate whey from cottage cheese as an extractant is proposed, a material which is considered to be a valuable raw material due to its composition and properties [23].

The dairy-plant enrichment additive was obtained by extracting pre-prepared yacon leaves (dried to a mass fraction of dry matter of 97–98% and crushed to a particle size of 1–2 mm) with ultrafiltrate of whey from cottage cheese. The effectiveness of the extraction process is contingent upon the degree of grinding of the extracted material, the hydraulic module, the pH of the extractant, the temperature, and the duration of extraction.

The grinding of the extracted material, specifically dry yacon leaves, was conducted to a degree of 1–2 mm, thereby increasing the contact surface with the extractant. A smaller particle size results in the formation of a thick layer of particles and their accumulation, which interferes with the action of the extractant and consequently reduces the extraction efficiency.

The experiments investigated the effect of the duration of the extraction process (τ, minutes), the GM hydraulic module, pH, and temperature (t, degrees Celsius) on the yield of food components from yacon leaves (Y, grams of solid weight per 100 grams of extract). The efficiency of the transfer of macro- and micronutrients from plant material to the milk medium was assessed by the mass fraction of dry matter in the extract.

In light of the intricate interplay between these factors and the extraction process, a concerted effort was made to curtail the experimental endeavours and procure dependable outcomes. To this end, methodologies for the design of multivariate experiments were employed, a stratagem that facilitates the attainment of a mathematical depiction of the examined process through the utilisation of a second-order polynomial model [19,20,21].

$$Y = b_0 + \sum_{i=1}^{k} b_i x_i + \sum_{i=1}^{k} b_{ii} x_i^2 + \sum_{i<j}^{k} b_{ij} x_i x_j , \quad (1)$$

where Y is the response function, g d.m./100 g of extract;
b_0, b_i, b_{ij}, b_{ii} – regression coefficients determined by the least squares method based on experimental data and characterising the average, linear, nonlinear interfactorial and quadratic effects of the respective factors on the response function;
x – scaled (coded) values of the variable regime factors τ, GM, pH and t;
i, j – factor numbers;
k – the number of factors in the experiment planning matrix.

The factors τ, GM, pH and t were coded according to the following relations:

$$x_1 = (\tau - 40)/30; \quad x_2 = (GM - 8)/4; \quad x_3 = (pH - 5{,}2)/4; \quad x_4 = (t - 40)/20, \quad (2)$$

where τ is the duration of the extraction process τ, min;
GM – hydraulic modulus (ratio of volumes of solid (dried and crushed yacon leaves) and liquid (whey ultrafiltrate from cottage cheese) phases;
pH – pH value;
t – extraction temperature, °C.

All factors under consideration are compatible and uncorrelated with each other. In selecting the variation intervals of the factors, specific characteristics of the process of extracting food components from yacon leaves with ultrafiltrate whey from cottage cheese were considered.

The experiments were conducted utilising an experiment plan comprising four factors and 18 experiments. The experiment plan's points were situated at the vertices of the cube, the midpoints of the edges, and the centre of the plan. The linear block of the plan consists of a half-replica of the full factorial experiment [24]. The experimental conditions, the coded and natural values of the factors, and the results obtained from the Y_{exp} experiments are presented in Table 1.

The effectiveness of the transfer of macro- and micronutrients from plant material to the milk medium was assessed by the mass fraction of dry matter in grams per 100 g of extract.

The processing of the experimental results and all necessary calculations were carried out using sequential regression analysis [19, 20]. The fundamental principle underlying this approach is the implementation of the least squares method in matrix form, which facilitates the calculation of the regression coefficients, the assessment of their significance, the elimination of the coefficient with the minimum ratio of its value to the critical value from the group of insignificant coefficients, and subsequent recalculation of the regression coefficients. The cyclical procedure is terminated when only significant regression coefficients remain in the equation. The Fisher's test is then utilised to assess the adequacy of the regression equation with the experimental data.

Table 1 - Matrix of planning experiments in coded and natural values of factors and the results of experiments

№ serial	Factors								The content of d.m., g/100 g of extract	
	1		2		3		4		$Y_{exp.}$	Y_{est}
	x_1	τ, min	x_2	GM	x_3	pH	x_4	t, °C		
1	1	70	-1	4	-1	1.4	-1	20	1.42	1.48
2	-1	10	1	12	-1	1.4	-1	20	0.44	0.35
3	-1	10	-1	4	1	9.4	-1	20	0.14	0.12
4	1	70	1	12	1	9.4	-1	20	0.70	0.63
5	1	70	-1	4	-1	1.4	1	60	1.72	1.65
6	-1	10	1	12	-1	1.4	1	60	0.78	0.78
7	-1	10	-1	4	1	9.4	1	60	0.28	0.28
8	1	70	1	12	1	9.4	1	60	1.10	1.06
9	0	40	1	12	-1	1.4	1	60	1.80	1.78
10	-1	10	0	8	-1	1.4	-1	20	0.40	0.43
11	1	70	0	8	1	9.4	1	60	0.95	1.01
12	-1	10	1	12	-1	1.4	0	40	0.78	0.87
13	-1	70	0	8	1	9.4	1	60	0.96	0.95
14	0	40	1	12	1	9.4	-1	20	0.68	0.80
15	1	70	-1	4	1	9.4	0	40	0.58	0.56
16	1	70	-1	4	0	5.4	1	60	0.75	0.83
17	0	40	-1	4	1	9.4	-1	20	0.38	0.35
18	0	40	0	8	0	5.4	0	40	1.52	1.44

The results of four experiments conducted in parallel at the centre of the study were utilised to calculate the sample variance of the reproducibility of the experiments, which was s^2=0.001235. This was then employed to evaluate the significance of the regression coefficients.

The regression coefficients were calculated in accordance with the aforementioned algorithm in the coded variables, thus enabling the subsequent determination of the following quadratic regression equation in the coded variables:

$$Y = 1{,}444634 + 0{,}411734\, x_1 + 0{,}295232\, x_2 - 0{,}270801\, x_3 + 0{,}149432\, x_4 - 0{,}203064\, x_1^2 - 0{,}306496\, x_2^2 + 0{,}166343\, x_3^2 - 0{,}307179\, x_4^2 - 0{,}383733 x_1 x_3 + 0{,}068460\, x_2 x_4 \quad (3)$$

The statistical evaluation of the obtained equation demonstrated that, in accordance with Fisher's criterion, it provides a satisfactory description of the experimental data. This is evidenced by the calculated value of Fisher's criterion, F_p=7.62, which does not exceed its critical value, F_{cr}=8.49, at the specified significance level, α=0.05. Furthermore, the number of degrees of freedom for the numerator, f_h=3, and the denominator, f_{dn}=7, were considered. The calculated values of the mass fraction of dry matter Y_{est} (g d.m./100 g of extract) determined by the adequate equation (3) are given above in Table 1.

A preliminary analysis of the obtained equation (3) demonstrates that the mass fraction of dry matter (g d.m./100 g of extract) is influenced by all the factors under consideration (τ, GM, pH and *t*). The joint interaction of the extraction duration τ and pH, as well as the GM hydromodule and temperature *t*, has a significant effect, as evidenced by the regression coefficients b_{13} (-0.383733) and b_{24} (0.068460). The minus signs in the quadratic coefficients of factors x_1, x_2, and x_3 indicate the existence of a maximum *Y* for factors τ, GM, and *t*.

In view of the nonlinearity of the obtained regression equation, it is extremely challenging to analyse the influence of each of the studied factors, as well as their interaction, on the yield of extractives. However, it is possible to obtain a visual representation of the indicated influence of each factor and their pairwise interaction from the response surfaces constructed according to the above equation (3). Concurrently, the values of the other two factors were hypothesised to be constant at optimal levels within the area of study.

According to the above equation (3), the optimal values of extraction modes in the studied range of changes in the factors τ, GM, pH, and *t* were obtained using the MS Excel add-in ‘Solution Finder’, which ensure the maximum yield of dry matter *Y*:

– in coded variables x_1 = 1.0, x_2 = 0.515, x_3 = -1.0, x_4 = 0.301;

– in natural variables τ = 70 min; GM = 10; pH = 1.4; *t* = 46°C.

In the context of these optimal conditions, the yield of dry extractive substances was found to be 2.57 g d.m./100 g of extract. This value is significantly higher than the yield of dry substances of yacon in the experiments conducted. In Experiment 8, the highest yield was recorded, at 1.8 g d.m./100 g of extract, which is 1.43 times less than the optimal yield.

The findings of the present study demonstrate that the maximum yield of dry extracted substances is attained at an extraction duration of 70 minutes. This is the point at which the upper limit of this factor is reached, as is commonly accepted in the extant literature. The remaining optimal values of the regime factors (GM, pH and *t*) do not exceed the scope of the study.

Consequently, the most effective extraction methods were identified by removing the constraints on extraction time. The following optimal values for the extraction modes were obtained:

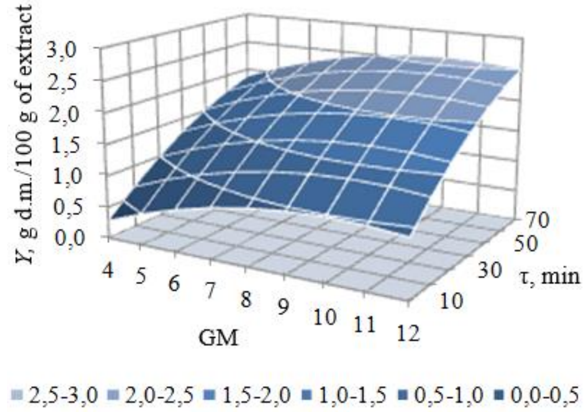
– in coded variables x_1 = 1.959, x_2 = 0.515, x_3 = -1, x_4 = 0.301;

– for natural variables: τ = 98.76 min; GM = 10.06; pH = 1.4; *t* = 46.01°C.

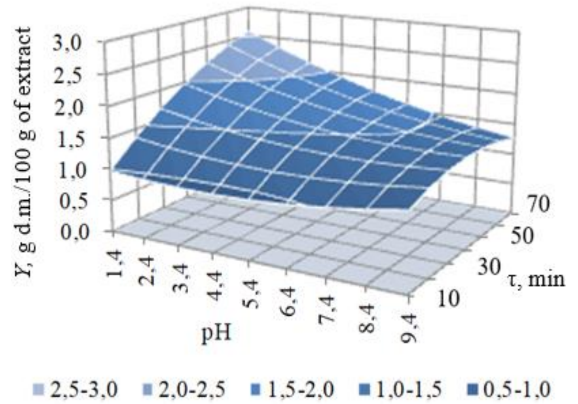
In these conditions, an increase in the extraction time to τ = 98.76 min resulted in a yield of extractive substances that reached 2.75 g/100 g of extract. This is equivalent to a 7% increase in yield when compared with the 70 minute extraction process. A comparative analysis of the parameters demonstrated that an augmentation in the duration of thermostatting (τ) from 0 to 70 minutes results in an enhancement of extraction completeness. However, at τ > 70 minutes, the mass fraction of solids in the extract attains interfacial equilibrium, thereby rendering further extraction inefficient. Furthermore, it can be concluded that the extraction duration of more than 70 minutes is impractical due to the additional energy consumption and reduced productivity.

The experimental verification of the optimal modes of extraction of yacon nutrients was determined by planning multifactorial experiments (τ = 70 min; GM = 10; pH = 1.4; t = 46°C). The yield of dry matter was found to be 2.48 g d.m./100 g of extract, which coincides with the maximum value of the optimality criterion *Y* within the error.

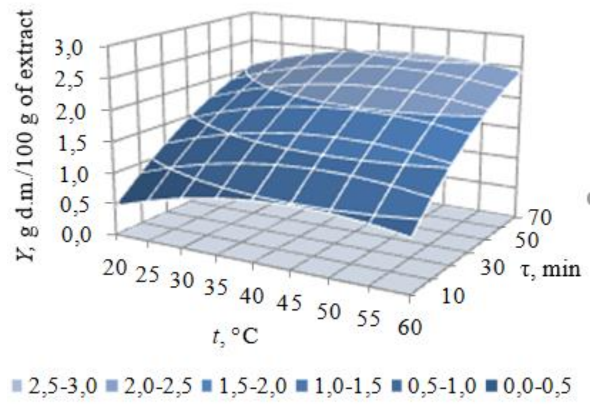
Utilising the ascertained optimal values of the extraction modes, we constructed response surfaces that provide a visual depiction of the influence of the studied factors, τ, GM, pH, and *t*, on the yield of yacon dry matter (Fig. 1).



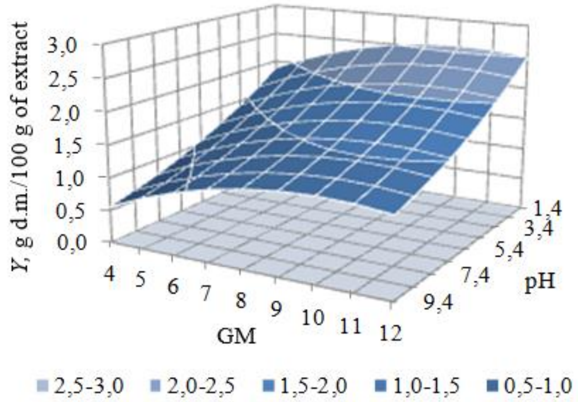
a) the influence of τ and GM on the yield of d.m. (pH=1,4; *t*=46 C)



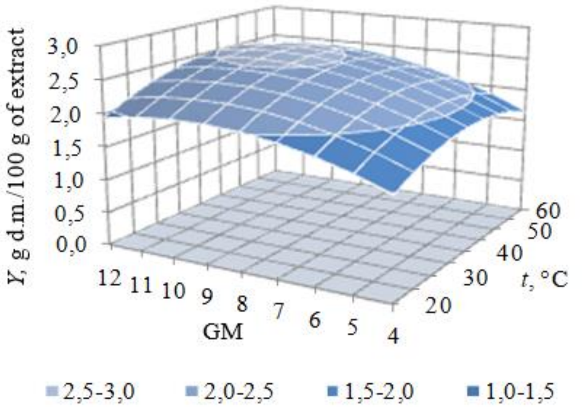
b) the influence of τ and pH on the yield of d.m. (GM=10; *t*=46 C)



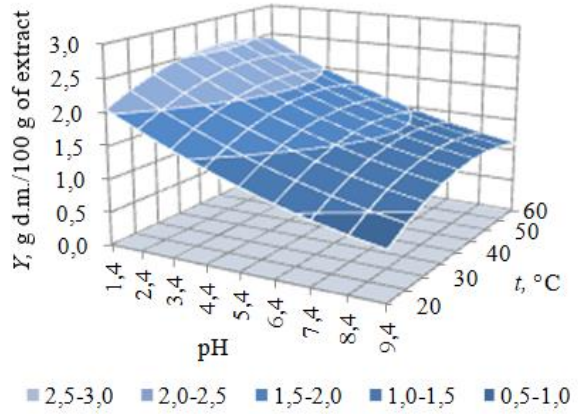
c) the influence τ and *t* on the yield of d.m. (GM=10; pH=1,4)



d) the influence GM and pH on the yield of d.m. (τ=70 min; *t*=46 C)



e) the influence GM and *t* on the yield of d.m. (τ=70 min; pH=1,4)



f) the influence pH and *t* on the yield of d.m. (τ=70 min; GM=10)

Fig. 1. Response surfaces of the dependences of the extractive solids yield on the extraction time τ, hydraulic module GM, pH, and extractant temperature *t*

The response surfaces illustrate that with the augmentation of the aforementioned factors exhibiting negative regression coefficients (τ, GM and *t*), the yield of yacon dry matter initially escalates, subsequently reaching a nadir as optimal values are attained.

As illustrated in Fig. 1*e*, the GM and *t* factors exhibit a mutual influence, indicated by a regression coefficient b_{13} with a «plus» sign. This suggests that their mutual influence will increase when they simultaneously either increase or decrease.

The regression coefficient, b_{13}, which is indicative of the mutual influence of GM factors and *t*, is expressed as a positive number. This suggests that the mutual influence of these factors on the yield of dry matter yacon will increase when they simultaneously increase or decrease until they reach optimal values. This hypothesis is clearly confirmed in Fig. 1*e*, which shows that the maximum *Y* (2.57 g d.m./100 g of extract) is achieved at the optimal values of GM (10) and *t* (46°C).

It has been demonstrated that an augmentation in the hydraulic module results in an escalation in the intensity of extraction of biologically active substances from plant material in the milk medium. However, when selecting the optimal ratio of raw materials and extractant, changes in the organoleptic characteristics of the milk-plant system must be considered, as these may result in a specific unconventional taste for milk-containing products. When substantiating the modes of thermal exposure, it was taken into account that the intensity of the diffusion extraction process increases with increasing temperature. However, it is also vital to ensure that the extraction temperature does not exceed the threshold of denaturation changes in proteins, as this could lead to the destruction of vitamins and organic substances [18].

The influence of the pH factor, the quadratic regression coefficient of which has a plus sign in equation (3), is opposite: with its increase, the yield of yacon dry matter first decreases and then begins to increase. As previously mentioned, equation (3) also contains the two-way interaction coefficients b_{13} and b_{24}. The coefficient b_{13} is accompanied by a minus sign, denoting an enhancement in their mutual influence when the levels of the variables are at opposing extremes. This phenomenon is illustrated in Figure 1*b*, which demonstrates that the maximum yield of yacon dry matter (2.57 g d.m./100 g of extract at the specified GM = 10, t = 46°C) is attained at a minimum pH = 1.4 and a maximum extraction time τ=70 min. However, a reduction in the pH of the extraction system to 1.4 necessitates the presence of a high concentration of citric acid monohydrate in the solution, approximately 2 mol/L. It has been established that, at an extraction pH of 1.9–2.0 and τ = 70 min, the extraction of yacon solids at the level of 2.4 g d.m./100 g of extract is ensured, while the concentration of citric acid in the solution is 0.1–0.2 mol/l. This has the effect of dramatically reducing the consumption of citric acid monohydrate and facilitating the subsequent neutralisation of citric acid, thereby enabling the desired organoleptic characteristics of the additive to be obtained. Therefore, it can be deduced that the extraction pH value of 1.9–2.0 is rational.

The rational parameters for the extraction of food components of the prepared yacon leaves with whey ultrafiltrate from cottage cheese (rational parameters for obtaining the EDPA) have been confirmed through experimentation. These parameters are as follows: the ratio of the volumes of solid and liquid phases (hydromodulus) is 1:10; the pH of the extractant is 1.9–2.0; the extraction temperature is 45±2°C; and the extraction time is 65–70 minutes. This process enables the extraction of dry matter at a rate of 2.4 g d.m./100 g of extract.

The extraction process for EDPA was conducted on a vibratory mixer in accordance with established process parameters. The extraction process involved the separation of the extract from the pulp through a centrifugal separation technique at a rotational speed of 4,000 rpm for a duration of 10–15 minutes. The extraction process was followed by a purification stage, which entailed the utilisation of a membrane filter.

Following the extraction process, the sample is purified by membrane filtration. Subsequently, citric acid is eliminated to adjust the active acidity of the extractant (whey ultrafiltrate from cottage cheese), with the objective of achieving a pH value between 1.9 and 2.0. The presence of citric acid has been demonstrated to exert a detrimental effect on the organoleptic characteristics of the additive, giving rise to a sour taste. The issue can be resolved through the conversion of citric acid into alternative metabolic forms that do not exhibit adverse organoleptic properties. Specifically, this conversion results in the formation of calcium citrate, an organic salt that is efficiently absorbed by the human body. In experimental trials, the efficacy of incorporating 27–30 g of calcium carbonate ($CaCO_3$) per litre of extract, followed by ageing for 8–15 minutes, has been demonstrated. This process enables the complete conversion of citric acid present in the extract into the organic form of calcium citrate. These parameters permit the reaction between calcium carbonate and citric acid in equivalent amounts. The resulting mass is then subjected to a drying process via spray drying, with the resultant moisture content being 4.5±0.2%.

Thus, it has been established that the following raw materials should be used to produce a dairy-plant enrichment additive

– ultrafiltrate of whey from cottage cheese in accordance with the current regulatory documents;

– raw materials of yacon leaves in accordance with the current regulatory documents;

– citric acid (E330) in accordance with DSTU GOST 908-2006;

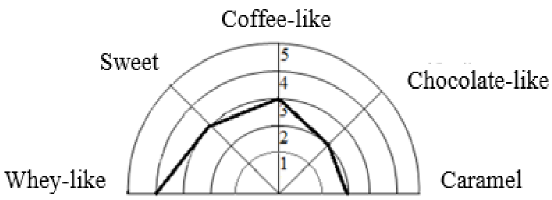
– calcium carbonate (E170) in accordance with the current regulatory documents (DSTU-N CODEX STAN 192:2014).

The implementation of the method for the production of a dairy plant enrichment additive can be carried out under the conditions of traditional technologies, with correction for the developed modes.

In order to resolve the technological challenges associated with the development of novel products, it is imperative to possess a comprehensive understanding of the primary organoleptic properties, along with the chemical composition of the EDPA, with particular emphasis on its calcium content.

The development of technology has enabled the production of a neutral taste and smell EDPA, comprising physiologically valuable components of yacon, along with a regulated content of organically bound calcium in the form of citrate at a level of 31% (equivalent to 6.5 g of mineral calcium per 100 g of EDPA).

With regard to organoleptic characteristics, EDPA is a fine powder (lumps may be present that crumble easily under mechanical action), with a colour ranging from white to light yellow, a neutral taste with a pleasant coffee flavour. This phenomenon can be attributed to the presence of osmophoretic components in the leaves of yacon, in which 60 volatile compounds have been identified. However, the specific aroma is primarily associated with the presence of spatulenol, β-caryophyllene, and cinnamic acid derivatives, including caffeic and chlorogenic acid [9]. The flavour spectrum of the prototype is illustrated in Figure 2.



Final aftertaste: none
Persistence: fairly long lasting
Overall impression: 3

Fig. 2. Flavour spectrum profile of an enrichment dairy-plant additive

A detailed analysis of the chemical composition of the EDPA was conducted, yielding the following results: 95.5%±1.8% dry matter, 1.47%±0.05% protein, 50.0%±1.4% carbohydrates, 0.6%±0.01% lipids, 1.05%±0.05% phenolic substances, 1.18%±0.05% tannins, and 41.2%±1.2% ash (including 31.0%±1.2% calcium citrate and 6.5%±0.3% calcium).

The EDPA obtained contains components of yacon leaves that are of physiological value, has a low energy value, reduces blood glucose and insulin levels, stimulates immune defence and improves the functional capabilities of the immune system. The present study investigates the modification of the chemical composition of whey ultrafiltrate from cottage cheese by extracting essential substances from yacon leaves and enriching it with a metabolically active form of calcium – citrate. The objective is to obtain a new supplement containing components of dairy and vegetable raw materials, which most fully meets modern concepts of rational nutrition.

The primary catalyst for transformations within the food market is the implementation of innovative technological solutions. The introduction of the functional food concept has become a general development trend. The nutrient composition and organoleptic properties of EDPA demonstrate the feasibility of utilising them in the production of a range of health foods and beverages. The introduction of the relevant concept has the potential to engender a unique product and service experience for consumers. This experience will appeal to those who value non-standardisation, healthy lifestyles and innovative approaches.

Approbation of study results.

Implementation of the method for the production of a dairy-plant enrichment additive can be carried out under the conditions of traditional technologies with adjustment to the developed modes. Based on the results of the scientific substantiation and development of the EDPA, a pilot batch was produced and tasted at Traderesource LLC.

Conclusions

1. A promising area of contemporary research is the combination of raw materials of animal and vegetable origin, which allows the production of food products with a balanced composition. With regard to the rational use of whey from cottage cheese, the following priority research areas have been identified: firstly, the development of methods for modifying the chemical composition of whey through the extraction of plant materials, and secondly, the development of new technological solutions for the production of safe functional foods.

The experimental studies and mathematical modelling have enabled the establishment of rational technological modes for the production of EDPA by extracting food components of yacon with whey ultrafiltrate from cottage cheese. The ratio of the volumes of the solid and liquid phases (hydromodule) is 1:10, the pH of the extractant is 1.9–2.0 at an extraction temperature of 45±2°C for τ = 65–70 min. This process enables the extraction of dry matter at a rate of 2.4 g d.m./100 g of extract. Following the extraction process, the sample is purified by centrifugation and membrane filtration. Thereafter, the citric acid that was utilised to regulate the active acidity of the extractant is eliminated through the addition of an equivalent amount of calcium carbonate (27–30 g CaCO3 / 1 l of extract), which is then held for 8–15 min. This process ensures the conversion of citric acid contained within the extract to the organic form of calcium citrate. The resulting mass is then subjected to a drying process via spray drying, with the objective of achieving a moisture content of 4.5±0.2%.

2. It has been ascertained through experimental means that, in accordance with its organoleptic characteristics, the EDPA is a finely dispersed powder (lumps may easily crumble under mechanical action), with a colour ranging from white to light yellow, a neutral taste with a pleasant coffee flavour.

3. Studies of the chemical composition have demonstrated that the EDPA contains 95.5%±1.8% dry matter, 1.47%±0.05% protein, 50.0%±1.4% carbohydrates, 0.6%±0.01% lipids, 1.05%±0.05% phenolic substances, 1.18%±0.05% tannins, and 41.2%±1.2% ash (including 31.0%±1.2% calcium citrate containing 6.5%±0.3% calcium).[1]

4. The nutrient composition and organoleptic properties of EDPA demonstrate the feasibility of utilising it in the technologies of a number of health foods and beverages. The implementation of the relevant concept has the potential to engender a unique product and service experience for consumers, attracting those who value non-standard, healthy lifestyles and innovative approaches.

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ОБҐРУНТУВАННЯ ТЕХНОЛОГІЇ ДОБАВКИ МОЛОЧНО-РОСЛИННОЇ ДЛЯ ВИКОРИСТАННЯ У СКЛАДІ ФУНКЦІОНАЛЬНОЇ ПРОДУКЦІЇ

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Анотація. Перспективним напрямком сучасних досліджень є поєднання сировини тваринного і рослинного походження, що дозволяє отримати харчові продукти зі збалансованим складом. Модифіковано хімічний склад ультрафільтрату сироватки з-під сиру кисломолочного шляхом екстрагування біологічно-активних речовин листової частини рослини Якон (Smallanthus sonchifolius) родини Айстрові (Asteraceae). Листя якона використовували за умови попередньої підготовки: висушування до масової частки сухих речовин 97–98% і подрібнення до розміру часток 1–2 мм. Науково обґрунтовано раціональні технологічні режими отримання добавки збагачувальної молочно-рослинної шляхом екстрагування речовин якона ультрафільтратом сироватки з-під сиру кисломолочного: співвідношення твердої та рідкої фаз (гідромодуль) 1:10; pH екстрагента 1,9–2,0 за температури екстракції 45±2°C протягом τ = 65–70 хв. Це дає можливість вилучити сухі речовини на рівні 2,4 г с.р./100 г екстракту. Екстракт відокремлювали від жому центрифугуванням при частоті обертання 4000 об/хв протягом 10–15 хв. Надалі проводили очищення екстракту шляхом мембранної фільтрації, після чого додавали 27–30 г кальцію карбонату ($CaCO_3$) / 1 л екстракту з витримуванням протягом 8–15 хв., що дає можливість повного переведення лимонної кислоти, що міститься в екстракті, в органічну форму – цитрат кальцію. Отриману масу сушать шляхом розпилювального сушіння до вологості 4,5±0,2%. За органолептичними характеристиками добавка є тонкодисперсним порошком (можлива наявність грудочок легко розсипчастих під впливом механічної дії), колір – від білого до світло-жовтого, нейтрального смаку з приємним кавовим присмаком. Добавка збагачувальна молочно-рослинна містить сухих речовин – 95,5±1,8%; білка – 1,47±0,05%; вуглеводів – 50,0±1,4%; ліпідів – 0,6±0,01%; фенольних речовин – 1,05±0,05%; дубильних речовин – 1,18±0,05%; золи – 41,2±1,2% (у тому числі 31,0±1,2% кальцію цитрату, що містить 6,5±0,3% кальцію). Використання розробленої добавки в технологіях низки оздоровчих харчових продуктів, напоїв створює унікальний продуктовий та сервісний досвід для споживачів, привертаючи тих, хто цінує нестандартність, здоровий спосіб життя та новаторські підходи.

Ключові слова: добавка збагачувальна молочно-рослинна, сироватка з-під сиру кисломолочного, якон, екстракція, хімічний склад, кальцій, оздоровчі властивості.