Досліджено вплив подрібнення на якість порошку обніжжя бджолиного за технологічними та фізико-хімічними показниками. Встановлено вплив механічної обробки на дисперсність продукту. Показано, що подрібнення може мати значний вплив на фітохімічні та технологічні характеристики порошку. Обґрунтовано вибір типу подрібнювача та, використовуючи метод математичного моделювання, оптимізовано технічні параметри для отримання високоякісного продукту

Ключові слова: флавоноїди обніжжя бджолиного, дисперсність порошку, технологічні властивості порошку обніжжя, фітохімічна активність

Исследовано влияние измельчения на технологические и физико-химические показатели обножки пчелиной. Установлено влияние механической обработки на дисперсность продукта. Показано, что измельчение может иметь значительное влияние на фитохимические и технологические характеристики порошка. Обоснован выбор типа измельчителя и, используя метод математического моделирования, оптимизированы технические параметры получения высококачественного продукта

Ключевые слова: флавоноиды обножки пчелиной, дисперсность порошка, технологические свойства порошка обножка, фитохимическая активность

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OPTIMIZATION OF TECHNOLOGY FOR SHREDDING THE BEE POLLEN

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1. Introduction

A significant number of study results [1] indicate massive disruptions in the diet of a modern human. These include excessive consumption of modified animal fats, lack of valuable proteins, polyunsaturated fatty acids, dietary fibers, deficiency of vitamins of the group B, A, and C, mineral substances, etc.

Solving the specified problem is possible through the development of technologies of food products whose formulation components would include natural enrichers containing a significant number of natural essential nutrients.

At present, bee products (Pat. BG 111284, Pat. UA 37155 U) are more and more used in order to enrich milk products [2–4]. Of all those products, especially valuable is the bee pollen (BP) [5–7]. There are data indicating that flower pollen, due to its composition and, therefore, by the possibilities to influence the human body, outperforms all known and widely advertised preparations [8]. A special feature of the flower pollen is that using it in the unprocessed state is not recommended. The assumption was made on that the pollen will be better absorbed if crushed [9].

We did not find any available information on the methods and techniques of preparing flower pollen to be used in the composition of a sour-milk drink. Thus, this issue remains open and requires scientific substantiation and experimental research.

2. Literature review and problem statement

There are many technologies in the food industry that, for different purposes, imply reducing the size of solid components. For example, to speed up the extraction or increase an active surface of the solid component. Crushing can reduce thermal treatment during cooking, particularly, blanching, frying, etc. [10].

The term "shredding" is commonly used and implies reducing the size of the solid substance by mechanical action through such operations as the crashing, cutting, grinding, etc. The mechanism of the process of shredding is the deformation of the particle of a solid material until the moment of breaking or crashing. Destruction of solid materials caused by cracks and defects in the structure is achieved by applying several types of force. Compression forces are employed for rough crashing of solid materials. Rough grinding implies reducing the size down to approximately 3 mm. Impact forces can be universal and so are used for coarse, medium and fine grinding of various food materials. The force of friction is applied, mainly, for fine grinding of hard brittle food materials in order to obtain a powder from particles the size of micrometers [10, 11]. Hammer and screw (cutting) shredders are capable of ensuring a degree of grinding within 2–5 mm [12]. Planetary and ball mills can crash a solid material down to 10–30 µm.

The results of optimization of parameters of planetary shredder show that powder quality is affected by such parameters as rotation speed of the working body, the amount of portion of the shredded material [14]. It was established that an increase in speed reduces the time of shredding while the approximation of volume of the portion to boundary marks leads to deterioration of results [14]. Prolonging a treatment period exerts a positive impact on the quality of the finished product, however, this process is not infinite and, at a certain point, a growth in efficiency stops [15].

3. The aim and objectives of the study

The aim of present research is to optimize a technology of shredding bee pollen in order to obtain a high-quality powder by its technological and physical-chemical indicators.

To achieve the set aim, the following tasks have been solved:

– to conduct morphological study of the shredded BP;

– to explore the impact of dispersity on the phytochemical and technological properties of the BP powder;

– to substantiate the choice of the type of shredder for dispersing BP;

– to optimize technical parameters of shredding BP using a method of mathematical modeling.

4. Materials and methods for studying the effect of shredding on the quality of bee pollen

4. 1. Materials that were examined in order to optimize the shredding technology of bee pollen

We used samples of the polyfloric BP that were collected in the Carpathian Mountains. Humidity of BP was not higher than 10 %, the size of flecks – 3±1 mm, color – yellow, shades of green and brown, scent – floral-honey, taste – sweet.

Preparation of the samples implied implementation of a series of activities aimed at improving usability of the samples of material of natural origin for research [19].

In this paper, we employed standard biochemical, physical, organoleptic microscopic techniques, a method of mathematical modeling, and other methods for estimation of quality parameters of the bee pollen powder [19].

5. Results of research into quality of the shredded bee pollen by its technological and physical-chemical indicators

Results of studying the influence of mechanical treatment on the quality of dispersing (Fig. 1) revealed that BP can be shredded to the size that varied from 120 to 8 µm. This can have a significant influence on the phytochemical activity and quality of the treated product by a number of indicators.

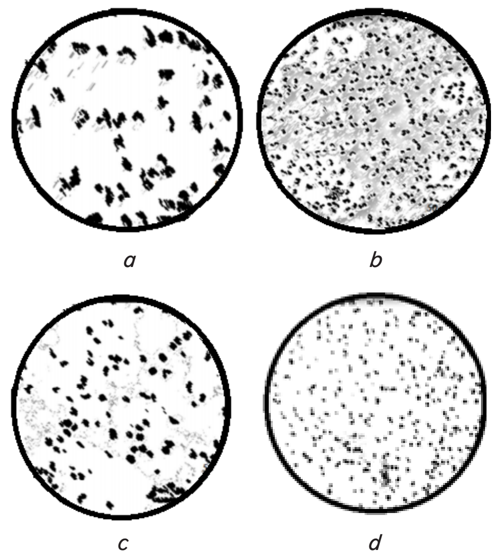


Fig. 1. Morphological features of the bee pollen powder with particles of different size: *a* — 115±5 µm; *b* — 20±2 µm; *c* — 15±2 µm; *g* —10±2 µm

Flavonoids are a group of phytochemical substances that is of interest to scientists in the field of food chemistry, nutrition, biotechnology. Flavonoids served as an indicator of phytochemical activity of BP samples with different dispersity (Fig. 2).

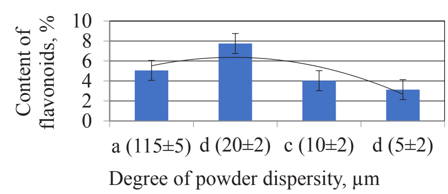
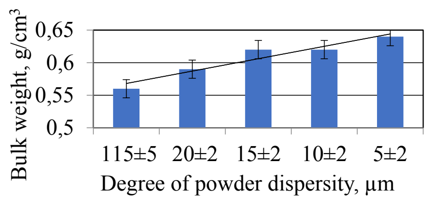


Fig. 2. Effect of shredding on the content of flavonoids in the bee pollen powder

The content of flavonoids in BP of group *b* (20±2) increased compared with group *a* (115±5) by 53 %. However, with an increase in the degree of dispersity, the content of flavonoids in groups *c* (10±2) and *d* (5±2) noticeably decreased. Result of the studies conducted demonstrate that dispersing the natural food additives contributes to the release of useful biosubstances. However, very fine shredding reduces the content of flavonoids in the treated product, possibly due to the rise in temperature during mechanical treatment.

Dispersity of powder affects its technological properties (Fig. 3, *a*). Bulk weight tends to grow with an increase in dispersity from 115 to 3 µm; thus, 1 cm^3 of powder with a dispersity of 115±5 µm weighed 10 percent less than the powder with a dispersity of 15±2 µm, and 13 % less than the powder with a dispersity of 5±2 µm. Such an effect of positive correlation could be useful for the technology of BP powder formation into granules or other forms of release.



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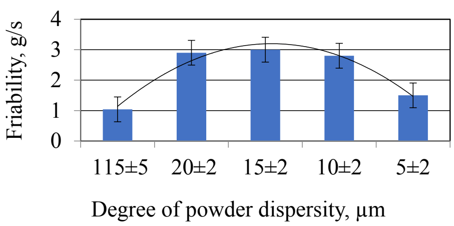


b

Fig. 3. Effect of the bee pollen powder dispersity on its: *a* — bulk weight; *b* — friability

Friability of the BP powder with a dispersity of 15±2 μm is 65 % higher than that of the powder with a dispersity of 115±2 μm (Fig. 3, *b*), which would enable a more uniform distribution of the material while mixing it with other components. However, an increase in the dispersity to 5±2 μm is the cause of the negative effect that reduces the rate of pouring out the powder by 50 % as compared with the best result. Therefore, the optimal degree of shredding for BP is the size of 15±5 μm.

The most important parameters that influence resulting characteristics of the powder is the type of shredder, speed of the working body, the time of shredding, the degree of filling a container [20].

In order to substantiate a choice of the type of shredder, we carried out a series of experimental research underlying which is the estimation of homogeneity and dispersity of the shredded material (Table 1).

Table 1

Qualitative characteristics of the powder obtained by using different shredders, n=5, p≤0.05

No. of experiment	Type of shredder	Characteristic of the bee pollen powder	
		homogeneity, %	dispersity, μm
1	Cutting	98±2.0	60±3
2	Mill-mortar	97±1.0	12±3
3	Ball	99±0.5	15±1
4	Impact	97±2.5	42±3

It was determined that treating BP with different types of shredders enables obtaining a powder with different quality characteristics. When using a cutting shredder, we managed to receive a homogeneous powder (98±2.0 %), which was not small enough at 60±3 μm. The powder obtained by an impact shredder was similar to the previous sample in terms of quality characteristics. The best quality of the processed material, for the examined characteristics, was achieved when using the mill-mortar and ball shredders whose operating principle is the action of friction force and impact force.

Monitoring electricity consumption by the three types of shredders indicates the feasibility of employing a mill-mortar for shredding BP. This is due to the fact that in contrast to the use of a highly effective ball-type shredder applying the mill-mortar saves energy [21, 22].

Homogeneity is one of important qualitative characteristics of powders, which depends on several factors, the most important being the number of mill rotations (X_1), shredding duration (X_2) and weight of the BP batch (X_3). The optimization of technical parameters of the BP shredding was carried out taking into account the influence of the above factors on the percentage of particles the size of ≤20 μm in the shredded BP. The number of levels of factors depended on our expectations about the order of a polynomial model, which was suited for the approximation of an unknown real surface and was equal to three levels. We selected as the zero level of the examined factors: X_{10}=4 min.; X_{20}=100 g; X_{30}=75 rpm. Intervals of variation for each factor are equal to, respectively, λ_1=2 min.; λ_2=50 g; λ_3=5 rpm. Then the upper and lower levels of factors will make up:

$$X_1^+=4+2=6,$$

$$X_1^-=4-2=2,$$

$$X_2^+=100+50=150,$$

$$X_2^-=100-50=50,$$

$$X_3^+=75+5=80,$$

$$X_3^-=75-5=70,$$

alternatively, in the coded units:

$$x_1^+=(X_1^+-X_{10})/I_1=(6-4)/2=+1,$$

$$x_1^-=(X_1^--X_{10})/I_1=(2-4)/2=-1,$$

$$x_2^+=(X_2^+-X_{20})/I_2=(150-100)/50=+1,$$

$$x_2^-=(X_2^--X_{20})/I_2=(50-100)/50=-1,$$

$$x_3^+=(80-75)/5=+1,$$

$$x_2^-=(75-80)/5=-1.$$

The number of variants of experiments, required to determine an impact of the set of factors X_1, X_2, X_3 on the process of shredding, will be calculated by raising the power 2^3:

$$N=2^3=8.$$

Research results (y_i) and the averages of homogeneity value of the obtained powder ($\hat{y}$) for each of the eight variants of technical parameters in three experiments are given in Table 2.

By using the mean actual values, we shall calculate regression coefficients from formulae (2), (3).

As a result of the calculations, we obtained a series of coefficients: b_0=92.5; b_1=1.0; b_2=2.25; b_3=1.75; b_{12}=0.25; b_{13}=–0.25; b_{23}=1.5.

Table 2

Results of implementation of a full-factorial experiment, n=3, p=0.05

No.	Response value, %					Variance (S^2)*
	actual				estimated	
	y_1	y_2	y_3	$\hat{y}$	Y	
1	88	92	87	89	90	7
2	90	94	89	91	90	7
3	88	93	89	90	92	7
4	92	96	91	93	92	7
5	90	93	89	90	91	4
6	90	94	89	91	92	7
7	95	100	96	97	97	7
8	98	100	99	99	99	1

Note: the sum of variation in each line equals 47

The regression equation (1), in this case, takes the following form:

$$y=92.5+1x_1+2.25x_2+1.75x_3+$$
$$+0.25x_1x_2-0.25x_1x_3+1.5x_2x_3.$$

However, b_{12}, b_{13} are not meaningful since they are smaller than the value of a Student's coefficient that is equal to 1 for the number of degrees of freedom $f=(m-1)N=(3-1)8=16$ and a significance level of $0.05t=2.12$.

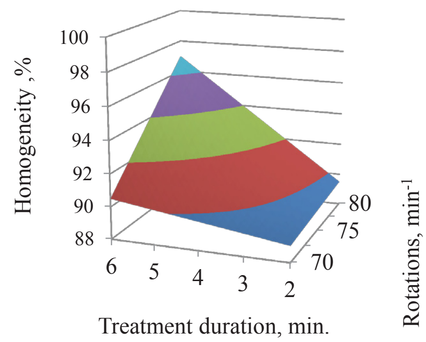
In order to assess significance of regression coefficients, we performed a statistical analysis and determined the variance (Table 3). Adequacy of the equation was tested by the Fisher estimation criterion, which is 2.18. A tabular value of the Fisher criterion is equal to 2.9. It is larger than the estimated, which means that the equation is adequate to the given process.

The interaction between variation factors is visually represented by the response surfaces of dependence of the powder homogeneity on the duration and intensity of treatment and on the weight of a biomaterial's batch (Fig. 4, 5).

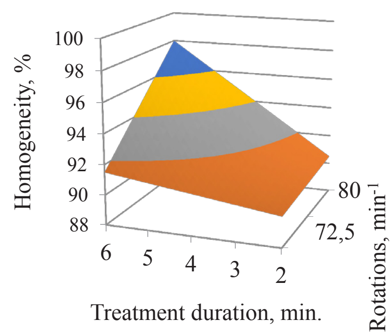
An analysis of the interaction between factors reveals that any value of X_1 for the lower level of X_2 cannot ensure a homogeneity above 90 % since the material contains not less than 8 % of the powder with a dispersity >20 µm. Mathematical models (Fig. 4, *a–c*) show that the quality of the treated product is larger affected by the duration of shredding process than the intensity of work of the shredder. In summary, the best effect is achieved under conditions when both factors X_1 and X_2 acquire their highest levels. In particular, the number of working body rotations of the shredder is ≥80 rpm; treatment duration is ≥6 min. Moreover, the effect is strengthened by the joint action of such factors as the speed of rotation and duration of shredding.

The results show that the homogeneity of powder depends to a larger extent on the duration of shredding rather than the weight of material. However, the highest quality can be achieved by maximally loading the cup (150 g) and turning on the shredder for 6 min. at speed not lower than 80 rpm.

Therefore, the optimal technical parameters of the process of shredding bee pollen in a mill-mortar are as follows: the shredder's working body rotation frequency is 70–80 rpm (min^{-1}), duration of treatment is 6 minutes, weight of the batch is 150 g.



a



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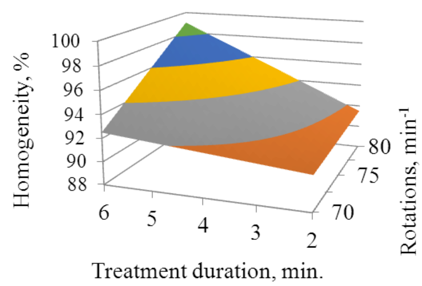

c

Fig. 4. Dependence of the bee pollen powder homogeneity on the intensity and duration of treatment, for the case: *a* – a batch of 50 g; *b* – a batch of 110 g; *c* – a batch of 150 g

6. Discussion of results of optimization of the bee pollen shredding technology

Based on the results of optimization of technical parameters of shredding BP, it was established that the quality of the finished product in terms of technological characteristics is largely affected by the duration of treatment. The weight of the loaded material exerts a smaller effect while the lowest impact on powder quality is produced by the speed of rotation of the shredder's working body. The studies related to the shredding of BP were not reported in the scientific literature. However, we have found a work on the optimization of parameters of shredding an inorganic material where it was argued that in order to obtain a powder with a high degree of grinding, important is the intensity of work of the shredder. It was noted that when the volume of a portion approaches the boundary marks, it results in the effect deterioration [14]. Fig. 6 shows that the speed of rotation of the working body affects insignificantly quality of the finished product and demonstrates a lack of negative impact from the maximum load of a mortar. The contradictions in the results obtained might be related to a different nature of the treated material, as well as to the differences in the number of parameters during full-factorial experiment.

Based on the results of biochemical studies, we established the feasibility of treating BP in order to increase a level of flavonoids in it. The data obtained agree with other results [23], which indicated a reduction in the level of flavonoids in a finely-dispersed powder from a biomaterial of natural origin, which is also represented in Fig. 3. It was proven that most flavonoids are generated in plants under stressful conditions, which is why such various factors as ultraviolet, chemical substances, high temperatures, and, in particular, shredding, contribute to an increase in these substances [24]. A reduction in the level of flavonoids in the samples with a high dispersity is caused, most likely, by the rise in temperature of the treated material as all the phytochemical substances are over sensitive to high temperatures.

It should be noted that the high degree of shredding can additionally lead to such negative phenomena as the agglomeration and deterioration of technological characteristics of the powder (Fig. 3), compromising a positive effect, reducing the active surface and bringing down bioavailability of essential nutrients of the treated product. Similar results were received by other authors as well [25].

7. Conclusions

1. Based on the results of morphological studies, it was found that by using modern types of shredders it is possible to shred bee pollen to particles the size from 120 to 8 μm.

2. The research has shown that the degree of dispersity of the powder affects phytochemical activity of pollen since the content of flavonoids in the pollen increases in the case of shredding to particles the size of 15±5 μm. The content of flavonoids in the powder with a dispersity of ≤10 μm becomes less. Based on the results of research into technological properties of the bee pollen powder, we recommend shredding bee pollen to particles the size of 15±5 μm.

3. It is substantiated to employ a mill-mortar in the technology of shredding bee pollen as the most effective shredder by the results of estimation of homogeneity and dispersity of the finished product.

4. By applying the plan full-factorial experiment, we optimized technological parameters of shredding bee pollen in a mill-mortar: speed of the working body is 70–80 rpm (min^{-1}), duration of treatment is 6 minutes, weight of the batch is 150 g.

References

1. Beal, T. Global trends in dietary micronutrient supplies and estimated prevalence of inadequate intakes [Text] / T. Beal, E. Massiot, J. E. Arsenault, M. R. Smith, R. J. Hijmans // PLOS ONE. – 2017. – Vol. 12, Issue 4. – P. e0175554. doi: 10.1371/journal.pone.0175554
2. Rashid, A. Studies on Quality Parameters of Set Yoghurt Prepared By the Addition of Honey [Text] / A. Rashid, Er. S. N. Thakur // International Journal of Scientific and Research Publications. – 2012. – Vol. 2, Issue 9. – P. 1–10.
3. Yerlikaya, O. Effect of bee pollen supplement on antimicrobial, chemical, rheological, sensorial properties and probiotic viability of fermented milk beverages [Text] / O. Yerlikaya // Mljekarstvo. – 2014. – P. 268–279. doi: 10.15567/mljekarstvo.2014.0406
4. Shleykin, A. G. Vliyanie saharnogo siropa, meda i zlakov na reologicheskie svoystva yogurta [Text] / A. G. Shleykin, N. V. Barakova, M. N. Petrova, N. P. Danilov, A. E. Argymbaeva // Nauchnyy zhurnal NIU ITMO. – 2015. – Issue 2. – P. 24–34.
5. Snezhko, O. Enhancing food safety of pollen by means of irradiation [Text] / O. Snezhko, N. Lomova, S. Narizhnyy, Z. S. Mingaleeva // Ukrainian Food Journal. – 2015. – Vol. 4, Issue 1. – P. 32–39.
6. Lomova, N. N. Influence of incorporating honey, royal jelly and pollen on biotechnological processes of dairy drink [Text] / O. O Snezhko, N. N. Lomova // Eastern-European Journal of Enterprise Technologies. – 2014. – Vol. 2, Issue 12 (68). – P. 62–65. doi: 10.15587/1729-4061.2014.23359
7. Lomova, N. N. The biomass of Streptococcus thermophiles and Bifidobacterium longum in dairy medium with bee pollen [Text] / N. N. Lomova, O. O. Snezhko, S. A. Narizhnyy // Biotechnologia Acta. – 2015. – Vol. 8, Issue 1. – P. 71–75. doi: 10.15407/biotech8.01.071
8. Solomka, V. A. Cvetochnaya pyl'ca i zdorov'e [Electronic resource] / V. A. Solomka, E. V. Tyndyk // Available at: http://dopomoha.kiev.ua/firms/med-pilca.htm
9. Rimpler, M. Von Bienen gesammelte Blütenpollen: Eigenschaften und Verwendung [Text] / M. Rimpler // Ärztezeitschrift für Naturheilverfahren. – 2003. – Vol. 44, Issue 3. – P. 158–165.
10. Barbosa-Cánovas, G. V. Food Powders [Text] / G. V. Barbosa-Cánovas, E. Ortega-Rivas, P. Juliano, H. Yan. – NY: Springer, 2005. – 372 p.
11. Dziki, D. The size reduction theories of solid foods [Text] / D. Dziki, B. Gladyszewska, R. Rozylo, R. Polak, S. Rudy, A. Krzykowski // TEKA. Commission of Motorization and Energetics in Agriculture. – 2012. – Vol. 12, Issue 2. – P. 41–45.
12. Barnwal, P. Influence of pin and hammer mill on grinding characteristics, thermal and antioxidant properties of coriander powder [Text] / P. Barnwal, K. K. Singh, A. Sharma, A. K. Choudhary, S. N. Saxena // Journal of Food Science and Technology. – 2015. – Vol. 52, Issue 12. – P. 7783–7794. doi: 10.1007/s13197-015-1975-0
13. Chauruka, S. R. Effect of mill type on the size reduction and phase transformation of gamma alumina [Text] / S. R. Chauruka, A. Hassanpour, R. Brydson, K. J. Roberts, M. Ghadiri, H. Stitt // Chemical Engineering Science. – 2015. – Vol. 134. – P. 774–783. doi: 10.1016/j.ces.2015.06.004

14. Zhang, F. L. Parameters optimization in the planetary ball milling of nanostructured tungsten carbide/cobalt powder [Text] / F. L. Zhang, M. Zhu, C. Y. Wang // International Journal of Refractory Metals and Hard Materials. – 2008. – Vol. 26, Issue 4. – P. 329–333. doi: 10.1016/j.ijrmhm.2007.08.005
15. Gour, S. Manufacturing Nano-Sized Powders Using Salt- and Sugar-Assisted Milling [Text] / S. Gour. – Philadelphia: Drexel University, 2010. – 133 p.
16. Murthy, T. P. K. Grinding Studies of Mango Ginger: Mathematical Modelling of Particle Size Distribution and Energy Consumption [Text] / T. P. K. Murthy, B. Manohar // American Journal of Food Science and Technology. – 2013. – Vol. 1, Issue 4. – P. 70–76.
17. Chen, Q. M. Effect of Superfine Grinding on Physicochemical Properties, antioxidant Activity and Phenolic Content of Red Rice (Oryza sativa L.) [Text] / Q. M. Chen, M. R. Fu, F. L. Yue, Y. Y. Cheng // Food and Nutrition Sciences. – 2015. – Vol. 06, Issue 14. – P. 1277–1284. doi: 10.4236/fns.2015.614133
18. Bauer, J. F. Pharmaceutical Solids: Size, Shape, and Surface Area [Text] / J. F Bauer // Journal of Validation Technology. – 2009. – P. 37–44. – Available at: http://www.ivtnetwork.com/sites/default/files/PharmSolids_01.pdf
19. Merzlov, S. Investigation of the process of bee pollen comminution [Text] / S. Merzlov, N. Lomova, S. Narizhniy, O. Snizhko, V. Voroshchuk // EUREKA: Life Sciences. – 2017. – Issue 5. – P. 39–44. doi: 10.21303/2504-5695.2017.00426
20. Biyik, S. The Effect of Milling Speed on Particle Size and Morphology of Cu25W Composite Powder [Text] / S. Biyik, M. Aydin // Acta Physica Polonica A. – 2015. – Vol. 127, Issue 4. – P. 1255–1260. doi: 10.12693/aphyspola.127.1255
21. Sahoo, A. Correlations for the grindability of the ball mill as a measure of its performance [Text] / A. Sahoo, G. K. Roy // Asia-Pacific Journal of Chemical Engineering. – 2008. – Vol. 3, Issue 2. – P. 230–235. doi: 10.1002/apj.133
22. Lomova, N. M. Pervynna pidhotovka apiproduktiv u biotekhnolohyi yohurtu «Medovyi» [Text] / N. M. Lomova, S. A. Narizhnyi, O. O. Snizhko // Naukovi dopovidi NUBiP Ukrainy. – 2016. – Issue 7 (64). – Available at: http://journals.nubip.edu.ua/index.php/Dopovidi/article/view/7717/7413
23. Chen, Y. Physicochemical properties and adsorption of cholesterol by okra (Abelmoschus esculentus) powder [Text] / Y. Chen, B.-C. Zhang, Y.-H. Sun, J.-G. Zhang, H.-J. Sun, Z.-J. Wei // Food Funct. – 2015. – Vol. 6, Issue 12. – P. 3728–3736. doi: 10.1039/c5fo00600g
24. Zaiter, A. Effect of particle size on antioxidant activity and catechin content of green tea powders [Text] / A. Zaiter, L. Becker, M.-C. Karam, A. Dicko // Journal of Food Science and Technology. – 2016. – Vol. 53, Issue 4. – P. 2025–2032. doi: 10.1007/s13197-016-2201-4
25. Otte, A. Assessment of Milling-Induced Disorder of Two Pharmaceutical Compounds [Text] / A. Otte, M. T. Carvajal // Journal of Pharmaceutical Sciences. – 2011. – Vol. 100, Issue 5. – P. 1973–1804. doi: 10.1002/jps.22415