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The efficiency of ionocavitational processing and storage in the nitrogen medium of oilseeds

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Abstract. The efficiency of ionocavitational processing and storage in the nitrogen medium is studied, and mathematical modeling calculations are also presented. In the course of the work, physico-chemical and physiological-biochemical indices of flax varieties "Kustanai amber" were determined. As a result of the study, it was proved that ionocavitational processing of flax seeds "Kustanai amber" and storage in the medium of pure nitrogen can ensure, by reducing the intensity of its breathing during storage, the minimum natural loss of solids and the necessary indicators of seed quality.

Key words. Control sample, ion processing, cavitation, storage, flax, oilseeds.

1. Introduction

Oilseed crops are diverse in the plant kingdom and belong to several families. Some oilseed crops are used as food for humans and feed for animals. They have been characterized based on their edible and industrial uses. Vegetable oils are also used by industries for producing pharmaceutical products: soap, varnishes, paints, putty, printing inks, erasers, coating, plastics, and greases. Linseed oil is used in protective coatings. Thus, oilseeds, oils/fats, and oil cake/meal play an important role in foreign exchange earnings [1]. The increased moisture content and temperature are the starting factors of physico-chemical and biochemical processes, accompanied by exothermic processes, which ensure the overcoming of the activation barrier by the grain mass in adjacent areas [2–4]. The intensity of all processes in the grain

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mass depends mainly on the same factors: humidity, grain temperature and the environment, air access. Storage of grain mass in the regulated gas environment inhibits the development of microflora, reduces the intensity of respiratory gas exchange, and prolongs the shelf life [5].

2. Method

Experimental studies were carried out in accordance with the plan of full-factor experiments at room temperature 18–23 °C. The influence of certain factors on the storage processes of oilseeds, including flax "Kustanai amber", has been established. Physico-chemical and physiological-biochemical indicators were determined according to established methods: the mass fraction of moisture was determined according to GOST 10856-96, the mass fraction of fat was determined in accordance with GOST 29033-91 and GOST 10857-64. The acid number of oilseeds was determined from 10844-74, the germination was determined in accordance with GOST R 51410-99 (ISO 729-88). The intensity of respiration was measured with a gas analyzer of carbon dioxide PKU-4 [6]. Among the indicators that assess the condition of each batch of grain during storage, include: temperature, humidity, impurity content, pest infestation and freshness of the grain (odor and color), and in batches of barley grain additionally check its viability, germination energy and germination capacity. Correctly organized control over the quality and state of the grain during storage makes it possible to prevent all undesirable processes occurring in the grain mass in a timely manner and to bring the grain to a stable state with minimal costs and realize it without losses [7–8]. During the storage of oilseeds, significant changes occur in the chemical composition of the seeds. Firstly, it concerns the lipid complex (fat hydrolysis, increase of acid number, etc.) and other compounds (proteins, carbohydrates, etc.). The most intensive processes of deterioration of seed quality occur in the case of intensive development of microorganisms, for which a high fat content is a favorable nutrient medium. To reduce or avoid the intensive development of microflora is possible only by rapid cooling of the batch and by maintaining the preset storage regime.

In the laboratories of research institutes of the Almaty Technological University, laboratory studies of physico-chemical and physiological-biochemical indicators were performed, which change during the storage of oilseeds. According to the plan of full-factor experiments, we determined the influence of conditions and individual factors on changes in physico-chemical and physiological-biochemical indicators and on the safety of flax varieties "Kustanai amber". The quality indices of the control (not processed) flax samples of the variety "Kustanai amber" are given in Table 1. The experimental planning matrix with the experimental conditions and the results of determining the quality indicators of the treated crops are given in Tables 2 and 3. The regression equations obtained on the basis of processing the results of the experiments are given below in the corresponding mathematical models used in optimizing the processing regimes of the cultures studied. All the equations obtained adequately describe the experimental data.

Table 1.Results of experiments of flax control samples "Kustanai amber"

Samples	Indicators of function						
	Germination (%)	Respiration of CO_2, vol. (%)	Intensity of respiration mg of CO_2 per 100 g of dry matter in 24 h	Humidity before processing (%)	Nature (g/l)	Fat (%)	Acid number (mg KOH/g)
	y_1	y_2	y_3	y_4	y_5	y_6	y_7
Flax humidity 8.09 %	87	0.06	8.98	8.09	666	37.6	2.06
Flax humidity 13.44 %	36	1.10	27.64	13.44	613	32.42	16.29

When storing oilseeds, it is necessary to reduce their natural losses, which directly depend on the intensity of the respiration of the grain (seeds), on which their dry substances are expended. Therefore, the respiratory rate (function y_3), which depends nonlinearly on the investigated factors of exposure (different for each culture and method of processing), and which should be minimized, was chosen as the objective function of the evaluation criteria of efficiency for ionocavitational processing. As a limitation for processed oilseed crops, the following criteria and ranges of their variation (limitations) were chosen:

–germination, y_1 (80–100 %); CO_2 release during respiration, y_2 (0–1.10); humidity after processing, y_4 (7–14 %); acid number of fat, y_7 (1–4 mg KOH/g).

Such criteria for assessing the quality of the studied crops as nature (y_5) and the mass fraction of fat (y_6) were not included due to their insignificant change in the processing of grain and seeds.

Calculations of the coefficients were carried out with respect to matrices in natural dimension, and accordingly the equations were also obtained in natural dimension. This is why, after recalculating the remaining significant coefficients, both the values of the coefficients themselves and their confidence errors change.

The general form of equations for 4 factors:

$$y = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + b_{12}x_1x_2 + b_{13}x_1x_3 + b_{14}x_1x_4 + b_{23}x_2x_3 + \\ + b_{24}x_2x_4 + b_{34}x_3x_4 \,.$$

In the equations, the factors are designated in natural notation, since x_1 denotes the coded values of the factors. Then the equation has this form:

$$y = b_0 + b_1C + b_2P + b_3w + b_4\tau + b_{12}CP + b_{13}Cw + b_{14}C\tau + b_{23}Pw + b_{24}P\tau + b_{34}w\tau \,.$$

The legend of the equations in the tables is as follows: C is the concentration of ions, (unit/cm^3), P denotes the excessive pressure (atm), w stands for the humidity content of samples (%), τ represents the processing time (min) and τ_1 is the processing time with nitrogen (min).

Table 2. Conditions and results of full-factor experiments of PFE-2^4 on ionic cavitation processing of flax "Kustanai amber"

Concentration of the ion $C_i \times 10^3$ (units/cm^3)	Overpressure (cavitation) (ati)	Humidity of samples before processing (%)	Processing time (min)	Germination (%)	Respiration of CO_2 (vol. %)	Intensity of respiration (mg of CO_2 per 100 g of dry matter in 24 hours)	Actual humidity after processing (%)	Nature (g/l)	Fat (%)	Acid number (mg KOH/g)
Factors x_i				Changes of indices after processing						
x_1	x_2	x_3	x_4	y_1	y_2	y_3	y_4	y_5	y_6	y_7
60	4	13	20	63	1.1	16.16	13.19	621	32.22	14.4
0.5	4	13	20	46	1.1	18.39	13.26	620	32.67	17.65
60	4	8	20	100	0.04	5.08	8.00	673	37.93	2.05
0.5	4	8	20	98	0.04	8.67	8.01	671	37.41	1.81
60	4	13	10	65	1.1	15.86	13.33	614	32.83	14.32
0.5	4	13	10	63	1.1	18.39	13.28	619	32.62	15.24
60	4	8	10	98	0.04	8.67	8.04	670	37.49	1.62
0.5	4	8	10	93	0.04	27.52	8.08	669	37.66	1.04
60	1	13	20	67	1.1	24.69	13.14	623	32.84	13.74
0.5	1	13	20	60	1.1	49.83	13.35	612	32.94	12.67
60	1	8	20	84	0.04	11.66	8.04	671	37.65	1.64
0.5	1	8	20	83	0.04	8.67	8.04	670	37.41	1.59
60	1	13	10	68	1.1	17.14	13.36	613	32.96	16.94
0.5	1	13	10	53	1.1	17.75	13.26	618	32.41	14.82
60	1	8	10	86	0.05	14.06	8.10	668	37.21	1.96
0.5	1	8	10	77	0.04	24.52	8.03	671	37.10	1.74

Table 2. Conditions and results of full-factor experiments of PFE-2^4 on ionic cavitation processing of flax "Kustanai amber" in a medium of pure nitrogen

Concentration of the ion $C_i \times 10^3$ (units/cm^3)	Overpressure (cavitation) (ati)	Humidity of samples before processing (%)	Processing time (min)	Processing time with nitrogen (min)	Germination (%)	Respiration of CO_2 (vol. %)	Intensity of respiration (mg of CO_2 per 100 g of dry matter in 24 hours)	Actual humidity after processing (%)	Nature (g/l)	Fat (%)	Acid number (mg KOH/g)
Factors and conditions of experiments					Quality indicators of flax after processing						
x_1	x_2	x_3	x_4	x_5	y_1	y_2	y_3	y_4	y_5	y_6	y_7
60	4	13	20	15	78	0.46	11.40	13.12	621	32.71	7.99
0.5	4	13	20	15	62	1.04	9.90	13.24	621	32.62	7.60
60	4	8	20	15	100	0.02	6.88	8.03	672	37.98	1.34
0.5	4	8	20	15	100	0.03	1.50	8.04	671	37.36	1.01
60	4	13	10	15	76	0.58	14.92	13.36	614	32.48	8.10
0.5	4	13	10	15	69	1.10	7.93	13.24	620	32.65	7.68
60	4	8	10	15	85	0.02	5.98	8.08	670	37.12	1.14
0.5	4	8	10	15	93	0.03	11.97	8.04	669	38.01	1.07
60	1	13	20	15	49	0.94	7.28	13.18	622	32.46	7.94
0.5	1	13	20	15	56	1.06	14.60	13.39	612	32.71	8.03
60	1	8	20	15	100	0.03	15.25	8.01	670	38.06	1.22
0.5	1	8	20	15	100	0.03	12.56	8.05	670	37.84	1.09
60	1	13	10	15	67	1.10	15.87	13.37	613	31.88	7.84
0.5	1	13	10	15	69	0.46	16.80	13.21	619	32.13	7.96
60	1	8	10	15	100	0.02	17.36	8.16	668	37.61	1.33
60	1	13	10	5	82	0.26	18.09	13.36	615	32.68	8.06
0.5	1	13	10	5	91	1.10	16.18	13.31	620	32.16	7.94

The obtained processing regimes minimize the intensity of respiration of flax seeds, which after processing under optimum conditions is 0.806 mg CO_2 per 100 g dry matter in 24 hours, and at the same time ensure the basic quality indicators: –germination 97.17 %, –CO_2 release during breathing 0.046 vol. %, –actual humidity after processing 8.14 %; –acid number of fat 1.92 mg KOH/g.

Thus, ionocavitational processing of flax seeds "Kustanai amber" in the ordinary air environment can ensure, by reducing the intensity of its breathing during storage, the minimum natural loss of solids and the necessary indicators of seed quality. Figure 1 shows the complex nature of the dependence of the objective function (respiration intensity) on the factors influencing it $-P$, w and τ_1, confirming the obtained optimization results.

As can be seen from the analysis of the joint effect on the respiration intensity of the factors w and τ_1 (at a pressure $P^{\text{opt}} = 4$ atm), the lowest respiratory intensity, equal to 0.806 mg of CO_2 per 100 g of d.m., is observed in dry flax seeds $w = 8\%$, processed under pressure for 20 minutes.

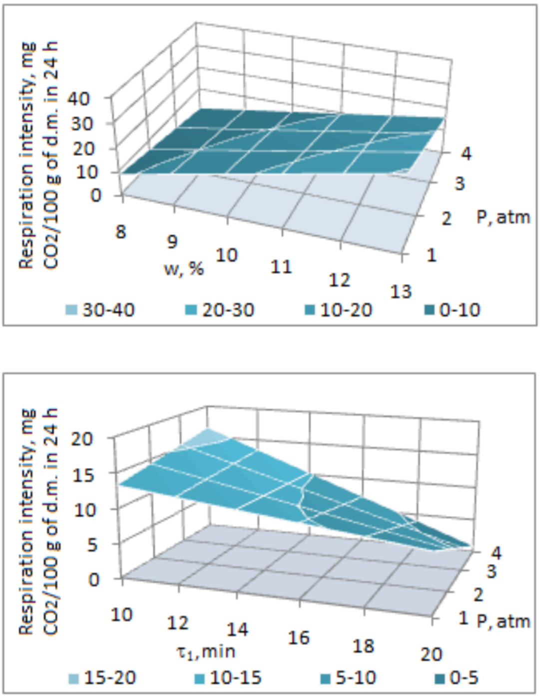

Fig. 1. Surfaces of the response depending on the respiration intensity of flax seeds "Kustanai amber" from the factors P, w and τ_1

The mathematical model for optimization regime of ionocavitation processing of flax seeds in a pure nitrogen environment is as follows:

$$y_3 = 19.78 - 0.494 \times 10^4 C_i - 2.11P - 0.279\tau_2 + 0.467 \times 10^5 C_i \tau_2 +$$

$$+0.148Pw - 0.0955P\tau_1 \text{ mg } CO_2/100\,\text{g d. m.} \to \min\,,$$

Limitations on indicators of the quality of flax is

$$80\,\% \le y_1 = 139.71 - 5.36w \le 100\,\%,\ 0 \le y_2 = -1.32 + 0.168w \le 1.1\,vol.\,\%\,,$$

$$7\,\% \le y_4 = 1.018w \le 14\,\%\,,$$

$$0.5 \cdot 4\,\mathrm{mg\,KOH/g} \le y_7 = -9.73 + 0.063P + 1.36w - 0.00607P\tau_2 \le 4\,\mathrm{mg\,KOH/g}\,.$$

Limitations on the range of changing the regime parameters of processing are

$$0.5 \cdot 10^3\ \mathrm{units/cm}^3 \le C_i \le 60 \cdot 10^3\ \mathrm{units/cm}^3,\ 1\,\mathrm{atm} \le P \le 4\,\mathrm{atm}\,,$$

$$8\,\% \le w \le 13\,\%,\ 10\,\mathrm{min} \le \tau_1 \le 20\,\mathrm{min},\ 5\,\mathrm{min} \le \tau_2 \le 15\,\mathrm{min}\,.$$

Using the obtained mathematical model, by the nonlinear programming method was determined the optimum regimes of ionocavitation processing of flax "Kustanai amber" in a medium of pure nitrogen: $C_i^{\mathrm{opt}} = 0.5 \times 10^3\,\mathrm{units/cm}^3$, $P^{\mathrm{opt}} = 4\,\mathrm{atm}$, $w^{\mathrm{opt}} = 8\,\%$, $\tau_1^{\mathrm{opt}} = 20\,\mathrm{min}$ and $\tau_2^{\mathrm{opt}} = 15\,\mathrm{min}$.

Thus, ionocavitational processing of flax seeds "Kustanai amber" in a pure nitrogen environment can ensure, by reducing the intensity of its respiration during storage, the minimum natural loss of solids and the necessary indicators of seed quality. Figure 2 shows the complex nature of the dependence of the objective function (respiration intensity) on the factors influencing it - C_i, P, w, τ_1 and τ_2, which confirms the obtained optimization results.

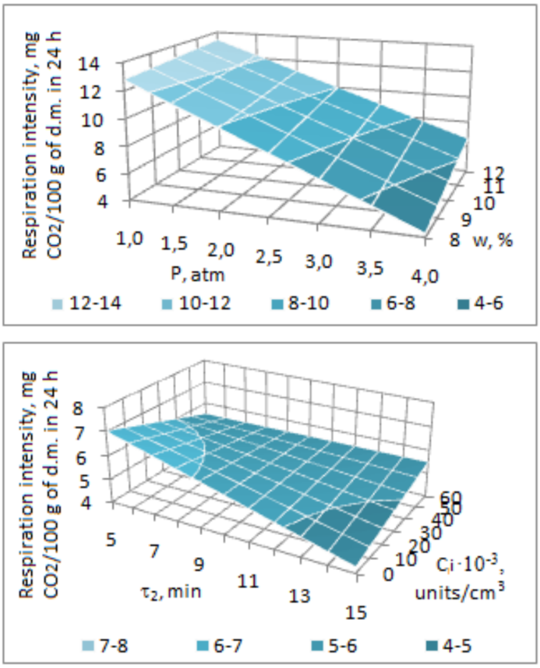

Fig. 2. Surfaces of the response depending on the respiration intensity of flax seeds "Kustanai amber" from the factors C, P, w, τ_1 and τ_2

Based on the optimization carried out, the methods and regimes of ionocavitational processing of oilseed crops in the usual air medium and pure nitrogen environment were determined, which allow to minimize the intensity of their respiration and, as a consequence, to reduce the natural loss of solids during storage. The obtained optimal results are summarized in Tables 4–5.

An even more striking effect is obtained by ionocavitational processing of oilseed crops in the conditions of the usual air environment (Table 4). In treated cultures, the intensity of respiration is slowed by 2.20–11.14 times in comparison with the control. All indicators of the quality of oilseeds have also improved.

Table 4. Optimum regimes and quality indices of flax "Kustanai amber", which has undergone ionocavitation processing under normal air conditions

Crop	Optimal processing modes				Opt. values of quality indicators after processing				
	$C_i \cdot 10^3$ (units /cm^3)	P (atm)	w (%)	τ_1 (min)	y_1 (%)	y_2 (vol. %)	y_3 (mg CO_2/100 g d. m. for 24 h)	y_4 (%)	y_7 (deg)
processed	60	4	8	20	97.17	0.046	0.806	8.14	1.92
control, $w = 8.09$ %	–	–	–	–	87	0.06	8.98	–	2.06

Comparative analysis of the results of processing of oilseeds in a pure nitrogen environment (Table 5) showed the following: the intensity of respiration of treated oilseed crops, as well as during processing in ordinary air, is higher, by 2.11–2.27 times. The acid number of fat in oilseeds with optimal processing conditions in a nitrogen medium (Table 5) is reduced almost twice (by 43–1.98 %).

Table 4. Optimum regimes and quality indices of flax "Kustanai amber", which has undergone ionocavitation processing under normal air conditions

Crop	Optimal processing modes					Opt. values of quality indicators after processing				
	$C_i \cdot 10^3$ (units /cm^3)	P (atm)	w (%)	τ_1 (min)	τ_2 (min)	y_1 (%)	y_2 (vol. %)	y_3 (mg CO_2/100 g d. m. for 24 h)	y_4 (%)	y_7 (deg)
processed	0.5	4	8	20	15	96.83	0.028	4.26	8.14	1.04
control, $w = 8.09$ %	–	–	–	–	–	87	0.06	8.98	–	2.06

In all processing options, the acid number of fat decreased. We also emphasize that with all processing options, the best effect is observed for dry crops. The moisture content of grain and seeds after processing is practically unchanged. The oilseed crops processed under optimal conditions were laid for long-term storage, during which their condition was monitored. The results showed that the best preservation was observed for oilseeds that had undergone ionocavitational processing and were stored in a pure nitrogen medium.

3. Conclusion

We have determined the effects of conditions and individual factors on changes in physico-chemical, physiological-biochemical indicators and the preservation of oilseeds. Oilseeds were processed with ionocavitational flows. Then they were delivered to a modular granary, to study the effect of nitrogen. As a result of the study, it was determined that for cultivated oilseed crops ionocavitational flows and further storage in a nitrogen medium is more effective. When stored in the nitrogenous environment of oilseed crops, the state of the grain in terms of moisture mainly affects the germination, respiration intensity, acid number and other indicators. During the study of oilseeds, treated with ionocavitational flows and further storage in a nitrogenous environment, showed better results than those not stored in a nitrogen medium. Optimal variants of processing and storage modes were established as a result of solving linear and nonlinear mathematical modeling, which were used to obtain the data of 2^4 and 2^5 full-factor experiments.

1. Under the conditions of ordinary air and in pure nitrogen environment, optimal processing regimes allow to reduce the intensity of respiration and the acid number of fat, which leads to an improvement in the state of oilseeds during storage.

2. To ensure long-term storage of flax seeds, ionocavitational processing and storage in pure nitrogen environment showed better results than storage in usual air and with control samples.

3. Under conditions of ionocavitational processing and storage in the environment of pure nitrogen of oilseed crops, the terms of safe storage increase.

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