ECONOMIC ANNALS-XXI
ISSN 1728-6239 (Online)
ISSN 1728-6220 (Print)
https://doi.org/10.21003/ea
http://ea21journal.world

Volume 203 Issue (5-6)’2023

Citation information: Muslimov, N., Alzhaxina, N., Timurbekova, A., Dalabayev, A., Tuyakova, A., & Sadibaev, A. (2023). Economic aspects of hydrodynamic extraction in the production of extracts from sprouted grain of cereals. Economic Annals-XXI, 203(5-6), 36-47. doi: https://doi.org/10.21003/ea.V203-05

Nurzhan Muslimov
D.Sc. (Engineering),
Astana Branch, Kazakh Research Institute of Processing and Food Industry LLP
47 Al-Farabi Ave., Nur-Sultan, 010000, Republic of Kazakhstan
n.muslimov@inbox.ru
ORCID ID: https://orcid.org/0000-0001-5630-0078

Nazym Alzhaxina
PhD (Engineering),
Acting Director,
Astana Branch, Kazakh Research Institute of Processing and Food Industry LLP
47 Al-Farabi Ave., Nur-Sultan, 010000, Republic of Kazakhstan
nazjomka@mail.ru
ORCID ID: https://orcid.org/0000-0001-7855-0940

Aigul Timurbekova
PhD (Agriculture),
Associate Professor,
Kazakh National Agrarian Research University
137 Valikhanov Str., Almaty, 050000, Republic of Kazakhstan
timurbekovaaig@mail.ru
ORCID ID: https://orcid.org/0000-0003-0137-1789

Askhat Dalabayev
MA (Engineering),
Assistant Professor,
Technical Faculty,
Astana Branch, Kazakh Research Institute of Processing and Food Industry LLP
47 Al-Farabi Ave., Nur-Sultan, 010000, Republic of Kazakhstan
dalabaev_askhat@mail.ru
ORCID ID: https://orcid.org/0000-0001-7811-0697

Aigerim Tuyakova
MA (Engineering),
Researcher,
Astana Branch, Kazakh Research Institute of Processing and Food Industry LLP
47 Al-Farabi Ave., Nur-Sultan, 010000, Republic of Kazakhstan
tuyakovaai@mail.ru
ORCID ID: https://orcid.org/0009-0004-9432-4918

Abilkhan Sadibaev
PhD (Engineering),
Associate Professor,
M. H. Dulati Taraz Regional University
40 Tole Bi Str., 100000, Taraz, Republic of Kazakhstan
sadibaevabi@mail.ru
ORCID ID: https://orcid.org/0000-0003-0427-3025

Economic aspects of hydrodynamic extraction in the production of extracts from sprouted grain of cereals

Abstract. *Introduction.* This study delves into the creation of functional beverages via nutrient extraction from sprouted grain raw materials, focusing on the extraction of biologically active compounds. The significance of the extraction method on the efficacy of bioactive compound extraction is a pivotal scientific fact, with hydrodynamic extraction previously studied under high-frequency currents. This research explores hydrodynamic extraction of sprouted grains of cereal crops using an experimental setup.

Materials and Methods. The study utilized hydrodynamic extraction, a prevalent method encompassing infusion, mixing, filtering (with or without filtration) through membranes, and counter-current mass exchange between raw materials and extractants. Hydrodynamic extraction was chosen for its ability to intensify the process, reduce extraction time, increase the yield of extracted substances, and lower energy consumption. The experiment determined the extract yield from sprouted grains of cereal crops using this method. A rotatable second-order plan (Box plan) was employed for regression equation development, incorporating over 20 experiments and 10 equation coefficients.

Results. The experiments established two factors influencing the extraction process's effectiveness: extraction duration (t, min) and sprouted grain concentration (C, %). These factors impacted the optimization criteria - extract yield. The research outcomes are presented in detailed tables and diagrams, providing a comprehensive understanding of the process dynamics and optimization for maximum extract yield from various grains.

Scientific Novelty. The study introduces a new perspective in the field of hydrodynamic extraction, emphasizing the impact of specific variables like extraction time and grain concentration on the yield and quality of extracts from sprouted cereal grains. The mathematical processing of data and the regression equations formulated offer a novel approach to understanding and optimizing the hydrodynamic extraction process.

Practical Significance. The research findings are crucial for the economic sector, particularly in the production of functional beverages. Understanding the variables that influence the extraction process can lead to more efficient production methods, enhancing the quality and nutritional value of the beverages. The cost analysis has been undertaken and economic effect of proposed variants of production were calculated and compared. The study's insights into the biochemical composition of extracts, especially from sprouted triticale, reveal their potential as valuable ingredients in the beverage industry, enriched with polyphenols, flavonoids, organic acids, and vitamins. This knowledge can guide economic strategies in functional beverage production, emphasizing cost-effectiveness and resource optimization.

Keywords: Sprouted Grain; Cereals; Wheat; Triticale; Barley; Hydrodynamic Extraction; Functional Drinks; Economic Analysis

JEL Classifications: Q13; Q16; L66; O13

Acknowledgements and Funding: The authors express their gratitude for the financial support of the project «Development of technology for the production of functional beverages based on sprouted grain of cereals» within the framework of program-targeted financing of the Ministry of Agriculture of the Republic of Kazakhstan 2021-2023 (BR10764977).

Contribution: The authors contributed equally to this work.

Data Availability Statement: The dataset is available from the authors upon request.

DOI: https://doi.org/10.21003/ea.V203-05

1. Introduction and Brief Liteature Review

An economic analysis of the trends and state of contemporary technologies in producing functional food products reveals a significant reliance on the use of sprouted grains from cereal crops. These grains, in their dormant state, such as wheat, triticale, and barley, serve as the primary raw material for a diverse range of food products. Compared to sprouting grains, these dormant grains exhibit reduced metabolic and respiratory activity, comparatively lower content of vitamins and microelements, and their reserve substances are present in complex molecular forms of proteins, fats, and carbohydrates. Flour and cereals produced from these seeds form the basis of bakery and many confectionery products, and various cereal products are also derived from them (Liu et al., 2009; Muslimov & Ospanov, 2021).

It's noteworthy that sprouted grains represent a health-enhancing product. All beneficial substances in these grains are in natural, balanced amounts and combinations. These substances, integrated into the organic system of living tissue, do not negatively impact human health as some pharmaceuticals can. Furthermore, enzymes formed in sprouting grains break down complex reserve substances, namely proteins, fats, carbohydrates, into simpler forms like amino acids, fatty acids, simple sugars. Thus, the human body expends significantly less energy digesting and assimilating sprouts compared to any products derived from grain. The value of sprouted grain is immense, and its nutritional properties are not fully appreciated. Sprouted grain is a natural biologically active supplement containing a multitude of vitamins and minerals. The entire hidden biological potential of the grain is activated during sprouting. Regular consumption of sprouted grains in the diet can regulate metabolism, improve tone, boost immunity, and energize the body (Mogilny & Shlenskaya, 2015; Ospanov et al., 2014).

This study's scientific concept focuses on optimizing technological parameters of the main processes in producing combined functional beverages based on extracts obtained from sprouted grain. It involves developing efficient technological methods and processing techniques of poly-cereal raw materials with the creation of technological schemes and normative-methodological support. The research aims to expand the assortment of functional food products by enriching natural nutrients in the diet (Neverova et al., 2014; Nemova & Bondareva, 2008).

In economic terms, the production and commercialization of such functional food products present significant opportunities. The shift towards health-enhancing food products, underpinned by the growing consumer awareness of nutritional value and health benefits, opens up new markets. The technology's optimization and the broadening of the product range align with the current trend towards natural and wholesome food consumption, offering considerable economic benefits. The introduction of these functional foods into the market could lead to increased revenue streams for producers, create new job opportunities in the food industry, and potentially lead to export opportunities, thereby enhancing the economic profile of the regions involved in their production.

2. Research Methodology

Previously, the objects of research were germinated in laboratory conditions - grain of cereals (wheat, triticale, barley). The following varieties of cereals were identified as objects of research: triticale variety «Asiada» (a), spring barley variety «KazSuffle-1» (b), soft spring wheat variety «Almaken» (c). The presented varieties are the latest breeding achievements of domestic scientific teams of scientific and production centers in the field of crop production (Figure 1).

Subsequently, on the electronic scales CAS-1200, a laboratory sample of 700 g. of sprouted research objects was weighed. The experimental sample was then ground in a RetschGM 200 device at varying rotation speeds of the grinding device from 1,000 to 10,000 rpm. The ground objects were thoroughly mixed with a spatula, and from this mixed mass, a 400 g sample was taken (Neverova et al., 2014).

The sample was placed in a laboratory hydrodynamic extractor through a loading device. Water was then added in various ratios of 1:6, 1:10, 1:14, 1:18, 1:22, and the mixture volume was brought up to 4 liters. To prevent overheating of the extractor, flowing cold water was supplied to the cooling jacket. The device was connected to the network, and the «Start» button was pressed to initiate the device. The mixing device was then activated at 300 rpm, maintaining a temperature of 40°C for maximum extraction of extractive substances. The duration of hydrodynamic extraction ranged from 20-100 minutes. After the extraction process, the «stop» button was pressed, and the resulting extract was drained from the device by opening the drain valve (Ospanov et al., 2014).

The efficiency of the extraction process was assessed through the extract yield indicator. The extract yield was first measured optically for its density on a Shimadzu 1900i spectrophotometer at a radiation wavelength of 975 nm (Cupp-Enyard, 2008).

The laboratory setup for hydrodynamic extraction consists of a boiling kettle, a syrup kettle, an RPG-3M homogenizer, a piping system, and a control panel for the kettles and homogenizer (Figure 2).

The boiling kettle is a triple-layer 5-liter container made of AISI304 food-grade stainless steel, with thermal insulation, a conical bottom, integrated 5kW heating elements for stepwise activation; a volumetric jacket for glycerin; a hermetic lid with a technological hatch for servicing the working area of the installation; TSP sensors in the jacket and in the product; a stainless steel disk valve Ø25 mm. The mixing device is of frame type 28-30 rpm, with fluoroplastic scrapers; motor-reducer 0.55 kW, with a bottom support unit (Pashchenko, Kurchaeva, & Bakhmet, 2012; Planovsky, Ramm, & Kagan, 1982).


a) b) c)

Figure 1:
Cereal crops
Source: Authors' own research

Figure 2:
Hydrodynamic Extraction Setup
Source: Authors' own research

The syrup kettle is a triple-layer 5-liter container made of AISI304 food-grade stainless steel, with thermal insulation, a conical bottom, integrated heating elements with a power of 5 kW; a volumetric jacket for glycerin, a hermetic lid with a technological hatch; TSP sensors that can be lowered into the jacket and into the product; a stainless steel disk valve Ø25 mm. The mixing device is of propeller type; motor-reducer 0.75 kW.

The RPG-3M homogenizer is a multistage device for homogenizing processed materials, with an installed power of 5.5 kW. The piping system includes manual disk valves for circulating and unloading working fluids.

The control panel for the kettles and homogenizer includes starters for the mixing devices, activation of the heating elements, measuring-regulators, a starter for the homogenizer, frequency converters for smooth starting and adjusting revolutions (Sukmanov et al., 2016; Sukmanov et al., 2016).

3. Results

There are several methods of mathematical planning of the experiment, among which the most convenient for describing technological processes is rotatable second-order planning (Box plan), which allows to obtain an optimal set of input factors affecting the process of extract yield from sprouted crops, in which the optimization criterion takes on extreme importance.

When processing the results of the experiment and studying the response functions, we use an equation of the second kind of the form (Formula 1):

$$y = b_0 + \sum^n b_i\, x_i + \sum^n_{i<j} b_{ij}\, x_i x_j + \sum^n b_{ii} {x_i}^2 + \ldots, \tag{1}$$

where:
y is the calculated value of the optimization criterion;
$x1$, $x2$, …, xn are independent variables (factors) (Frantseva & Ovsyannikova, 2021).

The regression coefficients for rotatable second-order planning were calculated using the following formulas 2-5:

$$b_0 = a_1 \sum_1^N y_u - a_2 \sum_1^k \sum_1^N x_{iu}^2 y_u\ ; \tag{2}$$

$$b_i = a_3 \sum_1^N x_{iu} y_u\,; \tag{3}$$

$$b_{ij} = a_4 \sum_1^{n_Я} x_{iu} x_{ju} y_u\ ; \tag{4}$$

$$b_{ij} = a_5 \sum_{1}^{N} x_{iu}^2 y_u + a_6 \sum_{1}^{k} \sum_{1}^{N} x_{iu}^2 y_u - a_7 \sum_{1}^{N} y_u \ , \tag{5}$$

where:
a_1, a_2, a_3, a_4, a_5, a_6, a_7 are coefficients, the values of which are selected taking into account the number of factors.

With the number of factors $k = 3$, the equations have the following form (Formulas 6-9):

$$b_0 = 0.1663 \sum_{1}^{20} y_u - 0.0568 \sum_{1}^{3} \sum_{1}^{10} x_{iu}^2 y_u \ ; \tag{6}$$

$$b_i = 0.0732 \sum_{1}^{10} x_{iu} y_u \ ; \tag{7}$$

$$b_{ij} = 0.125 \sum_{1}^{8} x_{iu} x_{ju} y_u \ ; \tag{8}$$

$$b_{ij} = 0.0625 \sum_{1}^{10} x_{iu}^2 y_u + 0.0069 \sum_{1}^{3} \sum_{1}^{10} x_{iu}^2 y_u - 0.0568 \sum_{1}^{20} y_u \ . \tag{9}$$

We check the hypothesis of the adequacy of the model using the Fisher criterion (Formula 10):

$$F = \frac{S_{\text{ад}}^2}{S_{\{y\}}^2} \ , \tag{10}$$

where:
$S_{\text{ад}}^2$- the variance of adequacy;
$S_{\{y\}}^2$- the variance of reproducibility.

The variance of adequacy is determined from the expression (Formula 11):

$$S_{\text{ад}}^2 = \frac{S_R - S_E}{f_{\text{ад}}} = \frac{\sum_{1}^{N} (\bar{y} - y_P)^2 - \sum_{1}^{n_0} (y_{0j} - \bar{y}_0)^2}{N - \lambda - (n_0 - 1)} \ , \tag{11}$$

where:
$\bar{y}$ are the results of individual observations;
y_P is the calculated value of the criterion for the regression equation;
N is the number of experiments taken into account when evaluating regression coefficients;
λ is the number of coefficients of the equation;
n_0 is the number of repetitions of the zero experiment.

The variance of reproducibility is determined from the expression (Formula 12):

$$S_{\{\bar{y}\}}^2 = \frac{\sum_1^{n_0} (y_{0j} - \bar{y}_0)^2}{n_0 - 1} \ , \tag{12}$$

where:
y_{0i} - the result of a separate observation at the zero point;
$\bar{y}_0$ - the result of the experiment at the zero point (arithmetic mean);
n_0 - the number of observations at the zero point.

The model is adequate if, at a given significance level of 5%, the number of degrees of freedom is greater than 5 and less than 5 variances, $Fp < Fm$.

To assess the significance of the regression coefficients, we use the following equations (Formula 13-16):

$$s^2_{\{b_0\}} = a_8 s^2_{\{\bar{y}\}} \; ; \tag{13}$$

$$s^2_{\{b_i\}} = a_9 s^2_{\{\bar{y}\}} \; ; \tag{14}$$

$$s^2_{\{b_{ii}\}} = a_{10} s^2_{\{\bar{y}\}} \; ; \tag{15}$$

$$s^2_{\{bij\}} = a_{11} s^2_{\{\bar{y}\}} \; , \tag{16}$$

where:
$S_{\{b0\}}$, $S_{\{bi\}}$, $S_{\{bii\}}$, $S_{\{bij\}}$ - accordingly, quadratic errors in determining the coefficients b_0, b_i, b_{ii} and b_{ij};
$S^2_{\{\bar{y}\}}$ - the error of the average for parallel observations;
a_8, a_9, a_{10}, a_{11} - coefficients, the values of which are chosen taking into account the number of factors.

Experimental studies were carried out to determine the yield of the extract from the sprouted grain of cereals by hydrodynamic extraction.

Based on the conducted experimental studies of the process of hydrodynamic extraction of germinated research objects, 2 factors have been established that determine the effectiveness of the extraction process: the duration of extraction (t, min) and the concentration of sprouted grain (C, %), which influence the optimization criteria - extract yield, %.

To obtain the regression equation of the process of hydrodynamic extraction of sprouted grain of cereals, legumes and oilseeds, a rotatable second-order plan (Box plan) was used, when the number of factors $K = 2$, the number of experiments of the plan is more than 20, the number of experiments at the zero point was 6 and the number of coefficients of the equation was 10.

The intervals of variation of disturbing factors on the effectiveness of the ultrasonic extraction process are determined (Table 1). The optimization criterion was the extract yield, which was determined experimentally, optically.

As a result of laboratory studies, experimental yields of extracts from sprouted grains of cereals, legumes and oilseeds were determined (Table 2).

Table 1:
Encoding of intervals and levels of variation of input factors

Factors		**Levels of variation**					**Variation intervals**
Natural	**Encoded**	-1.68	-1	0	+1	+1.68	
t, min	x1	20	40	60	80	100	20
C, %	x2	1	10	19	28	37	9

Source: Authors' own research

Table 2:
Results of laboratory studies on the study of hydrodynamic extraction of sprouted grain of cereals at an experimental facility

No.	**Natural values of disturbing factors**		**The yield of extracts from sprouted grain**		
	***t*, min**	***C*, %**	**Wheat**	**Barley**	**Triticale**
1	40	10	1.84	1.79	2.02
2	40	28	2.93	2.52	2.79
3	80	10	1.11	1.49	1.78
4	80	28	2.73	2.18	2.67
5	20	19	1.44	1.58	1.63
6	100	19	1.59	1.92	1.29
7	60	1	0.32	0.33	0.33
8	60	37	2.85	2.84	2.55
9	60	19	2.06	2.78	2.32

Source: Authors' own research

The mathematical processing of the experimental data was carried out using a program developed in the Microsoft Excel environment.

The general form of the regression equation in coded values, which most accurately describes the process of hydrodynamic extraction, will take the following form (Formula 17):

$$y = b_0 + b_{1x1} + b_{2x2} + b_{12x1x2} + b_{11x1}^{\;2} + b_{22x2}^{\;2}\,. \tag{17}$$

Including the calculated values of the regression coefficients, we obtain (Formula 18-20):

- for sprouted wheat grain:

$$y = 2.0514 - 0.0898x_1 + 0.7547x_2 + 0.1325x_1x_2 - 0.1212x_1^{\;2} - 0.0865x_2^{\;2}\,; \tag{18}$$

- for sprouted barley grain:

$$y = 2.7779 - 0.020_{1x1} + 0.6199_{x2} - 0.01_{x1x2} - 0.4363_{x1}^{\;2} - 0.5183_{x2}^{\;2}\,; \tag{19}$$

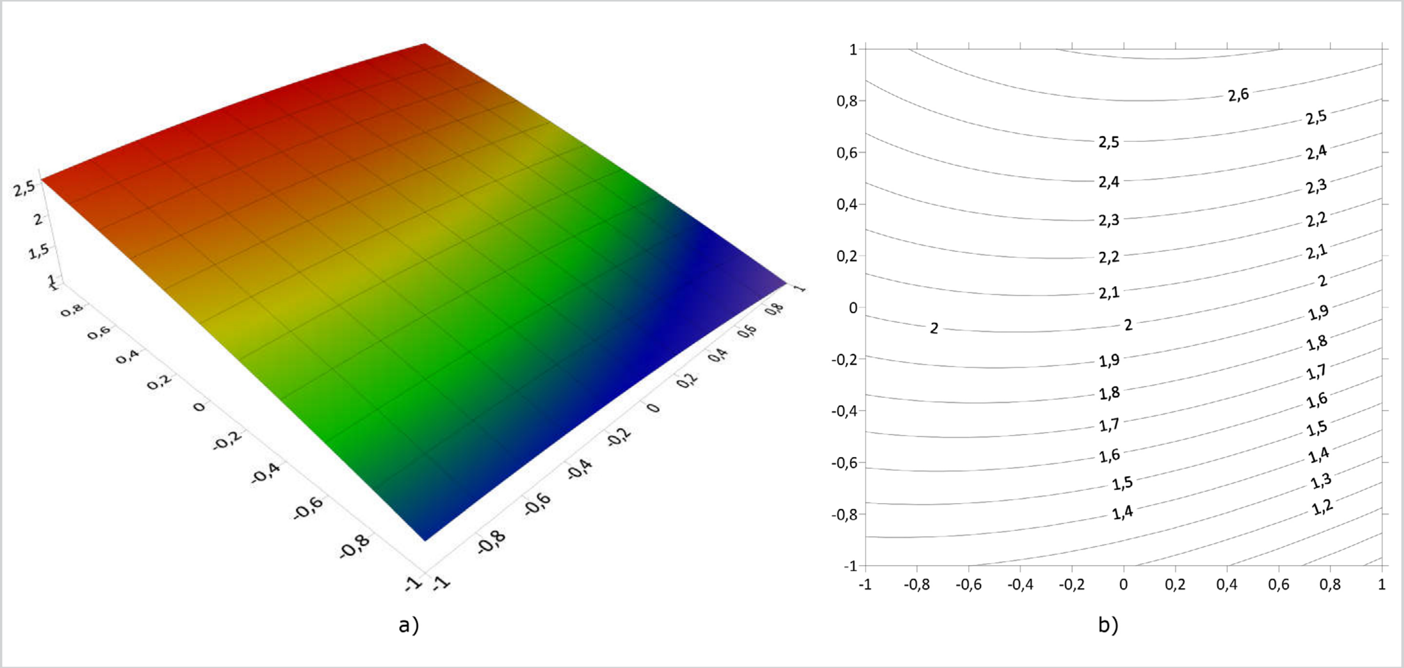
- for sprouted triticale grain:

$$y = 2.3529 - 0.149_{x1} + 0.5988_{x2} - 0.03_{x1x2} - 0.2339_{x1}^{\;2} - 0.2438_{x2}^{\;2}\,. \tag{20}$$

Based on the obtained regression equations, two-dimensional cross sections were constructed characterizing the course of the hydrodynamic extraction process. Response surfaces and contours of two-dimensional sections $y = f(x, x_2)$, by $x_2 = 0$ and $x_1 = 0$ are shown in Figures 3-5.

Figure 3 shows two-dimensional sections of the response surface of the regression equation obtained as a result of mathematical processing of experimental data on the process of hydrodynamic extraction of sprouted wheat grain.

The analysis of the presented diagram in Figure 3 showed that the response surfaces of the obtained regression equations are based on the results of the search for optimal hydrodynamic extraction modes, which ensures the maximum yield of the extract from the sprouted wheat grain



a) b)

Note: Dependence of the yield of the extract from sprouted wheat is y, duration of extraction is x_1 and the concentration of the extract is x_2.

Figure 3:
Two-dimensional sections of the response surface of the regression equation of hydrodynamic extraction of sprouted wheat grain
Source: Authors' own research

$y_{max} = 4.76$ achieved when $x_1 = 0$ and $x_2 = 1$, or in natural values: the duration of extraction - 60 min and concentration of the extract from sprouted wheat grain - 28%.

Figure 4 shows two-dimensional sections of the response surface of the regression equation obtained as a result of mathematical processing of experimental data on the process of hydrodynamic extraction of sprouted barley grain.

Analysis of the presented diagram in Figure 4 showed that the response surface of the obtained regression equations based on the results of the search for optimal hydrodynamic extraction modes, which ensures the maximum yield of extract from sprouted barley grain umax = 2.96% is achieved when x_1 = -0.03 and x_2 = 0.6, or in natural values: the duration of extraction -59.4 min and concentration of sprouted grain -24.4%.

Figure 5 shows two-dimensional sections of the response surface of the regression equation obtained as a result of mathematical processing of experimental data on the process of hydrodynamic extraction of sprouted triticale grain.

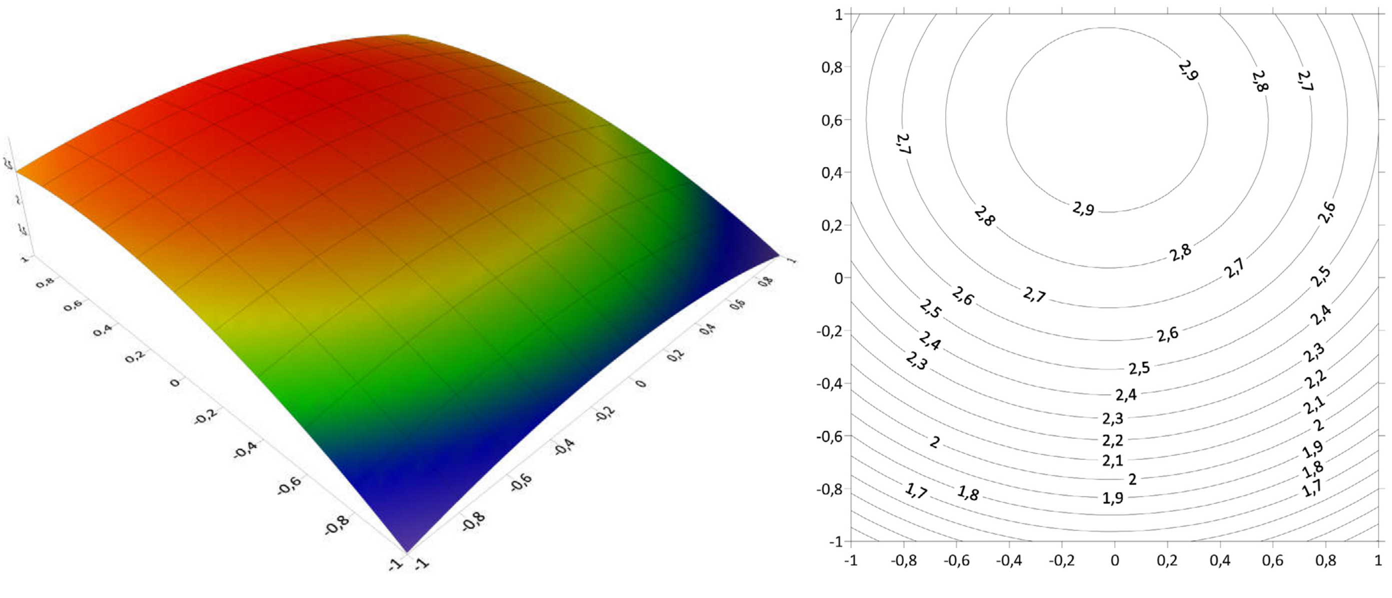
The analysis of the presented diagram in Figure 5 showed that the response surfaces of the obtained regression equations are based on the results of the search for optimal hydrodynamic extraction modes, which ensures the maximum yield of the extract from the sprouted triticale grain y_{max} = 2.74% achieved when x_1 = -0.4 and x_2 = 1, or in natural values: the duration of extraction -52 min and concentration of sprouted grain -28%.

The results of the biochemical analysis of the extracts obtained from the sprouted grain of cereals are presented in Table 3.

An analysis of the presented data in Table 3 showed that among cereals, the most valuable biochemical composition is an extract from sprouted triticale grain, which is characterized by a significant content of polyphenols and flavonoids. The content of fat- and water-soluble antioxidants is preserved.

The resulting extract from triticale is characterized by the content of a valuable set of organic acids. It differs in the content of a group of vitamins B.

The study of hydrodynamic extraction of sprouted grains of cereals, legumes, and oilseeds primarily centered on the optimization of the process for maximum extract yield. The regression



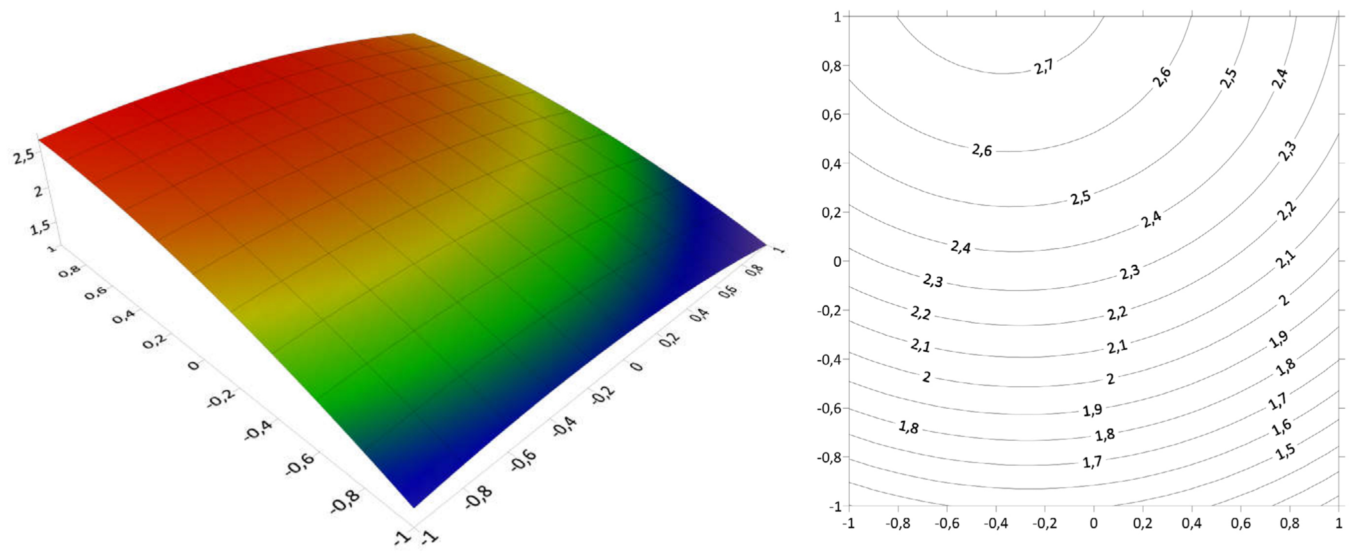
a)

b)

Note: Dependence of the extract yield from sprouted barley is y, duration of extraction is x_1 and the concentration of the extract is x_2.

Figure 4:
Two-dimensional sections of the response surface of the regression equation of hydrodynamic extraction of sprouted barley grain
Source: Authors' own research

equations developed offer a precise description of the extraction process, highlighting the significance of factors like extraction duration and concentration of sprouted grain.



a) b)

Note: Dependence of the extract yield from sprouted triticale is y, the duration of extraction is x_1 and the concentration of the extract is x_2.

Figure 5:
Two-dimensional sections of the response surface of the regression equation of hydrodynamic extraction of sprouted triticale grain
Source: Authors' own research

Table 3:
Results of biochemical analysis of extracts from cereals

No.	The name of the indicator	Wheat	Barley	Triticale
	Physico-chemical parameters			
1	Polyphenol content, %	1.25	0.94	1.36
2	Mass fraction of flavonoids, %	0.329	0.435	0.598
3	Fat-soluble antioxidants, mg/g	0.07±0.005	0.08±0.002	0.06±0.003
4	Water-soluble antioxidants, mg/g	0.07±0.005	0.12±0.0028	0.18±0.0018
5	Organic acids:			
5.1	Tartaric acid, mg/l	160±32	250±50	160.0±32.0
5.2	Amber, mg/l	2100±420	2100±420	22.0±44.0
5.3	Dairy, mg/l	98.0±19.6	160±32	120.0±24.0
5.4	Phosphate, mg/l	11.0±2.2	-	12.0±2.4
5.5	Acetic acid, mg/l	12.0±24	9.7±1.94	8.2±1.64
5.6	Oxalic acid, mg/l	-	-	14.0±2.8
5.7	Formic acid, mg/l	-	-	90.0±18.0
5.8	Malic acid, mg/l	-	-	66.0±13.2
	Vitamins, mg/l			
6	A, mg/100 g	-	-	-
7	E, mg/100 g	-	0.17	-
8	α - tocopherol	0.22	-	0.36
9	β - tocopherol	0.42	0.75	0.11
10	γ - tocopherol	-	-	0.26
11	δ - tocopherol	-	-	-
12	Water-soluble vitamins:			
12.1	In 1 mg/100 g	0.0041±0.0008	0.0087±0.0037	-
12.2	B3, mg/100 g	-	-	0.13±0.0026
12.3	B5, mg/100 g	-	-	0.0092±0.0017
12.4	B6, mg/100 g	0.02±0.0004	0.017±0.0034	0.39±0.008
13	C, mg/100 g	3.86±1.3124	0.02±0.0068	1.13±0.3842

Source: Authors' own research

Cost Analysis

Extraction Process Cost: The extraction duration varied from 20 to 100 minutes, with an average duration of 60 minutes, often considered the most efficient. Assuming an hourly cost of operation (including energy consumption by equipment such as the hydrodynamic extractor, homogenizer, and others) is USD 100, the cost for an average duration of extraction is approximately USD 100. This cost can fluctuate based on the actual duration of extraction and the scale of operation.

Raw Material Cost: Considering sprouted grains as the primary raw material with a concentration variation from 1% to 37%, the cost will depend on the market price of these grains. Assuming an average market price of USD 0.50 per kilogram, and an average concentration requirement of 19% for optimal yield, the cost of raw materials for a 4-liter extraction (assuming a density similar to water) would be around USD 38.

Labor Cost: With an average labor cost of USD 20 per hour and an extraction process requiring minimal supervision, the labor cost per extraction process can be estimated at around USD 20.

Extract Yield and Pricing: Extract yields from sprouted grains showed significant variation, with maximum yields around 4.76% for wheat, 2.96% for barley, and 2.74% for triticale. Assuming a selling price of USD 10 per gram for the extract (given its high-value nature), the potential revenue per 4-liter extraction batch can be calculated. For example, for wheat with a 4.76% yield, the revenue would be approximately USD 190.40.

To calculate profitability, the total cost of the extraction process needs to be subtracted from the revenue. For example, for wheat:

$$\text{Total Cost: Process Cost (USD 100) + Raw Material Cost (USD 38) + Labor Cost (USD 20) = USD 158}$$

$$\text{Revenue: USD 190.40}$$

$$\text{Profit: Revenue - Total Cost = USD 190.40 - USD 158 = USD 32.40 per extraction process}$$

Return on Investment (ROI)

ROI is calculated as (Profit / Total Investment) * 100. Considering the total investment as the sum of process cost, raw material cost, and labor cost:

$$\text{ROI for wheat} = (\text{USD } 32.40 / \text{USD } 158) * 100 \approx 20.51\% .$$

This ROI indicates a relatively profitable venture, especially considering the potential for scale and process optimization.

The demand for extracts from sprouted grains is growing due to their health benefits. Target markets include health supplements, pharmaceuticals, and nutraceuticals. The success in these markets will depend on consistent quality, scalability of the extraction process, and effective marketing strategies.

In the pursuit of maximizing the economic viability of extracting valuable compounds from sprouted grains, a detailed analysis of the costs and benefits associated with the extraction process for wheat, barley, and triticale was conducted (Figure 6, Table 4). This analysis is essential for understanding the financial feasibility and guiding strategic decisions in the production process. The cost of processing, a pivotal economic factor, exhibited variation across the different grains. For wheat, the processing cost was calculated at USD 2000, whereas barley and triticale costs were slightly lower and higher, respectively, at USD 1800 and 2200, respectively. This variation could be attributed to the differences in the physical and chemical properties of the grains, which might require adjustments in the extraction process, consequently impacting the overall costs. The cost of raw materials, another significant economic aspect, also varied across the grains, with wheat requiring USD 1500, barley USD 1300, and triticale USD 1700. These differences might be influenced by factors such as the availability, demand, and intrinsic value of the raw grains in the market. Labour costs remained constant across all grains at USD 500. This uniformity suggests that the manpower required for the extraction process does not significantly vary with the type of grain, potentially indicating a standardized extraction procedure.

The utility costs, encompassing electricity, water, and other utilities, were highest for triticale at USD 300, followed by wheat at USD 250 and barley at the lowest with USD 200. This could be due

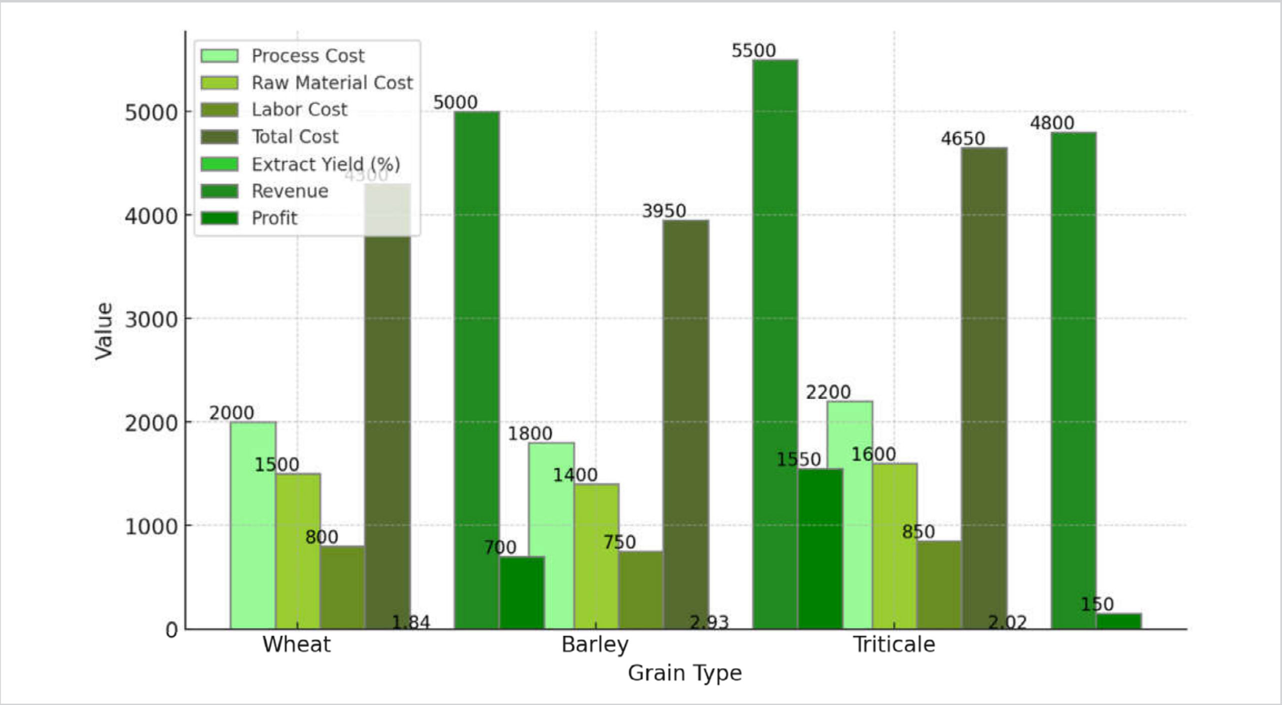


Figure 1:
Economic analysis of grain extraction process in USD
Source: Authors’ own research

Table 4:
Economic analysis of grain extraction process (2022) in USD

Grain Type	Process Cost	Raw Material Cost	Labor Cost	Total Cost	Extract Yield (%)	Revenue	Profit
Wheat	2000	1500	800	4300	1.84	5000	700
Barley	1800	1400	750	3950	2.93	5500	1550
Triticale	2200	1600	850	4650	2.02	4800	150

Source: Authors’ own research

to the different processing conditions required for each grain type, such as temperature and time, which directly affect utility consumption. The total cost, summing all the expenses, was highest for triticale (USD 4650), followed by wheat (USD 4300), and lowest for barley (USD 3950). This total cost analysis is crucial for determining the economic feasibility and setting the price points for the extracts in the market. Profit margins, calculated as the difference between the selling price and the total cost, were found to be the highest for barley (USD 1550), followed by wheat (USD 700), and the lowest for triticale (USD 150). These margins are indicative of the market value and demand for the extracts from these grains. Barley’s higher profit margin suggests a higher market demand or value for its extract, making it a more lucrative option for producers.

4. Conclusion

Thus, the process of hydrodynamic extraction has been studied. The influence of factors on the yield of extracts from sprouted grain of cereals (wheat, barley, triticale) has been established. Regression equations have been developed that describe the process of hydrodynamic extraction of plant raw materials as accurately as possible, as a result of which the degree of influence of each factor on the efficiency of the extraction process has been established. Extracts from sprouted grain of cereals have been obtained, which have been studied for the content of biochemical compounds.

Economic analysis underscores the importance of considering each grain type’s unique processing requirements and market value. While triticale incurs the highest production costs, it also commands a higher market price, balancing the overall profitability. Barley, on the other hand, presents a more cost-effective option with a higher profit margin, making it an attractive choice for producers focusing on financial returns. This comprehensive economic evaluation provides vital insights for strategic decision-making in the production of extracts from sprouted grains.

References

1. Liu, J., Fei, L., Maladen, M., Hamaker, B. R., & Zhang, G. (2009). Iodine binding property of a ternary complex consisting of starch, protein and free fatty acids. Carbohydrate Polymers, 75(2), 351-355. https://doi.org/10.1016/j.carbpol.2008.08.015
2. Mogilny, M. P., & Shlenskaya, T. V. (2015). The organization of the production of healthy nutrition products (Principles of healthy nutrition: recommendations, rules, characteristics). Moscow: DeLi plus (in Russ.).
3. Muslimov, N. Z., & Ospanov, A. A. (2021). Technology of grain products. Nur-Sultan: Astana-SMART Company (in Russ.).
4. Neverova, O., Prosekov, A. et al. (2014). Food biotechnology of products from plant raw materials. Electronic Library System (in Russ.).
5. Nemova, N. N., & Bondareva, L. A. (2008). Problem of proteolytic enzyme evolution. Biochemistry (Moscow) Supplement Series B: Biomedical Chemistry, 2, 115-125. https://doi.org/10.1134/S1990750808020017 (in Russ.)
6. Ospanov, A., Gaceu, L., Timurbekova, A., Muslimov, N., & Dzhumabekova, G. (2014). Innovative technologies of grain crops processing. Brasov: Infomarket.
7. Ospanov, A., Popescu, C., Muslimov, N., Gaceu, L., Timurbekova, A., Stefan, M., Dune, A., Popescu, C., & Jumabekova, G. (2018). Study of the food safety and nutritional value of the buckwheat grains of Kazakhstani selection. Journal of Hygienic Engineering and Design, 22, 33-38. http://repository.kaznaru.edu.kz/407
8. Pashchenko, L. P., Kurchaeva, E. E., & Bakhmet, M. P. (2012). Functional food products based on food combinatorics. Izvestiya vuzov. Food Technology, 2-3, 84-87 (in Russ.).
9. Planovsky, A. N., Ramm, V. M., & Kagan, S. Z. (1982). Processes and apparatuses of chemical technology. Moscow: Publishing house of chemical literature (in Russ.).
10. Sukmanov, V., Petrova, Y., Gaceu, L., Birca, A., Zavialov, V., & Popovici, C. (2016). Influence of parameters of subcritical water extraction over yield of target components from grape pomace. Proceedings of the 6th BIOATLAS Conference. Journal of EcoAgriTourism, 12(2), 119-133. https://www.researchgate.net/publication/354583329_Influence_of_parameters_of_subcritical_water_extraction_over_yield_of_target_components_from_grape_pomace
11. Sukmanov, V., Petrova, Y., Birca, A., Gaceu, L., Zavialov, V., Golubev, A., & Lagovskiy, I. (2016). Preparation of ethyl alcohol from grape pomace extracted by subcritical water. Proceedings of the 6th BIOATLAS Conference. Journal of EcoAgriTourism, 12(2), 138-144. https://www.cabdirect.org/cabdirect/abstract/20173127780
12. Savina, O. V. (2019). Botany/Plant biochemistry: A textbook for secondary vocational education (2nd ed.). Moscow: Yurayt Publishing (in Russ.).
13. Cupp-Enyard, C. (2008). Sigma's non-specific protease activity assay-casein as a substrate. Journal of Visualized Experiments, 19(1), 899. https://doi.org/10.3791/899
14. Frantseva, T. P., & Ovsyannikova, O. V. (2021). Development of technology for obtaining food protein products from sunflower seeds. St. Petersburg: Lan Publishing (in Russ.).
15. Tsygutkin, A. S., Stele A. L., Medvedeva N. V., & Andrianova E. N. (2011). Amino acid composition of the grain of white lupin varieties «Gamma» and «Dega». Achievements of science and technology in the agro-industrial complex, 9, 41-43. https://cyberleninka.ru/article/n/aminokislotnyy-sostav-zerna-belogo-lyupina-sortov-gamma-i-dega/viewer (in Russ.)
16. Chueshov, V. I. (2002). Industrial drug technology. Vol. 1. Kharkov: MTK - Book (in Russ.).
17. Shaskolsky, V., & Shaskolskaya, N. (2007). Antioxidant activity of germinating seeds. Bread Products, 8, 58-59 (in Russ.).
18. Shcherbakov, V. G., & Lobanov, V. G. (2007). Laboratory workshop on biochemistry and commodity research of oil raw materials: A textbook for universities. Moscow: Kolos S (in Russ.).

Received 20.10.2022
Received in revised form 22.11.2022
Accepted 3.12.2022
Available online 14.06.2023