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Efficient mathematical models of ion-ozon cavitation treatment for long-term storage of grain legume crops

Auyelbek Iztayev[1], Madina Yakiyayeva[1,5], Talgat Kulazhanov[1], Maigul Kizatova[1], Meles Maemerov[1], Georgii Stankevych[2], Botagoz Toxanbayeva[3], Zhanar Chakanova[4]

Abstract. The efficiency of ion-ozone cavitation treatment during long-term storage of legumes has been studied. Mathematical models of ion-ozone treatment cavitation efficiency have been developed. As a result of the study, it was proved that ion-ozon cavitation treatment of grain legume crops seeds of pea and chickpea beneficially affects the improvement of seed properties, and the germination of pea and chickpea varieties rises to 100 %, i.e. germination increases compared to the control sample from 10 % to 17 %. After ion-ozone cavitation treatment, the physico-biochemical properties are more stabilized, breathing fluctuates in one range, and the process of mold formation also decreases. All these changes lead to a steady state of storage.

Key words. Control sample, ion-ozone treatment, cavitation, storage, leguminous plants, peas, chick-pea.

1. Introduction

Legumes such as soybean, peas, field beans, and peanuts produce seeds that are naturally high in protein. These protein crops are an important source of protein in

[1]Almaty Technological University, Tole bi, 100, Almaty, Kazakhstan, 050012
[2]Odessa National Academy of Food Technologies, Kanatnaye Str., 112, Odessa, Ukraine, 65039
[3]Kazakh Scientific Research Institute of Mechanization and Electrification of Agriculture, Almaty, Kazakhstan, 050005
[4]Kazakh Scientific Research Institute of agricultural products treatment, Astana, Kazakhstan, 010000
[5]Corresponding author; e-mail: `yamadina88@mail.ru`

many parts of the world. Nonlegumes can also be used for seed protein production and include quinoa, cotton, and sunflowers. Many crop species produce oil-rich seeds that can be processed for their oil. Oil crops produce oils that contain fatty acids that vary in saturation. Oil crops include soybean, flax, sunflowers, canola, peanuts, and cotton. Soybean accounts for half of edible oil production [1–2]. Some of our most valuable food crops—peas, beans, peanuts and soybeans—are legumes that produce high protein grains for human consumption. Although considerable resources have been directed towards developing grasses, such as rice (whose full genome sequence is available), maize (whose genome is currently being sequenced), and wheat, only peanuts and soybeans within the legumes have been as thoroughly examined. Our increasing population and the concomitant need to adequately feed people to prevent particular health problems will necessitate a larger dietary contribution from legumes [3]. The ability to store wet grain without losses prompts us to look for new ways and technologies of storage, including using advanced foreign experience. One of the methods is storage of grain without air access. The physiological and biochemical foundations of grain storage have been developed for a long time. It is known that the need in oxygen by the majority of grain mass living components allows it to be preserved by isolation from atmospheric air or in a special oxygen-free environment. The absence of oxygen in intergranular spaces and over the grain mass significantly reduces the intensity of the breathing [4, 5].

2. Method

The storage of legumes has received considerable attention, particularly because of the potential for immense loss of food through biological aging in addition to microbial, insect, and rodent infestation. Physical factors such as moisture, temperature, and oxygen concentration affect the rates of deterioration and infestation. The amount of water in the seeds and the environment seems to play the dominant role in determining the rate of seed deterioration during storage.

According to the plan of full-factorial experiments, we determined the influence of conditions and individual factors on changes in physico-chemical, physiological properties and on the preservation of peas. In the laboratory of Food Safety Scientific Research Institute of Almaty Technological University, physicochemical, physiological and microbiological indicators affecting the storage of peas and chickpeas have been studied. The results of the study are shown in Tables 1–2.

3. Results

We have determined the initial data of seed, physico-biological and physiological indicators of "Aksai leafless" pea control samples with moisture content up to 14 % and above 18 %. Table 1 shows that the germinating capacity of dry pea grain is 92 %, and the wet state is 80 %. At the same time, the breathing rate of the wet sample is 3.3 times higher in comparison with dry grain.

Table 1. Results of control samples experiments on "Aksai leafless" pea

Samples	Function indicators								
	Germination (%)	Breathing CO_2 (vol. %)	Intensity of breathing mg CO_2 per 100 g of dry matter in 24 hours	Humidity before treatment (%)	Grain unit (g/l)	Protein (%)	Acidity (deg)	Mold (ufc/g)	Yeast (ufc/g)
	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9
"Aksai leafless" pea, humidity $\leq$ 14 % w/o treatment	92	0.03	7.46	14.23	793	21.79	2.62	n/a	28
"Aksai leafless" pea, humidity $\geq$ 18 % w/o treatment	80	0.20	24.67	18.12	777	20.63	3.66	n/a	C/P

Table 2. Results of control samples experiments on "Ekarda elita" chickpeas

Samples	Function indicators								
	Germination (%)	Breathing CO_2 (vol. %)	Intensity of breathing mg CO_2 per 100 g of dry matter in 24 hours	Humidity before treatment (%)	Grain unit (g/l)	Protein (%)	Acidity (deg)	Mold (ufc/g)	Yeast (ufc/g)
	y_1	y_2	y_3	y_4	y_5	y_6	y_7	y_8	y_9
"Ekarda elita" chickpeas, humidity $\leq$14 % w/o treatment	91	0.03	12.56	14.58	764	20.88	2.43	n/a	72
"Ekarda elita" chickpeas, humidity $\geq$18 % w/o treatment	83	0.96	17.39	18.05	740	20.03	3.87	n/a	C/P

Grain unit is decreases to 16.0 g/l with humidity increasing, and protein by 1.16 %, acidity increases by 1.04 degrees, according to microbiological indicators mold is not detected. To establish the mathematical interrelationships of the studied seed, physico-biochemical, physiological and microbiological indicators with the influencing regime factors of ion-ozone cavitation treatment, full-factorial experiments 2^4 were conducted. It was determined in this study that during low and high concentration of ion, ozone, cavitation the protein content remains at the same level, i.e. concentration and time of the treatment do not affect the protein content changes. The moisture content of the grain differs at high moisture content there is a low amount of protein, and at moisture of 14.0 % it is slightly above. The acidity of samples with high humidity decreases after treatment with ion-ozone streams in the presence of cavitation. In addition, high level of legume crops seeds germination was observed. Also, the following influences of the conditions and individual factors on the changes in physico-chemical, physiological properties and on the safety of chickpeas have been determined: protein content, fat, acidity, germination energy, germination capacity, breathing rate and mold formation, which are given in Table 2.

The presented data from Table 3 shows that the control samples of the "Ekarda elita" chickpeas have an average percentage of germination from 63 % to 86 %. The same characteristic changes have dry and medium dry, wet and moist conditions, as have been established in the pea variety. A noticeable change is in the release of CO_2. Acidity and the amount of yeast increases with high moisture content of the grain. On the basis of the data comparison in two variants by moisture groups, it can be noted that the intensive state of grain mass breathing is observed when the grain is stored with a moisture content equal to or greater than 18 %.

The results of mathematical modeling were processed and the modes of ion-ozone technology with excess pressure drop for legume crops were determined, such as: "Aksai leafless" pea and "Ekarda elita" chickpeas. The results of the study are shown in Table 3. Data processing and calculations were carried out using the algorithm developed by Odessa National Academy of Food Technologies and PLAN sequential regression analysis program. Calculations of the coefficients are carried out with respect to matrices in the natural dimension and, accordingly, the equations are obtained in the natural dimension. This is why, after recalculating the remaining significant coefficients, both the values of the coefficients and their errors change. The general form of the equations for the fourth factors is

$$y = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + b_{12}x_1x_2 + b_{13}x_1x_3 + b_{14}x_1x_4 +$$

$$+ b_{23}x_2x_3 + b_{24}x_2x_4 + b_{34}x_3x_4 \,,$$

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

$$y = b_0 + b_1C + b_2P + b_3w + b_4\tau + b_{12}CP + b_{13}Cw + b_{14}C\tau +$$

$$+ b_{23}Pw + b_{24}P\tau + b_{34}w\tau \,,$$

where C is the ratio of ion concentration to ozone concentration (units/mg), P denotes the excess pressure (atm), w stands for the samples humidity (%) and τ represents the treatment time (min).

Table 3. Results of full-factorial experiments 24 hours after ion-ozone cavitation treatment of "Aksai leafless" pea

No.	Quality indicators	Form of equation	Function values		Statistical indicators								
			min	max	Student criterion	Diss. errors of experience inadequacy		Mean square deviation		Number of DOF		Fisher criterion	
					t_{cr}	s_{2y}	s_{2ag}	s_y	s_{ag}	N_{s2y}	N_{s2ag}	F_c	F_{cr}
1.	Germination (%)	y_1=157.25 +1.146C –7.953P –4.306W –0.051τ	84.0	98.1	4.304	5.29	13.92	2.30	3.73	2	14	2.63	19.42
2.	Breathing CO_2 (vol. %)	y_2=–0.77 +0.002C +0.05P +0.06W +0.0100τ –0.0005CP –0.004PW –0.0008$W\tau$	0	0.19	4.304	0.000016	0.0002	0.004	0.014	2	8	12.50	19.37
4.	Actual humidity after treatment (%)	y_4=0.624 –0.110P +0.982W	14.11	18.14	4.304	0.0225	0.0063	0.15	0.08	2	15	3.56	3.68
5.	Grain unit (g/l)	y_5=857.65 +0.322C +0.628P –4.706W +0.471τ	784.31	784.31	4.304	384.55	117.163	19.61	10.82	2	15	3.28	3.68
6.	Protein (%)	y_6=27.0 –0.13C –0.198P –0.17W	22.38	23.41	4.304	0.22	0.15	0.47	0.39	2	14	1.43	3.74
8.	Yeast (ufc/g)	y_8=5.46C +1.89W –0.14τ –0.36CW	14.76	32.36	4.304	0.396	1.193	0.63	1.09	2	12	3.00	19.41

Table 3 of ion-ozone cavitation treatment shows that the most probable value of min and max fluctuations of seed, physico-biochemical and physiological properties for "Aksai leafless" pea allow us to control the treatment parameters for sustainable storage. Considered factors differently affect the level of significance and interaction with the studied indicators will be inadequate in the process of long-term storage of legume crops. Based on the obtained equations from Table 3, it is possible to compile mathematical models for the effectiveness of ion-ozone cavitation treatment (IOCT), which determine the rational parameters of IOCT, providing stable storage conditions of legume crops at an ambient temperature from 18 to 23 °C. As a result of comparison, the data obtained from Table 3 make it possible in the future to determine the optimal region in providing technological qualities of grain legume crops during long-term storage.

4. Conclusion

We have determined the effects of conditions and individual factors on the changes in physicochemical, physiological properties and on the conservation of legume crops during storage. Grain legume crops were treated with ion-ozone streams with the cavitation. Physicochemical (protein, moisture, grain unit, acidity, etc.), physiological (germination, breathing rate) and microbiological (molds and yeast) indicators affecting the storage of legume crops were studied in the laboratories of Almaty Technological University. It was determined that for treated grain legume crops with ion-ozone cavitation streams the storage in the air is more effective than control samples. When grain legume crops are stored, the state of the grain in terms of humidity mainly affects the germination, breathing rate, grain unit, fat content, acid number and microbiological indicators for the growth of mold and yeast. In the course of the study grain legume crops treated with ion-ozone cavitation streams showed better results than control samples.

Ion-ozon cavitation treatment of legumes seeds favorably improves the seed properties in the dry state with a high concentration of ions compared to ozone with a treatment time of up to 10 minutes. As a result, the germination of peas and chickpeas seeds is 93 % and 100 %, i.e., increases compared to the control sample from 10% to 17 %. After ion-ozone cavitation treatment, the physico-biochemical properties are more stable, and the intensity of breathing fluctuates in the same range. All these changes leads to a steady state of storage. Under such conditions of ion-ozon cavitation treatment of legume crops seeds, a tendency is observed to synthesize the protein molecule, and Tables 2 and 4 show that the protein content increases from 0.5 % to 1.5 %.

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