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Fundamentals and Prospects for the Technologies Development for Post-Harvest Grain Processing and Seed Preparation

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Abstract. The authors identified the main factors that influenced significantly the technological support of post-harvest processing processes over the past decades. They showed that in recent years, many farms faced the necessity to solve the problem of improving the seeds quality and reducing their losses in the process of post-harvest processing of grain in the shortest possible time. (*Research purpose*) To conduct a historical analysis of machine technologies for post-harvest grain processing and seed preparation and determine promising directions for their development. (*Materials and methods*) The authors used the historical-analytical method applied to technical systems, in particular, to technologies of post-harvest grain processing and seed preparation. The research objects were the original works of domestic and foreign authors for more than a 100-year period and other regulatory and technical documentation. (*Results and discussion*) The authors presented the results of the machine technologies for post-harvest grain processing and seed preparation evolution in the Russian Federation over the past 100 years. They considered the scientific, technological, technical and organizational issues of the machine technologies for grain processing and seed preparation development. It was determined that the scientific foundations for creating domestic separating machines were developed in the 30s of the last century. They noted that in 1934 the first domestic mobile grain cleaning machine with a capacity of 10 tons per hour for cleaning grain and 6-8 tons per hour for cleaning seeds was created and put into production. The following key stages were identified: in the 60s, an in-line technology of post-harvest grain processing was developed; by the end of the 70s, with the completion of work on the creation of units and complexes, all processes of post-harvest grain processing for the first time in the country were fully mechanized. (Conclusions) The authors proved that labor productivity in the industry increased 7-10 times, the cost of grain processing decreased 2-3 times, its losses decreased, manual, unskilled labor was excluded. They identified promising directions for the development of grain processing and seed preparation technologies.

Keywords: seeds, grain, post-harvest grain processing, grain cleaning machines, seed cleaning machines, grain dryers, technologies of in-line seed preparation.

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Основы и перспективы развития технологий послеуборочной обработки зерна и подготовки семян

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Реферат. Определили основные факторы, существенно повлиявшие на технологическое обеспечение процессов послеуборочной обработки в течение нескольких десятилетий. Показали, что в последние годы перед многими хозяйствами встала необходимость решения проблемы повышения качества семян и уменьшения их потерь в процессе послеуборочной обработки зерна в кратчайшие сроки. (*Цель исследований*) Провести исторический анализ машинных технологий послеуборочной обработки зерна и подготовки семян и определить перспективные направления их развития. (*Материалы и методы*) Использовали историко-аналитический метод в приложении к техническим системам, в частности к технологиям послеуборочной обработки зерна и подготовки семян. Объекты исследований – оригинальные работы отечественных и зарубежных авторов за более чем 100-летний период и другая нормативно-техническая документация. (*Результаты и обсуждение*) Представили результаты эволюции машинных технологий послеуборочной обработки зерна и подготовки семян в РФ в течение последних 100 лет. Рассмотрели научные, технологические, технические и организационные вопросы развития машинных технологий обработки зерна и подготовки семян. Определили, что научные основы создания отечественных сепарирующих машин были разработаны в 30-е годы прошлого века. Отметили, что в 1934 году создана и поставлена на производство первая отечественная передвижная зерноочистительная машина производительностью 10 тонн в час на очистке зерна и 6-8 тонн в час – на очистке семян. Выявили последующие ключевые этапы: в 60-х годах разработана поточная технология послеуборочной обработки зерна; к концу 70-х годов с завершением работ по созданию агрегатов и комплексов все процессы послеуборочной обработки зерна впервые в стране были полностью механизированы. (Выводы) Доказали, что производительность труда в отрасли повысилась в 7-10 раз, в 2-3 раза снизилась стоимость обработки зерна, сократились его потери, ручной, неквалифицированный труд был исключен. Определили перспективные направления развития технологий обработки зерна и подготовки семян.

Ключевые слова: семена, зерно, послеуборочная обработка зерна, зерноочистительные машины, семяочистительные машины, зерносушильные машины, технологии поточной подготовки семян.

To ensure competitiveness and obtain high-quality products, modern agricultural farms must use healthy seeds, free from impurities, including seeds of other crops and weeds. For precision agriculture, as well as for use in precision seeding systems, seeds must be sized, free from mechanical damage, and also have high germination.

The seed industry, and with it the processes of post-harvest seed treatment, emerged at the beginning of the 19th century in European countries [1]. Its sustainable development over two centuries made it possible to reduce significantly the gap between the breeder and the industrial grower in order to bring the selection achievements to the farm without reducing the seeds quality. The seed industry includes technological and economic applications of many aspects of science, technology and business. It becomes a highly specialized industry, an important and integral part of efficient and highly productive farms.

In recent decades, domestic and foreign scientists' and specialists' researches were aimed at improving the seeds and grain quality in the process of post-harvest processing [2, 3]. However, despite the accumulated knowledge in the field of post-harvest grain processing, the seeds preparing technology for sowing is still somewhat of an art.

The transition to a market economy in the early 90s had a significant impact on the seed industry in the Russian Federation. The structure of grain-producing farms changed radically, in most of them the grain production volume decreased significantly. The form of grain producers ownership changed. Many people needed modern grain and seed cleaning equipment, and had extremely limited financial capabilities due to low profitability. The task of improving the seeds quality and reducing their losses in the process of post-harvest processing of grain and seeds preparation in the shortest possible time became extremely urgent.

An important aspect of crop production technological support in recent decades was the construction of expensive seed plants by transnational companies. For example, in the Pavlovsky district of the Voronezh region in September 2020, construction began on the Tanais seed plant of the French company Lidea. The volume of investments in the project was estimated at 2.6 billion rubles [4].

In this situation, questions about the potential of the domestic scientific and technical support of post-harvest processing of grain and seeds preparation technologies arise. The necessity for their further development and adaptation to market conditions posed new challenges for science and industry.

The research purpose is to carry out a historical analysis of the machine technologies of post-harvest processing of grain and seeds preparation and to determine the promising directions of their development.

Materials and methods. The authors used the historical-analytical method as applied to technical systems, in particular, to the technologies of post-harvest processing of grain and seeds preparation. The research objects are original works of domestic and foreign authors for more than a century: monographs, dissertations, research institutions reports, machine testing stations protocols, scientific journals, materials of numerous conferences, as well as descriptions for domestic and foreign patent documentation. Information and analytical materials of foreign and domestic agricultural exhibitions held in recent decades were also used.

Results and discussion. In pre-revolutionary Russia, in poor peasant farms, the grain harvest was processed mainly by hand, and in strong and landowners, they used hand-operated machines: winders, graders and triremes [5, 6].

For a long time, cleaning grain and seeds was based on manual labor. Especially a lot of it was required in the 30s on the leaks created in the country of collective farms, where large masses of grain were accumulated. People "swarmed" in hundreds, worked with shovels, baskets, buckets, sacks. Later they began to use primitive winders for two people. But there were still not enough workers. Life required other, more productive means of cleaning.

After 1917, the first scientific institutions for the agriculture mechanization were created in our country. One of the most important tasks that they solved was post-harvest processing of grain and seeds.

In 1934, under the leadership of the head of VIM mechanization laboratory of seed business Ulrich N.N. the first domestic mobile grain cleaning machine with a capacity of 10 tons per hour for grain cleaning and 6-8 tons per hour for seed cleaning and a VIM-2 machine with a capacity of 2-3 tons per hour were created and put into production. The latter served as a prototype for a whole family of machines built on its basis: VIM-SM-1, OS-3.0, OSM-3U, OS-4.5, etc. (*Fig. 1*). The laboratory specialists Z.L. Titz, G.T. Pavlovsky, I.E. Kozhukhovsky, P.P. Kolyshev, I.G. Voronov took an active part in the development and improvement of machines working bodies and technological schemes [7, 8].

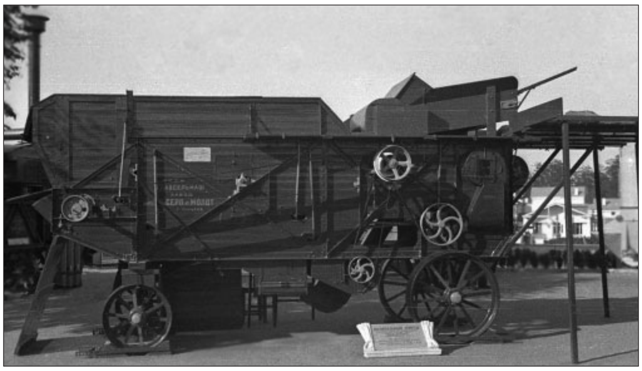

Fig. 1. Mobile air-sieve machine VIM-SM-1 with manual loading, produced at "Hammer and Sickle" plant (Kharkov)

Until the end of the 40s – the beginning of the 50s of the last century, most of the grain, leguminous and cereal crops harvest was processed on field and stationary grain complexes of collective and state farms with scattered grain cleaning and grain drying machines. A significant amount of grain was delivered to grain receiving points and elevators without processing. Such an organization of post-harvest grain processing required the involvement of many hundreds of thousands of workers and collective farmers for its implementation, led to commodity losses and a decrease in the quality of a large volume of grain. The labor costs and funds for post-harvest processing of grain and seeds preparation were particularly high. Heavy physical labor in unsanitary conditions, premature failure of equipment that worked in open areas were typical when processing grain and seeds with scattered machines on grain complexes.

The research carried out during this period made it possible to develop the initial provisions of the organization and technology of in-line post-harvest grain processing, characterized by the continuity of all processing stages in accordance with the technological process and a short production cycle. The basis of in-line processing was made up of complexes of machines and equipment at field grain complexes, grain-cleaning and grain-cleaning-drying points of collective and state farms.

The accelerated rise in grain production in the 50s became a systemic factor in the agriculture development. A successful solution to the grain problem was real only if the harvest was processed in a timely manner. The preservation and preparation of a huge amount of grain in a short agrotechnical period was possible only with the use of industrial processing methods.

The recommendations developed in the Agroengineering Center VIM on equipping the field grain complexes, the technological process of processing grain at its site, in the grain-cleaning and grain-cleaning-drying station of the collective farm and state farm, as well as on the correct choice of a set of machines, became widespread in the country's farms. Grain-receiving enterprises also widely used recommendations for seed treatment. In accordance with these recommendations, the country's farms were equipped with tens of thousands of field grain complexes, one- and two-line grain cleaning and grain cleaning and drying stations, where mobile machines were combined into lines [9].

Particular attention was paid to taking into account the peculiarities of cleaning and drying grain in farms of various zones. In the 1950s, there was an extremely limited selection of industrially supplied machinery and equipment for post-harvest grain processing and seed preparation. Grain and seed cleaning machines of that time were only stationary, with manual loading, cumbersome, and inefficient. Up to 4-5 people were required to service each vehicle. The problem of mechanizing grain processing was very acute. It was necessary to develop recommendations for the optimal combination of machines into production lines. During this period, the development of Machine Systems, agrotechnical (initial) requirements and technological parameters of stationary machines and equipment became relevant, which could form the basis of stationary industrial-type enterprises for post-harvest grain processing and seed preparation.

At the end of the 50s, post-harvest processing of grain and seeds was carried out mainly on open profiled grain complexes, and as soon as possible in order to neutralize the influence of weather. That was why grain cleaning machines and loaders were required with a higher capacity than were available. In addition, the existing grain cleaning equipment was stationary. To move it, a lot of people or equipment was required, distracted from other work. One of the main tasks assigned to design organizations, science and industry was the creation of self-propelled machines of high performance. In 1961, such a machine – ORP-20, a heap cleaner with a mobile capacity of 20 tons per hour – was developed at the State Design Bureau for grain cleaning machines and grain loaders at the Voronezhselmash plant [10]. The cleaner was in great demand and was produced in tens of thousands of units per year. Instead of the OVP-20A, the OVS-25 machine was put into production at the Voronezhselmash plant in 1983 (*Fig. 2*). Stationary machines OS-4.5 and self-propelled machines SM-4.5 made it possible to obtain seeds of the required quality.

At the beginning of the 60s of the XX century, the technological foundations of in-line machine processing of grain and seeds were scientifically substantiated and

Fig. 2. Self-propelled heap cleaner OVS-25

developed, which made it possible to fundamentally change the technical and social nature of production [7, 11].

The scientific basis for the transition to flow technology was made up of research in the following areas:

- technological properties of grain and seeds as an object of machine processing;
- modes of cleaning, separation, artificial drying of seeds, food and feed grains;
- justification of the required number of technological operations and the sequence of their implementation;
- scientific foundations for the construction and implementation of flow technology for processing grain and seeds;
- a system of machines and equipment sets, taking into account the variety of natural and climatic conditions, purpose, farms specialization, grain production volumes, as well as agrotechnical requirements;
- methodological and organizational principles of testing machines for post-harvest processing of grain and seeds.

When developing and implementing flow technology, the following features and requirements were taken into account:

- a significant difference between farms in terms of grain production requiring processing;
- significant differences in the physical, mechanical and technological properties of the processed material (culture, purpose, growing area);
- high contamination and moisture content of the grain heap arriving for post-harvest processing;
- a variety of climatic conditions (dry zones, zones of excessive and normal moisture);
- the maximum possible protection of service personnel and technical equipment from the negative effects of the external environment.

The solution to the problem was achieved as a result of the implementation of the following basic principles:

- combination of working bodies (machines) for performing technological operations in the form of a single unit (complex) of maximum technical readiness;
- creation of a family of unified units (complexes) of various capacities based on a basic multi-purpose model;
- using the block principle of constructing production lines for various purposes (seeds, feed grain, food grain, using specialized units – blocks);
- ensuring the versatility of working bodies and equipment, widespread use of interchangeable tools and simplest devices.

Work on the creation of production lines began in 1962. A system of unified production lines in the form of grain cleaning units and grain cleaning and drying complexes with maximum factory readiness with a capacity of 5; 10; 20 tons per hour, seed-cleaning attachments for them with a capacity of 5 tons per hour and grain-rice cleaning units with a capacity of 5 tons per hour. In the 60s and 70s of the XX century, grain cleaning units with a capacity of 40, 50 and 100 tons per hour were added, seed-cleaning attachments with a productivity of 10 tons per hour and grain-rice-cleaning-drying complexes with a productivity of 5 tons per hour (*Table 1*, *Fig. 3*) [10, 12, 13].

When creating production lines, it was envisaged that all units and complexes equipment should be designed for industry supply, and their construction was reduced mainly to installation.

By 1990, the domestic industry supplied agriculture with about 100 thousand complete production lines, which, according to the Central Statistical Administration of the USSR, provided processing using the most advanced technology up to 85-88% of the gross grain harvest, about 80-85 million tons.

Table 1

Technical characteristics of grain cleaning units and complexes

Indicators	ZAV-25	ZAV-40	ZAV -50	KZS-20SH	KZS-25	KZS-40SH
Productivity, t/h	25	40	50	16	20	16
Installed power, kW	81	45.4	148	131.5	221	160.1
Overall dimensions of the main structure, m:						
length	19.6	13.6	36.0	25.7	26.3	25.7
width	8.4	8.4	8.5	11.3	18.5	8.4
height	13.7	10.4	13.7	16.0	17.0	16.0
Mass of machinery and equipment, t	41.0	22.3	74.5	38.9	69.0	51.5
Specific metal consumption, t·h/t	1.64	0.56	1.49	2.43	3.45	3.22
Specific energy consumption, kW·h/t	3.24	1.14	2.96	8.3	11.05	10.01

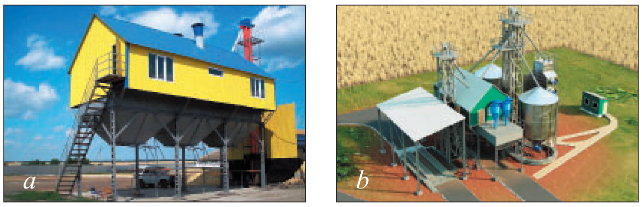

Fig. 3. Grain cleaning unit ZAV-40 (a) and grain cleaning and drying complex KZS with bunkers for temporary storage (b) in a modern design

Together with the technological task, a major social problem was solved: hard manual labor was replaced by the operator work at the control panel. Labor productivity increased 7-10 times compared to the system of mobile machines operating on grain complexes. During the harvesting period and during the preparation of seeds for work on grain complexes, it took 600 thousand less people. The processing cost was reduced by 2-3 times. In the 1980s, the annual economic effect obtained in agriculture as a result of the complete mechanization of post-harvest grain processing and seed preparation amounted to 1.2-1.6 billion rubles. [10].

Units and complexes are used as universal in many farms, they processed grain for both food and seed purposes. In this case, they were used in conjunction with standard seed-cleaning attachments built according to individual projects [14]. The use of aggregates and complexes for the preparation of seeds could not be considered an optimal solution, since in this case the seeds were subject to increased injury, there were relatively large losses in fodder waste or food grain. In addition, the problem of cleaning equipment from grain residues from the previous processed culture remained fundamentally important and unsolved.

Regardless of the new units and complexes introduction start for many years the bulk of the harvested grain would be processed on them. In this regard, additional measures were needed to reconstruct these units and complexes in order to improve their technical level and adapt to the tasks of specific farms. It was also necessary to make significant changes in the design of the modernized units and complexes.

According to the technologies and initial requirements developed at Agroengineering Center VIM in collaboration with Head Specialized Design Office on machines for cleaning grain of the Voronezhselmash plant, the Petkus enterprise (GDR) serially produced and supplied to the USSR sets of machines and equipment for seed cleaning and drying enterprises with a capacity of 1.25 tons per hour and lines for processing grass seeds with a capacity of 0.5 tons per hour. A series of standard projects was created, according to which the construction of seed processing plants was carried out [10].

In the 80s of the XX century, various options for post-harvest treatment and preparation of corn seeds were investigated. It was established that the technology of post-harvest treatment and seed preparation that developed more than 30 years ago and was used all the years did not correspond to the technologies and technical means of sowing corn, caring for it and harvesting that changed during this time, and increased requirements for post-harvest treatment of seeds, especially parent forms and hybrids.

The developed seed preparation technology provided:

- guaranteed receipt of first class seeds with minimal injury and maximum yield;
- the necessary flexibility when adjusting for the processing of different quality small and large batches;
- reducing the cost and labor intensity of seed processing and storage.

The scientifically grounded scheme for calibrating seeds into 4 fractions based on the shape and size of seeds became widespread not only in our country but also abroad.

The developed technology of post-harvest processing of seeds of parental forms and maize hybrids was used in the reconstruction of more than 70 plants and points for seed processing with a capacity of 250 and 500 tons per season, built according to standard designs. This made it possible to almost completely satisfy the needs of farms for high-quality seed. According to the Institute of Maize, the widespread use of hybrid seeds increased the crop yield by 20-30%.

In 1986-1989 the technology of in-line machine preparation of high-quality sunflower seeds was developed [15]. On farms, it was carried out with grain cleaning units of the ZAV type and complexes of the KZS type according to the same scheme as the treatment of grain crops seeds. Studies showed that the essential features of sunflower seeds did not allow them to be processed according to the "grain scheme". When using aggregates and complexes, a high degree of injury to seeds by transporting devices was noted, seeds cleaning from difficult-to-separate impurities were not ensured, and seed material calibration was impossible [16].

The technology included processing sunflower seeds in two stages:

- the first – reception, preliminary cleaning, drying, cleaning and temporary storage for the purpose of post-harvest ripening;
- the second – final cleaning, seeds calibration, dressing and inlay.

In accordance with this technology, the point for preparation and storage of sunflower seeds with a capacity of 400 tons per season was designed, built in the experimental farm of the V.S. Pustovoit All-Russian Research Institute of Oil crops (VNIIMK) "Berezanskoe" of the Krasnodar Territory and tested. The new technology provided an increase in the yield of 1st class seeds from the material coming from the field from 50 to 90%. The use of intermediate storage for post-harvest ripening with subsequent secondary and final cleaning made it possible to remove non-germinating, damaged and weak seeds from the seed material. According to VNIIMK, the yield of oilseeds with such preparation of the seed increased by 0.1 tons per hectare and more [7].

Research of the specific conditions and requirements for enterprises for post-harvest processing, storage and preparation of seeds in elite seed farms in the early 90s showed that the narrowest place for the seeds production of high reproduction remained their post-harvest processing and preparation.

In order to solve a problem of national importance, Agroengineering Center VIM developed a technology and structure for an enterprise for post-harvest processing, preparation and storage of seeds in elite seed farms. The implementation of the development made it possible to accelerate the rate of new varieties seeds reproduction, regularly carry out variety change and variety renewal, maintain the sowing qualities of seeds during post-harvest processing, and provided an increase in yield by 0.2-0.4 tons per hectare [17].

Traditionally used post-harvest processing of grain and seeds preparation technologies included air sieve machines, triers, and final cleaning machines (*Table 2*).

The principles of seed cleaning in domestic and foreign machines in the post-harvest processing of grain and seeds preparation were similar. The main foreign technologies advantage was high reliability, the use of robotic process control systems. However, the increase in the reliability of foreign machines was often accompanied by a significant increase in the machines mass, as well as the volumes occupied by them. For example, the analysis of machines for preliminary and primary cleaning of the company Cimbria (Denmark) showed that with an increase in productivity on wheat grain from 5 to 20 tons per hectare, the volume of the machine and its base area increased in a straight line (*Fig. 4*). In this case, the mass did not change significantly. However, with a productivity increase of more than 20 tons per hectare, the machines mass, as well as their dimensional characteristics, increased intensively, which in turn increased the equipment cost.

The outstripping prices growth for machinery and equipment in comparison with the agricultural products cost led to the fact that the agricultural producer could not purchase expensive machinery. Grain cleaning equipment was physically worn out by 70-80%. The provision of large and medium-sized farms did not exceed 35% of the required number of machines, and small and private farms had practically no required equipment. At the same time, the existing equipment for the separation of grain and seeds in terms of its operational indicators – specific productivity, efficiency, reliability and energy intensity – did

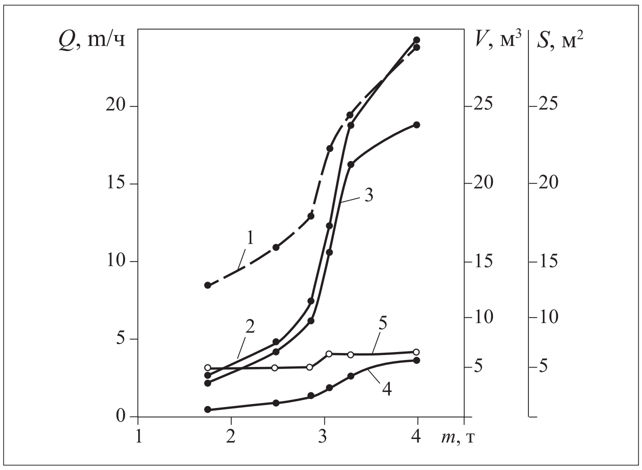

Fig. 4. Dependencies of productivity (Q), volume (V), base area (S) and mass (m) of air-sieve machines of DELTA SUPER family of Cimbria company (Denmark): 1 – volume; 2 – productivity on the seeds of the main grain crops; 3 – productivity on corn seeds; 4 – productivity on grass seeds; 5 – base area

not meet the increasing requirements for the seed and commercial material quality.

In this regard, the task of a scientific search for the development reserves of air-screen separators according to the criteria of the work quality, reducing the machines cost, increasing their versatility is especially urgent.

On the territory of the Russian Federation, there are more than 1000 species of weed seeds, some of them are easily isolated from the seeds of cultivated plants on modern grain-cleaning machines, and to isolate others, special machines and complex processing technologies are required [11, 18, 19]. It is generally recognized, for example, that it is difficult to isolate wild oat and barley seeds from oats, rye and wheat from rye, barley from wheat, wild radish and wheat from buckwheat, mustard and dodder from alfalfa, etc. The seeds of cultivated and weed plants that are difficult to separate are those in which the sizes and speed of soaring coincide with the indicators of the main crop or differ insignificantly from them [20].

For all grain crops seeds, the main disadvantage that reduced their quality was the content of hard-to-separate seeds of other cultivated plants in them. For this reason, about 40% of the sowing material of wheat, 46% of barley, 63% of rye, cultivated on the farms' grain complexes, did not meet the requirements for conditional seeds. This

Table 2

Main characteristics of grain and seed cleaning machines

Cleaning operations	Productivity, t/h	Power, kWt	Weight, kg	Specific energy consumption, kW·h/t	Specific metal consumption, t·h/t
Preliminary	5-50	5.4	1045	0.26	52
Primary	10-50	8.6	2170	0.28	91
Secondary	4-10	10.8	1773	1.32	286
Trier	7.5-10	3.3	1520	0.26	128,3
Final	2.5-9	10.6	1120	2.19	207

situation was the result of improper agricultural technology of growing crops for seeds, violation of the technical conditions for the operation of seed cleaning equipment and its imperfections [20].

The contamination of the seed material of a particular variety with seeds of other varieties or cultivated plants was a great danger. Biologically better adapted to local conditions and having a higher reproduction rate, these weeds could multiply rapidly and displace crops of the main variety. In production conditions, a species admixture was especially dangerous in seed crops: contamination of winter wheat with rye, soft wheat – durum, barley – oats and wheat, rice – red-grain weed forms, etc.

Due to the high multiplication factor of weeds, their number in the crop became hundreds of times higher than the content in the original seed, therefore, there were cyclical and progressively increasing difficulties with clearing the seed or killing weeds in the field. Due to the low efficiency of the measures applied in all directions, the costly problem of combating weed fields became an inevitable, habitual and planned measure, implemented mainly by the large-scale use of chemicals.

In order to achieve the fields cleanliness as in the leading grain-producing countries, it was necessary to simultaneously and effectively combat weeds when cleaning seeds from them, disinfecting manure and destroying weed plants in the fields.

The most important indicator that determined the seeds quality, and hence the yield, was their germination capacity. Its norms, specified in the standards, were established by laboratory values. Field germination of seeds was almost everywhere less than laboratory germination, it depended both on it and on meteorological and agrotechnical conditions. According to a number of sources, the field germination of seeds of major grain crops could be reduced by 10-40%. It turned out that on average 10-40% of seeds that normally germinate under laboratory conditions did not germinate in the field [21, 22]. In many soil and climatic zones, a decrease in field germination reduced yield. With a decrease in field germination by 1%, the yield of spring grain crops decreased by 1.5-3.0%, winter crops – by 1.0-1.5% [11].

One of the key reasons for the decrease in field germination of seeds was their injury. The problem of preventing injury to seeds by machines at all stages of their production, including post-harvest processing of grain and seeds preparation, became extremely important [23, 24]. To solve it, it was necessary to conduct comprehensive research with the participation of biologists, engineers and breeders.

Seeds sorting in our country and abroad is still the least developed part of the technology for preparing seeds for sowing [25, 26]. The problem is that the yielding and associated sowing qualities are assessed according to agronomic indicators: viability, germination, germination energy and growth strength, and sorting machines can separate seeds only by physical properties: size, individual weight, density. It has not yet been possible to find a direct or indirect relationship between the agronomic and the indicated physical properties of seeds.

It is assumed that one of the underutilized resources to improve the efficiency of seed sorting is the use of fractional technologies. They are promising for sorting due to the fact that seed machines separate the source material according to a complex criterion, which depends on the totality of physical and mechanical grain properties. Controlling the seeds physical properties during fractionation increases the cleaning efficiency on downstream machines.

In post-harvest processing of grain and seeds preparation technologies, before the material receipt for processing, as well as during processing, it is necessary to analyze the material for the content of impurities in it, that is, analysis of purity. In domestic technologies, this work is performed mainly by hand, which requires a large amount of laboratory technicians labor. In addition, manual analysis does not allow seed cleaning lines optimal control, which significantly hinders the effective control of the process and leads to the seeds loss and a decrease in their quality [27]. In foreign practice, technical means of technological lines control, including automatic sampling of material entering for processing and during its processing, have become an integral part of technologies [28, 29]. In this aspect, the development of systems for automatic sampling and laboratory machines for monitoring the purity of the processed material and analysis of impurities is a particularly urgent scientific and design problem.

Justification of machine technologies system, the nomenclature of technical means that ensure the minimum costs in most various grain-producing farms is a purely scientific task, and without its solution there is only the path of the spontaneous formation of the post-harvest processing industry, which will lead to a decrease in the profitability of production and an increase in the grain cost.

New technologies of grain-producing agricultural enterprises should provide the possibility of post-harvest processing and grain storage in the conditions of the farm with implementation at a time favorable to the owner.

The prospective development of the technological base of the post-harvest processing of grain and seeds preparation should be focused on the implementation of various options in the organization of post-harvest processing [30]. Along with the traditional continuous processing of grain with bringing it to the specified conditions in one pass, two-stage processing should be widely used, including:

- at the first stage – reception, preparation of food and seed grains for short-term storage (preliminary cleaning, temporary ventilation and/or drying if necessary) and storage of grain and seeds during the harvesting period;
- at the second stage – processing of food and seed grain with bringing to the required conditions in the post-harvest period.

The implementation of a two-stage technology will reduce grain losses and preserve its quality, as well as dramatically reduce capital costs for high-performance complex equipment, the loading of which is limited by the harvesting period.

Thus, the analysis of the development of machine-technological systems for post-harvest grain processing over the past 100 years showed that during this period, scientific, design organizations and industry created a system for post-harvest grain processing, which ensures its processing flow, the complex mechanization of post-harvest grain processing was completed.

The materials presented in this article reflect the historical aspects of the creation and development of technologies for post-harvest grain processing, as well as some priority areas for further technological development of grain processing and seed preparation.

Conclusions

1. Until the 60s of the 20th century, grain and seeds were taken on farms in open areas or covered complexes, using machines and mechanisms separately. All auxiliary technological operations - feeding the starting material into the machine, shipping the cleaning fractions, their packing or the formation of collars - were carried out manually. To service the machines and carry out loading and unloading operations, it was necessary to attract up to 100-150 people to work on grain complexes. When processing grain on separate machines, hard physical labor, negative environmental impact, significant losses and unsatisfactory quality of grain and seeds, and premature failure of equipment were characteristic.

2. In the late 50s and early 60s, with an increase in grain production and an increase in the country's combine fleet, equipment was required to mechanize work on open profiled grain complexes. One of the main tasks assigned to science, design organizations and industry was the creation of self-propelled machines of high performance. In 1961 a mobile heap cleaner ORP-20 with a capacity of 20 tons per hectare was developed. It was in great demand and was produced in tens of thousands of pieces a year. In a modernized form, OVS-25 is in demand at the present time.

3. By the end of the 70s, with the completion of work on the creation of units and complexes, all processes of the post-harvest processing of grain and seeds preparation for the first time in the country were fully mechanized. As a result, labor productivity in this industry increased by 7-10 times, the cost of processing grain decreased by 2-3 times, its losses decreased, manual, unskilled labor was excluded.

4. Changes in recent years have necessitated fundamental changes in technological support, structure and nomenclature of machines and equipment for post-harvest processing of grain and seeds preparation.

The main scientific task was the development of a system of post-harvest processing of grain and seeds preparation technologies, adaptive to the variety of zonal conditions and the characteristics of farms with different forms of ownership and volumes of grain production.

Particular attention should be paid to the development of a two-stage technology with the implementation during the harvesting period of operations that ensure the grain stability during storage, and in the post-harvest period – bringing grain and seeds to the required conditions.

5. One of the essential resources for increasing the efficiency of post-harvest processing of grain and seeds preparation technologies is fractional technologies. They are promising due to the fact that many grain and seed cleaning machines separate the source material on a complex basis, which depends on the totality of physical and mechanical properties of grain.

Controlling the properties of seed mixtures in the process of in-line processing by fractionation is an urgent scientific task of developing technologies for post-harvest seed preparation, especially when separating difficult-to-separate impurities and low-productive seeds from the main seed material.

6. The development of technologically effective, sparing and low-cost technologies of post-harvest processing of grain and seeds preparation, available to producers of various forms of ownership and with different volumes of grain production, is possible only on the basis of new knowledge about the processes of separation and preservation of the biological potential of grain and seeds.

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