Results of Experimental Researches of Plant Material Twin-Screw Compactor

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Summary: *The usage of latest technological means of plant material compaction will reduce production costs by saving the livestock nutrients during a storage period. The results of twin-screw compactor experimental researches are presented. They will enable to reduce production costs by saving livestock nutrients during storage. The data will provide plant material with high output density avoiding the relaxation effect. Mathematical equations of productivity, power capacity and energy intensity are given depending on the design and kinematic parameters. Surfaces of mathematical equations' responses are also presented.*

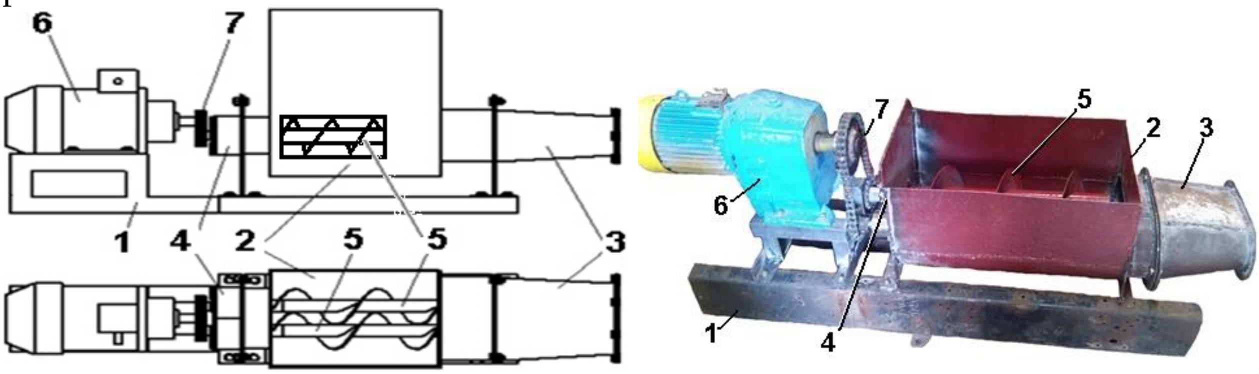
Key words: *plant materials, twin-screw compactor, structurally - kinematic indicators, haylage, alfalfa, storage, nutrients.*

Introduction A lot of attention has been paid to the research of plant materials since the ancient times. Straw materials compaction as alternative fuel can be considered the first attempts. Devices for straw materials compaction have been used around since the end of the ninetieth century. Around the same time there were the first attempts to give scientific grounding of the process [1]. But more detailed researches of the stem materials' compaction were introduced in the early twentieth century.

At the present stage everyone knows that during the feed storage it is necessary for the feed mass to avoid air contact. This is achieved by various means, such as inert gases storage filling, plant materials compacting, tamper and storage covering with airproof films or uploading into polymer sleeves at the same time.

Namely the plant material compacting processes got wide distribution. This is due to the direct compression of freely placed particles the air drive from plant materials takes place L. Chvorostjanov [2], A. Semenichin [3], A. Zubrilin [4] and other scientists were interested in these issues. But their solution has not been found till now. The different theories of plant materials compacting, porosity, packing and other were suggested. This issue is still actual one due to the 15 % loss of nutrition. We think that the problem of plant materials compacting needs to be developed in the future.

Material and methods Variation levels of independent factors and their combinations are given for plant materials twin – screw compactor (Fig. 1). These factors are presented by the three - level matrix of full-factor analysis of the second order. Three factors, such as rotation speed *n* (min^{-1}), the window height coefficient (ratio of height windows inlet for feeding the pre-compacted weight to the screw diameter) and pre – compaction plant materials density ρ ($kg \cdot m^{-3}$) are presented in table 1.



a) b)

1 – frame; 2 – bunker; 3 – diffuser; 4 - bearing unit; 5 – screw; 6 – motor – reducer; 7 - chain transmission.

Fig. 1 – Twin – screw plant material compactor:
a – design and technological scheme;
b - general view.

Table 1 – Variation levels for the plant materials twin – screw compactor research.

№	Level of factors					
	Encrypted			Original		
	X_1	X_2	X_3	n	k	r
1	-1	-1	-1	25	1.25	320
2	1	-1	-1	125	1.25	320
3	-1	1	-1	25	1.95	320
4	1	1	-1	125	1.95	320
5	-1	-1	1	25	1.25	720
6	1	-1	1	125	1.25	720
7	-1	1	1	25	1.95	720
8	1	1	1	125	1.95	720
9	-1	0	0	25	1.6	520
10	1	0	0	125	1.6	520
11	0	-1	0	75	1.25	520
12	0	1	0	75	1.95	520
13	0	0	-1	75	1.6	320
14	0	0	1	75	1.6	720

Experiment was conducted to obtain data for the next parameters: productivity Q, power consumption N, energy intensity E and output density R according to Table 1.

Result and discussion As a result of experimental research the data in triple repetition were obtained. These parameters are screw speed rotation n, window height coefficient k and input density ρ. After that their average values are calculated and shown in Table 2.

Table 2 - Average values of parameters during researches for the plant material twin – screw compactor

№	Screw speed rotation, n, min^{-1}	Window height coefficient, *k*	Input density, ρ, $kg \cdot m^{-3}$	Productivity, Q, $kg \cdot h^{-1}$	Power consumption, N, kW	Energy intensity, E, $kJ \cdot kg^{-1}$	Output density, R, $kg \cdot m^{-3}$
Haylage compacting							
1	25	1.25	320	174	4.19	88.22	808
2	125	1.25	320	527	7.20	54.10	633
3	25	1.95	320	233	4.18	63.70	815
4	125	1.95	320	405	6.17	52.61	678
5	25	1.25	720	199	5.85	113.54	764
6	125	1.25	720	343	8.19	88.85	620
7	25	1.95	720	684	5.39	25.63	855
8	125	1.95	720	591	6.75	33.54	748
9	25	1.6	520	237	4.79	77.51	806
10	125	1.6	520	394	6.98	61.79	666
11	75	1.25	520	137	6.58	149.04	378
12	75	1.95	520	301	5.85	90.57	446
13	75	1.6	320	156	5.79	112.68	417
14	75	1.6	720	253	6.94	111.99	430
Straw materials compacting							
1	25	1.25	260	200	2.40	46.57	813
2	125	1.25	260	248	7.20	112.17	670
3	25	1.95	260	473	2.80	24.27	700
4	125	1.95	260	337	4.57	51.13	655
5	25	1.25	480	244	2.40	41.00	702
6	125	1.25	480	460	5.00	43.60	776
7	25	1.95	480	162	5.43	139.03	567
8	125	1.95	480	240	5.00	77.03	738
9	25	1.6	370	250	2.47	42.43	711
10	125	1.6	370	307	4.80	55.87	726
11	75	1.25	370	164	3.90	85.77	485
12	75	1.95	370	169	3.90	98.80	409
13	75	1.6	260	191	3.90	83.53	455
14	75	1.6	480	144	4.30	116.03	442

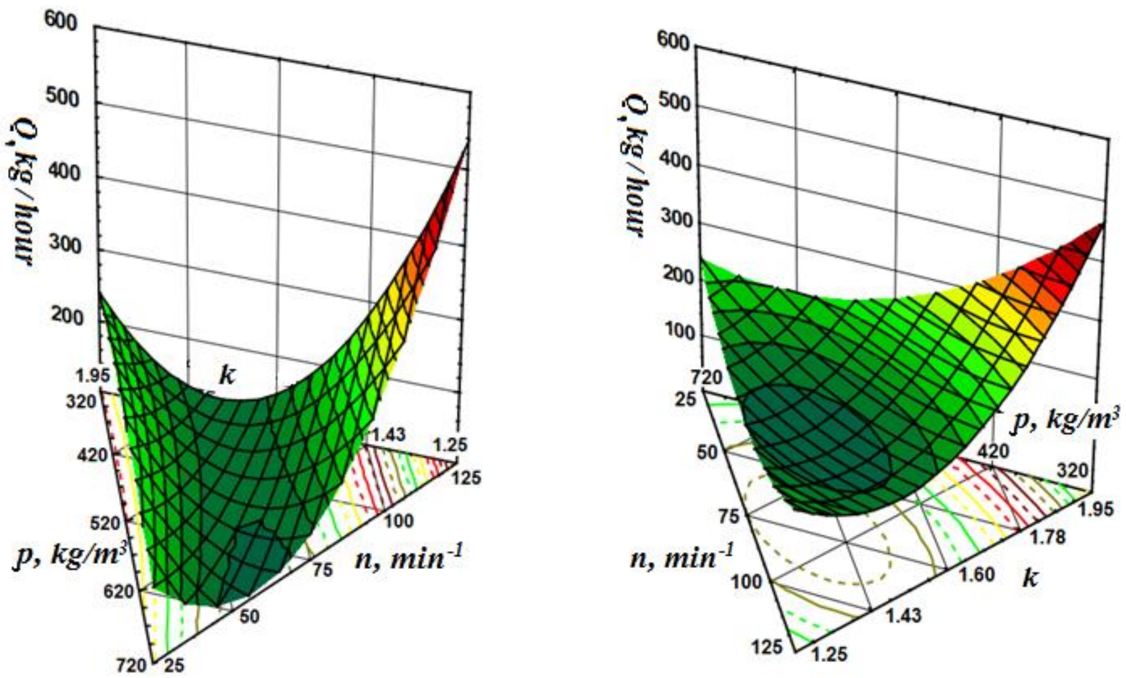
Evaluation of the obtained data of the experimental research it has to be noted that window height coefficient is statistically significantly correlated with the productivity end power capacity, but power consumption only depends on the input density.

Preliminary evaluation of experimental data defining values of productivity, power capacity and power consumption with the help via the Student's t test, scope of truncated sample test and Cochran test with level of significance $\alpha = 0.05$ have proved that incorrect values were found.

As a result of the processing extended matrix of research dependent factors with the addition of paired interactions of independent factors and their squares executed in decoded form based on Table. 2 using STATISTICA 8.0 we get coefficients of regression equations presented in Table. 3 as a second order polynomial with partially withdrawn insignificant coefficients provided that the adequacy and efficiency are saved.

The contents of Table. 3 shows that calculated Fisher's criterion F for all values is larger than tabular criterion F_T and determination coefficients for regression equations values with corresponding experimental data exceed the minimum (0.75), indicating that the operability of obtained mathematical models.

The changing in productivity Q (kg·h^{-1}) of the plant materials twin – screw mixer-compactor for haylage and straw material depending on the screw rotation speed n (min^{-1}), window height coefficient k and input density ρ (kg·m^{-3}) according to data of Table 3 is illustrated in Fig. 2.



a) б)

Fig. 2 – Response surface of twin – screw compactor productivity depend on speed rotation, window height coefficient and input density: a) haylage; б) straw material.

Analyzing the response surface it should be noted that productivity increase Q is connected with screws' speed rotation increase. The maximum productivity compactor reaches $n = 100$ min^{-1}. We also should point out insignificant influence of plant material input density. The maximum productivity is observed when the input density for straw material $\rho = 420$ kg·m^{-3} and for haylage $\rho = 620$ kg·m^{-3}, in its turn it is connected with subsequent loosening carried out by the first screw, and the following structuring of plant material during the transition from the first to the second screw. The rise of window height coefficient leads to growth of twin – screw compactor productivity because a throughput increases. The highest productivity is achieved at the window height coefficient for straw material compaction *k* = 1,8 and for haylage compaction *k* = 1,43.

Table 3 - The coefficients of regression equations and statistical evaluation of equations

Parameters	Productivity, Q, $kg \cdot h^{-1}$	Power consumption, N, kW	Energy intensity, E, $kJ \cdot kg^{-1}$	Output density, R, $kg \cdot m^{-3}$
Haylage				
Free member	1634.059	0.801	0.130	1380.411
Rotation speed	-	0.074	1.948	-21.881
Window coefficient	-1487.907	1.409	-23.164	-
Input density	-2.382	0.003	0.467	-0.703
R. speed × W. coefficient	-2.984	-0.014	0.397	0.539
R. speed × Input density	-0.006	-1.625E-05	3.554E-04	7.675E-04
W. coefficient × Input density	1.420	-0.002	-0.209	0.297
R. speed × R. speed	0.057	-1.410E-04	-0.019	0.128
W. coefficient × W. coefficient	378.571		11.607	-32.857
Input density × Input density	0.001	3.188E-06	-1.512E-04	1.956E-04
The freedom degree of inadequacy	5	5	4	5
The freedom degree of the experiment	8	8	9	8
Calculated criterion *F*	14.285	27.572	87.778	801.902
Tabular criterion $F_т$	6.757	6.757	8.905	6.757
Current level of significance *p*	4.742E-03	1.007E-03	3.104E-04	2.440E-07
Coefficient of determination r^2	0.960	0.978	0.997	0.999
Straw materials				
Free member	-438.960	11.425	288.803	1303.739
Rotation speed	-5.494	0.137	4.542	-20.641
Window coefficient	603.714	-9.685	-259.374	61.750
Input density	1.199	-0.023	-0.749	-0.130
R. speed × W. coefficient	-2.294	-0.051	-0.738	1.390
R. speed × Input density	0.005	-6.163E-05	-0.002	0.005
W. coefficient × Input density	-1.185	0.010	0.383	-0.082
R. speed × R. speed	0.048	0.000	-0.015	0.105
Квадрат вікна	63.571	2.719	41.495	-72.143
W. coefficient × W. coefficient	2.297E-04	1.270E-05	3.151E-04	-1.722E-04
The freedom degree of inadequacy	4	4	4	4
The freedom degree of the experiment	9	9	9	9
Tabular criterion $F_т$	149.493	54.140	46.834	58411.467
Current level of significance *p*	8.905	8.905	8.905	8.905
Coefficient of determination r^2	1.080E-04	8.050E-04	1.070E-03	7.164E-10
Calculated criterion *F*	0.997	0.997	0.991	1.000

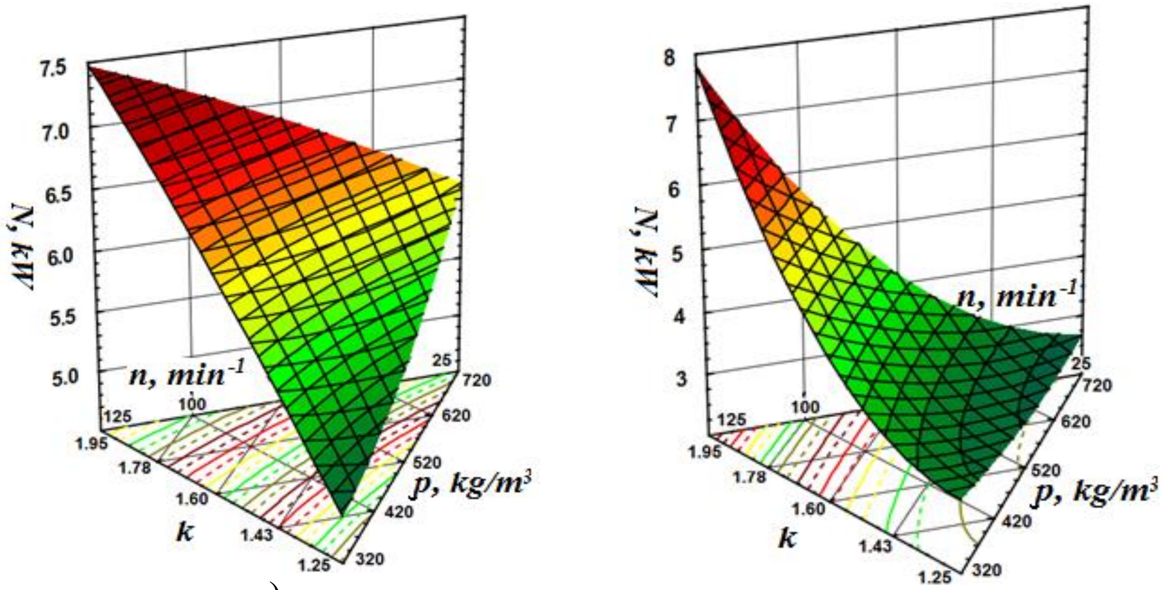
The response surface of twin–screw compactor productivity for haylage has considerably steeper shape than for straw material, in its turn this is connected with higher humidity and lower coefficients of friction (both internally and on the compactor surfaces.

The changes in power consumption N (kW) of the plant material twin – screw mixer-compactor for haylage and strow material depending on the screw rotation speed n (min^{-1}), window height coefficient k and input density ρ (kg·m^{-3}) according to data of Table 3 are illustrated in Fig. 3.

Analyzing the response surfaces it should be noted the power consumption increases at rotation speed and window height coefficient increasing that is due to productivity increase. Increased input density also affects power consumption rising, but it not so significant as the previous indicators.

Comparing power consumption of haylage and strow material compaction it should be noted rather rapid rising of power consumption at increasing of window height coefficient and rotation speed for haylage, while during strow material compacting there is a sharp increase in power consumption only when window height coefficient reaches 1.43 and rotation speed reaches 65 min^{-1}.

During haylage compaction significant increase in power consumption is observed at the window height coefficient k = 1.3 and rotation speed n = 45 – 50 min^{-1}. It is primarily connected with different viscosity of researched materials because the haylage viscosity exceeds considerably the straw materials viscosity. Also it is necessary take into account different humidity of these materials.



a) б)

Fig. 3 – Response surface of twin – screw compactor power consumption depend on rotation speed, window height coefficient and input density: a) haylage; б) strow material.

The changes in energy intensity E (kJ·kg^{-1}) of the plant material twin – screw mixer-compactor for haylage and strow material depending on the screw rotation speed n (min^{-1}), window height coefficient k and input density ρ (kg·m^{-3})

according to data of Table 3 are illustrated in Fig. 4.

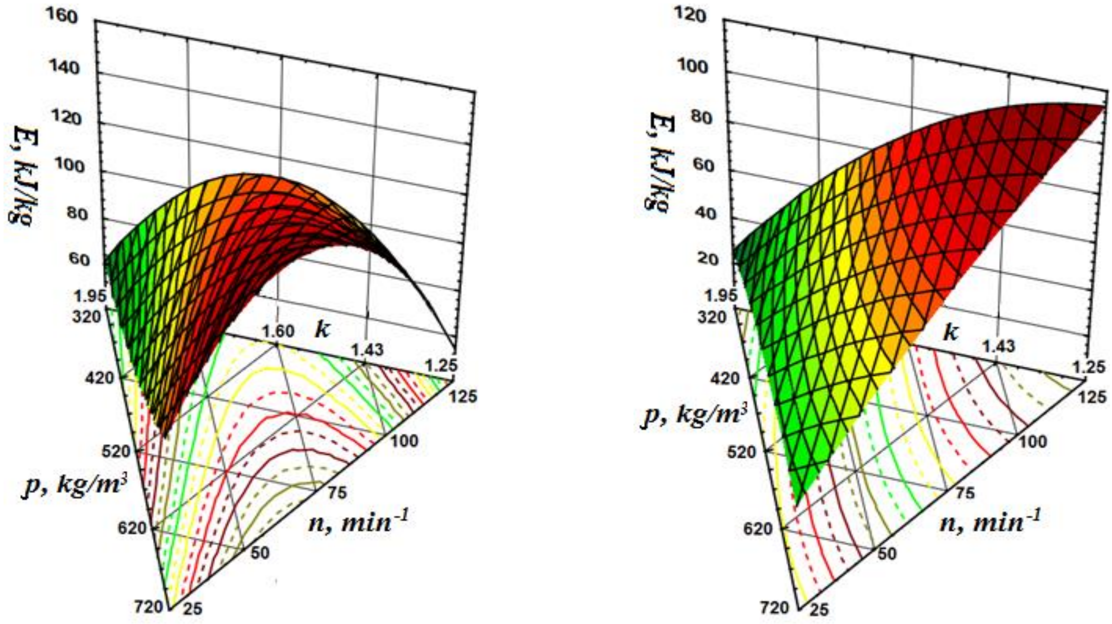


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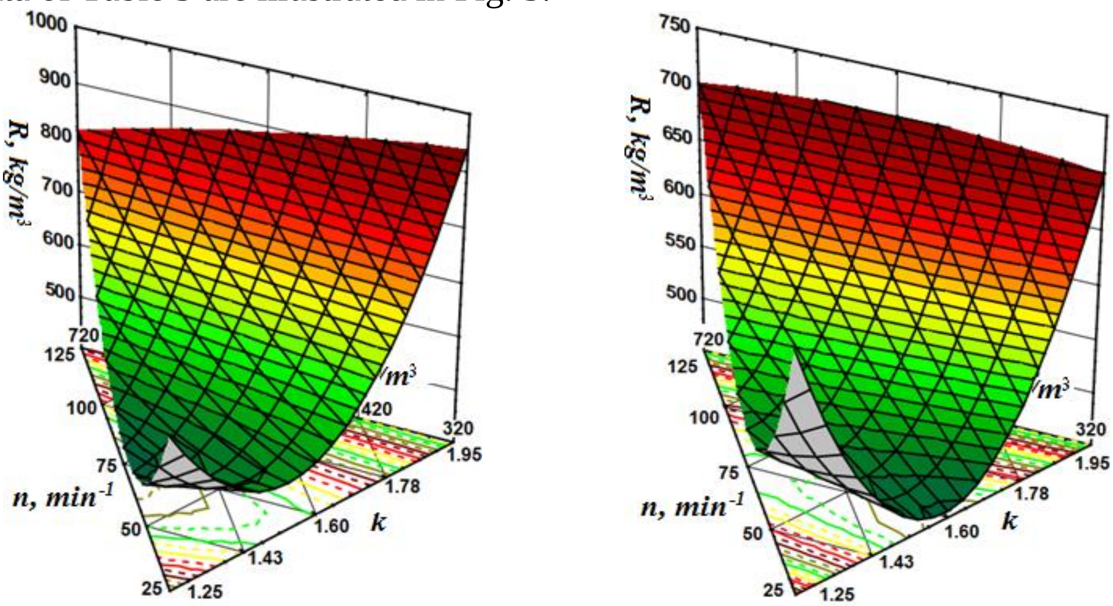
Fig. 4 – Response surface of twin –screw compactor energy intensity depend on rotation speed, window height coefficient and input density: a) haylage; б) strow material.

The changes in output density *R* (kg·m^{-3}) of the plant material twin – screw mixer-compactor for haylage and strow material depending on the screw rotation speed *n* (min^{-1}), window height coefficient *k* and input density *ρ* (kg·m^{-3}) according to data of Table 3 are illustrated in Fig. 5.



а) б)

Fig. 5 – Response surface of twin –screw compactor output density depend on rotation speed, window height coefficient and input density: a) haylage; б) strow material.

Analysis of the response surface shown in Fig. 4 allows to conclude that applying compaction process parameters to maximize productivity we can get preferred output density, namely for haylage compaction R = 800-900 kg·m^{-3}, for strow material R = 600 -700 kg·m^{-3}.

On the basis of the research we think that it is appropriate to apply the following parameters for plant materials compactor: for haylage compaction the window height coefficient k = 1,6, input density (at the compactor entrance) ρ = 620 kg / m^3, screw rotation speed n = 100 min^{-1}, whereas for straw material compaction: the window height coefficient k = 1,8, density at the compactor entrance ρ = 420 kg / m^3 and screw rotation speed n = 100 min^{-1}.

Conclusions and future work The results of experimental researches have helped to identify the ways of quality improving and energy saving of the plant material storage. Reducing the energy loss is achieved through the use of a new technology - plant material structuring. This allows enhancing the output density of the plant material. Higher density allows to remove more air (up to 20%) avoiding the relaxation effect that will reduce the losses of nutrients during the storage period.

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