В даний час велика увага приділяється виробництву екологічно чистих продуктів харчування. Наукова концепція нанонауки розглядає синтез іонноозонної суміші без шкідливих домішок оксидів азоту і вуглецю при обробці, переробці і збереженні продуктів харчових виробництв на основі різнополярності електричного струму. Саме негативна полярність іонноозонної суміші і позитивна полярність оброблюваного продукту із застосуванням кавітації в електромагнітному полі підвищує біологічну та екологічну цінність продуктів.

Розширення асортименту макаронних виробів для різних категорій і верств населення вимагає використання перспективних сировинних ресурсів, до яких відноситься зерно тритикале.

Запропоновано метод пошуку шляху підвищення якості зерна тритикале з кавітацією і без кавітації на іонозонній установці і подальша його переробка на борошно. На основі проведення повнофакторних експериментів 2^3 і 2^4 розроблені рівняння регресії, що дозволяють порівнювати результати іонозонної обробки між собою і виявляти основні технологічні властивості тритикале сорту «Таза». Вхідними змінними служать режимні параметри іоноозонної обробки (концентрація іонозону, вологість до обробки і час обробки) та іоноозонно-кавітаційної обробки (надлишковий тиск, концентрація іонозону, вологість до обробки і час обробки). Вихідними змінними є: серед показників фізичних властивостей – щільність, маса 1000 зерен; серед біохімічних властивостей – масова частка білка і вміст сирої клейковини, та макаронних властивостей – твердозерність і питома робота на деформацію. Це дає можливість оцінювати ефективність для макаронного виробництва.

Доведено, що технологічні властивості контрольного і обробленого іонозоном зразка істотно розрізняються. Запропонована технологія обробки іоноозонним кавітаційним потоком зерна тритикале на хлібоприймальних підприємствах дозволяє підвищити фізичні, біохімічні та макаронні властивості борошна, що підвищує ефективність макаронного виробництва більш ніж на 15 %

Ключові слова: тритикале, іоноозон, іонозонна установка, повнофакторний експеримент, кавітація, технологічні властивості, макаронів

UDC 633.11
DOI: 10.15587/1729-4061.2019.174805

PREPARATION OF TRITICALE FLOUR BY ION-OZONE TREATMENT FOR PASTA QUALITY IMPROVEMENT

G. Daribayeva
Doctoral student *
E-mail: Daribaeva.80@mail.ru
G. Magomedov
Doctor of Technical Sciences, Professor, Head of Department
Department of Bakery, Confectionery, Pasta, and Grain Processing Technology
Federal State Budget Educational Institution of Higher Education "Voronezh State University of Engineering Technologies"
Revolyutsii ave., 19, Voronezh, Russia, 394036
E-mail: mmg@inbox.ru
B. Iztaev
PhD*
E-mail: baurgoldman@mail.ru
N. Zhexenbay
PhD
Department of Technology of Food Products**
E-mail: nurshash1@mail.ru
B. Tyussyupova
PhD
Department of Analytical, Colloid Chemistry and Technology of Rare Elements
Al-Farabi Kazakh National University
Al-Farabi ave., 71, Almaty, Kazakhstan 050040
E-mail: baimuratovna78@mail.ru
*Department of Technology of Bakeries and Processing Productions**
**Almaty Technological University
Tashkent str., 348/4, Almaty, Kazakhstan, 050061

Received date 09,07,2019
Accepted date 05.08.2019
Published date 09.08.2019

1. Introduction

In order to expand the range, by increasing the nutritional value and improving the quality of pasta from wheat flour, safe and effective technologies for the production of pasta were developed with the addition of various food additives from non-traditional raw materials used in the production of pasta [1, 2].

In this regard, it is impossible not to note a very promising hybrid of wheat and rye grain varieties that is triticale. Productivity is very high up to 12–14 t/ha and biochemical composition is higher and better matched protein and vitamins and minerals [3]. The shortage of durum wheat for pasta is reduced. Improving the nutritional value and pasta properties is relevant with adding triticale flour. It is indispensable to the effective preparation of triticale grains for processing. For the first time, ion-ozone treatment of triticale grains with and without cavitation to enhance the effect of oxygen and ozone ions on biological cells was used.

Ion ozone grain treatment in the field of cavitation produces disinfection, destroys insect pests, and at the same time accelerates the process of controlled grain processing. Qualitatively improves and accelerates redox processes, on the basis of quantum-physical processes, increases the biological value of the product, which contributes to its effective use in the stream. Innovative universal ion-ozone processing line produces pure ozone, molecular and atomic oxygen ions of the air without impurities. Their use is carried out in air. To activate their action on biological objects, a cavitation process of up to 4 MPa is used on special created devices that provide a sharp decrease in accumulated overpressure. All this made it possible to combine with the cavitation process of ionic, ozone, ion-ozone in two media up to 4 MPa as ordinary cavitation. As a result of combining, positive results occur. At the same time, penetrating into the endosperm the ion-ozonated mixture contributes to its softening, forming in it supercritical stresses of the processed product. Since the humidity of the outer and inner layers of the endosperm is different, they swell unevenly, which causes the stress state of the material. In addition, starch and proteins in the endosperm cells also swell unevenly. As a result, when the critical values and the electric field in the endosperm are reached, the formation of microcracks begins with an increase in their number and uniform distribution over the grain surface. Cavitational ion-ozone treatment of water used to moisten the grain before grinding it at milling plants provides rapid diffusion of water and intensive hydration of proteins and starch. This made it possible to reduce the number of used bins, improve the rhythm of work and profitability. The use of such technology in the conditions of constantly deteriorating wheat quality allows to obtain high-quality flour from low-grade grain. The technology of ion-ozone-cavitational processing of grain is ecologically safe and does not use chemicals and types of radiation harmful to humans, animals and the environment [4].

The solutions obtained using this method make it possible to activate biological processes in the cells, which has a positive effect on finished pasta, namely, rheological characteristics. This indicates that the topic of research dedicated to quality improvement by ion-ozone treatment of triticale grain for the use in pasta is relevant.

2. Literature review and problem statement

Pasta is export-oriented, popular and consumed in large quantities, it is possible to actually and effectively carry out prevention of various types of diseases through the release of products of improved quality and increased nutritional value, due to various additives [5].

The quality of pasta from einkorn is explored. Einkorn is a diploid relative of durum wheat and bread wheat, which is valued for its high content of protein, carotenoids and tocopherols, as well as for its excellent organoleptic properties [6]. The purpose of the study was to evaluate its suitability for the production of pasta and the quality of its products. Dry einkorn pasta was different from durum wheat pasta in most ways, including size, carotenoid content [7].

The study shows the effect of corn micronization on the quality characteristics of pasta. As a result, micronized corn flour with gums can be used in the preparation of corn pasta with good quality characteristics. But there remained unresolved issues related to nutritional value. There are not enough indicators that increase nutritional value [8]. It discusses the structural properties, characteristics of denaturation and aggregation, as well as solubility, as well as the foaming, emulsifying and gelling properties of the proteins amaranth, buckwheat and quinoa. In addition, the technological impact of the inclusion of amaranth, buckwheat and quinoa in bread, pasta, noodles and biscuits, as well as strategies affecting the functionality of proteins of pseudo-cereal flour is discussed. The disadvantage of this method is that in the literature on pseudo-cereal proteins it is often controversial and contradictory, especially in the methods used to obtain globulins and glutelins.

In the research, pasta was made from wheat flour, replacing 10, 20 and 30 % of wheat with flour ditches from ecotypes $L1$ and $L2$. The purpose of this study was to investigate the production of high-fiber and protein-rich pasta made from mixtures of wheat and ditch [9].

In order to increase the nutritional value of macaroni products, additives have been added. But not all of them provided treatment of raw materials, which improve the quality of the pasta. Regression models are not developed to compare the results.

Among plant crops, cereals occupy a leading place in terms of production and growth rates. Among the variety of non-traditional raw materials in pasta production, interest is triticale flour.

Triticale has proven extremely popular as a renewable energy source for both animal feed and the food industry [10]. It comes out from [11] that the optimal concentration of triticale bran can be included into yogurt. From this present study, we can conclude that triticale bran shows promise as a source of prebiotics with antioxidant activity for future functional foods.

Malted triticale has the potential to produce high-quality beer. It is identified and selected as the best line suitable for malt production and brewing. Ten triticale lines show protein content (11.97–14.52 %) and carbohydrates (77.24–82.87 %) useful for malt production [12].

11 genotypes of triticale are analyzed and compared with wheat and rye in [13]. The beneficial properties of triticale starch suggest that targeted selection can be used to improve the quality of triticale grains and opens up the possibility of using triticale.

In [14], the active films of triticale flour were made up with the addition of bacteriocin-like substances with antimicrobial activity. These results show that triticale flour films can provide an alternative strategy for active food packaging applications.

As a result of research, triticale can be used not only as feed for poultry, but as a food product. However, research about using triticale for pasta production is not found.

3. The aim and objectives of the study

The aim of the work is to prepare and improve the quality of triticale flour by ion-ozonized and ion-ozone cavitation treatment as important additives improving nutritional values and consumer qualities of finished pasta products.

Based on the objectives of the study, the following tasks were set:

– to investigate and compare the effects of ion-ozone and ion-ozone cavitation treatment on the physical, biochemical and macaroni properties of "Taza" triticale grain;

– to develop regression models describing the change indicators of physico-biochemical and macaroni properties of triticale flour based on conducting full-factor experiments for ion-ozone and ion-ozone cavitation treatment;

– to make optimization models of linear programming for the establishment of technological modes of processing triticale flour providing the necessary pasta properties when used in pasta production.

4. Objects and methods of research of grain processing

In experimental studies, two methods of treating triticale at room temperature of 18...25 °C were studied:

– ion-ozone treatment;

– ion-ozone cavitation treatment.

In the case of ion-ozone processing, triticale grain is loaded into the ion-ozone unit (Fig. 1), filled with ion-ozone mixture with an ozone concentration of 0.5 mg/dm^3 to 4 mg/dm^3 (or from $0.5 \cdot 10^{-3}$ to $4 \cdot 10^{-3}$ mg/cm^3) and the content of molecular ions in the range from 500 to 60,000 units/cm^3. At the same time, the ratio of ion concentration (units/cm^3) to ozone concentration (mg/cm^3) $C_{i/o}$ is $(1...15) \cdot 10^{-6}$ units/mg, i. e. 1...15 million units/mg. Further, for 10...20 minutes, ion-ozone active ventilation of triticale grain is performed. Humidity before grain processing ranges from 13 to 20 %.

When ion-ozone cavitation processing of the grain after active ventilation, the cavitation installation is sealed. Into the tank, the ion-ozone mixture is injected until an overpressure of 2 to 4 atm is created. After that, excess pressure in the tank is dramatically reduced, while ozone tends to explode (the higher the excess pressure, the more powerful the ozone explosion). The abrupt release of overpressure and the ozone explosion power add up.

Fig. 1. Ion-ozone cavitation equipment

During the explosion, cavitation processes occur, during which the pores of the processed triticale grain increase, where the ion-ozone mixture penetrates more efficiently. Ozone destroys harmful impurities and harmful insects. Molecular oxygen ions based on quantum-physical processes increase the biological value of the product [15, 16].

The following factors were chosen as factors affecting the properties and quality indicators of the processed triticale grain:

– the ratio of ion concentration (million units/cm^3) to ozone concentration (mg/cm^3) $C_{i/o}$, million units/mg; (for ion-ozone treatment with and without cavitation);

– overpressure (for ion-ozone cavitation treatment) P, atm;

– humidity of the samples before processing w, %;

– processing time τ_1, min.

In the experiments for the studied triticale grain, the following quality indicators were determined:

Y_1 – humidity after processing, %;

Y_2 – nature, g/l;

Y_3 – grain density, g/cm^3;

Y_4 – mass of 1,000 grains, g;

Y_5 – protein, %;

Y_6 – raw gluten, %;

Y_7 – starch, %;

Y_8 – Green index, ml;

Y_9 – hardness of grain, units;

Y_{10} – specific work deformation test, ea.

The same quality indicators were also determined for the control (not processed) grain sample of triticale.

To optimize the processing of triticale grains, the following indicators were selected as the objective functions:

– for physical properties – density (y_3);

– for biochemical properties – protein (y_5);

– for pasta properties – hardness of grain (y_9).

The rest of the above indicators of grain quality were considered as limitations.

Taking into account a relatively large number of factors, in order to reduce the number of experiments and obtain reliable results in research, planning methods were used that were full factorial experiments of the FFE-2^3 type and FFE-2^4. FFE-2^3 type for ion-ozone treatment and FFE-2^4 for ion-ozone cavitation treatment. To reduce the effect of uncontrolled parameters on the results, experiments were randomized using random number tables [17].

A special disintegrator DPO-320-7.8 mill was used for preparing macaroni flour from triticale cultivated by ionizers (Fig. 2).

Fig. 2. Disintegrator DPO-320-7.8

Depending on the speed of the specified rotor, the fraction varies: at the maximum speed of the rotor, the smallest fractions at the frequency of 50 Hz, with the rotor rotation velocity – the maximum amount of fractional powders are crushed at a frequency of 20 Hz.

Methods of analytical studies of grain after processing.

In accordance with all the analyses characterizing the technological properties according to State standards (10846-91, 52377-2005, 1482-2005) and "InfraLUM FT-12"

(St. Petersburg, "Lumex") infrared analyzers, the analyzer has conducted research. InfraLUM FT-12 infrared analyzer is a stationary laboratory instrument that can quickly determine the composition and quality of grain.

On the basis of the least-squares research conducted by the algorithms and sequential regression analysis programs developed at the Odessa National Academy of Food Technologies, regression equations were obtained. The resulting equation (Fisher criterion) describes a dependence of the quality indicators of the above processed corn triticale, respectively on the conditions and modes of their ion-ozone minutes and ion-ozone cavitation treatment.

The essence of the sequential regression analysis was that the least-squares method, implemented in a matrix form, was used to calculate the regression coefficients. Their significance was checked and the insignificant coefficient was removed with a minimum ratio of its value to a critical value and then the regression coefficients were recalculated again. This procedure ended when only significant regression coefficients remained in the equation. Then, according to the Fisher criterion, the adequacy of the regression equation was tested for experimental data [18, 19].

The systems of equations compiled for triticale grains are mathematical models. That make it possible to predict changes in the main quality indicators studied depending on the ion-ozone and ion-ozone-cavitation modes.

Further, the tasks of safe technological processing regimes were formulated and solved, including the justification of the objective function. Bilateral restrictions (limits of change) indicators of the function of restrictions on the values of factors and criteria for assessing the quality of triticale grain.

Considering the non-linearity of the objective function and the criteria for evaluating the grain quality, the search for safe processing modes was performed using the Newton method [20].

For a visual illustration of the nature of the dependence of various objective functions on the factors influencing them, the resulting regression equations were presented as response surfaces (two-factor dependencies). Dependencies of simple linear nature are not graphically interpreted [21].

When constructing such two-factor dependencies, the other significant factors included in the regression equations were fixed at safe levels.

The granulometric composition of various samples of flour and powders was determined by means of the GIU-1 through the information and measuring system (SI).

The strength of the finished pasta was determined by the "Structurometer CT-2" device. Based on the speed law, which determines the rheological characteristics of foodstuffs, the study is conducted on the control of load-kinetics (time-to-mechanical load change) and dynamics (mechanical load on the depth of indenter), measured by the movement of various vertically fixed verifiers.

5. Research results of full factor experiments

The results of the influence of 2^3 ion-ozone treated "Taza" triticale on its technological properties are presented (Table 1). The quality indicators of the control and processed triticale grains are given.

With safe modes X_1>1,000 units/mg, X_2=13.0–20.0 %; X_3=10 min, the biochemical properties of the dough are improved, which also increases its pasta properties. The specific work of deformation of the test increased from 225.50 ea to 285.78 ea compared with the control sample. At the same time, a short processing time: within 10 minutes, preserves and improves the physical and biochemical properties of dough made from the flour of "Taza" triticale grains [22].

Based on the studies, mathematical regression models describing changes in the main indicators for evaluating the technological properties of the processed triticale grain were obtained (Table 2). This makes it possible to determine the safe conditions of the ion-ozone treatment, which ensure that rational technological regimes are justified. Table 2 shows the regression models obtained on the basis of 2^3 full-factor experiments on the main indicators of grain, flour and dough for "Taza" triticale.

Table 1

Conditions and results of FFE-2^3 experiments on ion-ozone cavitation treatment of triticale "Taza"

Experiment No.	Ratio of ion concentration to ozone, million units/mg ($C_{i/o}$)	Humidity before treatment,% (w)	Processing time, min (τ)	Technological properties									
				Physical				Biochemical				Pasta	
				Humidity after proe cessing,%	Nature, g/l	Density, g/ cm^3	Weight of 1000 grains, g	Mass fraction of protein%	Raw gluten,%	Starch, %	Green's index, ml	Hardness, units	Specific work of deformation test, ea
	Experimental conditions			Quality indicators									
	Control (without treatment)			13.2	687	1.16	50	11.82	20.59	61.78	19.08	45.76	225.50
				19.9	593	1.06	54	8.60	20.77	59.09	19.31	57.24	408.91
	X_1	X_2	X_3	Y_1	Y_2	Y_3	Y_4	Y_5	Y_6	Y_7	Y_8	Y_9	Y_{10}
1	15	20	20	14.78	665	1.12	57	13.23	19.92	60.75	19.43	46.75	245.7
2	1	20	20	13.89	644	1.08	56	12.94	20.03	60.92	16.07	41.72	238.6
3	15	13	20	13.06	694	1.16	55	13.77	20.99	62.07	24.35	37.74	236.9
4	1	13	20	13.33	695	1.16	54	12.84	20.52	61.91	23.41	47.88	237.4
5	15	20	10	15.64	648	1.15	54	13.29	20.37	60.52	21.23	36.08	255.3
6	1	20	10	17.91	611	1.16	58	13.90	21.89	60.68	24.66	41.59	285.8
7	15	13	10	12.92	698	1.05	54	12.80	21.19	61.89	25.36	49.43	241.3
8	1	13	10	13.05	694	1.14	52	13.50	20.51	62.17	22.29	40.70	225.5

Table 2

Characteristics of the regression equations for the main indicators of quality by the least-squares method, taking into account the inter-factor interactions for "Taza" triticale grain

Indicators	Type of equation (optimization)	Numerical Characteristics			
		Averagevalue	Standard deviation	Criteria	
				Fisher $-F_p$	Student $-t_{cr}$
1000 grains mass	Y=43.0357+0.7857*X_3	56	SY=1.400 Sag=2.4349	F_p=3.02 F_{kp}=19.42	4.304
Acidity	Y_{ac}=5.574–0.0455*X_1–0.344167*X_2–0.238988*X_3–0.1565*X_4+0.0023*X_1*X_4+0,0192*X_2*X_3+0.008393*X_3*X_4	1.24	SY=0.0500 Sag=0.1978	F_p=15.66 F_{kp}=19.37	4.304
Raw gluten	Y_{rg}=0.535+0.1846*X$_2$	20.99	SY=0.2300 Sag=0.6364	F_p=7.66 F_{kp}=19.42	4.304
Specificwork of deformation	Y_{swd}=111.614881–5.663*X_1+6.0308*X_2+612.5736*X_3–3.973929*X_4+0.407*X_1*X_4	274.99	SY=6.9500 Sag=24.9642	F_p=12.90 F_{kp}=19.39	4.304

From the data of Table 2, it can be seen that the whole equation at a high level adequately describes the change in physicochemical and macaroni properties. As a result, 9 regression equations were obtained by the studied indicator of the quality of triticale grains. To establish the optimal values of ion-ozone and ion-ozone cavitation treatment modes, linear programming models were compiled. Physical, biochemical and macaroni properties, selected indicators of target functions, and the remaining indicators are used as restrictive functions. Restrictions on quality indicators are chosen to correspond to a good quality level according to the standard for triticale grain. From the beginning, we consider the optimization of the operating parameters of the ion-ozone processing of triticale grains.

Restrictions on the range of variation of regime parameters and ion-ozone processing of all the studied grain samples were as follows:

1 million units/mg $\leq C_{i/o} \leq$15 million units/mg;

13 % $\leq w \leq$20 %;

10 min $\leq \tau_1 \leq$20 min.

Taking into account the permissible ranges of the studied factors ($C_{i/o}$, w and τ), the mathematical models for the safe ion-ozone treatment regimes for triticale of the "Taza" variety are as follows.

Physical properties:

– objective function

$1.0 \leq y_3 = 1.127$, g/cm$^3 \leq 1.28 \rightarrow$max;

– restrictions on quality indicators:

$11.0 \leq y_1 = 8.51 + 0.474 \cdot w - 0.00810 \cdot w \cdot \tau$, %$\leq 22.0$;

$650 \leq y_2 = 794.1 - 7.61 \cdot w$, g/l$\leq 800$;

$30.0 \leq y_4 = 49.11 + 0.35 \cdot w$, $g \leq 60.0$;

Biochemical properties:

– objective function

$11.0 \leq y_5 = 11.68$, %$\leq 15.5 \rightarrow$max;

– restrictions on quality indicators:

$19.0 \leq y_6 = 20.68$, %≤ 30.0;

$58.0 \leq y_7 = 61.36$, %≤ 65.0;

Pasta properties:

– objective function

$21.0 \leq y_9 = 110.25 - 5.72 \cdot w - 2.71 \cdot \tau + 0.110 \cdot C_{i/o} \cdot w - 0.0997 \times C_{i/o} \tau + 0.252 \cdot w \cdot \tau$, units$\leq 71.0 \rightarrow$max;

– limitation of specific work on the test deformation:

$240 \leq y_{10} = 196.14 + 3.010 \cdot w$, $ea \leq 360$.

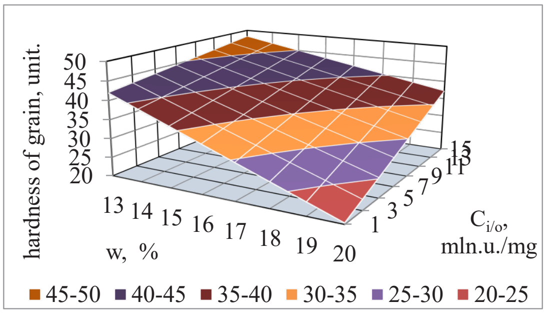
The safe modes of ion-ozone processing for various purposes, determined on the basis of the above mathematical models, are summarized in Table 3.

Table 3

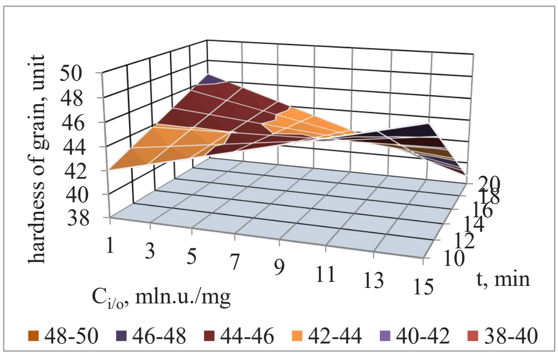
Optimal regimes and quality indicators of "Taza" triticale grain after ion-ozone treatment on device

Properties (designation) of grains	Processing Modes			Objective function	Quality indicators (limitations)
	$C_{i/o}$, mln. unit/mg	w, %	τ, min		
Physical	1	13	10	Y_3=1.127 g/cm^3	Y_1=13.62 %; Y_2=695 g/l; Y_4=53.75 g
Biochemical	1	13	10	Y_5=11.68 %	Y_6=20.68 %; Y_7=61.36 %;
Pasta	15	13	10	Y_9=48.05 unit	Y_{10}=235.3 ea
	1	20	10	Y_{10}=256.3 ea	Y_8=20.4 ml

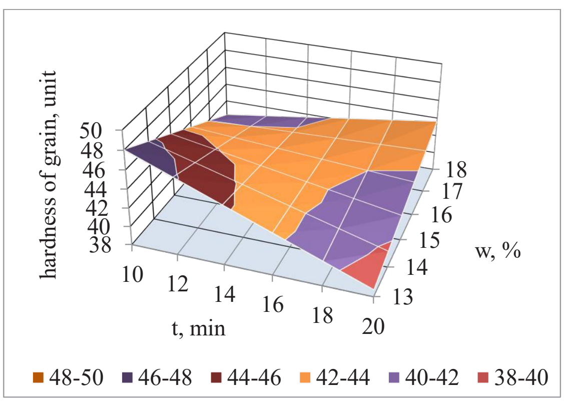
Fig. 1 shows the response surfaces of the target functions of "Taza" triticale examined, depending on the factors $C_{i/o}$, w and τ. The most difficult of them are the macaroni properties of grain – characterized by the dependencies of grain hardness on the factors $C_{i/o}$ and τ, as well as w and τ. Due to the significance of the pairwise interaction coefficients, the influence of each of these factors significantly depends on the values of the pairwise factor. Thus, an increase in the factor $C_{i/o}$ increases grain hardness only with minimum values of τ. At maximum, it leads to a decrease in grain hardness. The dependence of grain hardness on the factors $C_{i/o}$ and w has an unambiguous directly proportional character, an increase in $C_{i/o}$ and a decrease in w lead to an increase in grain hardness.



a



b



c

Fig. 3. Response surface of the dependencies of the studied objective functions of "Taza" triticale on the factors $C_{i/o}$, w and τ (the values of factors not taken into consideration are fixed at safe levels): *a* — dependence of grain hardness on the concentration of ion-ozone and humidity; *b* — dependence of grain hardness on treatment time and of ion-ozone concentration; *c* — dependence of grain hardness on humidity and processing time

The results of the influence of 2^4 ion-ozone cavitation treated "Taza" triticale on its technological properties and quality indicators of the control and processed triticale grains are given in Table 4.

When processing ion-ozone-cavitation flow mode X_1>1,000 u/mg, X_2=4.0 atm; X_3=13.0–20.0 %; X_4=20 minutes improves the physical properties of the dough, which also increases its pasta properties. The specific work of the deformation test is increased from 225.5 ea to 372.3 ea compared with the control sample. Such changes are associated with ion-ozone cavitation treatment regimes. With a decrease in the concentration of ions, an increase in the moisture content of the grain, a mass of 1000 grains, and the specific work of deformation are observed. At 10 min, the specific work of deformation and dough increases by 138.77 ea compared to the 20 minute. At the same time, a short processing time: within 10 minutes, preserves and improves the physical and biochemical properties of the dough made from the flour of "Taza" triticale grain.

The amount of protein and the density of dry grain during ion-ozone cavitation treatment did not change and remain on a par with samples of untreated grain, and the moist (20 %) of grain protein is restored after treatment. Ion-ozone-cavitation treatment of grain much increased the amount of wet gluten to 7.24–7.80 %, starch at 1.30–5.60 %, mass of 1,000 grains at 14.0–14.8 g comparing with control.

Restrictions on the range of changes in the processing parameters of all the studied crops were as follows:

1 million units/mg$\leq C_{i/o}\leq$15 million units/mg; 1 atm ≤4 atm.

13 % $\leq w \leq$20 %; 10 min $\leq \tau \leq$20 min.

Taking into account the permissible ranges of the studied factors ($C_{i/o}$, P, w and τ), the mathematical models for safe ion-ozone-cavitation treatment modes for triticale of "Taza" variety are presented below.

Physical properties:

– objective function

$1.0\leq y_1=1.431-0.0198\cdot w$, g/cm$^3\leq 1.28\to$max;

– restrictions on quality indicators:

$11.0\leq y_1=-0.197C_{i/o}+1.100\cdot w+0.0149C_{i/o}\cdot\tau-0.00911\cdot w\cdot\tau$, %≤22.0;

$650\leq y_2=887.4-14.8\cdot w$, g/l≤800;

$30.0\leq y_4=43.04+0.786\cdot w$, g≤60.0;

Biochemical properties:

– objective function

$11.0\leq y_5=14.51-0.205\cdot w$, %≤15.5→ *max*;

– restrictions on quality indicators:

$19.0\leq y_6=20.54+0.185\cdot P$, %≤30.0;

$58.0\leq y_7=61.57$, %≤65.0;

Pasta properties:

– objective function

$21.0\leq y_9=80.06+9.15\cdot P-3.72\cdot w+0.701\cdot\tau-0.167C_{i/o}\cdot P+0.242P\cdot w-0.292\cdot P\cdot\tau$, units≤71.0→max;

– limitation of specific work on the test deformation:

$240\leq y_{10}=111.61-5.66\cdot C_{i/o}+6.03\cdot P+12.57\cdot w-3.97\cdot\tau+0.407\cdot C_{i/o}\cdot\tau$, %≤360.

Summary data on the optimization of ion-ozone-cavitation treatment modes and the resulting grain quality indicators for "Taza" triticale are given in Table 5.

Table 5 shows that to improve all the properties of triticale, the treatment should be carried out for 10 minutes at $C_{i/o}$=1 million units/mg and grain moisture 13 %.

Table 4

Conditions and results of FFE-2^4 experiments on ion-ozone-cavitation treatment of "Taza" triticale

Experiment No.	Ratio of ion concentrations to ozone, million units/mg ($C_{i/o}$)	Excess pressure (cavitation), atm (P)	Humidity before treatment,% (w)	Processing time, min (τ)	Technological properties									
					Physical				Biochemical				Pasta	
					Humidity after proecessing,%	Nature, g/l	Density, g/cm^3	Weight of 1000 grains, g	Mass fraction of protein%	Raw gluten,%	Starch, %	Green's index, ml	Hardness, units	Specific work of deformation test, ea
	Experimental conditions				Quality indicators									
	X_1	X_2	X_3	X_4	Y_1	Y_2	Y_3	Y_4	Y_5	Y_6	Y_7	Y_8	Y_9	Y_{10}
1	15	4	20	20	21.8	570	1	61	9.17	21.9	60.89	18.8	18.4	371.5
2	1	4	20	20	17.8	602	1.05	56	10.91	20.2	62.40	21.6	11.2	273.5
3	15	1	20	20	18.9	591	1.05	57	9.94	20.3	59.18	17.3	32.3	331.8
4	1	1	20	20	17.6	610	1.03	56	11.50	21.2	61.90	23.5	21.9	279.2
5	15	4	13	20	12.9	695	1.25	57	11.77	20.3	62.36	17.8	47.6	226.8
6	1	4	13	20	12.9	696	1.16	56	12.22	22.1	61.81	29.9	52.0	250.7
7	15	1	13	20	12.9	695	1.12	53	11.80	20.9	62.20	22.1	49.3	237.3
8	1	1	13	20	12.9	696	1.14	52	11.84	20.5	62.19	23.9	50.6	225.0
9	15	4	20	10	19.8	586	1.05	60	10.33	21.6	60.51	22.5	21.6	334.3
10	1	4	20	10	20.6	579	1.0	62	10.25	22.4	59.93	25.7	28.5	372.3
11	15	1	20	10	17.8	603	1.06	57	11.10	20.5	61.64	18.8	28.3	286.6
12	1	1	20	10	20.5	590	1.04	61	10.08	20.8	60.90	18.9	14.6	327.4
13	15	4	13	10	12.9	698	1.18	50	11.77	20.8	62.24	23.2	51.4	230.9
14	1	4	13	10	13,1	697	1.18	51	11.90	20.8	62.20	22.1	46.7	236.7
15	15	1	13	10	13.1	689	1.18	53	11.75	20.4	62.23	24.4	48.3	230.2
16	1	1	13	10	12.5	694	1.18	54	11.70	21.1	62.59	23.4	46.2	234.7

Table 5

Optimal regimes and quality indicators of "Taza" triticale grain after ion-ozone-cavitation treatment

Properties (designation) of grains	Treatment modes				Objective function	Quality indicators (limitations)
	$C_{i/o}$, mln . unit/mg	P, atm	w, %	τ, min		
Physical	1	1	13	10	Y_3=1.17 g/cm^3	Y_1=32.07 % Y_2=695 g/l; Y_4=53.25 g
Biochemical	1	1	13	10	Y_5=11.84 %	Y_6=20.72 % Y_7=61.57 %;
Pasta	15	1	13	20	Y_9=53.2 unit	Y_{10}=238.8 ea
	1	4	20	10	Y_{10}=345.8 ea	Y_8=21.4 ml

Graphic dependences of the studied objective functions on the factors $C_{i/o}$, P, w and τ are shown in Fig. 2. It is possible to note the contradictory nature of the dependencies for the grain hardness on $C_{i/o}$–P and P–τ, as well as the specific work of the deformation of the test on $C_{i/o}$–τ.

With a pressure of 4 atm, the effect of treatment duration on the objective functions has the dependence of grain hardness on the joint interaction of $C_{i/o}$–P and P–τ. And the influence of the factors $C_{i/o}$ and w, as well as w and P on grain hardness is unambiguous. With increasing $C_{i/o}$ and P, an increase in the moisture content of the grain reduces grain hardness.

For comparison, the quality indicators of the control (not processed) samples and the safe indicators obtained after their ion-ozone (IO) and ion-ozone-cavitation (IOC) processing are presented in Table 6.

Table 6 shows apparently the safest, ion-ozone and ion-ozone-cavitation processes for the deteceable physical, biochemical properties of proteins. For macaroni products, they are distinguished by grain moisture. Suspicious modes resulted from the treatment of the submerged grain (20 %). For physicochemical, biochemical, pasta properties, the best results are obtained from the treatment of silicon (13 %).

Table 6

Summary of the optimal quality parameters and triticale after ion-ozone and ion-ozone-cavitation treatment in comparison with control (unprocessed) samples

Indicators	"Taza" triticale			
	IO		IOC	
	Optimum	Control	Optimum	Control
	Physical properties			
Y_1, %	13.62	–	32.07	–
Y_2, g/l	695	687	695	687
Y_3, g/cm^3	1.127	1.16	1.17	1.16
Y_4, g	53.75	50	53.25	50
	Biochemical properties			
Y_5, %	11.68	11.82	11.84	11.82
Y_6, %	20.68	20.59	20.72	20.59
Y_7, %	61.36	61.78	61.57	61.78
Y_8, ml	20.4	57.24	21.4	57.24
	Pasta properties			
Y_9, unit	48.05	45.76	53.2	45.76
Y_{10}, ea	256.3	408.9	345.8	408.9

We found the optimum modes for the processing of the triticale technology used for the production of macaroni by processing through the ion-ozone and ion-ozone-cavitation equipment. Further, the triticale cultures, which had the highest yield in all their properties, were molded using a single-rotary eight-row disintegrator DPO-320-7.8.

The degree of grain grinding in this device is adjusted by changing the rotor speed, and grinding is carried out from the largest to the smallest particles. The granulometric composition of powdered flour particles at 20 and 50 Hz with the disintegrator is shown in Fig. 5.

The size of the charged particle was 204 μm at 50 Hz and 309 μm at 20 Hz. High flour granules (pellets) do not fully absorb moisture when they are paste and retain their original shape when compressed. Granulometric composition of flour affects its moisture absorption capacity, which is why it is tight and smooth with its strength to the physical properties of the dough. According to the requirements of the applicable GOST 2306-66 and 12307-66, the top slab of macaroni flour should be 250–530 μm.

The flour received this requirement and prepared macaroni, including 20 % of triticale flour for wheat flour. The reason for 20 % of the triticale mixture is that research has revealed that the rheological properties of macaroni are of high significance and are well-preserved. The good quality of macaroni products, first of all, depends on the rheological properties of the pastry. Durability and deformation characteristics of dry macaroni products are one of the most important indicators of their quality. Fig. 6 illustrates the effect of ion-ozone cavitation on the wheat flour and the triticale treated without the cavitation on macaroni strength.

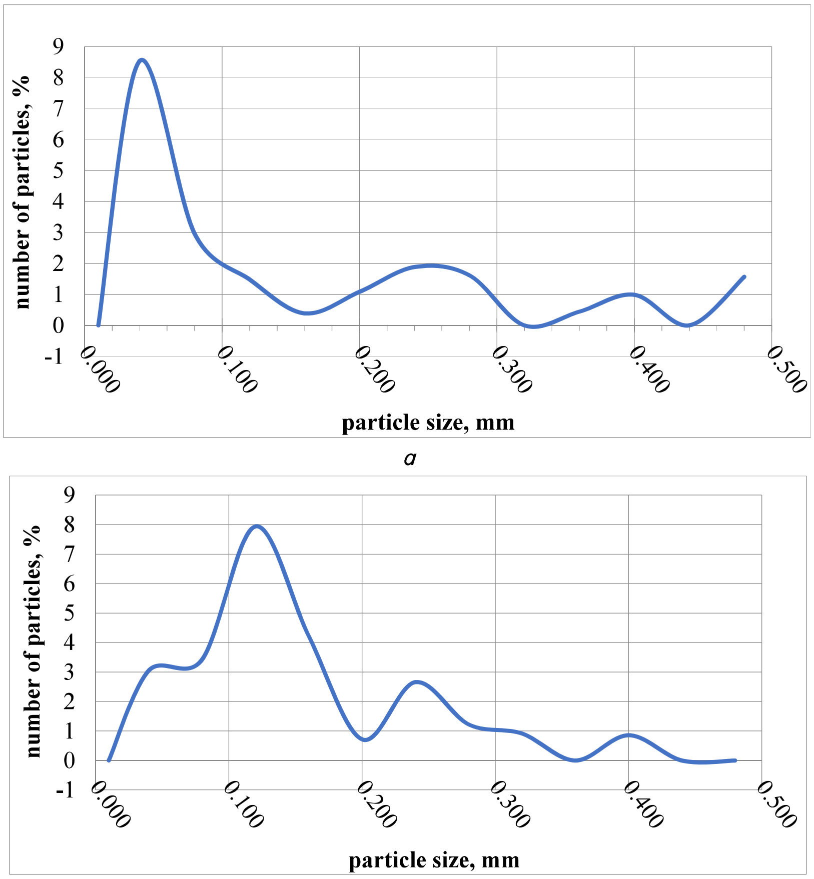


Fig. 5. Particle size distribution of the crushed flour at various frequencies: *a* — 20 Hz, *b* — 50 Hz

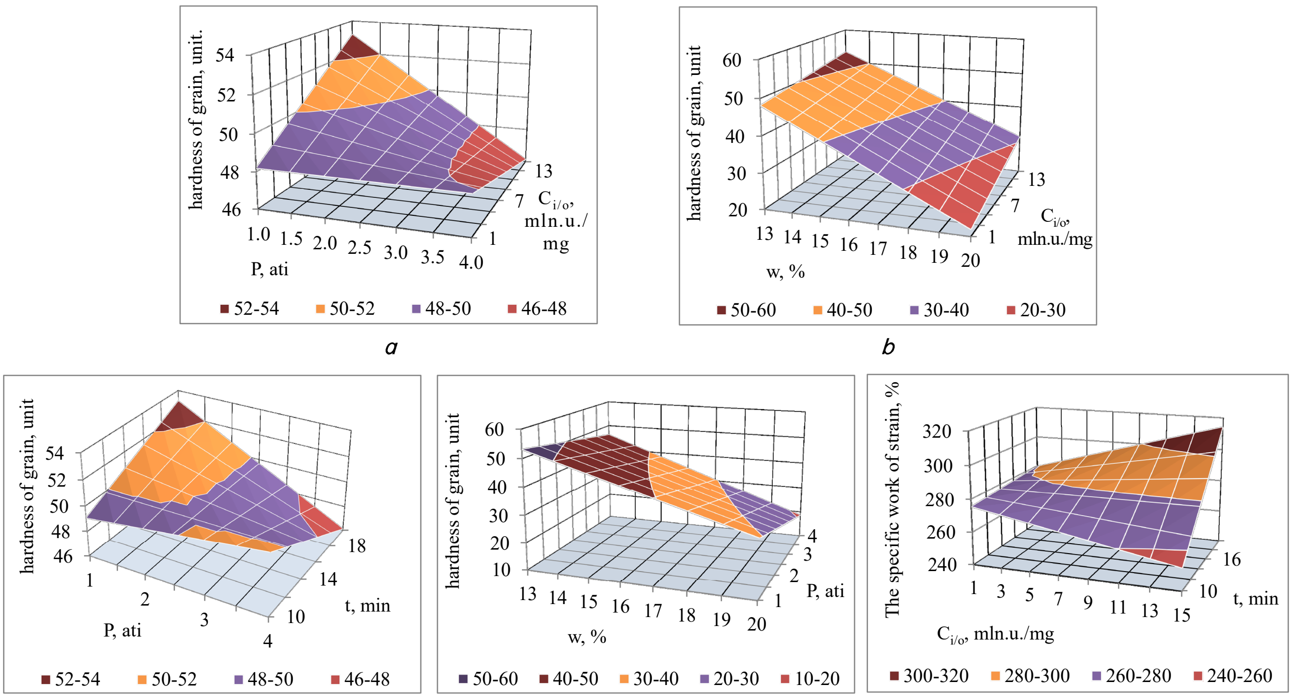


Fig. 4. Response surface of the dependencies of the studied objective functions of "Taza" triticale on the factors $C_{i/o}$, *P*, *w* and τ (the values of factors not taken into consideration are fixed at safe levels): *a* — dependence of grain hardness on ion-ozone concentration and cavitation pressure; *b* — dependence of grain hardness on ion-ozone concentration and humidity; *c* — dependence grain hardness on the processing time and cavitation pressure; *d* — dependence of grain hardness on cavitation pressure and humidity; *e* — dependence of the specific work of deformation on processing time and ion-ozone concentration

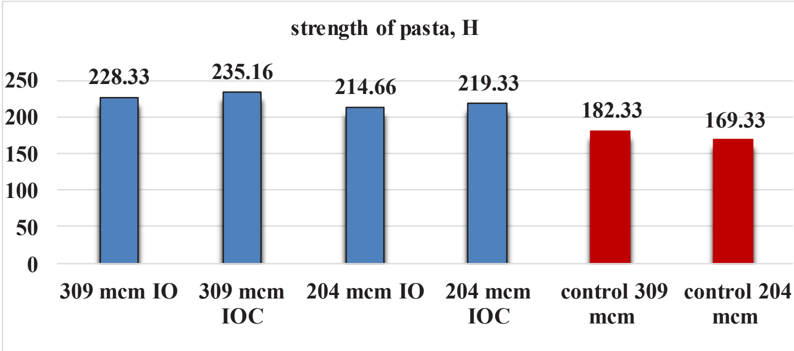


Fig. 6. Influence of ionized and ion exchange cavitated triticale mixture on pasta strength

The diagram illustrates the difference in the strength of macaroni products, prepared in 80 % of wheat flour, with ion-ozone (IO) and 20 % triticale ion-ozone cavitation (IOC). The results of the research show that the strength of macaroni depends on the size of the flour particles. When using triticale treated with ion-ozone cavitation at 309 µm powder of flour, macaroni has a maximum value of 235.16 N. Accordingly, the same change in powdered flour at 204 µm is equivalent to 219.33 N. Control samples are made from the initial crop flour that has not been processed. Compared to the results obtained, the quality of pasta was observed when using flour, processed by ion-ozone cavitation at 309 µm by size of flour particles.

6. Discussion of the results of studies on grain preparation for processing

Reliable scientific results were obtained on determining the influence of the ion-ozone and ion-ozone cavitation processing separately on the physico-biochemical and on some indicators of the pasta properties of triticale. Such a change occurs due to the penetration of the molecules of oxygen ions and ozone into the cells of triticale grains. This leads to the activation of biological processes in them, which is reflected in the improvement of properties and on the general condition of triticale grain. It can be noted here that the more intense the interaction with ionic molecules, the stronger the effect on the physico-biochemical properties. This method of grain processing by ion-ozone flow was created by us for the first time and differs significantly from other electrophysical effects in its physical essence. The agent of ion-ozone flux is atmospheric air and their special parameters are produced and regulated by a special generator. Flows affect objects in full. Their intensity depends on the power of the source and the amount of pressure for feeding into the grain mass.

It is necessary to develop experimental pilot plants that allow working in real conditions to establish reliable test results for further practical implementation. This enables the creation of industrial designs of an ion-ozonation unit with computer controls during their operation [23].

The disadvantages of this study are that such an aggregate has not been created, which work universally for different branches of the food and processing industry of the agro-industrial complex. We first created an environmentally friendly unit that improves the food safety of products and environmental protection. There is scientific and technical documentation for the full implementation of the tasks for their use in enterprises.

At the present time, there are many problem, food and grain processing enterprises to improve the quality and safety of products, the destruction of pests, microorganisms during long-term storage. Ion-ozone technology provides solutions to such problematic issues.

7. Conclusions

1. Ion-ozone and ion-ozone-cavitation treatment of triticale improves the technological properties in general. Biochemical properties remain particularly stable and physical and pasta properties undergo slight changes. The analysis of the obtained results also showed that the ratio of ion concentration to ozone concentration for practically all processing regimes is 1 mln. unit/mg. The exception is the pasta properties of "Taza" triticale (IO, IOC), for which 15 mln. unit/mg.

The cavitation pressure and treatment duration for different properties affect differently. Improving the technological quality of triticale grains based on bioenergy impact is of current importance in improving the nutritional value and environmental safety of processed products.

2. Regression equations describing changes in the technological indicators of the quality of the properties of "Taza" triticale in ion-ozone and ion-ozone-cavitation preparation of grain are developed and calculated.

3. Based on the above compiled linear and nonlinear programming of mathematical models, safe processing modes are determined. Safe levels of triticale quality indicators after treatment with the ion-ozone and ion-ozone-cavitation equipment, which makes it possible to obtain improved qualities of pasta are also summarized. That is, for grain hardness the safe optimum is 48.05 units. (IO) and 53.2 units. (IOC), for specific work of deformation test –256.3 ea (IO) and 345.8 ea (IOC).

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