UDC 001.891.58:005.336.1:658.562.3:636.085.55-046.67

THE DEVELOPMENT ADVANCED GRANULATION TECHNOLOGY OF COMPOUND FEEDS

B. Yegorov, Doctor of Engineering Science, Professor, *E-mail:* bogdanegoroff58@gmail.com
N. Batievskaya, post-graduate student, *E-mail*: natabatievskaya@gmail.com
Department of mixed feeds and biofuel technology
Odessa National Academy of Food Technologies, Kanatna str., 112, Odessa, Ukraine, 65039

Abstract. The advantages of using granular mixed fodders in comparison whith the loose compound feeds have been analyzed in the article. A detailed analysis of the production of granulated feed in the world and in Ukraine for the last ten years has been presented. The article is dedicated to the justification of the use of granulation technology in the feed industry. The advantages and disadvantages of granulation technology are presented, as well as the structural scheme of the traditional technology of production of granulated mixed fodders with the receipt of granules grains is considered. The detailed analysis of technological processes of the traditional technology ofgranulated mixed fodders production with the receipt of granule grains with the description of technological regimes of each process has been given. The main disadvantages of traditional technology of granulated feed production have been considered and possible solutions of these problems are presented. As the development of the feed industry is characterized by the intensification of technological processes aimed primarily at improving sanitary quality, the methods of preliminary wet-heat preparation of mixed fodder, in particular, the application of expansion to the granulation process, have been presented as the basis for further development of the advanced granulation technology. The advantages of using expansion, the principle of the expander and the technological features of the process have been considered. The generalization of the conducted analytical and experimental studies allowed develop the advanced technology of granulation in the form of a blend granulated crumb, which will increase the output of finished products. The technology for the production of granulated compound feed in the form of a blend granulated crumb and expanded crumb have been presented in the article. The description of technological processes and technological regimes (moisture of products, use of sieves, vapor pressure, steam consumption, duration, etc.) has been presented too. The physical and microbiological characteristics of granulated and expanded feed, as well as granulated grains and expanded grains are given.

Key Words: food technology, animal feed industry, granulation technology, expansion, compound feed.

РОЗРОБКА УДОСКОНАЛЕННОЇ ТЕХНОЛОГІЇ ГРАНУЛЮВАННЯ КОМБІКОРМІВ

Б.В. Єгоров, доктор технічних наук, професор, *E-mail*: bogdanegoroff58@gmail.com
Н.О. Батієвська, аспірант, *E-mail*: natabatievskaya@gmail.com
Кафедра технології комбікормів і біопалива
Одеська національна академія харчових технологій, вул. Канатна, 112, м. Одеса, Україна, 65039

Анотація. Проаналізовано переваги використання гранульованих комбікормів перед розсипними. Представлено детальний аналіз виробництва гранульованих комбікормів у світі та в України за останні десять років. Обгрунтувано доцільність застосування технології гранулювання в комбікормовій галузі. Вказано переваги та недоліки технології гранулювання, а також розглянуто структурну схему традиційної технології виробництва гранульованих комбікормів з отриманням крупки гранул. Надано детальний аналіз технологічних процесів традиційної технології виробництва гранульованих комбікормів із отриманням крупки гранул із описанням технологічних режимів кожного процесу. Розглянуто основні недоліки традиційної технології виробництва гранульованих комбікормів та представлено можливі рішення даних проблем. Так як розвиток комбікормової промисловості характеризується інтенсифікацією технологічних процесів, направлених, в першу чергу, на підвищення санітарної якості, представлено способи попередньої волого-теплової підготовки комбікорму, зокрема застосування експандування перед процесом гранулювання, як основу для подальшої розробки удосконаленої технології гранулювання. Розглянуто переваги використання експандування, принцип дії експандера та технологічні особливості процесу. Узагальнення проведених аналітичних та експериментальних досліджень дозволило розробити удосконалену технологію гранулювання у вигляді суміші крупок, яка дозволить збільшити випуск готової продукції. У статті представлено технологію виробництва гранульованих комбікормів у вигляді суміші крупки гранул та крупки експандату. Представлено опис технологічних процесів та технологічні режими (вологість продуктів, використання сит, тиск пари, витрати пари, тривалість та інше). Надано фізичні та мікробіологічні характеристики гранульованого та експандованого комбікорму, а також гранульованої крупки та крупки експандату.

Ключові слова: технологія харчування, комбікормова промисловість, технологія гранулювання, експандування, питомі витрати електроенергії, комбікорм.

DOI: http://dx.doi.org/10.15673/fst.v13i2.1402

Introduction. Formulation of the problem

The Food and Agriculture Base United Nations believes that by 2050 the demand for food will increase by 60%, it is expected that livestock production in 2010–2050 will increase by about 1.7% per year, moreover, the projected growth in meat production by almost 70%, milk production by 55%, fish production by 90%. Since, human nutrition depends on high-quality feeding of animals, it is very important to feed agricultural animals with high-quality compound feed, that the population consumed quality animal products.

The feed industry is one of the most competitive sectors in the agricultural sector [1]. In 2016, the world compound feeds production amounted to about 734.5 million. tons of compound feeds (Figure 1) [2,3]. One of the largest producers of Asian compound feeds is a Thai company "Charoen Pokphand" that produces 18 million tons of compound feeds in different parts of East Asia. USA is one of the largest producers of compound feeds in 2013-2018. Global compound feeds production provides an approximate annual turnover of more than 400 billion. (Figure 2).World compound feeds production in 2018 reached approximately 1 billion tons [2,3].

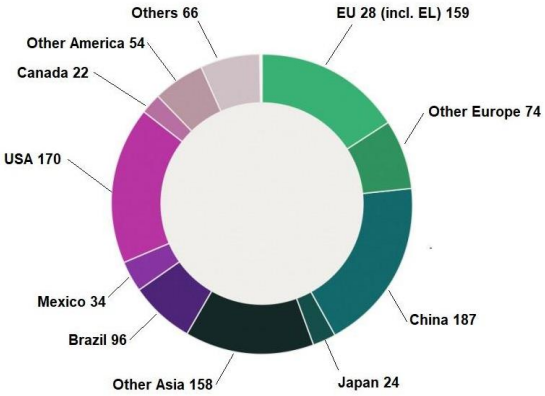

Figure 1. Production of animal feed in the world, 2016, [2, 3]

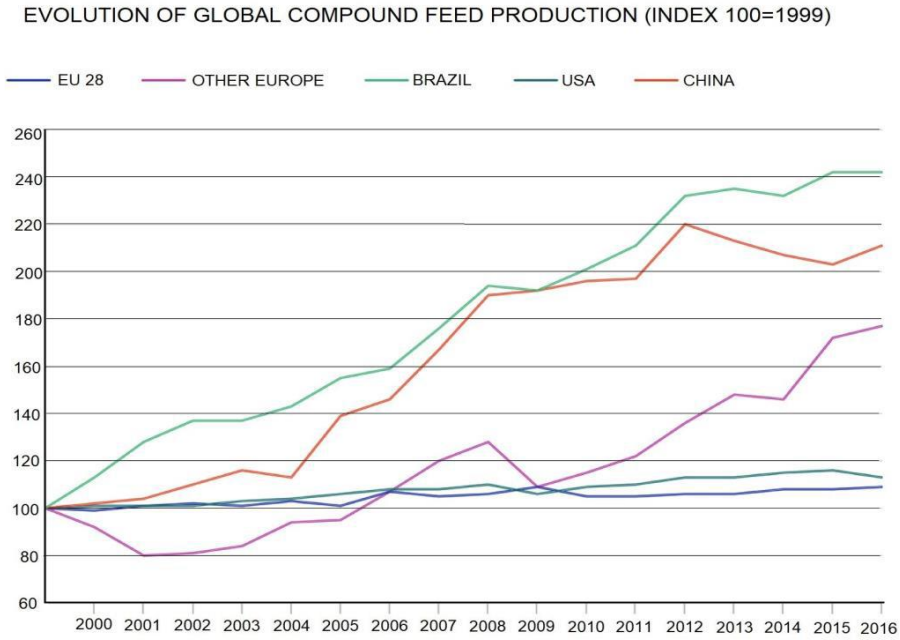

Figure 2. Statistics of compound feeds production in the world, from 2000 to 2016, [2, 3]

The feed industry, like many other sectors of the food and processing industry, is experiencing significant changes. Despite the general growth in the production of compound feeds, structural changes in the assortment of products are observed, which were caused by changes in animal husbandry and poultry farming [4].

Analysis of recent research and publications

The feed industry of Ukraine is quite significant in the agro-industrial complex of the country. The industry provides livestock and food industry development. Facility of the feed industry produce feed, feed concentrates, protein-vitamin and protein-mineral-vitamin supplements, premixes and whole milk replacers and other feed products. The feed industry is quite promising on account of the existence of a powerful raw material base in Ukraine, but it strongly depends on the state of animal husbandry and poultry farming in the country. Leaders of compound feeds production in Ukraine for 2015–2017 are Kiev (25–30%), Cherkasy (15–19%), Dnipropetrovsk (12–15%) regions. Market leaders from 2012 to 2016 were, on average, "Katerinopolsky elevator", "Mironovsky elevator",

"Complex Agromars". The market share of other feed manufacturers is more than 60%.

A weighty and integral process in the production of compound feeds is the process of granulation feed products. Granulated compound feeds has several advantages over loose compound feeds, which have been described above. But at the same time, granulation technology is one of the most energy-intensive and expendable processes. In the feed industry, there is the issue of developing methods, methods, modes or technologies which will reduce the specific consumption of electricity in the production of feed products. One of the important targeted ways to improve the granulation process is the development of new granulation technologies, using existing equipment, but changing the very structure of the technology.

The traditional process of compound feeds production includes the following technological processes (Figure 3), such as cleaning the components of grain and protein raw materials, preliminary grinding of components, weighing and dosing, mixing the finished mixture of components, obtaining loose compound feeds. Loose compound feeds moistened with subsequent granulation.

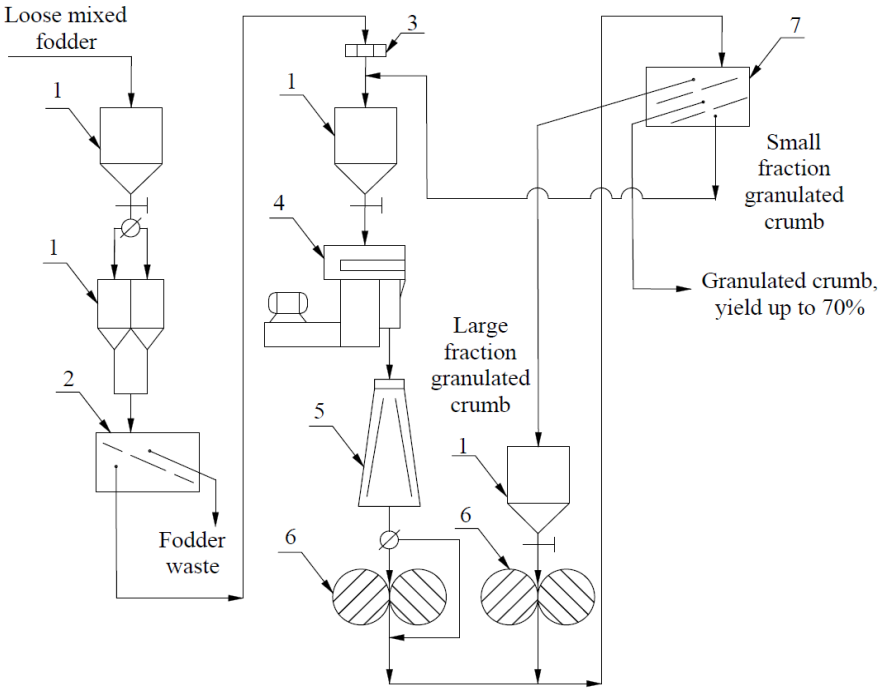

Figure 3. Scheme of the technology of granulation of mixed fodders with getting granulated crumb
1 – temporary storage bunker; 2 – separator, for the cleaning; 3 - magnetic separator; 4 – granulator; 5 – cooler; 6 - crusher 7 – separator, sifting machine;

In the granulator, loose compound feeds are coming in which the mixture and nutrients, minerals, amino acids, oils and others are mixed according to a specific recipe. Compound feed is pushed through the holes of the matrix of the granulator and leaves the granulator as a granulated feed – granules. After granulation, the granules are cooled. Next, the granules can be crushed, then by sieving to obtain granulated crumb. The grinding products are sifted onto individual sifters to control the amount of products. Descent from the upper sieve is sent to regrind. Passage this sieve receives a mealy fraction, which is sent to re-granulation. Passage upper sieve and located below sieve in the sifter get granulated crumb. The yield of finished products (granulated crumb) is not more than 70% [1]. After passing through all the processing steps, the finished granulated feed in the form of granules or granulated crumb is easily stored or packaged in a compact form.

Among the main drawbacks of using traditional granulation technology are the following: disintegration of thermolabile vitamins is possible (C up to 25–30%) and thermolabile vitamins (A up to 30% E, K up to 15%). Additional installation of a dryer for drying granules, additional costs for the purchase of auxiliary equipment (for example installation of a pre-conditioner, moisturizer or expander before granulator, in order to better pre-moisten the product), additional staff for maintenance equipment. Also, with traditional granulation technology, the yield of granulated crumb is low in percentage terms (not more than 70%), which leads to the re-granulation of the product of the mealy fraction, which increases the unit cost of electricity for the process. That is, the main disadvantage is the high unit cost of electricity for this process. The existing domestic technological lines for granulating and pelletizing compound feeds have a relatively high

productivity and, at the same time, a high energy intensity for producing granulated compound feeds.

Scientists have proposed many solutions to reduce energy consumption in the production of granulated animal feed [5]. The main solution was the use of preliminary wet-heat treatment. The fact is that when applying of preliminary wet-heat treatment the compound feed is moistened and heated, it acquires the best thermoplastic properties in comparison loose compound feed and which is not processed of preliminary wet-heat treatment. Due to this, the matrix of the press granulator does not wear, as well as reducing the unit cost of electricity during the granulation process [6].

Started studying effect of preliminary wet-heat treatment on the digestibility of nutrients of individual ingredients compound feed [7]. This has also been the subject of much research. In general, hydrothermal or hydromechanical processing of compound feed allows you to modify the digestibility of nutrients, including proteins, amino acids and carbohydrates. Although preliminary wet-heat treatment often improves nutrient absorption, the application of heat can lead to chemical reactions, such as the Maillard reaction between the aldehyde group of sugars and amino acids, which significantly reduces the availability of nutrients. Feed ingredients with a high content of thermolabile amino acids should be heat treated with caution. In addition, it is known that heat treatment of compound feed can have a significant effect on viscosity, through varying amounts of water-soluble polysaccharides in the grain. Reduced protein availability can lead to depressive growth and increased mortality of young farm animals [6,7].

The existing methods of water-heat treatment were analyzed, namely: moistening, micronization, conditioning, double granulation. But in the course of practical experience, these methods did not give the expect results. Figure 4 show the main methods of preliminary preparation of compound feed before granulation, using of preliminary wet-heat treatment.

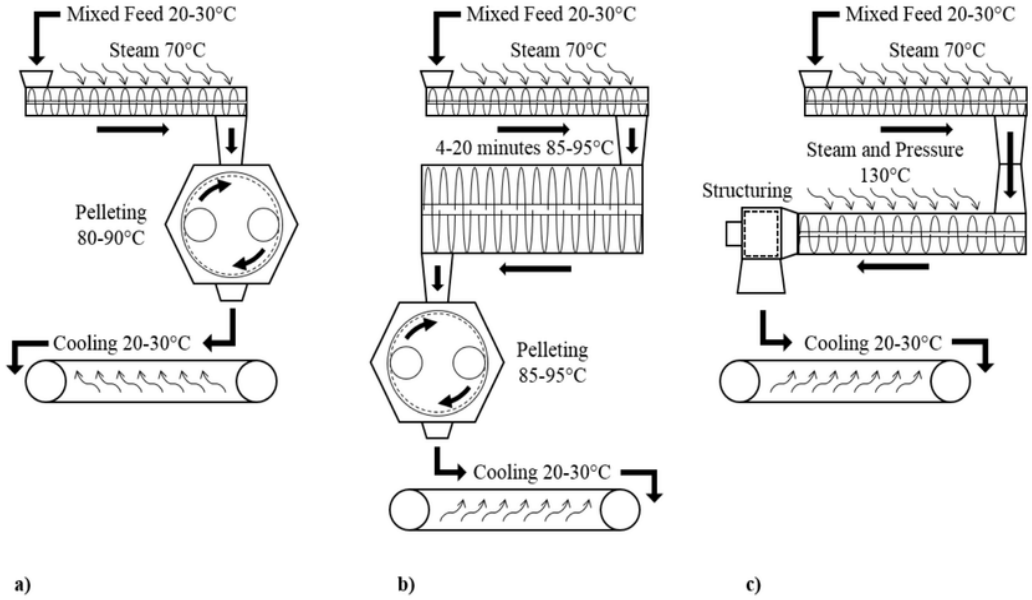

Figure 4. Scheme of the granulation of compound feed using of preliminary wet-heat treatment.
а) conventional; using pre-wetting; в) with long term conditioning; с) ; using pre-expanding

At the same time, great attention was paid to the technological processes pre-expanding of compound feed (figure 4c). The practical application of the pre-expanding before granulation has established itself thanks to positive indicators. This process provides sanitized compound feeds without destroying vitamins and nutrients. In the product that is processed in the expander, you can add a large amount of liquid components (up to 15–20%), while sometimes there is a need to dry the processed product. With this processing of compound feed in the expander, the performance granulator increases significantly.

Such technology assumes that loose feed is initially moistened and acquires more structural and mechanical properties. There is partial denaturation of the protein, which entails an increase in protein digestibility, as well as gelatinization of starch and destruction of the pulp and lignin complexes, which significantly increases the nutritional value and assimilation of nutrients. Further, the compound feeds gets into the expander. In the expander under the influence of high pressure and temperature occur structural and mechanical and chemical changes of the product, partial destruction of fungal and bacterial microflora is carried out sanitary and hygienic properties are improved [7-9]. This line was implemented in some advanced compound feed plant.

For example, in the modern production "Vinnytsia Poultry Farm" namely the branch "On-farm complex for the production of compound feed". A reduction in energy consumption was achieved, but in general the effect was not high on the granulation line. Such lines are used in

enterprises, but when it comes to large-scale production and sales, the question of energy costs is associated with economic feasibility.

According to the company Amandus KAHL (Germany), the use of expanders allows to get compound feeds of high sanitary quality. Today, modern large-scale companies for the production of high-quality technological equipment for the feed industry ("Andritz group", Austria) let out expanders, allowing to get expanded compound feed, which is ready for feeding in the form solid expandate, without the use of a further granulation process [10,11]. This technological solution opens up new opportunities. This was the impetus for new developments and research in the technology of granulation of compound feeds.

Guided by this, the idea was born to create a line of granulation, get a separate product – solid expandate, at the same time to reduce the main load on the press granulator.

Thus it is possible to produce granulated compound feed and expanded compound feed geting out of them granulated crumb and expanded crumb and mix them. So, firstly, it is necessary to prove possibility of use expandate as a separate product, it was not previously practiced.

For this, it is necessary to carry out physicochemical and microbiological indicators expandate. Confirm, on the basis of the experiments performed, that expandate further use will not affect the quality in the opposite direction, and the compound feed will be of the appropriate nutritional quality.

With a positive result, the next step will be an energy audit, determining the energy efficiency potential through a comparative energy audit of the basic and proposed granulation technologies.

The purpose of the work is to develop an improved granulation line with obtaining the expropriation, as a separate product, in the production of granulated compound feed in the form of crumb.

To achieve this aim, the research **objectives** have been defined:

– to develop improved granulation technology for the production of compound feeds in the form granulated crumb and expanded crumb;

– to determine physical and microbiological characteristics of granulated compound feed and expandate, produced by the improved granulation technology compound feed.

Research materials and methods

Experimental studies were conducted at the Odessa National Academy of Food Technologies. Microbiological studies were carried out at the Department of Biochemistry, Microbiology and Nutrition Physiology, and the chemical and physical properties of the products of experience at the Department of Combined Feed Technology and Biofuels.

Physical and technological properties were evaluated by indicators such as moisture content, bulk density, flowability, angle of repose, crushability. The complex of laboratory equipment was used to determine the physical and technological properties: oven, thermostat, desiccator, pycnometer, a device for determining the angle of the bulk slope, a set of sieves, electronic and analytical scales, weights, caliper.

The change in the composition and quantity of microflora during storage of granules, expandate, granulated crumb and expanded crumb was carried by microbiological method. Quantity of Mesophilic Aerobic and Facultative Anaerobic Microorganisms (QMAFAnM) were determined by sowing method on the medium of meat-peptone agar (MPA), micromycetes – on the medium of wort agar (WA), bacteria of the paratyphoid group (*Salmonella* and *E. coli*) – on the Endo environment after their accumulation on liquid special media [12-14].

Results of the research and their discussion

A number of studies were conducted at the department of technology of animal feed and biofuel ONAFT, and the following technological solution was proposed (figure 5).

The essence of the developed technology lies in the following operations. The developed technology production granulated compound feed in the form of a blend granulated crumb and expanded crumb provides: expansion raw materials, separate granulation prepared raw materials, getting granule, getting granulated crumb, getting expandate, getting expanded crumb and mixing crumb getting a blend granulated crumb and expanded crumb.

As was given in the literature review, with traditional granulation technology, all 100% of the recipe for loose compound feed, it is moistened, expanded and granulated to obtain only crumbs from granules. Our advanced granulation technology differs from the traditional one, because we get a separate product, an expandate, this reduces the load on the granulator, it is not 100% loaded, getting expanded crumb and mixing with granulated crumb.

The method is carried out in the following order (figure 6): the finished loose compound feed is processed in moisturizer, where it is heated to a temperature of + 50°C to + 85°C for 5–10 seconds and moistened content of 18–22%. Exercise of such processing provides compound feed thermo-plastic properties. The next stage of processing is carried out using expander. Moisture compound feed in expander is 16–22%, temperature of + 50°C to + 85°C. Expanding the raw material destroys the microflora on its surface, which improves the sanitary and hygienic, dietary and taste properties of the final compound feed. The processing of feed in the expander is as follows. In the expander, the process of pressing the processed raw material occurs through ring-type matrix. Since almost half of the friction surface acquires movements under the action of a separate drive, the specific energy consumption is significantly reduced. Expanding combines hydrothermal effects with mechanical shear forces.

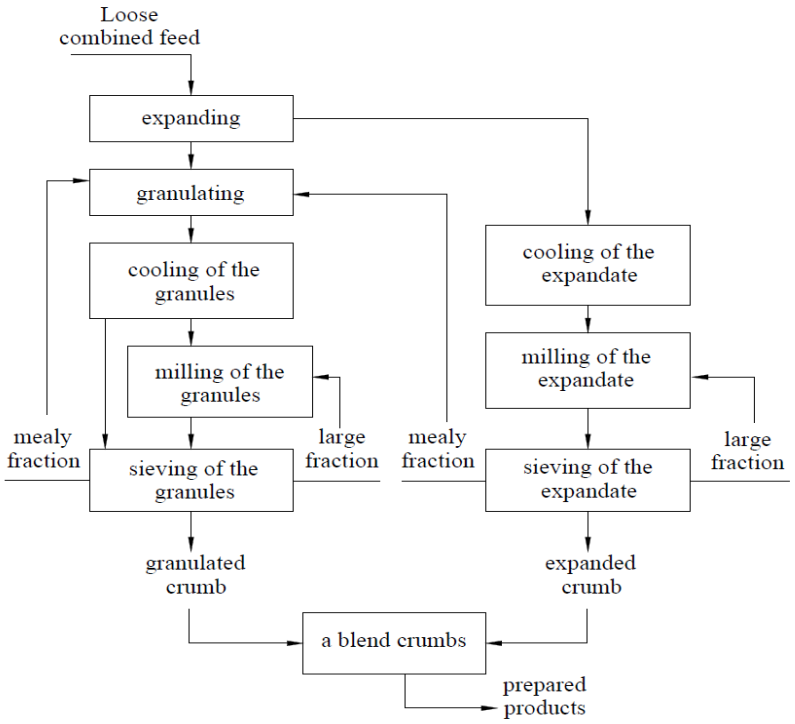

Figure 5. Scheme of the granulation technology with using pre-expanding and obtaining granulated crumb and expanded crum

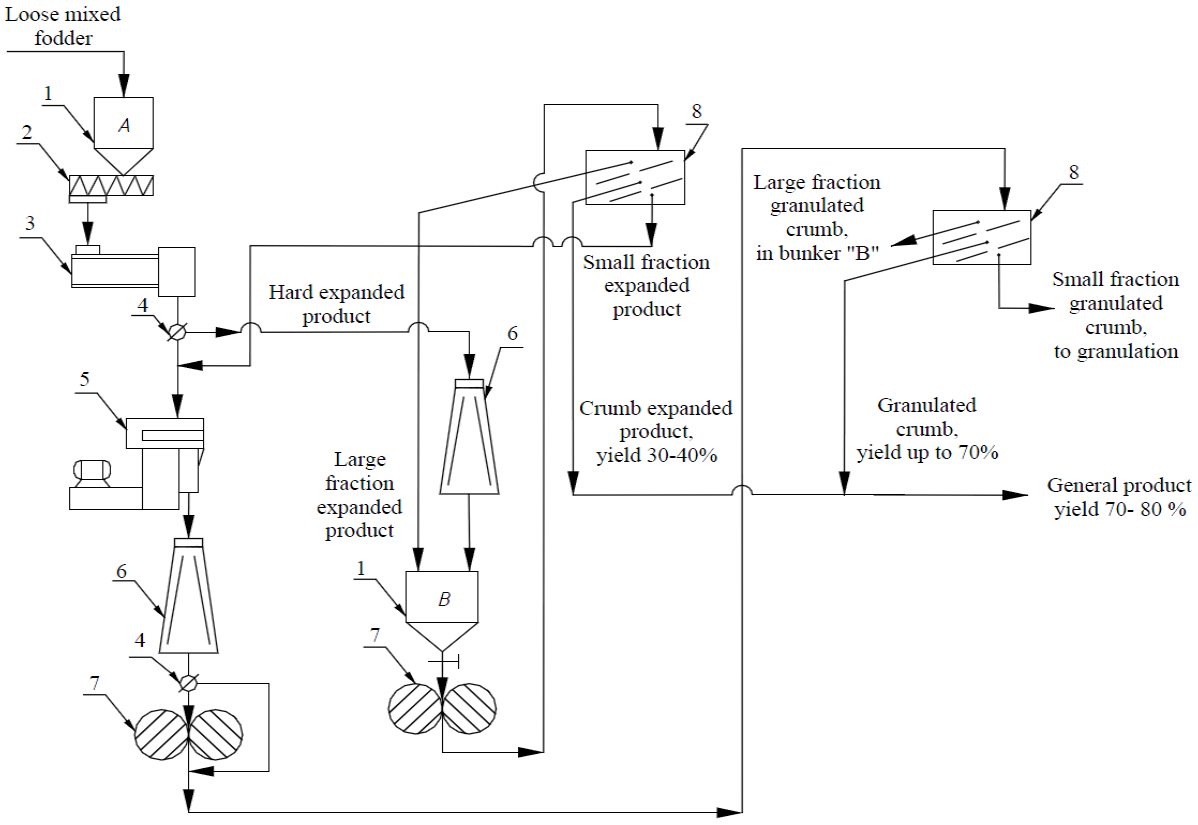

Figure 6. Improvement scheme of the granulation technology with obtaining granulated crumb and expanded crumb: 1 – temporary storage bunker; 2 – moisturizer; 3- expander; 4 – changeover valve; 5 – granulator; 6 – cooler; 7 – crusher; 8 – separator, sifting machine.

The compound feed is subjected to short-term processing with a maximum exposure time of 3–6 seconds, the temperature at which the feed is exposed to, is relatively higher than during granulation and reaches from 80–130°C. The moisture of the product in the expander is 16–22%, the resulting product - the expandate has a moisture content of 13–14%, its temperature is approximately 85–95°C. Expandate has the form of pieces, sizes from 20–50 mm [9,10]. Part of the expandate is cooled, crushed and sieved, to obtain expanded crumb, and part granulated in a granulator under standard processing conditions.

The matrix is the main working body of the granulator press. Since the cost of the matrix is high, the feed mills pay great attention to their preservation and proper operation. The clip in turn is intended to compound feed in the granulator, pushed between the rotating matrix and the pressing rollers and pressed through the holes of the matrix, where granules are formed under the action of high pressure. The gap between the rollers and the die determines the degree of compression. At normal close location of the rollers from the surface of the matrix granules of the required hardness come out. The gap between the rollers and the matrix determines the degree of compression. At normal close location of the rollers from the surface of the matrix granules of the required hardness come out. The gap between the inner surface of the matrix of the press granulator and the pressing roller is 0.3–0.5 mm [1]. The performance of the granulator, as well as the service life of the matrix and the rollers, will depend on how faithfully the processes of regulating the gaps between the matrix and the streets have been conducted. The gap value can be checked by the deformation of the aluminum wire missed between the die and the drum. It depends on the correctness of the gap clearance between the matrix and the streets, will depend on the performance of the granulator, as well as the service life of the matrix and rollers. The gap value can be checked by the deformation of the aluminum wire missed between matrix and rollers.

A very small gap between the rollers and matrix gives a thin solid layer of product, does not provide the necessary protection against wear matrix. Reducing the size of the gap to 0.2 mm will reduce the durability of the matrix, since pre-compression compound feed layer occurs, which increases the pressure in the holes of the matrix, and the granules go out of increased hardness. In such cases, matrix can even become completely clogged with the product, and then the press stops completely. Also, if you reduce the gap between rollers and matrix is less than the norm – the matrix can crack. If the gap between rollers and matrix is increased to 0.5 mm, the strength of the obtained granules decreases. The fact is that a preliminary increase in the layer of compound feed occurs and the granules are not pressed to the appropriate hardness. That is, the standard size of the gap between matrix of the granulator press and the pressing rollers should be 0.3–0.5 mm [1,15].

In the granulator under the influence of high pressure and temperature occur structural-mechanical and chemical transformations of the product, increases the degree of absorption of animal nutrients. The compound feed treated with steam has a moisture content of 15–18% and a temperature of 60–90°C, steam pressure, as a rule, is 0.2–0.5 MPa, steam consumption is 50–80 kg/ton.

The granules obtained after granulation have a temperature of 60–80°C, they are sent to the cooling stage. The duration of cooling is 300-900 s, depending on the type of cooler and the size of the granules. The temperature of the granules after cooling should not exceed ambient temperature by more than 10°C, and moisture should not exceed 14.5%.

After this stage, chilled products are obtained in the form of granulated compound feed, which are crushed. Crush products on roller shredders, using the following modes: the number of flute 2.0–2.8 per 1 cm of the surface of the roller; roll gap 0.1 to 0.2 mm. Next, the grinding products (granulated crumb and expanded crumb) are sifted onto separate screeners to control the amount of products. The grinding products are sent to a separator, in which two sieves are installed: upper is №30. Descent from upper sieve sent for re-grinding. The bottom sieve in the separator set №10. The passage of this sieve is received mealy fraction, which is sent to re-granulation. The passage upper sieve and descent sieve getting crumb.

With the help of the software package "Optima Expert Expert", at the department "Technology of feed and biofuels" calculated compound feed recipes for young broiler chickens from 2 to 3 weeks. On the basis of the obtained improved granulation technology, the physical properties, chemical composition, sanitary quality and permissible storage periods of the studied products were determined.

The prepared components, according to the compiled recipe, in an amount of 3 kg, were mixed together in a batch mixer. All components of the recipe were mixed for 60–360 seconds at a frequency of rotation of the mixing unit n=1,33 c^{-1} Next, the prepared components in the mixer were sent to the grinding stage. Grinding was carried out on a laboratory hammer crusher. Experimental manufacture of samples of granules and exporters conducted, guided by the "Rules of the organization and conduct of the technological process of production of feed industry" at the production press granulator and production expander on the basis of the department of technology of animal feed and biofuels. 3 kg of the finished mixture was expanded, then 2 kg was pelleted, cooled, ground and sifted. The residue of pure expandant in the amount of 1 kg was cooled and also crushed and sieved.

To determine the yield of finished products conducted the following studies. Separated on a set of sieves appropriate diameter of the separator holes according to the technology. Upper sieve with a diameter of 3.0, bottom sieve with a diameter of 1.0. The samples

were screened on a laboratory separator for 300 seconds manually or for 600 seconds. Remainder on the sieve weighed on a technical scale with an accuracy of ± 0,1 g and expressed as a percentage relative to the weight of the sample. As a result of sieve analysis of the distribution of grinding products, the following results were obtained.

A sample of the crushed granules was 2 kg. Descent from upper sieve amounted to 25% (500 g), it sent for re-grinding. The passage bottom sieve amounted to 13% (260 g), which is sent to re-granulation. The passage upper sieve and descent sieve getting granulated crumb amounted to 62% (1 kg 240 g).

A sample of the crushed expandate was 1 kg. Descent from upper sieve amounted to 33% (330 g), it sent for re-grinding. The passage bottom sieve amounted to 38% (380 g), which is sent to re-granulation. The passage upper sieve and descent sieve getting expanded crumb amounted to 27% (270 g). As a result of the application of an improved granulation technology, according to the proposed method, the total yield of finished products – a blend granulated crumb and expanded crumb amounted to 85±4%, taking into account losses. (62% granulated crumb and 27% expanded crumb). With the traditional technology of granulation of loose compound feed, the yield granulated crumb is up to 70% [1].

The physical properties granulated compound feed and expanded compound feed, as well as granulated crumb and expanded crumb, have been determined; determined the quantitative and qualitative composition of microflora during storage of finished products granulated crumb and expanded crumb; all definitions were carried out using standardized research methods [12-14]. The results are presented in table 1.

Table 1 – Characteristics the physical properties of research products

Parameters	Granulated compound feed (granules)	Expanded compound feed (expandate)
Moisture content, %	12.3	11.2
Bulk density, kg/m^3	680	460
Flowability, cm/s	7.7	7.4
Angle of repose, degree	38	43
Crushability, %	11	-

In the process of preliminary expansion, the mass fraction of moisture decreased. Granule and expandate have satisfactory physical performance: in the process of expansion, the angle of repose increased by 13.15%, and the flowability improved by 3.9%. The profound structural-mechanical changes that occurred during the process of additional expansion are indicated by a decrease in bulk density of the feed mixture by 32.4%.

In the research products were determined QMAFAnM, the presence of paratyphoid bacteria (*Salmonella*), the number of micromycetes (fungi and yeast) [15-17]. The results of studies of the effect of extrusion on the microbiological indicators of research products are given in table. 2

Table 2 – Research of microbiological indicators of the quality of research products as a result use preliminary wet-heat treatment

Parameters	Before granulation	After granulation	After granulation with preliminary expansion	Decrease, % after granulation	Decrease, % After granulation with preliminary expansion
QMAFAnM, CFU/g	$18*10^4$	$2.6*10^4$	$1.1*10^4$	86	94
Yeast, CFU/g	Not found			-	-
Mushrooms parasites mycelial, CFU/g	$0.9*10^2$	$0.4*10^2$	$0.1*10^2$	55	75
Salmonella	Not found			-	-

The analysis of the conducted research indicates that bulk compound feed is characterized by a significant presence of microbes, which argues the need for heat treatment to disinfect the product. Studies in all samples prior to granulation showed a large amount of the presence of yeast, Escherichia coli and Salmonella bacteria. As a result of the preliminary expropriation process, the sanitary properties of research products (granules and expandate) are significantly improved. Under the influence of high temperature, the total number of bacteria decreased by 94%, and mushrooms parasites mycelial by 75%, which allows you to effectively store granulated crumb and expanded crumb.

Conclusion

On the basis of the conducted analytical and experimental studies, an improved technology granulating the production compound feeds, with getting expandate as a separate product, getting granulated crumb and expanded crumb was developed.

As a result of the application of an improved granulation technology, according to the proposed method, the total yield of finished products - a blend granulated crumb and expanded crumb amounted to 85±4%, taking into account losses (62% granulated crumb and 27% expanded crumb). With the traditional

technology of granulation of loose compound feed, the yield granulated crumb is up to 70%.

The physical properties granulated compound feed and expanded compound feed, as well as granulated crumb and expanded crumb, have been determined. In the process of preliminary expansion, the mass fraction of moisture granulated crumb and expanded was decreased and amounted to 11.2% That will contribute to long-term storage of finished products. Granule and expandate have satisfactory physical performance, namely: angle of repose is 43 degree; flowability is 7.4 cm/s; bulk density accounted for 460 kg/m^3. Such a decrease in bulk density is indicative of profound structural-mechanical changes.

Microbiological studies have been carried out. In products that have been researched such as granulated crumb and expanded crumb, definitely: QMAFAnM accounted $1.1*10^4$ CFU /g; quantity of micromycetes (fungi and yeast) accounted $0.1*10^2$ CFU/g; the presence of bacteria of the paratyphoid group (*Salmonella*) was not revealed.

List of references:

1. Єгоров Б.В. Технологія виробництва комбікормів: підручник для студентів вищих навчальних закладів. Одеса, 2011. 448 с.
2. Process technologies, equipment, plants, and systems // ANDRITZ: [Website]. 2019. URL: https://www.andritz.com/group-en (viewed on: 10.12.2018).
3. IFIF represents and promotes the global feed industry // The International Feed Industry Federation (IFIF) : [Website]. 2019. URL: https://ifif.org/ (viewed on: 25.12.2019).
4. Yegorov B., Malaki I. Technological bases of processing tomato pomace in feed additives // Ukrainian Food Journal. 2014. V. 3. № 2. P. 228-235.
5. Jorgensen L.L., Jensen B.A., Poulsen H.O. Effects of expanding, pellet and grinding on Salmonella typhimurium infection, growth performance and gastro-intestinal ecosystem in slaughter in pigs (in Danish). The National Committee for Pig Production, Copenhagen, Denmark; 2010.
6. Purushotham B., Radhakrishna P.M., Sherigara B.S. Effects of Steam Conditioning and Extrusion Temperature on Some Anti-nutritional Factors of Soyabean (Glycine max) for Pet Food Applications // American Journal of Animal and Veterinary Sciences. 2007. V. 2. №1. P. 1-5. DOI : 10.3844/ajavsp.2007.1.5
7. Badgley CH, Moghtader JO, Quintero ET, Zakem EO, Chappell JA. Organic Agriculture and the Global Food Supply. Renewable agriculture and food systems. University of Michigan; 2007
8. Danish Agriculture and Food Council // Agriculture and Food. 2010. V. 2. №1. P. 174.
9. Guillermo MH, Miguel GV, PedroYC. Extruder Design to Elaborate Animal Feed from Crop Residues, American Society of Agricultural and Biological Engineers, St. Joseph, Michigan; ASAE Annual Meeting; 2002
10. Yegorov B.V., Batievskaya N.O. Application of granulation technology in various industries // Зернові продукти і комбікорми . 2017. Т. 17, вип. 3. С. 33-38. http://orcid.org/0000-0002-9380-2891
11. Rosentratel K.A. et al. Small-scale extrusion of com masa by-products // Cereal Chem, 2005. V. 82(4). P. 436-446. DOI:10.1094/CC-82-0436
12. Смирнова Т.А., Кострова Е.И. Микробиология зерна и его продуктов. Москва: Агропромиздат; 1989.
13. Ильяшенко Г.Н., Ботова Е.А., Пичугина Т.В., Ильяшенко А.В. Микробиология пищевых производств. Москва: Колос; 2008.
14. Мардар М. Зміна споживних властивостей нових видів екструдованих продуктів в процесі зберігання залежно від виду пакування // Товарознавчий вісник. 2014. С. 105-113.
15. Правила організації і ведення технологічного процесу виробництва комбікормової продукції . МАКУ, Київський інститут хлібопродуктів, 1998. 220 с.
16. Gabriel I.M,. Mallet S.H., Leconte M.J. Differences in the digestive tract characteristics of broiler chickens fed on complete pelleted diet or on whole wheat added to pelleted protein concentrate. British Poultry Science; 2003
17. Physical and nutritional effects of pelleting of broiler chicken diets made from wheat ground to different coarsenesses by the use of roller mill and hammer mill / Svihus B.J. et al. // Animal Feed Science and Technology. 2004. V. 117, Is. 3-4, P. 281-293. https://doi.org/10.1016/j.anifeedsci.2004.08.009

References:

1. Єgorov BV. Tehnologiya virobnictva kombikormiv. Odesa: Drukarskii dim; 2011
2. ANDRITZ. Process technologies, equipment, plants, and systems [Internet]. Austria; 2019 [updated 2019 February 27; cited 2018 December 22]. Available from: https://www.andritz.com/group-en.
3. IFIF. The International Feed Industry Federation (IFIF) [Internet]. Germany; 2019 [updated 2019 January 01; cited 2018 December 01]. Available from: https://ifif.org/
4. Yegorov BV, Malaki IS Technological bases of processing tomato pomace in feed additives. Ukrainian Food Journal. 2014 Jun; 3 (2):228-235.
5. Jorgensen LL, Jensen BA, Poulsen HO. Effects of expanding, pellet and grinding on Salmonella typhimurium infection, growth performance and gastro-intestinal ecosystem in slaughter in pigs (in Danish). The National Committee for Pig Production, Copenhagen, Denmark; 2010.
6. Purushotham BB, Radhakrishna PM, Sherigara BS. Effects of Steam Conditioning and Extrusion Temperature on Some Anti-nutritional Factors of Soyabean (Glycine max) for Pet Food Applications. American Journal of Animal and Veterinary Sciences. 2007; 2 (1):1-5. DOI : 10.3844/ajavsp.2007.1.5
7. Badgley CH, Moghtader JO, Quintero ET, Zakem EO, Chappell JA. Organic Agriculture and the Global Food Supply. Renewable agriculture and food systems. University of Michigan; 2007.
8. Danish Agriculture and Food Council. Agriculture and Food [Internet]. Denmark: 2010 [updated 2019 January 31; cited 2019 January 5]. Available from: https://agricultureandfood.dk/
9. Guillermo MH, Miguel GV, PedroYC. Extruder Design to Elaborate Animal Feed from Crop Residues, American Society of Agricultural and Biological Engineers, St. Joseph, Michigan; ASAE Annual Meeting; 2002.
10. Yegorov BV, Batievskaya NO. Application of granulation technology in various industries. Зернові продукти і комбікорми. 2017; 17 (3): 33-38. http://orcid.org/0000-0002-9380-2891
11. Rosentratel KA. Small-scale extrusion of com masa by-products. Cereal Chem. 2005; 82 (4):436-446. DOI:10.1094/CC-82-0436
12. Smirnova TA, Kostrova EI. Mikrobiologija zerna i ego produktov. Moskva: Agropromizdat; 1989.
13. Iljashenko GN, Botova EA, Pichugina TV, Iljashenko AV. Mikrobiologija pischevyh proizvodstv. Moskva: Kolos; 2008.
14. Mardar MP. Zmina spozhivnih vlastivostej novih vidiv ekstrudovanih produktiv v protsesi zberigannja zalezhno vid vidu pakuvannja. Tovaroznavchij visnik. 2014; 22 (7):105-113.

15. Pravila organizatsiï i vedennja tehnologichnogo protsesu virobnitstva kombikormovoï produktsiï. Kiev: MAKU, Kiïvs'kij institut hliboproduktiv; 1998.
16. Gabriel IM, Mallet SH, Leconte MJ. Differences in the digestive tract characteristics of broiler chickens fed on complete pelleted diet or on whole wheat added to pelleted protein concentrate. British Poultry Science; 2003.
17. Svihus BJ et al. Physical and nutritional effects of pelleting of broiler chicken diets made from wheat ground to different coarsenesses by the use of roller mill and hammer mill. Animal Feed Science and Technology. 2004; 117(3-4): 281-293. https://doi.org/10.1016/j.anifeedsci.2004.08.009

Отримано в редакцію 24.10.2018 Received 24.10.2018
Прийнято до друку 07.06.2019 Approved 07.06.2019

Цитування згідно ДСТУ 8302:2015

Yegorov B., Batievskaya N. The development advanced granulation technology of compound feeds // Food science and technology. 2019. Vol. 13, Issue 2. P. 118-127. DOI: http://dx.doi.org/10.15673/fst.v13i2.1402

Cite as Vancuver style citation

Yegorov B, Batievskaya N. The development advanced granulation technology of compound feeds. Food science and technology. 2019;13(2):118-127. DOI: http://dx.doi.org/10.15673/fst.v13i2.1402