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ORIGINAL ARTICLE

New energy-saving method for drying maize seeds

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The study aimed to analyze the known methods of energy-saving drying in chamber grain dryers, to study the technical and technological parameters of a new energy-saving drying method, and to establish its influence on the sowing and yield properties of seeds of maize hybrids and their parent components, to determine the technical-economic efficiency of drying when using different types of fuel. Various technical and technological energy-saving methods during drying of corn seeds are investigated, such as two-stage drying of cobs with drying in grain, the return of spent heat carrier to the drying zone (recirculation), application of maximum allowable temperatures of heating of cobs (intensive drying). To study a new method of drying maize hybrids and their parent components used a typical chamber dryer SKP-10 in combination with a new heat generator TPG-1/25, for burning plant materials. During the complex operation, the temperature and ventilation regimes, parameters of the working and spent heat carrier's relative humidity, drying speed, dryer productivity, and quality indicators of dried seeds were determined. Sowing qualities and yield properties of dried corn seeds at the new complex were at the level of control, and in some cases, exceeded it. For control were seeds were dried in a laboratory dryer at 39 °C with forced air circulation and indoors at 20-25 °C. The new drying method's technical-economic efficiency is determined, and the significant economic effect of using corn rods as fuel is established.
Keywords: chamber dryer, heat generator, types of fuel, technological process, seed quality, economic efficiency.

Introduction

Compared to other cereals, Corn seeds are harvested with high humidity, so there is a need for immediate drying (Barrozo et al., 2014; Chauhan et al., 2017; Jokiniemi & Ahokas, 2014). Drying of seed corn should be carried out in cobs, in special chamber dryers, at relatively low temperatures, which prevent seed injury (Abasi & Minael, 2014; Coradi et al., 2015; Coradi et al., 2016). The quality of seeds, sowing and yield properties, preservation, and sowing material cost depends on this process (Claumann et al., 2017; Suleiman et al., 2018).

Thermal drying of corn cobs is carried out following the Instructions, which requires significant energy consumption. Following the Instruction requirements, the drying temperature is 35-50 °C and depends on the grain's humidity and purpose (Zhidko et al., 1982; Naumenko et al., 1990). Considering the noted parameters, the norm of consumption of conditional fuel, which made 3.36 kg/t-% of moisture, or 20 kg on 1 planned ton, is established. It is calculated that the technical and operational performance of the chamber grain dryer is developed according to this norm: the energy consumption required to evaporate 1 kg of moisture is 8.56 MJ, the thermal efficiency is 30-35% of the theoretically possible and 55-60% relative to the best samples of mine grain dryers (Kyrpa & Kulyk, 2016).

Energy saving is becoming increasingly important due to the constant rise in prices for all types of traditional energy resources - diesel and gaseous fuels. The problem is exacerbated because corn seed production is gradually moving to temperate climates where better growing conditions are in place, but the grain is harvested at too high a humidity level and needs to be dried. There are various technical-technological methods of reducing energy materials' consumption in the technology of drying corn seeds (Table 1). Such techniques include two-stage drying of cobs with drying in the grain, the return of spent heat carrier to the drying zone (recirculation), the use of maximum allowable heating temperatures of cobs (Atanazevich, 1989; Kyrpa, 1986; Stankevych et al., 1997; Alejnikov, 2002; Fushimi & Fu, 2014; Amantea et al., 2018).

Table 1. Techniques of energy-saving drying and modernization of chamber grain dryers.

Drying	Fuel savings (liquid, gaseous), %	Modernization
On biofuels	100	New heat generator
Two-stage (cobs + grain)	25–29	Additional dryer
With coolant recirculation	20–26	Re-equipment
Intense	18–24	Re-equipment

All methods require some modernization of chamber dryers for corn. Due to modernization, it is determined that it is possible to achieve savings of gaseous and liquid fuels within 18–29%. Among the mentioned ways of energy saving, the two-stage method requires the highest costs, as it is necessary to install an additional grain dryer for drying corn in the grain and withstand mild temperatures. Methods that positively affect reducing energy consumption include sealing the dryers, maximizing the load on the drying chambers, and separating the lost grain from the cobs.

It should be noted that all known methods of energy saving were aimed only at technical and technological modernization of chamber grain dryers without changing the type of fuel. A fundamentally different energy-saving area is the use of vegetable fuels (corn rods, straw, sunflower husks, wood chips, pellets, sawdust) and heat generators for their combustion (Del Campo et al., 2014). Recently, various heat generators for burning biomass with a capacity of 0.5–5.0 MW have been offered in Ukraine and abroad, but not all of them are suitable for drying seed corn in cobs (Table 2). The main disadvantage is non-compliance with the drying temperature, the instability of the combustion process.

Table 2. Characteristics of heat generators for drying grain and seeds.

Model	Thermal power, kW	Manufacturer
Ekopal RM	700	Company "MetalERG", Poland
Kepler	Below 12000	Company "Kepler Weber" +, Brazil
Zanin	1000-2000	Company "Zanin F.lli", Italy
TG	500	PAT "Dozavtomaty", Ukraine
TPG	2000–3500	TOV "Steyt", Ukraine

The work aimed to establish the technical-technological and technical-economic parameters of the new energy-saving drying and establish its influence on the sowing and yield properties of corn seeds.

Materials and methods

All the necessary data were obtained by conducting experimental, laboratory, and field experiments in the conditions of the State Enterprise DG "Dnipro" of SE IGC of NAAS and TOV "Agrosphere" and theoretical analysis and mathematical calculations.
The experimental part of the research is related to the study of the energy-saving complex's technical and technological parameters - a chamber grain dryer, which is equipped with a new heat generator for burning corn rods brand TPG 1/25. The research methodology was following the recommendations for drying the seed material of cereals (Kul'kov & Kogan, 1977; Vitozhenc et al., 1983; Borodin & Mishhenko, 1985). The coolant's temperature was determined using thermographs brand M-16AN during the drying process at various points of the grain dryer, in parallel, recorded its relative humidity. A paddle anemometer determined the coolant volume is entering the grain dryer in various modes of operation of the fuel and ventilation department, fuel consumption - by direct weighing of corn rods that entered the heat generator's furnace. The drying rate of corn cobs (V, %/ h) was determined taking into account the duration of the process (τ, h), indicators of the initial (W1,%) and final (W2,%) moisture content of grain (Wз, %) and rods (Wc, %) by the formula:

$$V = \frac{\left[(W_1^3 \cdot 0,75) + (W_1^c \cdot 0,25)\right] - \left[(W_2^3 \cdot 0,8) + (W_2^c \cdot 0,2)\right]}{\tau},$$

where 0.75 and 0.25 - the ratio of grain and rods to drying; 0.8 and 0.2 - the ratio of grain and rods after drying.

All indicators were determined using instruments and methods used in the grain processing system.
The quality of seeds of maize hybrids and their parental forms, sowing, and yield properties were studied with laboratory and field experiments. In drying on the energy-saving complex, cob samples were taken to determine the quality of seeds. The control was the seeds, which were dried in the laboratory. Sowing qualities were determined according to the methodology of the state standard for seed quality assessment (DSTU 4138–2002) and according to the methods of the SE IGC of NAAS (Kyrpa, 2004). Quality indicators such as grain and rods moisture, the weight of 1000 kernels, heat cracking, germination energy, and germination by standard method and cold germination method determine the weight of 1000 sprouts were investigated. Grain moisture was calculated by the standard method by drying portions weighing 50 g in an oven SESH-3+M at a temperature of 130 oC for 40 minutes. For corn grain with more than 18% moisture content, two-stage drying with pre-drying of the sample was used.
The weight of 1000 kernels was determined by a laboratory-modified method; two samples of 500 kernels were taken from the seed sample, which was weighed to the nearest 0.01 g. The weight of each sample was calculated by the weight of 1000 kernels and obtained its average weight. The difference in the two samples' weight should not exceed 3% of the average weight of 1000 kernels. Heat and mechanical cracking were determined according to the methodology of the SE IGC of NAAS.
Field studies were performed according to the method recommended for maize (Lebid 'et al., 2008) on plots with an estimated area of 15.68 m2, in 4-fold repetition with a randomized location of plots. Accounting to field germination doing began when the seedlings were in a state of "awls," and their number on the site was not less than 10-15%. Before harvesting, the actual number of plants on the plot was counted. Maize cobs were harvested by hand, and samples weighing 5 kg were taken from the first and third replicates to determine the crop's structure. Samples of cobs were threshed, determined the yield and moisture content of grain. Data were processed by mathematical and statistical methods using computer programs (Dospekhov, 1985).
The amount of moisture was determined by the Duval formula, namely:

$$\lambda = \frac{(W_{cob1} - W_{cob2}) \cdot 100}{100 - W_{cob2}},$$

where Wear 1, 2 - weighted average humidity of corn cobs, respectively, before and after drying, %.
The formulas determined the weighted average humidity of cobs before drying (Wcob1) and after drying (Wcob2):

$$W_{cob1} = (W_1^з \cdot 0,75) + (W_1^c \cdot 0,25);$$

$$W_{cob2} = (W_2^з \cdot 0,8) + (W_2^c \cdot 0,2).$$

To calculate the technical-economic efficiency, the parameters of proposed energy-saving drying method and EXCEL spreadsheets recommendations were taken into account (Lesnikova & Harchenko, 2002; Kyrpa et al., 2015). Drying costs were calculated in 2019 prices.

Results and discussion

The most significant results on energy-saving and research and development work by various institutions of Ukraine and the former CIS were obtained at the Institute of Grain Crops of NAAS of Ukraine (formerly the All-Union Research Institute of Corn, Institute of Grain Farming, Institute of Steppe Agriculture) and Odessa National Academy food technology. The studied drying systems included the parameters of its optimization and preservation of product quality (Weigler & Mellmann, 2014).

Two-stage drying. Significant energy savings were achieved by two-stage drying of corn seeds. The method included drying cobs in a chamber corn dryer SKP-6 to a grain moisture content of 20–22%, threshing cobs, drying grain to a moisture content of 12–13% in a mine grain dryer 2DSP-32OT, at mild temperatures (Table 3). Liquid diesel fuel was used in the fuel and ventilation department of the dryer.

Table 3. Technical and economic indicators of two-stage drying of corn seeds (Odessa region, Lyubashivsky elevator), 1986.

Drying method	Grain drying rate, %/h	The productivity of the SKP-6 dryer chamber, t-%/h	Fuel consumption, kg/t-%	Injury,%	Germination,%		Grain yield, t/ha
					GOST	field	
Control*	0.277	14.9	3.5	28.9	99	85	4.90
Two-stage drying	0.654	19.7	2.1	81.1	63	52	4.08

Note: * – regulated method of drying

With the help of two-stage drying, it was possible to improve the technical-technological indicators significantly. Thus, the total duration of drying was reduced by almost 2 two times, and fuel consumption was reduced by 40%. However, the germination energy and seed germination at the threshing stages and drying in the grain on the mine grain dryer decreased due to significant mechanical injury.

Recirculation of the heat carrier. Recirculation drying significantly reduced fuel consumption. The recirculation mode worked as follows: drying began in the normal mode, then after 25-30 hours, the recirculation system was connected and periodically changed the direction of movement of the heat carrier. To ensure this mode's operation, a diffuser with a diverter valve was installed between the grain dryer and the fuel and ventilation compartment to change the direction of movement of the heat carrier. This drying method was investigated on a chamber grain dryer SKPM-18M with the combustion of gaseous fuel (Table 4).

Table 4. Technical and economic indicators of the dryer SKPM-18 and the quality of corn seeds by different drying methods (SE DG "Dnipro"), 2014.

Drying method	Technical-economic parameters			Seed germination, %		Grain yield, t/ha
	speed drying, %/h	costs per 1 t-%				
		fuel, MJ	electricity kW-h	GOST	field	
Control*	0.28	87.9	1.50	96	82	7.20
Recirculation of the heat carrier	0.27	65.1	1.43	96	86	7.21
LSD 0.05					2.0	0.13

Note: * – regulated method of drying

During the grain dryer operation in the recirculation mode, fuel consumption was reduced by 26%, electricity by 5% compared with the control drying mode. Reuse of spent coolant did not impair corn seeds' quality; its germination and yield remained high. However, recycling required the modernization of the chamber corn dryer.

Intensive drying. To reduce energy consumption, regime the drying temperature is important (El-Abady, 2014; Huart et al., 2018). At intensive regime temperatures, drying occurs quickly, with lower specific consumption of energy materials and a higher utilization factor of the grain dryer (Table 5). Recirculation was carried out automatically using a remote clock mechanism.

The use of an intensive temperature regime (55 °C) increased the average drying speed of corn seeds by 20–27%, the productivity of the drying chamber by 15–21% provided high sowing and yield properties compared to the typical regime. However, increasing the carry heat temperature for a long time to 60 °C negatively affected seeds' yield properties, depending on their varietal characteristics and humidity. Therefore, intensive drying can be used for seeds of more heat-resistant hybrids of corn (excluding parent forms) with a harvesting humidity of 30-32%.

Energy-saving drying. There are various energy-saving drying methods, for example, using solar panels (Abdalgawad et al., 2018). We first conducted a study of the energy-saving drying method on the complex, which included a chamber corn dryer SKP-10 with a heat generator TPG-1/25. The heat generator operates in the mode of direct combustion of fuel - corn rods, the efficiency is 90-95%. The corn dryer is equipped with a reversing system (changing the direction of purging of the chambers) of the heat carrier at specific intervals.

Table 5. Influence of drying regimes and parameters on technical-economic indicators of SKP-6 dryer operation and quality of corn seeds (Lyubashivsky elevator, SE DG "Dnipro"), 1996–2014.

Drying method	Parameter drying		Technical-economic parameters		Seed germination, %		Grain yield, t/ha
	the temperature of the agent,° C	frequency of reversal, min.	speed of drying, %/h	the productivity of chamber, t -%/h	laboratory	field	
Control *	-	-	-	-	98	84.5	4.67
Typical	45-50	720-1440	0.3	15.1	96	80.9	4.54
Intensive	55	30	0.38	18.3	96	83.1	4.6
	60	30	0.39	19.2	95	83.0	4.32
			LSD 0.05 3.8 0.16				

Note: * - natural drying of cobs.

The drying temperature regime fluctuated from 38 to 43 °C, depending on cobs humidity; it decreased at the beginning of drying and increased (Fig. 1). During the drying process, the temperature difference between the corridors of the dryer was also recorded. Gradually, the temperature difference decreases and almost disappears at the end of drying.
The ventilation regime, which consisted of the corn dryer depending on the ventilation units' capacity, was also investigated. Two C-4-70 ventilation units with a capacity of 70 thousand m^3/h were installed in the dryer. Heat carrier flow was measured during both and each fan's operation separately at different modes of air access to the fuel-ventilation compartment (Table 6). With full air access, the specific consumption of coolant is 1393 m^3/h per ton of cobs, which fully satisfies the norm set for hybrids and parental components (800-1000 m^3, respectively). Simultaneously, the norm established for hybrids, even if one fan will work, is maintained. With limited access, the norm is maintained only for hybrids.

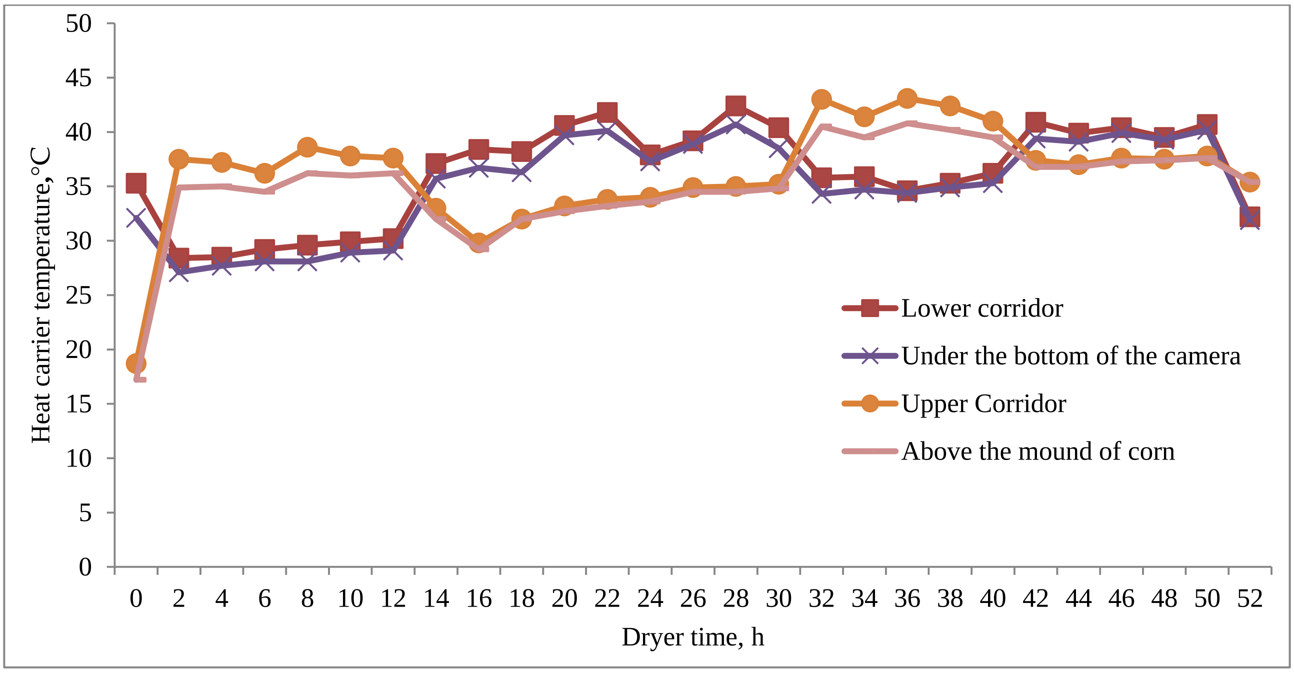

Fig. 1. Graph of temperature change of the heat carrier depending on the direction of purge and duration of drying

Table 6. Total and specific heat carrier supply depends on the dryer's fuel-ventilation department with the TPG-1/25 heat generator mode.

Air access regime	Two fans		Fan № 1		Fan № 2	
	total costs, m^3/h	specific costs*, m^3/h/t	total costs, m^3/h	specific costs*, m^3/h/t	total costs, m^3/h	specific costs*, m^3/h/t
Total	125400	1393	71812	798	53588	595
Limited	72520	806	38509	428	34011	377

Note: * - specific costs in terms of 90 tons of cobs.

In the drying process, the indicators of the relative humidity of the working and spent heat carrier are essential, on which the rate of moisture recoil of cobs depends. The heat carrier's relative humidity likely varies depending on the chemical composition of the fuel, the content of hydrogen, oxygen, carbon dioxin, and water vapor. In our experiments, the relative humidity of the operating

heat carrier ranged from 10 to 12%, which was used - 44-20%, depending on the drying duration. The relative humidity of the atmospheric air did not affect the parameters of the heat carrier. (Table 7).
The energy-saving drying method's overall efficiency is determined by certain technical-technological parameters - drying speed, dryer productivity, and quality indicators. In the experiments, both the drying rate and productivity depended on the cobs' weight, humidity, drying exposure, and the presence of the lost grain from the cobs (Table 8).

Table 7. Parameters of the relative humidity of the working and spent heat carrier depending on the exposition of drying.

Exposition of drying, h	The working of heat carrier		Spent heat carrier		Control - atmospheric air	
	relative humidity, %	temperature, °C	relative humidity, %	temperature, °C	relative humidity, %	temperature, °C
4.5	10	36.1	44	29.1	60	6.5
9.0	11	39.7	43	31.4	77	3.0
13.5	11	39.4	39	31.7	80	2.3
18.0	10	40.0	36	31.5	59	7.0
22.5	10	41.0	35	31.4	60	7.4
27.0	10	38.7	28	32.3	68	4.8
31.5	12	39.9	24	33.2	83	2.1
36.0	11	38.8	23	32.5	85	1.8
40.5	10	39.0	21	32.2	71	5.4
45.0	12	39.9	19	32.1	64	8.6
49.5	10	38.7	19	31.9	68	5.1
54.0	10	38.2	20	32.5	72	4.8

Table 8. Technical-technological parameters of the energy-saving method of drying cobs 2016-2019.

Hybrid / parent form	Weight of cobs, t	The moisture of cobs,%		Exposition of drying, h	Drying speed,% / h	Productivity, t -% / h
		before drying	after drying			
Orzhytsia 237 MV	6.0	21.8	11.0	28.0	0.33	2.3
DN Zoriana	18.4	26.9	11.2	54.0	0.25	5.3
DN Khortytsia	14.3	24.1	10.6	74.0	0.16	2.6
DB Khotyn	13.5	33.6	13.9	88.0	0.21	3.0
DN Pyvykha	15.1	29.2	10.9	88.0	0.18	3.1
Kros 255M	9.3	27.3	10.1	80.5	0.20	2.0
Kros 260M	12.0	37.3	13.3	88.0	0.25	3.3
Kros 254M	4.2	24.7	11.0	54.0	0.25	1.2
Kros 222S sterylna	3.94	25.8	10.2	54.0	0.29	1.3
DK744SVZM	4.2	27.2	10.9	36.5	0.39	1.8
DK365SVZM	11.4	32.2	12.1	61.5	0.30	6.0

Table 9. Influence of drying methods on sowing and yield properties of seeds of maize hybrids, 2016–2019.

Hybrid/line	Initial grain moisture,%	Drying method	Seed germination,%			Grain yield, t/ha
			laboratory	cold test	field	
Orzhytsia 237 MV	20.3	Control *	98	90	80	5,50
		Control**	95	92	81	5,40
		Energy saving	95	93	84	6,03
		$LSD_{0.05}$			4.6	0.33
DN Akvozor	21.5	Control *	96	93	82	7,61
		Control**	97	95	84	7,80
		Energy saving	98	95	81	7,79
		$LSD_{0.05}$			4.6	0.30
DB Khotyn	29.5	Control *	99	90	76	7,25
		Control**	97	90	80	7,27
		Energy saving	97	92	80	7,21
		$LSD_{0.05}$			4.4	0.35
Kros 254M	22.4	Control *	97	83	75	5,45
		Control**	98	79	73	5,44
		Energy saving	97	90	82	5,47
		$LSD_{0.05}$			4.2	0.53
Kros 255M	25.2	Control *	99	90	88	5,81
		Control**	98	86	87	6,03
		Energy saving	95	89	85	5,99
		$LSD_{0.05}$			3.9	0.53

Note: * - natural drying; ** - laboratory drying, t = 38 °C.

Of great importance is the effect of drying on the energy-saving complex on the quality of seeds. The control was natural drying indoors at a temperature of 20–25 °C and drying in a laboratory dryer with a heating temperature of 38 °C with forced ventilation, after drying of maize hybrids harvested with 20.3–29.5% moisture content, seeds with high germination rates. Field and laboratory germination rates for all hybrids were almost the same. The seed yield of the hybrid Orzhytsia 237 MV after drying on the energy-saving complex was higher than the seeds of laboratory drying.

The same happens when drying the seeds of the parent forms. The seeds, dried on an energy-saving complex, had high sowing and yielding properties. The seeds of the parent component Kros 254M after drying in a laboratory dryer slightly decreased germination.

The energy-saving drying method had a positive effect on positively affected the seed quality of maize hybrids and their parent components, collected with a moisture content of 20.3–29.5%. Laboratory and field germination was at the level of control. The yield did not decrease relative to control (Table 9).

The drying volume in the experiments was 7143.6 t-%. The drying process's main costs using different types of fuel (corn rods, diesel, and gaseous fuels) were determined based on the volume. Costs included the cost of fuel, electricity, and wages. The total cost of drying corn cobs using different types of fuel is: with diesel - 34.80 EUR / t; gaseous - 20.40 EUR / t; corn rods - 7.50 EUR / t (Table 10).

The use of a new TPG heat generator increases the cost of electricity and wages, compared to traditional drying methods on diesel and gaseous fuels. This is due to the heat generator's design features, a more complex fuel supply mechanism to the combustion chamber, and the presence of additional electric motors that ensure its operation. However, the use of this drying method, due to corn rods' cheapness, allows saving on the whole process about 60-80%, following the cost of drying on traditional fuels.

Table 10. Technical-economic efficiency of drying corn seeds depending on the type of fuel, in 2019 prices.

Parameters	Unit	Fuel		
		diesel	gaseous	corn rods
Fuel consumption:				
- physical	kg/t-%	2.30	2.60	8.80
- total for drying	kg	16430	18573	62864
Electricity consumption:				
- specific	kW/t-%	3.09	2.86	3.57
- total for drying	kW	22100	20400	25500
Money paid for work:				
- wages	euro/t-%	0.12	0.12	0.17
- total for drying	thousand euros	0.90	0.90	1.20
The cost of drying everything:				
- fuel	thousand euros	15.40	8.20	1.10
- electricity	thousand euros	1.30	1.20	1.50
	thousand euros	17.60	10.30	3.80
Total costs	euro/t	34.80	20.40	7.50

The operational heat carrier parameters (temperature, relative humidity, and volume) determined by us ensured fast and even drying of corn cobs without seed quality loss. After drying by a new method, conditioned seeds with high field germination and productivity were obtained. We established that corn rods' use as fuel gives a significant economic effect; the cost of drying is reduced by 415-895 UAH / t compared to other studied fuels.

Conclusions

Based on the research results analysis, the main methods of energy-saving drying of corn seeds in grain dryers of the chamber type are established; these are intensive drying, reversing, heat carrier recirculation, and two-stage drying. The most practical is the reversal and recirculation of the heat carrier, which reduces fuel consumption by 20-26% while maintaining the seeds' quality.

A fundamentally different direction of energy-saving based on new heat generators operating from biomass combustion has been identified. The main technical-technological parameters of the grain dryer SKP were determined, equipped with a heat generator TPG-1/25.

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