Organizational and Economic Justification for Super-Early and Early Harvesting of Grain Crops with Stripping Without Threshing for Highly Nutrient Feed Preparation

Viktor Pakhomov[1,2], Dmitry Rudoy[2], Oleg Bakhchevnikov[1], Nikolay Shevchenko[1,2], Anastasiya Olshevskaya[2], and Tatyana Maltseva[2(✉)]

[1] Agrarian Research Center "Donskoy", Nauchny Gorodok Str., 3, Zernograd 347740, Russia
[2] Don State Technical University, 1, Gagarin Sq, Rostov-On-Don 344003, Russia
vif.tatyana@yandex.ru

Abstract. Harvesting grain by stripping allows organizing separate harvesting for feed in the early stages and for food purposes in the phase of full ripeness. The aim of the study is the organizational and economic substantiation of the combined technology of stripping without threshing grain crops of the early stages of ripeness and the technology of preparing granulated fodder from an unmilled heap. The technical and economic assessment of the technology of harvesting winter wheat by stripping in the early stages of ripeness without threshing and processing it into fodder was carried out by comparing the operating and reduced costs for performing a set of technological operations. The cost of cleaning grain crops by stripping without threshing and separating the heap is 2.65 times lower than when using the technology of stripping with a combine threshing and separating the heap. The cost of performing operations on traditional (from grain) and new (from a grain heap) pelleted feed production technologies are practically equal. But the total cost of performing technological operations for harvesting grain by thrashing without threshing and preparing pelleted feed from an unmilled heap using the new technology is 24.3% lower than with the traditional technology of harvesting by stripping with threshing and preparing feed from grain. The use of the non-cereal part of the ear of early ripeness in the composition of the feed will increase the yield of raw materials from 1 hectare of the sown area by 20–30%. The proposed technology is cost-effective and promising for implementation in agricultural enterprises in the south of Russia.

Keywords: Ear · Stripping · Threshing · Grain heap · Early ripeness · Grain loss · Pelleted feed · Economic efficiency · Feed cost

1 Introduction

In Russia, at present, an urgent task is to increase the nutritional value of feed for farm animals, which is achieved by increasing the protein content in them. But the use of expensive protein supplements significantly increases the cost of feed [1]. Therefore, it

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is necessary to develop new technologies to increase the protein content in feed, making the most of the opportunities of the local plant raw material base [2].

The main raw material for the preparation of feed in Russia is feed grain, in particular grain of winter wheat. This grain, which has reached full ripeness, contains only 10–12% protein, which is not enough [2]. But if the grain is harvested in the early stages of ripeness, then it is possible to increase the protein content in the feed. Thus, a grain of waxy ripeness contains 12.5% of protein and 24% of gluten versus 11 and 22% in the phase of full ripeness [3].

It is usually preferred to harvest grain in the phase of full ripeness, based on its suitability for combine harvesting, low moisture content and better preservation during post-harvest processing and storage, while losing valuable nutrients. The reason is the fact that although the grain of the early stages of ripeness contains more nutrients and is more suitable for use in feed, the equipment and technologies available to a typical farm do not allow harvesting and preserving such grain without significant losses.

In addition to grain, an additional source of nutrients for fodder can be the non-cereal part of the ear of wheat, which contains 5% protein and 2% fat in the phase of full ripeness, and even more in the early stages [4]. But the traditional technology of combine harvesting does not include the operation of collecting and accumulating the non-grain part of the ear, which requires the development of new solutions.

The above considerations led to the emergence of K.S. Churilova's hypothesis about the need for separate harvesting of cereals for food and fodder purposes and its preliminary economic justification, which showed the prospects of using this technology [5–7]. But the lack of technical means at the disposal of agricultural enterprises that would allow for effective harvesting of wet grain in the early stages of ripeness made this possibility speculative.

Recently, more and more actively introduced a new technology for harvesting grain crops by stripping, based on the use of stripping headers [8]. As a result of its application, the ears of grain crops without stalks come from the header to the threshing device of the combine [9].

Threshing grain in the phase of milky and pasty ripeness, which has high moisture content and is still quite soft, will lead to its significant injury, and threshing ears will be difficult. Therefore, for use for feed purposes, the grain of the early stages of ripeness must be harvested as part of the grain heap without threshing and chaff separation.

The possibility of this is provided by the use of technology, according to which ears combed by a drum of a special trailed header are collected in a storage device, loaded into a vehicle, and then delivered for additional threshing and separation of the grain heap to a stationary [7, 10] (Fig. 1).

This technology for harvesting grain of full ripeness was proposed in the works of A.I. Buryanova [7, 10–13] and economically substantiated by I.B. Berenstein [14–17]. According to I.B. Berenstein, its application increases productivity by 65.6%, reduces fuel consumption by 39%, and the cleaning time decreases by 65% [16].

Obviously, this technology can be used for harvesting grain and non-grain part of an ear of early ripeness, eliminating the operation of threshing and separation of the ear into fractions. This will make it possible to organize the harvesting of grain in an agricultural enterprise at different times, i.e. part of the crop is harvested by a method

Fig. 1. Winter wheat harvesting with a trailed combing header loading unmilled grain heap into a vehicle

involving threshing, in the phase of full ripeness to obtain food and seed grain, and part - in the phases of milk, pasty or milky-wax ripeness by the method of stripping without separating the grain heap to obtain feed raw materials. Such an organization of harvesting, presumably, will make it possible to prepare grain raw materials for the production of feed with a higher content of protein and fat, further increasing it by preserving and using the non-grain part of the ear.

In addition to the possibility of harvesting feed with a high content of nutrients, the technology of harvesting grain strips in the early stages of ripeness allows to reduce the load on the combine farm of the farm during the harvesting of food and seed grain of full ripeness, which will allow it to be completed in a shorter time, thereby reducing losses from shedding of grains and a decrease in their quality when over-growing [13, 18, 19]. In addition, grain in the early stages of ripeness is much less prone to shedding than fully ripe, so harvesting it at this stage will further reduce losses [11].

The usual technology for processing feed grains into feed, consisting in grinding it, mixing it with additives and granulating the resulting mixture, is unsuitable for processing unmilled grain heaps of early ripening phases. It is necessary to modify it taking into account the properties of this type of raw material.

An obstacle for the processing of a grain heap, harvested at an early date, is its high moisture content – from 35 to 80%. Therefore, it is necessary to first reduce its moisture content to 20–30%. In the south of Russia, in summer conditions, a grain heap can be easily dried to the desired condition by atmospheric drying with the possibility of its intensification by using a drum-type drying unit.

Since the grain and non-grain materials are unevenly distributed in the resulting grain heap, it is desirable to pre-normalize it to obtain a more homogeneous mixture.

To ensure long-term storage in winter and ease of storage, it is rational to subject the obtained feed from the undivided grain heap to granulation. The research results of S.N. Zykovich show that a feed mixture containing chaff can be successfully granulated [12, 20]. The moisture content of the feedstock of 20–30% allows the use of inexpensive

screw presses for the formation of granules with low energy consumption and higher productivity in comparison with dry pressing granulators [13, 21–23]. In the process of pelleting, additional drying of the feed occurs, as a result of which the pellets will have the required moisture content of 12–18%.

Among other things, in favor of the new technology for the production of feed is the fact that when it is prepared from dry and strong grain of full ripeness, the crushing operation in a hammer mill requires significant energy consumption, while the softer and wetter grain of the early stages of ripeness, and even more so the non-grain part ears can be processed with low energy intensity.

The above considerations made it possible to develop and substantiate a technology for preparing feed for cattle and pigs from an undivided grain heap harvested in the early stages.

The purpose of the study is organizational and economic substantiation of the integrated technology of stripping without threshing grain crops of the early stages of ripeness and the technology of preparing granulated fodder from an unmilled heap.

2 Materials and Methods

The technical and economic assessment of the technology of harvesting winter wheat by stripping in the early stages of ripeness without threshing and processing it into fodder was carried out by comparing the operating and reduced costs for performing a set of technological operations [24]. The effectiveness of this technology was compared with the traditional technology of harvesting wheat and preparing feed from it. The criterion for comparison was the operational and total cost of performing technological operations, equated to the value of the reduced costs. The calculation of operating and reduced costs was carried out according to the generally accepted method according to the actual data obtained during the traditional harvesting of wheat and stripping in agricultural enterprises of the Zernograd district of the Rostov region. Wheat yield is taken at 5 t/ha. When evaluating technologies, the losses of grain during harvesting and from self-damping were taken into account. The calculation of grain losses during combine harvesting was carried out according to the method of A.A. Sukharev and N.G. Ignatieva [13, 25, 26] using the data of A.I. Buryanova and O.A. Kostylenko [21, 27, 28].

When calculating the economic efficiency of harvesting wheat by stripping, methodological techniques and actual data of I.B. Berenshtein [29–32] and A.I. Buryanov [13, 19], as well as data obtained at the Agrarian Research Center "Donskoy" during harvesting with stripper headers. The data on the cost of combine harvesting operations were obtained based on the analysis of fuel consumption for their implementation.

The composition of the combed heap of wheat is (by weight): free grain 60–80%; grains in ears of 10–20%; straw and chaff 20–30% [32].

When determining the cost of performing technological operations for preparing feed, we used our own data obtained at the Agrarian Research Center "Donskoy" and DSTU as a result of experimental studies of laboratory analyzes of the quality indicators of the starting material and final raw materials and production verification of the elements of these technologies.

A feature of this study is that the economic efficiency of the technology for harvesting grain and processing it for fodder was assessed collectively. We compared the traditional combine harvesting of full ripe grain by stripping with threshing and separating the grain heap, followed by cleaning the grain, crushing it, mixing with additives and granulating, and stripping early without threshing and separating the heap, followed by normalizing the heap, drying it, mixing it with additives, and granulation.

3 Research Results

As a result of theoretical and experimental research, a technology has been developed for harvesting grain crops for forage purposes by stripping at an early date at the stage of milk, pasty and milk-wax ripeness of grain. In the course of its implementation, the collection of wheat for fodder purposes is carried out by a specially designed trailed stripper header, which is aggregated by a wheeled tractor. The combed heap is immediately unloaded into the trailed storage hopper. The next technological operation is the reloading and transportation of the combed heap to a stationary processing point by vehicles with large-capacity bodies.

Unmilled grain heap is processed into feed using a new technology, including the following operations:

1. Normalization of raw materials to increase their homogeneity. The grain heap is processed in an expander operating in the mixer-normalizer mode (processing temperature 35–40 °C). As a result, a more homogeneous mixture (expanded) is obtained, with evenly mixed grain and non-grain part of the ear (sex). The resulting feed mixture has a moisture content of 40 to 60%.
2. The resulting expandate is subjected to atmospheric drying with tedding until it reaches a moisture content of 14–18%. The drying process can be intensified by using drum dryers.
3. Grinding the dried expand with a hammer mill.
4. Mixing of the crushed grain heap with mineral and other additives (3–7% of the feed weight) in a horizontal or inclined mixer.
5. Granulation of the feed mixture on a screw press, which ensures low energy consumption of the process.
6. Cooling and separation of granules, direction of screening for re-granulation.

Based on the data of the production check of the harvesting of grain by stripping, the comparative unit cost of performing operations for traditional and new technologies was determined (Table 1).

As shown by the results of the economic assessment, the cost of combining grain harvesting by stripping without threshing and separating the heap is 2.65 times lower than when using the technology of stripping with combine threshing and separating the heap. This is due to the fact that these operations account for 65% of the cost of performing the entire combine harvesting technology. The economic effect of the exclusion of threshing and separation of the heap from the technological scheme more than covers the negative effect of the increase in the cost of transporting the crop to the current (stationary) due to the excess of the mass and volume of the unthreaded heap over the clean grain.

Table 1. Specific cost of performing technological operations for harvesting grain crops by stripping, RUB/t

Stripping technology with threshing and grain separation (based on 1 ton of grain)		Stripping technology without threshing (based on 1 ton of grain heap)	
Operation	Execution cost	Operation	Execution cost
Ears stripping	105	Ears stripping	105
Ears threshing	320	–	–
Separation of the grain heap	65	–	–
Unloading grain	10	Loading a heap into a drive	12
Grain transportation on current	81	Transporting a heap to a stationary	102
Total	581	Total	219

Thanks to this economic effect, a significant reserve is created to reduce the cost of feed produced from unmilled grain heaps while simultaneously increasing its nutritional value due to harvesting at an earlier date.

Based on the data of the production check of methods for preparing pelleted feed for pigs, the comparative unit cost of performing operations for the traditional (from grain) and new (from the grain heap) technologies of its production was determined (Table 2).

Table 2. The cost of performing technological operations preparation of pelleted feed (per 1 ton of feed), RUB/t

Feed preparation technology from crushed grain		Feed preparation technology from unmilled grain heap	
Operation	Execution cost	Operation	Execution cost
Grain cleaning	115	Heap normalization	134
–		Drying heap	73
Grain grinding	234	Heap grinding	156
Mixing grain with additives	189	Mixing heap with additives	189
Feed pelletizing	235	Feed pelletizing	235
Cooling pellets	63	Cooling pellets	63
Separation pellets	12	Separation pellets	12
Total	848	Total	862

As shown by the results of the economic assessment, the cost of performing operations on traditional and new technologies for the production of pelleted feed are practically equal. The cost of preparing feed from an unmilled grain heap using the new

technology is only 1.6% higher. This can be considered a positive result, since the proposed technology is more complex than the traditional one and requires more operations, in particular, normalization (expansion) and drying of the heap. But grinding less durable in comparison with ripe grain of an expandate from an unmilled heap of early stages of ripeness requires a shorter duration of this operation and, accordingly, lower energy costs, which reduces the cost of this technological operation by 33% and, as a result, leads to an approximate equality of the cost of preparing granulated feed for traditional and new technologies.

However, due to the lower cost of harvesting wheat without threshing and separating the heap, the total cost of preparing feed using the new technology will be lower than for the traditional one.

The aggregate comparative unit cost of operations for traditional and new technologies for stripping and preparation of pelleted feed are shown in Table 3.

Table 3. The total cost of performing technological operations of stripping and preparation of pelleted feed, RUB/t

Technology	Execution cost	Technology	Execution cost
Stripping with threshing and grain separation	581	Stripping without threshing	219
Preparing crushed grain feed	848	Preparing feed from unmilled grain heap	862
Total	1429	Total	1081

Thus, the total cost of performing technological operations of stripping and preparing pelleted feed using a new technology, including early harvesting of cereals by stripping without threshing and preparing feed from an unmilled heap, is 24.3% lower than with the traditional technology of stripping with threshing and preparation of feed from grain with additives. As you can see, a slight excess of the cost for the technology of preparing feed from an unmilled heap over the traditional one is covered by a significant reduction in the cost of stripping due to the abandonment of threshing and separation of the grain heap.

But the advantages of the proposed technology for harvesting grain crops in the early stages and preparing granulated feed from them are not limited to a reduction in the cost of performing technological operations.

Harvesting of cereals, in particular wheat, by stripping in the early stages, when the grain is more firmly bound to the ear leads to a rather significant reduction in grain losses from shedding. Based on the data of prof. I.B. Berenshtein [15] and A.I. Buryanov [27], these possible losses were estimated by us at 0.3 t/ha (with a yield of 50 c/ha), i.e. 6% of the harvest. It is this figure that will increase the amount of raw materials for feed obtained from the harvesting area.

4 Discussion

The research results have shown the high economic efficiency of the proposed technology for harvesting grain in the early stages by stripping without threshing and preparing feed from an unmilled heap.

Earlier harvesting of a part of the sown area occupied by grain crops allows to reduce the load on combine harvesters in the most intense period when harvesting food and seed grain of full ripeness, which makes it possible to shorten its time and reduce grain losses from its stagnation.

The refusal to thresh the ears and separate the heap leads to an increase in the amount of feed raw materials obtained from 1 hectare of the sown area. Based on the well-known fact that the content of the non-cereal part (straw and chaff) in an unmilled heap is 20–30% by weight, the total amount of feed prepared by an agricultural enterprise can also be 20–30% more than in the production of feed from threshed grain of full ripeness. In addition, such feed has a higher nutritional value due to the increased protein content due to harvesting in the early stages of maturation. According to previous data, feed from grain heaps of early ripeness contains 9–11% more protein and has a better amino acid profile.

The proposed technology has natural limitations that restrain its application. Firstly, these are the tight deadlines in which it is possible to harvest crops in the early stages of ripeness, and they can be further reduced due to unfavorable weather conditions. And secondly, this is a limited time frame for the preparation of pelleted feed from the raw materials obtained. The fact is that an unmilled heap of early stages of ripeness has a shorter shelf life than a grain of full ripeness, which means that it must be processed in a short time.

Nevertheless, taking into account the existing advantages, the proposed technology of stripping and preparation of feed from grain crops of the early stages of ripeness is very promising for implementation in agricultural enterprises.

5 Conclusion

The results of the study allow us to conclude that the proposed technology of super-early and early stripping of feed grain of spike crops and production of granulated fodder from an unmilled heap is effective, allows, in general, for an agricultural enterprise to reduce grain losses during harvesting from shedding, to collect a product that is more valuable in terms of fodder properties, and to increase the nutritional value of the feed prepared from it.

The cost of cleaning grain crops by stripping without threshing and separating the heap is 2.65 times lower than when using the technology of stripping with a combine threshing and separating the heap. The cost of performing operations on traditional (from grain) and new (from a grain heap) pelleted feed production technologies are practically equal.

But the total cost of performing technological operations for harvesting grain by thrashing without threshing and preparing pelleted feed from an unmilled heap using the new technology is 24.3% lower than with the traditional technology of harvesting by

stripping with threshing and preparing feed from grain. The use of the non-cereal part of the ear of early ripeness in the composition of the feed will increase the yield of raw materials from 1 hectare of the sown area by 20–30%.

The proposed technology is cost-effective and promising for implementation in agricultural enterprises of the main grain-producing regions of Russia and has no foreign analogues.

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