RESEARCH ON THE TESTING OF AXIAL FLOW THRESHING APPARATUS FOR IMPROVING THEIR QUALITATIVE WORKING INDICES
/
CERCETĂRI PRIVIND TESTAREA APARATELOR DE TREIER CU FLUX AXIAL ÎN VEDEREA ÎMBUNĂTĂŢIRII INDICILOR CALITATIVI DE LUCRU AI ACESTORA

Cristea O-D[1)], Niţu M.[*1)], Constantin G.[2)], Munteanu M.[2)], Milea O-E.[2)], Zaharia R.[3)], Grădilă M.[3)]
[1)]INMA Bucharest / Romania; [2)] UNST Politehnica Bucuresti – ISB / Romania; [3)]ICDPP Bucharest / Romania
E-mail: rosumihaelan@yahoo.com
DOI: https://doi.org/10.35633/inmateh-70-58

Keywords: *separation, testing, seeds, axial flow, parameters, threshing*

ABSTRACT
The working process of the threshing apparatus is characterized by the qualitative working indices they achieve during operation. In order to maximize them with effect on reducing the percentage of seed losses, damaged seeds and impurities in the seed mass, respectively increasing the percentage of separated seeds, certain adjustments can be made on the component elements of a threshing apparatus in accordance with the type, quality and the condition of the material subjected to the threshing operation. In this paper, a
n axial flow threshing apparatus was tested under different conditions, in order to be able to obtain the data necessary to adjust the working parameters, which would allow it to be operated at the desired quality indices (losses, injuries and minimal impurities together with separation of seeds from ears and straw almost completely).

REZUMAT
Procesul de lucru al aparatelor de treier este caracterizat de indicii calitativi de lucru pe care îi realizează în timpul exploatării. Pentru maximizarea acestora cu efect asupra reducererii procentului pierderilor de semințe, semințelor vătămate şi al impurităţilor in masa de seminte, respectiv al cresterii procentului de seminţe separate, asupra elementelor componente ale unui aparat de treier se pot efectua anumite reglaje in concordanta cu tipul, calitatea si starea materialului supus operatiei de treier. În această lucrare a fost testat un aparat de treier cu flux axial în diferite condiţii, pentru ca în final să se poată obţine datele necesare reglării parametrilor de lucru, care să-i permită exploatarea la indicii calitativi doriţi. (pierderi, vătămari şi impurităţi minime coroborat separarea seminţelor din spice şi paie aproape în totalitate).

INTRODUCTION
The harvesting work of a grain combine integrates continuous evolutionary processes, which include the following stages: threshing process, cutting, cleaning and separation etc. (*Hanna et al., 2013; Vlădut et al., 2023*). An important role in the function of the combine is represented by the threshing process, seed wastage that occurs during process of harvesting being conditioned by threshing and technology process (*Fu et al., 2018; Ivan et al., 2015a; Khir et al., 2017; Ivan et al., 2015b*). The level of damage is direct index of seed threshing that can influence their value of market and storage (*Khazaei et al., 2008; Mirzazadeh et al., 2012*) depending on many factors, especially separation regime on the sieve (*Pruteanu et al., 2023; Pruteanu et al., 2017*).

To optimize the quality of the entire threshing process, the separation and modelling of the threshing process emerged as a need (*Vlădut et al., 2022; Vlădut et al., 2023*). Threshers with axial flow, appeared much later because the combines with longitudinal threshers appeared after combine with tangential apparat (after the 1970s). In a very short time, the first researches in the field were carried out, evolving rapidly until now, when a satisfactory modelling of the separation process was reached (*Sheychenko et al.; Qirui et al., 2020; 2018; Vlădut et al., 2022*). In general, the very good results obtained in the working process of this type of threshing apparat, achieving a percentage of separated seeds that often exceeds 99%.

According to the operations that the grain harvesting machines perform, they can carry out the working process in two modes: a stationary mode or in work (self-propelled), the work process in motion being the most widespread. The mechanical method of seed collection principle is based on impact frictional forces, especially combined impact and friction (*Fu et al., 2018; Cujbescu et al., 2021*).

A main component of the combine is the threshing and separating machine. Depending on the specified type, the combines can be of two types: with axial longitudinal flow or with tangential flow *(Li et al., 2020)*.

In the case of threshers that have an axial flow, the harvested ears move along the threshing machine following a helical trajectory, between the rotor and the counter-rotor (*Jiangtao et al., 2020*), during several rotations, the process of separation of ears in this type threshing apparat realizing in a longer period of time by the frequent impact of the ears with the bars of rotor respectively counter rotor at a low speed (*Sinha, 2014*).

Almost 80% of the percent of seeds are separated in the first part of the axial threshing apparat, and the rest of 20% of the seeds in the process of separation in the second part of the rotor (*Alizadeh et al., 2009*). In general, the threshing principle achieves very little seed damage with potential and higher threshing performance (*Sessiz et al., 2003; Abdeen et al., 2021*). On the other hand, the proportion of damaged seeds in threshing machines with axial flow has a lower percentage than that in threshing apparat with tangential flow (*Sinha, 2014; Jinshuang W et al., 2018*). The harvested grain is threshed as it moves transversely between the drum and counter-rotor in tangential flow threshing machines.

The threshing device has a major role in the performance of the machine (*Zhou et al., 2022; Abdeen et al., 2021*), because it can influence the degree of efficiency of the threshing process (maximum efficiency, with very good separation and very little loss of seeds) (*Zhou et al., 2022*), threshing power requirement and the efficiency and adaptability of the whole machine (*Su et al., 2021; Hud V., et al., 2023; Jinshuang W et al., 2018*).

Grain harvesting machines can only operate in inconstant soil, crop and environmental conditions and will have to guarantee as little seed loss as possible and a predefined quality stage of the final product (cereal seeds in the seed basket). During the harvesting process, the degree of efficiency for grain threshers and seed cleaners can undergo dynamic changes (*Guan et al., 2020; Song et al., 2022*). The wastage in the process of threshing, cutting, separating and cleaning changes progressively due to increase of the advance speed of the machine (combine) and with the decrease of the moisture level of the seeds, the threshing process efficiency increases with the reduction of displacement speed of the self-propelled combine. Also the working capacity of the threshing machine decreases by decreasing the peripheral speed of the rotor and by increasing the distance between the rotor and counter-rotor (*Suliman et al., 2012*).

The most important parameters that can characterize the performance of a combine can be listed: profitability rate, threshing production capacity, seed wastage, degree of seed impurities, cracked seeds and energy consumption (*Li et al., 2020; Ali et al., 2021; Hud V., et al., 2023*). The distribution of the air flow is based on significant working parameters of the harvesting machine, which can affect directly its performance indicators (reported by loss of seed and the degree of purity of the seeds) (*Xu et al., 2020*).

Degraded seeds have a reduced market value, their storage is negatively affected (*Masek et al., 2016*) and have a lower germination contribution. Reducing harvest and post-harvest losses is fundamental to ensure global food security. (*Guan et al., 2022*).

Furthermore, in the paper *(Aliev et al., 2018)*, analyses were made regarding the using air flow to separate sunflower seeds, removal of impurities and selection into size fractions in separators equipped with flat sieves having various sizes of meshes.

MATERIALS AND METHODS

For testing, an axial flow thresher was used (figure 1), which is intended for stationary threshing of wheat, rice, barley, oats, sorghum, peas, vetch, as well as other crops grown for seeds, this being made up of: feed basket - *1*, scraper conveyor - *2*, an intensive threshing and separation device - *3*, placed longitudinally on the thresher and driven by transmission - *4*, transmission that also has the role of speed variator.

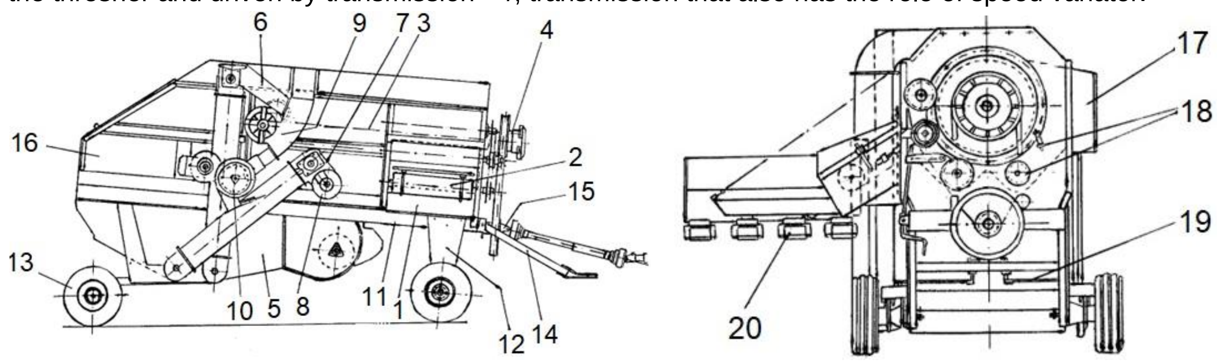

Fig. 1 – Axial flow thresher. Lateral and rear view

The thresher is provided with a cleaning system *5*, a seed elevator *6*, an elevator for the transportation of ears *7*, the additional threshing device *8*, the countercurrent cleaning system *9* and the device for sorting the seeds into three categories *10*. On the chassis *11* is mounted a transport system made up of supports with fixed wheels with tires *12*, pivoting wheels *13* and the drawbar *14*. The thresher is driven by a cardanic transmission *15*.

In the rear part of the thresher there is the chaff outlet, the lateral straw outlet *17*. Along the thresher there are transport screws that act as transmission shafts.

The thresher is equipped with a steering system and holes for bags. The intensive threshing and separation device consists of a rotor, with the beating rods mounted at an angle of 45°. The grate is provided with rods equally spaced from the beater and with possibility to adjust this distance.

The semi-cylindrical jacket is provided with flared separation holes and round conductors. The separating cylinder is equipped with the straw outlet and the rotor with curved blades, which acts as an agitator and straw blower.

Thresher operation

The mass of seeds or other crops to be threshed is placed in the feed basket from where the material is picked up by the scraper conveyor, with a flow rate proportional to the adjustable opening between the scrapers and the bottom of the conveyor, and inserted into the thresher. Under the action of the beater and counter-beater, 85-95% of the seeds are detached from the ears and more than 60% of the seeds are separated. Due to the action of the beater bars and the semi-housing, the threshing and the separation of the seeds continue up to a level of over 90%, and then the threshing, the separation of the seeds and the evacuation of the straw are finalized in the housing. The pile is a mixture of seeds and chaff that enters the cleaning system, where the chaff is separated and removed through a channel outside.

The seeds taken over from the cleaning are passed through the countercurrent cleaning and then reach the separating cylinder where through the mouths of the bags they are collected in three categories: weed seeds and broken seeds, good seeds and large impurities.

The thresher is operated with the help of a cardan from the power take-off of a U 445 or U 650M tractor. The purpose of these tests is to obtain the experimental data necessary to investigate the way the threshing processes are carried out and the separation of seeds and straw parts, the size of the losses during threshing and separation, depending on the flow variation, the peripheral speed of the beater, the S/SP mass ratio, feed speed and angle, beater – counter-beater distance.

Main characteristics

- machine type: intensive threshing machine;
- power required for operation: min. 27 HP;
- PTO speed: 540 rpm;
- working capacity: 0.8÷1.5 t/h;
- type of seed separation from straw: with perforated separation cylinder;
- type of cleaning system: with 2 cleanings;
- seed sorting system: cylindrical sieve sorter with 4 sorting holes for: small seeds / normal seeds / large impurities.
- seed collection system: in bags;
- hourly working capacity at actual time: 1.5÷4 kg/s;
- *threshing apparatus characteristics:*
    - beater length: 2000 mm;
    - beater diameter: 560 mm;
    - beater speed: 600÷1200 mm;
    - no. of beater bars: 8;
    - no. of counter-beater bars: 8;

The equipment used for experiments

For testing the axial threshing apparatus (to INMA Bucharest institute) a machine (batose) B-90 axial flow was used thresher, the length of threshing apparatus being 2,000 mm. The threshing machine was operated from the tractor power take-off with a cardan equipped with a one-way coupling.

Fig. 2 – Thresher lateral view

The material separated, resulted by threshing process was collection in a matrix (10x5) of collecting boxes, the dimensions of every box having (L x l x h): 200x200x100 [mm], numbered from 1 to 10 along the length, respectively: A, B, C, D, E on the width.

A tarp with the size 2x3 [m^2] was used for the collection of the material evacuate from the threshing apparatus (unthreshed ears, fragmented straw, chaff, unseparated seeds, etc.). The tensometric marks were mounted on the beater shaft to measure the moment of resistance.

The threshing machine has the housing of the apparatus with holes of 40x20 mm dimensions, the separation active surface of the housing representing about 55% of its total surface. In the sides of the housing, helical bars of 30 mm height and 500 mm length are mounted, which can be set up at 60° respectively 75°.

The parameters which influence the performance of the working process:

- rotor speed *n* [rpm], adjustable of 600÷1200 rpm (corresponding to this speed range); the peripheral speed of the rotor was in the limits: 22÷32 m/s;
- material flow rate *q*: 1.5÷4 kg/s;
- the distance δ between the rotor bars and the counter-rotor (δ_i = 12÷24 mm at the entrance, respectively δ_e = 3÷7 mm at the exit);
- material feeding speed: 3.1÷4.65 m/s;
- material supply angle: 15÷35° (measured with a clinometer).

The characteristic of the material used

For the experiments with the axial flow threshing apparatus, autumn wheat of Fundulea 4 variety (*Triticum aestivum*, variety *erythrospermum*), created at ICPT Fundulea through individual selection from the Fundulea 29/2*Lovrin 32 hybrid combination, was used.

The morphological characteristics of the Fundulea 4 variety are:

- plant height: 76÷86 cm;
- ear length: 7.6÷9.8 cm;
- seed weight in the ear: 1.0÷2.0 g;
- the absolute 1000 seed mass: 39÷45 g;
- average no. of siblings per plant: 1÷3.

The morphological characteristics of the material used in the tests:

- plant height: 74.05 cm;
- ear average length: 8.145 cm;
- the absolute 1000 seed mass: 44.4 g;
- average no. of seeds in the ear 32.25.
- seed moisture: 11.8÷18.1% (depending on the period of the tests);
- straw parts moisture: 18.2÷26.36% (depending on the period of the tests).

The material harvested was tied in sheaves with 200÷250 mm diameter and stored in a dry enclosure, so that during the 2 months that the experiments lasted, the moisture of the straw parts varied slowly from 22.8% to 11.1%.

The parameter modified during the experiments was the ratio of seeds/straw parts S/SP, which varied within the limits of 1/0.4÷1/2.5.

To determine the moisture content of the material in all experiments, the following were used: electronic balance, analytical balance, oven.

RESULTS

Several parameters' values were changed sequentially throughout the experiments, including the beater's peripheral speed, the material flow rate, the S/SP ratio, the feeding speed, and the separation between the beater and the counter-beater.

On the chassis of the threshing apparatus module, the block of boxes for collecting the separated material is positioned independently in the support guides.

A cover and removable panels for driving the material were strategically placed to catch the evacuated straw pieces, preventing it from spreading over the seeds.

The plant material necessary for the test was weighed and then placed on the supply conveyor belt, predominantly with the ears forward relative to the direction of travel.

In the tests carried out with the variation of the ratio (S/SP), before being placed on the conveyor belt, the plants were placed manually, ear to ear, aligned at the base of the stems. With the help of a circular saw, the stems were cut in the corresponding proportions of -25%, -50%, -75%, -97%. This corresponds to cutting heights of the plants at harvesting of respectively: 18.5 cm; 37 cm; 55.5 cm; 72.5 cm.

Putting the thresher into operation is done by starting the tractor engine, from its power take-off, operating the threshing apparatus, where the speed is verified and adjusted accordingly.

After finishing the experiment, the material collected in the boxes was weighed separately as follows:

- separated seeds;
- unthreshed and separated seeds (seeds that go in the return circuit).

Samples from the quantity of separated seeds were taken in order to calculate the moisture content of the seeds and the proportion of damaged seeds.

The block of collecting boxes was removed after the bulk of material collected on the tarpaulin was weighed and recorded. 50 numbered plastic or paper bags were filled with the contents of the 50 collection boxes. Figure 3 shows the image of a collecting box with separated material in it.

The material on the tarpaulin was handled carefully manually, being divided into evacuated straw sections, unthreshed ears (threshing losses), and threshed and unseparated seeds (separation losses). For each test, to measure the moisture of the straw parts, a sample was collected from the evacuated straw parts.

Fig. 3 - Collecting box with separated material

The separated material from the 50 bags was handled as follows: each bag's contents were weighed and then divided into separated seeds, separated but unthreshed ears (seeds for the thresher's return-ear circuit), and separated straw portions.

The separated seeds in each collection box were manually split into these parts and then weighed using an electronic scale. Preset seed quantities were taken from the entire mass of separated seeds, by the method of fractionation into quarters, to determine the moisture of seeds and to separate them into fractions as whole, broken and damaged seeds, that were then weighed using an electronic balance.

The moisture content of the seeds and of the straw parts was determined by drying them using a laboratory oven at a temperature of 105°.

Separated material processing for a test was performed on the same day of conducting the experiment and during the following day. All data was recorded into preliminary tables of measurements.

The results obtained during the tests are presented in tables 1 and 2 and in figure 4:

Table 1

Separate material [g]

Box no.	A	B	C	D	E	Sum [g / %]	
L1 = 20 cm	78.7	103.7	211.0	246.2	93.3	**732.9**	*11.25*
L2 = 40 cm	145.0	157.0	365.6	470.6	175.8	**1314.0**	*20.17*
L3 = 60 cm	134.2	191.3	397.0	391.1	158.0	**1271.6**	*19.52*
L4 = 80 cm	120.6	144.3	302.0	250.2	217.6	**1034.7**	*15.89*
L5 = 100 cm	104.4	98.6	166.5	173.8	177.9	**721.2**	*11.07*
L6 = 120 cm	79.5	67.3	86.8	92.5	92.7	**418.8**	*6.43*
L7 = 140 cm	76.0	44.0	89.8	103.6	202.2	**515.6**	*7.91*
L8 = 160 cm	49.6	44.1	79.3	126.2	147.3	**446.5**	*6.86*
L9 = 180 cm	5.4	2.1	7.3	21.2	18.3	**54.3**	*0.83*
L10 = 200 cm	1.0	0.14	0.55	0.97	1.97	**4.63**	*0.07*
L (2m)	**794.4**	**852.34**	**1705.85**	**1876.37**	**1284.24**	**6514.23**	***100.00***

Table 2

Separated seeds [g]

Box no.	A	B	C	D	E	Sum [g / %]	
L1 = 20 cm	17.2	39.4	107.9	194.0	76.9	**435.4**	*12.694*
L2 = 40 cm	50.1	65.0	196.7	363.7	146.4	**821.9**	*23.963*
L3 = 60 cm	53.6	76.7	230.0	284.0	121.0	**765.3**	*22.312*
L4 = 80 cm	55.3	67.0	195.4	174.9	132.3	**624.9**	*18.219*
L5 = 100 cm	65.2	51.8	104.5	107.3	91.5	**420.3**	*12.254*
L6 = 120 cm	36.8	18.6	22.7	21.0	28.6	**127.7**	*3.723*
L7 = 140 cm	28.5	12.3	14.6	2.1	33.1	**90.6**	*2.641*
L8 = 160 cm	22.0	12.0	10.6	8.7	30.0	**83.3**	*2.429*
L9 = 180 cm	3.8	1.0	1.1	5.0	5.5	**16.4**	*0.478*
L10 = 200 cm	0.83	0.04	0.16	0.35	0.81	**2.19**	*0.064*
L (2m)	**333.33**	**343.84**	**883.66**	**1161.05**	**666.11**	**3387.99**	***98.777***

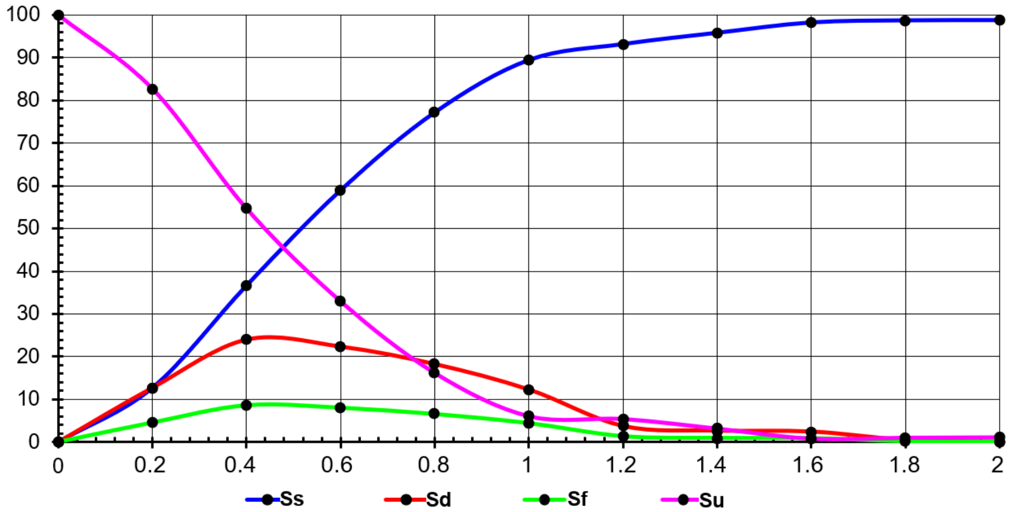

Fig. 4 - Variation in the percentage of separated (S_s), unthreshed (S_u), free (S_f) seeds and their distribution density (S_d) along the rotor's length, L

Tables 3-5 show the variations in losses depending on: *material feeding speed* (F_s) and *moisture* (m); *material feeding rate* (Q) and *moisture* (m), respectively the *peripheral speed of the rotor* (P_s) and *moisture* (m).

Table 3

Seed losses depending on material feeding speed and moisture

Parameters	Feeding speed [m/s]					
	F_{s1}	F_{s2}	F_{s3}	F_{s4}	F_{s5}	F_{s6}
	0.06	0.075	0.09	0.1323	0.225	0.36
	Material moisture [%]					
	9.48					
Losses in the threshing and separation process [%]	0.804	1.38	0.961	0.952	0.916	0.921

Table 4

Seed losses depending on the material feeding rate and moisture

Parameters	Material feeding rate [m/s]					
	Q_1	Q_2	Q_3	Q_4	Q_5	Q_6
	0.483	0.61	0.838	1.05	1.25	1.96
	Material moisture [%]					
	9,21					
Losses in the threshing and separation process [%]	0.699	0.788	0.916	0.921	1.223	1.38

Table 5

Seed losses depending on the peripheral speed of the rotor and moisture

Parameters	Peripheral speed of the rotor [m/s]					
	P_{s1}	P_{s2}	P_{s3}	P_{s4}	P_{s5}	P_{s6}
	19.478	21.048	23.248	28.274	38.761	41.469
	Material moisture [%]					
	11.92					
Losses in the threshing and separation process [%]	1.67	1.244	1.212	0.852	0.734	0.65

CONCLUSIONS

Carefully following the results of the tests, it can be observed that the main qualitative indices that are desired to be obtained in the grain harvesting process are very good, the separation of the seeds was achieved in a percentage of over 98.777÷98%, the losses of seeds during separation depending on the moisture (in the first place) but also on the material feeding speed, the feeding flow rate and the peripheral speed of the rotor, the maximum losses of 1.67% being obtained when a peripheral speed of the rotor below 20 m/s was used.

REFERENCES

[1] Abdeen M.A., Salem A.E., Zhang G. (2021). Longitudinal axial flow rice thresher performance optimization using the Taguchi technique. *Agriculture*, 11, 88. DOI: https://doi.org/10.3390/agriculture11020088.

[2] Ali K.A.M., Zong W., Md-Tahir H., Ma L., Yang L. (2021). Design, simulation and experimentation of an axial flow sunflower-threshing machine with an attached screw conveyor. *Appl. Sci. 11*, 6312. DOI: https://doi.org/10.3390/app11146312.

[3] Aliev EB, Yaropud VM, Dudin VYr, Pryshliak VM, Pryshliak NV, Ivlev VV. (2018). Research on sunflower seeds separation by airflow. *INMATEH – Agricultural Engineering*, 56(3): 119-128

[4] Alizadeh M.R., Bagheri I. (2009). Field performance evaluation of different rice threshing methods. *Int. J. Nat. Sci. Eng*. 3, 139–143.

[5] Cujbescu D., Gageanu I., Iosif A. (2021). Mathematical modeling of ear grain separation process depending on the length of the axial flow threshing apparatus, *INMATEH-Agricultural Engineering* 65 (3), pp.101-110;

[6] Fu J., Chen Z., Han L., Ren L. (2018). Review of grain threshing theory and technology. *Int J Agric & Biol Eng.* 11(3), 12–20.

[7] Govindaraj, M., Masilamani, P., Asokan, D., Selvaraju, P. (2017). Effect of Different Harvesting and Threshing Methods on Seed Quality of Rice Varieties. *Int. J. Curr. Microbiol. Appl. Sci., 6*, 2375–2383.

[8] Guan Z., Zhang Z., Jiang T., Li Y., Wu C., Mu S. (2020). Development and test of speed control system for combine harvester threshing and cleaning device. *INMATEH – Agricultural Engineering*, 61(2), 305–314. DOI: https://doi.org/10.35633/inmateh-61-33.

[9] Hanna, H. M., Quick, G. R. (2013). Grain harvesting machinery. *Handbook of Farm, Dairy and Food Machinery Engineering, Academic Press*, 223–257.

[10] Hud V., Lyashuk O., Hevko I., Ungureanu N., Vlăduț V., Stashkiv M., Hevko O., Pik A. (2023). Enhancement of Agricultural Materials Separation Efficiency Using a Multi-purpose Screw Conveyor-Separator, *AGRICULTURE* 13(4): 870, DOI: *10.3390/agriculture13040870,* agriculture-2291357, April 2022

[11] Ivan Gh., Vlăduţ V., (2015), The intensification of shaking process to the conventional cereal harvesting combines, *PROCEEDINGS OF THE 43 INTERNATIONAL SYMPOSIUM ON AGRICULTURAL ENGINEERING "Actual Tasks on Agricultural Engineering",* vol. 43, 417÷430, Opatija – Croatia;

[12] Ivan Gh., Vlăduţ V., Ganea I., (2015), Improving threshing system feeding of conventional cereal harvesting combine, *Proceedings of the 43 International Symposium on Agricultural Engineering "Actual Tasks on Agricultural Engineering",* vo. 43, 431-440, Opatija – Croatia;

[13] Jiangtao J., Jingpeng H., Shengsheng W., Ruihong Z., Jing P. (2020). Vibration and impact detection of axial- flow threshing unit under dynamic threshing conditions. *INMATEH – Agricultural Engineering* 60(1), 183–192. DOI: https://doi.org/10.35633/inmateh-60-21.

[14] Jinshuang W., Hua L., Jianbo Y., Guang M., Yongsen X. (2018). Design and test on an all-feed axial flow same diameter differential speed thresher. *INMATEH – Agricultural Engineering* 54(1), 73–80.

[15] Khazaei J., Shahbazi, F., Massah, J. (2008). Evaluation and modeling of physical and physiological damage to wheat seeds under successive impact loadings: mathematical and neural networks modeling. *Crop Science, 48(4)*, 1532–1544.

[16] Khir R., Atungulu G., Ding C., Pan Z.L. (2017). Influences of harvester and weather conditions on field loss and milling quality of rough rice. *Int J Agric & Biol Eng, 10(4),* 216–223.

[17] Li X., Du Y., Guo J., Mao E. (2020). Design, simulation, and test of a new threshing cylinder for high moisture content corn. *Appl. Sci.*, 10, 4925. DOI: https://doi.org/10.3390/app10144925.

[18] Masek J., Kumhala F., Novak P., Fic T. (2016). Influence of different threshing system design on grain damage. *Proceedings of the 15th International Scientific Conference Engineering for Rural Development*, Jelgava, Latvia, 25–27 May, 756–761.

[19] Mirzazadeh A., Abdollahpour S., Mahmoudi A., Bukat A.R. (2012). Intelligent modeling of material separation in combine harvester's thresher by ANN. *International Journal of Agriculture and Crop Sciences, 2012; 4(23),* 1767–1777.

[20] Muscalu A., Stan (Tudora) C., Sorică C., Vladuț N-V, Mîrzan O., Naie M. (2022). Experimental research on harvesting species of medicinal plants grown on small areas, *AgroLife Scientific Journal*, Vol. 11 (2) / 2022, pp. 110-115, ISSN ONLINE 2286-0126; Romania;

[21] Pruteanu A., Vlăduț V., Ungureanu N., (2017), Characterization of chicory herb (Cichorium intybus) of separation process on length of flat vibrating sieves, *Proceedings of the 45 International Symposium on Agricultural Engineering "Actual Tasks on Agricultural Engineering",* vol. 45, pp. 339-350, Opatija – Croatia;

[22] Pruteanu M.A., Ungureanu N., Vlăduț V., Matache M-G, Nițu M. (2023). Contributions to the optimization of the medicinal plant sorting process into size classes, *AGRICULTURE* 13(3): 645, DOI: *10.3390/agriculture13030645,* agriculture-2213009

[23] Qirui W., Hanping M., Qinglin. L. (2020). Modelling and simulation of the grain threshing process based on the discrete element method, *Computers and Electronics in Agriculture, 178,* ISSN 0168-1699. https://doi.org/10.1016/j.compag.2020.105790.

[24] Sessiz A., Ulger P. (2003) - Determination of threshing losses with a raspbar type axial flow threshing unit. *J. Agric. Engng.*, 40(4), 1–8.

[25] Sheychenko V., Anelak M., Kuzmych A., Gritsaka O., Dudnikov I., Tolstushko N. (2018). Investigation of the grain separation process in the three-drum threshing-separating device of a combine harvester, *Mechanization in agriculture & Conserving of the resources, 64 (2),* 42-45.

[26] Sinha J.P. (2014). Performance evaluation of axial flow and tangential axial flow threshing system for basmati rice (*Oryza Sativa*). *IJAFP 1(2)*, 44–49.

[27] Song Z., Diao P., Pang H., Zhao D., Miao H., Li X., Yang D. (2022). Design and experiment of threshing and separating device of corn grain harvester. *INMATEH – Agricultural Engineering*, 66(1), 182–190. DOI: https://doi.org/10.35633/inmateh-66-18.

[28] Su Z., Ding Z., Tian L., Lin X., Wang Z. (2021). Design and performance test of variable diameter threshing drum of combine harvester. *Food Sci Nutr.* 9, 4322–4334. DOI: 10.1002/fsn3.2402.

[29] Suliman A.E.R., Taieb A.A., Atallah M.M. (2012). Development of threshing system in combine harvester for improving of its performance efficiency in rice threshing. *Misr J. Ag. Eng*., 29(1), 143–178.

[30] Vlădut N.-V., Biris S.St., Cârdei P., Găgeanu I., Cujbescu D., Ungureanu N., Popa L.-D., Perişoară L., Matei G., Teliban G.-C. (2022). Contributions to the Mathematical Modeling of the Threshing and Separation Process in An Axial Flow Combine, *Agriculture* 12, 1520. https://doi.org/10.3390/agriculture12101520

[31] Vlădut N.-V., Ungureanu N., Biris S.St., Voicea I., Nenciu F., Găgeanu I., Cujbescu D., Popa L.-D., Boruz S., Matei G., Ekielski A., Teliban G.C. (2023). Research on the identification of some optimal threshing şi separation regimes in the axial flow apparatus, A*GRICULTURE* 2023 13(4): 838, DOI: *10.3390/agriculture13040838,* agriculture-2301663

[32] Xu T., Li Y. (2020). Effect of airflow field in the tangential-longitudinal flow threshing and cleaning system on harvesting performance. *Adv. Mater. Sci. Eng*, 4121595. DOI: https://doi.org/10.1155/2020/4121595.

[33] Zhou X., Wang Z., Tian L., Su Z., Ding Z. (2022). Innovative design and performance test of threshing-separating device for horizontal axial-flow combine harvester. *INMATEH – Agricultural Engineering*, 67(2), 497–508. DOI: https://doi.org/10.35633/inmateh-67-49.