PRELIMINARY STUDIES ON HORIZONTAL SCREW-TYPE DISPENSER WITH AND WITHOUT A COMPENSATING SCREW-CONVEYOR DEVICE

Dean Todorov[1], Bozhidar Kolev[2]

[1]PhD – student, Agrarian and Industrial Faculty, Department of Agricultural Machinery,
"Angel Kanchev" University of Ruse, Bulgaria
[2]Assoc. Professor, Eng., PhD, Department of Agricultural Machinery,
"Angel Kanchev" University of Ruse, Bulgaria

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Abstract - *Few studies have been performed on the dispensing process of concentrated and pelleted feed for small ruminants. This is why this study starts with preliminary experiments for identification of the scope of change in the selected factors with respect to productivity, dispensing error and specific energy consumption.*

***Key Words*:** **Dispensers, Auger, Small ruminants, Pelleted feed, Volumetric efficiency;**

1. INTRODUCTION

Previous studies performed both at national and international level [1, 2, 3, 4, 5, 6] have established that the quality of operation of screw-type dispensers is affected by different factors, such as: the type of material, the rotation speed of the auger, the slope of the auger, the level of feed in the hopper and the number of augers and other indicators that have been pre-established theoretically.

Few studies have been performed on the dispensing process of concentrated and pelleted feed for small ruminants. This is why this study starts with preliminary experiments for identification of the scope of change in the selected factors with respect to productivity, dispensing error and specific energy consumption.

2. EXPOSITION

The factors that affect the feed dispensing process can be manageable and unmanageable. Unmanageable factors can be either controllable or uncontrollable. Unmanageable controllable factors are reported and registered during the experiment, but they are not managed by the experimenter, whereas the unmanageable uncontrollable factors are the so-called accidental indicators that disturb the process – they remain hidden in the results obtained and they are the reason for the so-called experiment "noise".

The main technological, kinematic and constructive parameters of the studied structure can be defined as manageable factors. The following factors can be reasonably selected for manageable factors: auger rotation speed; number of augers, etc., whereas the unmanageable factors can include the feed humidity, the fractional composition of the feed, etc. Of course, not all manageable factors can be included in the experiment, since the number of experiments will increase significantly with the increase in their number. Therefore, based on the specific conditions and the specific object of study using one approach or another, and also based on ex-ante information, only the most significant factors have been selected.

The performance of an active experiment allows to influence the studied object, i.e. to actively participate in the process analysis so that the experiment can be managed. One of the significant prerequisites is lack of interdependence among the selected impacts (factors).

The created pilot device (fig. 1 and fig. 2) is used for conducting a series of single-factor experiments in order to establish the nature of the effect of the individual studied parameters on the dispenser functional indicators.

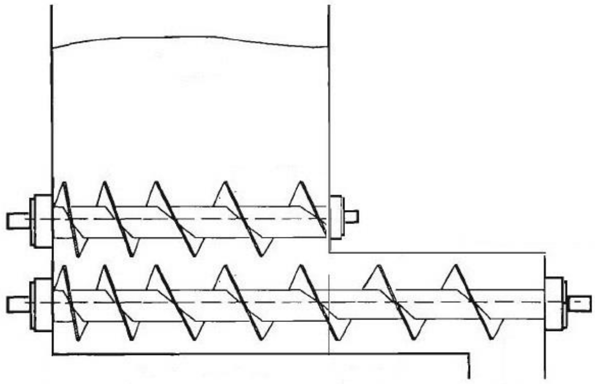

Fig - 1 Pilot dispenser with two augers

Based on the results, the optimal levels of variation of the manageable factors for the subsequent multi-factor experiment can be established. Generally, it is assumed that the manageable factors in single-factor experiments change to a larger extent as compared to the factors in the forthcoming planned mutli-factor experiment for the purpose of covering the optimal values. The optimal values will be in the centre of the scope of change in the factors associated with the planned multi-factor experiment.

Laboratory experiments were carried out in order to identify the effect of the main factors on the selected criteria at a humidity of W=11%.

During the single-factor experiments, the main material for dispensing used was pelleted feed with 6 mm diameter and average length of the pellets of 15 mm.

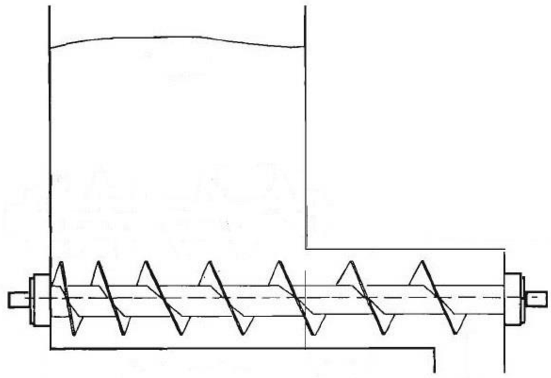

Fig - 2 Pilot dispenser with a single auger

The auger rotation speed and the electrical engine power were measured by using a frequency inverter. The weight of the dozes was measured using electronic scales.

3. PRELIMINARY SINGLE-FACTOR EXPERIMENTS OF A DISPENSER WITH A SINGLE AUGER – OPERATING AUGER

3.1 Productivity in case of operation with a single auger - operating auger

Table -1 Experimental results from dispensing with a single auger

Rotation speed, min.$^{-1}$	6	10	15	20	22.8	25	30	40
Theoretical productivity, kg/h	101.73	169.56	254.34	339.12	386.6	423.9	508.68	678.24
Experimental productivity, kg/h	94.4	140.2	212.1	306.4	320.2	379.2	466.2	560.4
1 trial	94.4	140.21	212.1	306.4	320.2	379.2	466.2	560.4

2 trial	94.42	140.23	212.14	306.5	320.26	379.28	466.29	560.5
3 trial	94.38	140.17	212.06	306.3	320.14	379.12	466.11	560.3
4 trial	94.41	140.21	212.12	306.43	320.23	379.24	466.25	560.45
5 trial	94.39	140.18	212.08	306.37	320.17	379.16	466.15	560.35
Average value	94.4	140.2	212.1	306.4	320.2	379.2	466.2	560.4
Mean quadratic value	0.001	0.0024	0.004	0.0218	0.009	0.016	0.0212	0.025
Volumetric efficiency	0.928	0.827	0.834	0.903	0.828	0.894	0.916	0.826

The auger rotation speed changes from 6 to 40 min-1. The productivity obtained ranges between 94.4 and 560.4 kg/h. The productivity at rotation speed of 22.8 min-1 is 320.2 kg/h (table 1 and chart 1).

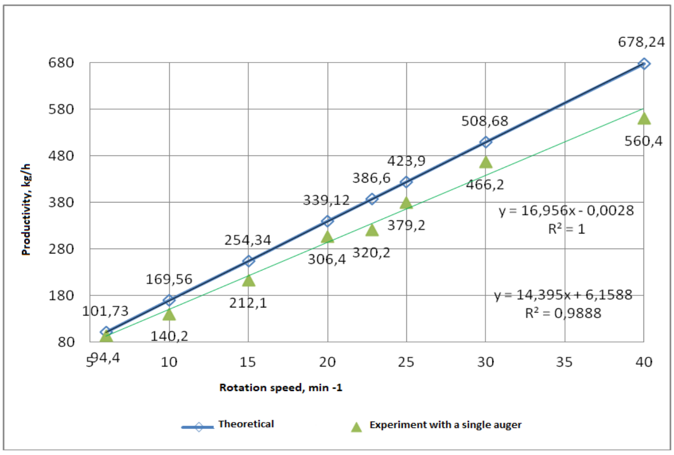

Chart -1 Productivity in case of dispensing using a single auger

3.2 Volumetric efficiency of the auger

As was previously established, the volumetric efficiency of the auger is the ratio of actual to theoretical productivity. The volumetric efficiency is within the rage of 0.828 to 0.928 with extremely high dispersion. These results are due to the rapid scooping of feed at the start of the auger. The static pressure along the working length of the auger is not uniform. This reduces the filling of the auger even when the values of the auger rotation speed are low. This constitutes an unacceptable quality of dispensing under real conditions.

3.3 Dispersion of productivity during operation with a single auger

The process dispersion and stability is also an issue of interest. This is evident from the graphs that follow.

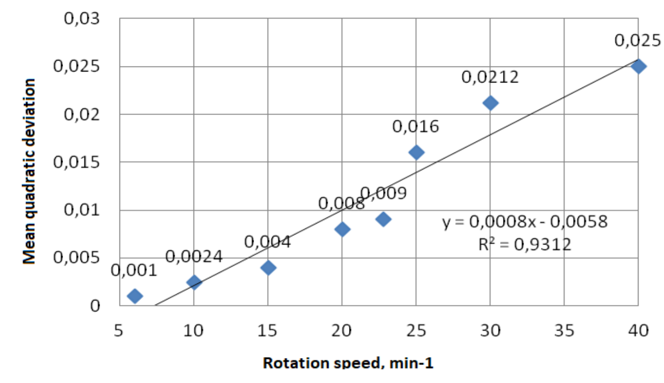

Chart -2 Dispersion of productivity as a result of the rotation speed

The dispersion of productivity during operation with a single auger is measured by mean quadratic deviation (chart 2). By increasing the rotation speed from 6 to 40 min-1, the mean quadratic deviation is within the range of 0.001 to 0.025. This constitutes an increase by a factor of 25. The higher the auger rotation speed, the higher the absolute dispersion is, with values of ±20 g at 6 min-1 to ±100 g at 40 min-1. This is an unacceptable deviation from the mean productivity at the different rotation speeds of the auger.

3.4. Error during dispensing with a single auger

The experimental productivity at different combinations of values of the manageable factors attributed to the dispenser productivity calculated theoretically will serve as a basis for analysis of their impact on the process.

In this way the error (conformity) with respect to the theoretical pre-defined (set) productivity will be calculated during the design of the auger.

Table -2

Rotation speed	6	10	15	20	22.8	25	30	40
Error, y_3,%	21.18	21.39	18.85	17.95	18.74	19.78	19.3	17.84
Error, ±g	20	30	40	50	60	75	90	100

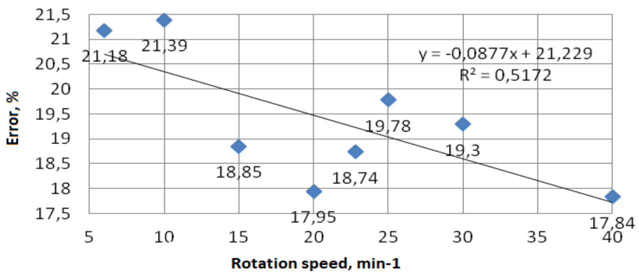

Chart -3 Error based on the rotation speed

The error during each series of trials with five repetitions varies between 21.18 % at 6 min-1 and 17.84 % at 40 min-1. The error range is 3.34 % within the interval of change in the rotation speed. The error is 18.74 % at rotation speed of 22.8 min-1.

The values of errors during operation with a single auger are unacceptably high.

3.5. Experimental results and calculation of the error during operation with a single auger

The share of the error y_5 in terms of the ratio of the mean value of experimental productivity to the theoretical (set) productivity is calculated in %:

$$y_5 = \frac{\frac{\Sigma Q_i}{n}}{Q_t}.100,\% , \qquad (1)$$

where:

ΣQ_i is the sum of productivities from repetitions at the respective value of the auger rotation speed, kg/h;

n – number of repetitions.

This indicator allows assessment of the error with respect to experimental productivity. Actually, this is how the process stability is assessed.

This coincides with the volumetric efficiency.

The values of errors during operation with a single auger are unacceptably high.

3.6. Results for the coefficient of variation

The "coefficient of variation" indicator y_4, % is represented by the popular statistics formula:

$$y_4 = \frac{S}{\bar{X}} = \frac{\sqrt{\frac{\Sigma\left(x_i - \bar{x}\right)^2}{n-1}}}{\frac{\Sigma x_i}{n}} \qquad (2)$$

where:
xi is the current value during the relevant repetition;
$\bar{X}$ – mean value;
N – number of repetitions.

Table -3

Rotation speed	6	10	15	20	22.8	25	30	40
Coefficient of variation	1.06	1.71	1.88	2.61	2.81	4.22	4.54	4.46

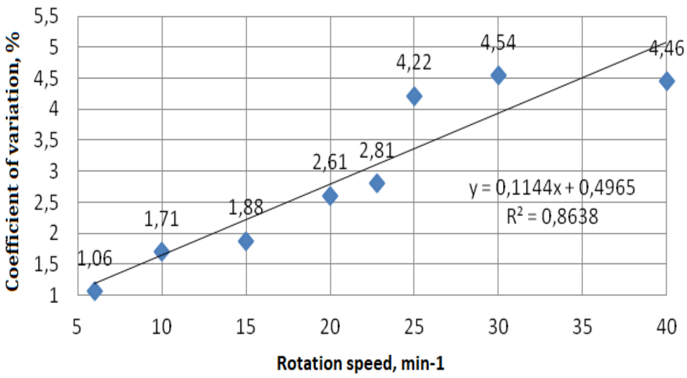

Chart -4 Coefficient of variation at different rotation speeds

The coefficient of variation (table 3 and chart 4) increases from 1.06 % at 6 min-1 to 4.46 % at 40 min-1, i.e. there is an increase by a factor of 4.2. The range is 4.46 – 1.06 = 3 %.

Functional indicators (such as productivity, volumetric efficiency, dispersion and error in productivity and coefficient of variation) are characterised by their linear relationship with the rotation speed. This is the result of the narrow interval of change in the auger rotation speed. During the research of reference materials, it was established that there is deviation from the linear relationship at a rotation speed of more than 200 min-1. All researchers have reported linear relationship up to this value.

The single-auger operation does not satisfy the requirements with respect to dispensing error, dispersion of productivity, coefficient of variation and volumetric efficiency. This is due to the fact that the level of feed is not reduced at a constant rate within the entire volume of the hopper during operation with a single auger. The level deviates sharply from a horizontal and levelled position of the feed. The auger has the capacity to remove more material at its start point and to better preserve the material level at the dispensing outlet. This is characteristic for operation with augers during the process of scooping materials from the hoppers.

There are two solutions to this problem. The first solution is to design an auger with a variable diameter. The larger diameter shall develop at the start of the auger operation, whereas the smaller diameter shall be at the outlet, where the final formation of the auger filling and dose take place. This solution is expensive and technologically challenging. The second solution is to install a second compensating auger with the same parameters. The second auger should be placed above the operating one in order to compensate for the more intensive scooping at the start of operation by returning the same part from the hopper mass that is left at the auger at the end of the working process. In this way, equal volumes of the material will be scooped at the entire volume of the hopper and uniformity and horizontality will be achieved while the level of the feed falls.

Because of the established faults in the process – significant lack of uniformity in the productivity and dispensing error, a second compensating auger had to be installed above the operating one. Extended single-factor experiments were conducted by using more factors – auger slope and feed level in the hopper.

4. Preliminary single-factor experiments of a dispenser with two augers – an operating auger and a compensating one.

Table -4 PRODUCTIVITY DURING OPERATION WITH TWO AUGERS – AN OPERATING AND A COMPENSATING ONE

Rotation speed, min.$^{-1}$	6	10	15	20	22.8	25	30	40
Theoretical productivity, kg/h	101.73	169.56	254.34	339.12	386.6	423.9	508.68	678.24
Experimental productivity, kg/h	98.8	165.4	246.24	325.9	371.3	400	483.25	630
1 trial	98	165.4	246.24	325.9	371.3	403	483.24	625
2 trial	99.5	167.4	249.24	329.9	375.8	404.5	489.25	639.7
3 trial	97.6	163.4	243.24	321.9	366.8	396.5	477.25	626.3
4 trial	99.5	166.4	247.74	327.9	373.6	395.5	486.26	626
5 trial	99.4	164.4	244.74	323.9	369	400.5	480.25	633
Mean quadratic value	0.925	1.581	2.372	3.162	3.574	3.937	4.745	6.281
Coefficient of variation,%	0.00936	0.00955	0.00963	0.0097	0.00963	0.00984	0.009819	0.00997

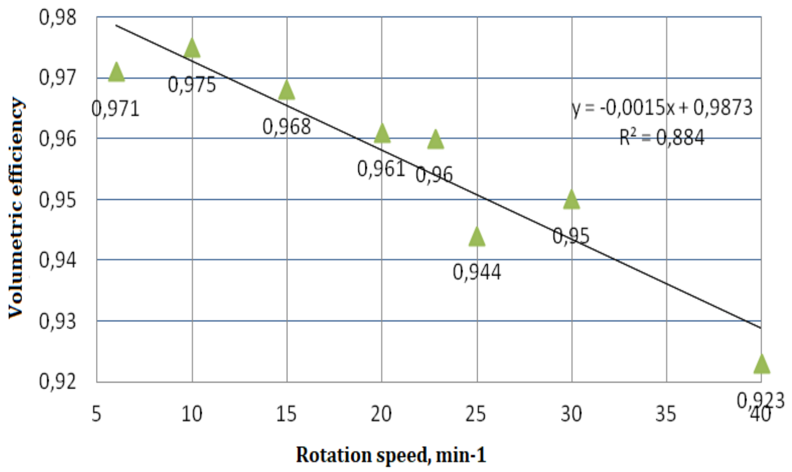

Chart -5 Volumetric efficiency at different rotation speeds of the auger

The volumetric efficiency constitutes the level of filling of the auger. It is expressed as the ratio of the experimental to the theoretical productivity. The dispersion of volumetric efficiency decreases sharply in case of operation with two augers (table 4 and chart 5). The volumetric efficiency increases as compared to operation only with an operating auger and ranges between 0.971 at 6 min-1 and 0.923 at 40 min-1. The range is 0.048.

4.1. Dispersion of productivity during operation with two augers

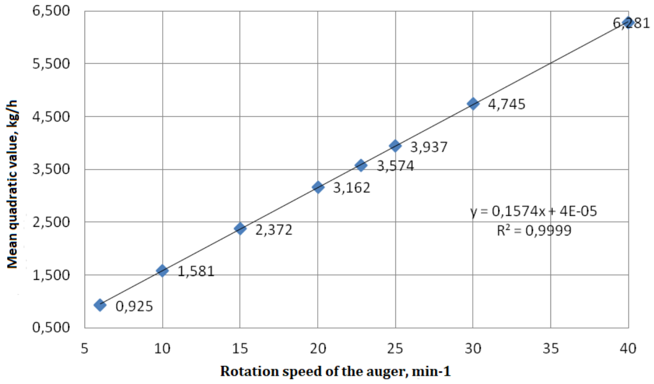

Chart -6 Mean quadratic value at different rotation speeds of the auger

The dispersion of productivity during operation with two augers is measured by mean quadratic deviation (chart 6) By increasing the rotation speed from 6 to 40 min-1, the mean quadratic value is with a range of 0.925 to 6.281. This constitutes an increase by a factor of 6.79. The higher the auger rotation speed, the higher the absolute dispersion is, where it reaches ±1 g at 6 -1 to ±7 g at 40 min-1. This is an acceptable deviation from the mean productivity at the different rotation speeds of the auger. Based on this indicator, the high stability of the process at increased auger rotation speed was established.

4.2. Coefficient of variation during operation with two augers y_4

The effect of rotation speed on the coefficient of variation is illustrated on chart 7.

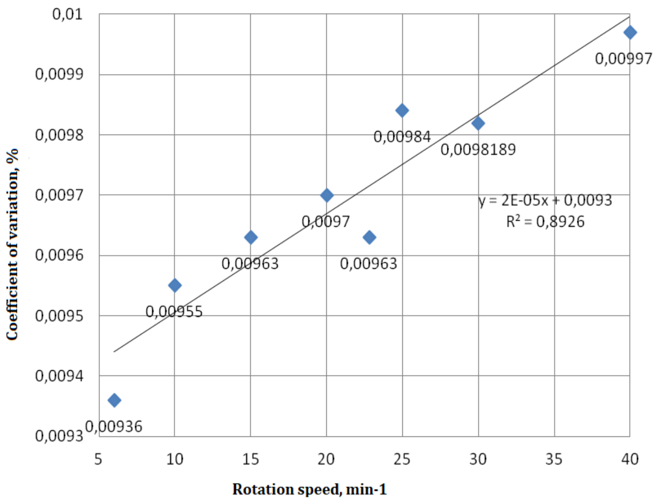

Chart -7 Coefficient of variation at different rotation speeds of the auger

The coefficient of variation changes from 0.00936 at 6 min-1 to 0.00997 at 40 min-1. These values serve as evidence for the high precision of dispensing.

It has been established that when the value of the coefficient of variation is below 3 %, the dispensing process is very stable and this is recommended for easily spilled materials, such as cooking salt, premix, urea or other materials dispensed in small quantities.

4.3. Dispensing error during operation with two augers

Dispensing error y_3 with respect to theoretical productivity

Table -5

Rotation speed min-1	Mean productivity value, g.	Theoretical productivity value, g	Theoretical mean value, g	[(theoretical mean value) /theoret.].100, %
1	5	6	7	8
6	98.8	101.73	2.93	2.88
10	165.4	169.56	4.16	2.45
15	246.24	254.34	8.1	3.18
20	325.9	339.12	6.92	3.42
22.8	371.3	386.6	13.22	3.61
25	400	423.9	23.9	4.45
30	483.25	508.68	23.68	5.64
40	630	678.24	48.24	7.11

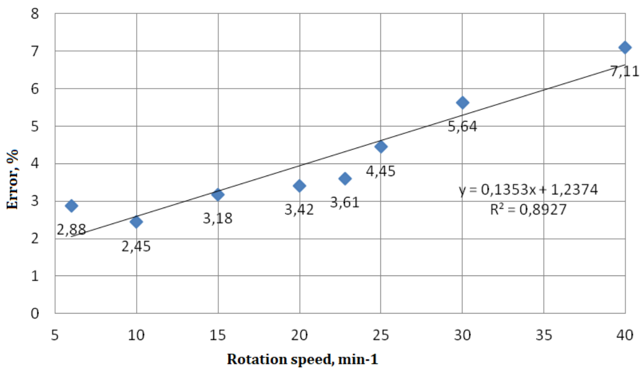

Chart -8 Dispensing error y_3 (as compared to pre-defined productivity) at different rotation speeds of the auger

The error is a very important indicator for dispensing. The error varies between 2.88 % at 6 min-1 and 7.11 % at 40 min-1 during operation with two augers. The range is 7.11 – 2.88 = 4.23 %. The error is 3.61% at 22.8 min-1. This is below the acceptable 5% for feed dispensing (table 5 and chart 8).

4.4. Specific energy consumption in case of dispensing with two augers

Table -6

Rotation speed, min.$^{-1}$	6	10	15	20	22.8	25	30	40
Productivity, kg/h	98.8	165.4	246.24	325.9	371.3	400	483.25	630
Power, kW	0.04936	0.08264	0.1235	0.1635	0.1869	0.2012	0.2453	0.318
Specific energy consumption, kWh/t	0.4996	0.5	0.5015	0.502	0.503	0.503	0.503	0.504

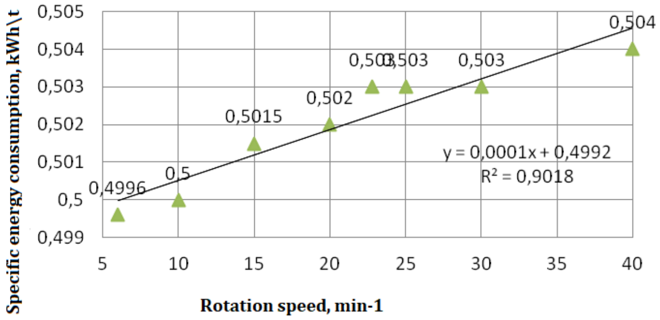

Chart -9 Specific energy consumption at different rotation speeds

The specific energy consumption parameter includes the necessary power for implementing the process. The measured power varies from 0.049 kW at 6 min-1 to 0.318 kW at 40 min-1. These values allow for proper selection of an electrical engine (table 6 and chart 9).

The specific energy consumption varies between 0.499 and 0.504 kWh/t.

At 22.8 min-1, the necessary power is 0.187 kW and the specific energy consumption is 0.503 kWh/t.

4.5. Effect of the feed level in the hopper on productivity

Table -7

Feed level in the hopper, m	0.4	0.5	0.6	0.7	0.8	0.9	1
Productivity, kg/h	397.3	398	398.2	398.8	399.2	399.4	399.8

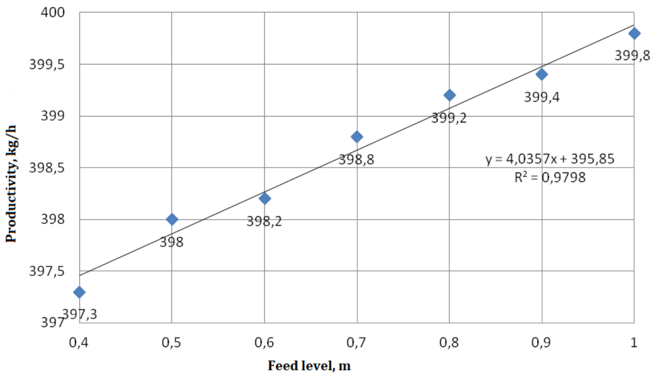

Chart -10 Effect of the feed level on productivity

The experimental data from the conducted trials are given in table 7 and are illustrated graphically on chart 10.

The trials have been conducted at auger rotation speed of 22.8 min-1, since this is the speed at which productivity close to the nominal productivity calculated for the auger is achieved.

The range of the difference between the lowest and the highest level is between 397.3 and 399.8 kg/h, i.e. 2.5 kg/h. The higher the level, the higher the productivity by 2.5 kg/h and vice versa. At an average level of 0.7 m, productivity is 398.8 kg/h, the deviation is negative - 1.5 kg/h lower to a level of 0.4 m and positive - 1.0 kg/h higher to a level of 1 m. Productivity at the average level is equal to 398.8 +1.0 – 1.5 kg/h or 398.8 kg/h (+0.25 – 0.37)%.

The process is stable and productivity changes based on a linear relationship with some minor deviations.

4.6. Effect of the auger slope on productivity

Table -8

Auger slope, º	-10	-5	0	5	10
Productivity, kg/h	388.15	395.48	398.8	405.49	408.7

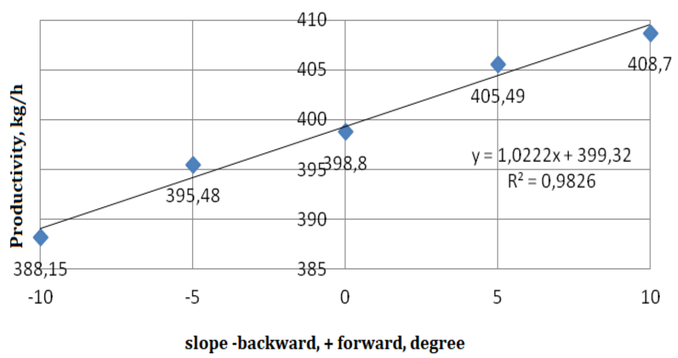

Chart -11 Effect of the auger slope on productivity

The experimental data from the conducted trials are given in table 8 and are illustrated graphically on chart 11.

The difference in productivity from -10 to +10 degrees is 20.55 kg/h. At an average value of 398.8 kg/h (horizontal position of the auger) 10.65 kg/h (at -10 degrees) and 9.9 kg/h (at +10 degrees), it is -2.67 % and +2,48 %, respectively. This change is within the limit of 3 % and has minor impact on the dispensing process. However, it is not recommended to operate the dispenser at a slope of more than 10º in both directions.

5. CONCLUSIONS

It was established that during operation of the dispenser with a single operating auger, the process is unstable and the dispensing precision error exceeds 18% which is the result of the uneven filling of the interturn space.

The established volumetric efficiency (between 0.828 and 0.928) has a high dispersion due to the insufficient filling of the auger;

The higher the auger rotation speed, the higher the absolute dispersion of the dose mass, where it changes from ±20 g at 6 min-1 to ±100 g at 40 min- -1;

The introduction of a second, compensating auger in the dispenser improves the process stability, reduces the dispensing error (3.61% at 22.8 min-1) and increases the volumetric efficiency to 0.971 at 22.8 min-1, i.e. the experimental values for productivity obtained tend to the ones calculated theoretically;

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AUTHORS

Eng. Dean Todorov, PhD-student
Major field of study: Agricultural Engineering

Assoc. Professor Eng. Bozhidar Kolev, PhD
Major field of study: Agricultural Engineering