МАШИНОСТРОИТЕЛЬНЫЕ КОМПОНЕНТЫ

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GARBA Muhammad Bello, M. Sc. in Eng.
Postgraduate Student[1]
E-mail: engrbello@bsatu.by

SHUPILOV Aleksandr A., Ph. D. in Eng., Assoc. Prof.
Head of the Department "Standardization and Metrology"[1]
E-mail: shypilov.a.a.sm@bsatu.by

[1]Belarusian State Agrarian Technical University, Minsk, Republic of Belarus

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# RESULTS OF STUDIES ON OPTIMIZATION OF SEEDER MECHANISM FOR SOWING VEGETABLE SEEDS IN CELL TRAYS

*Experiments were carried out to optimize the parameters of cell tray vegetable seeder with the aim of adopting it to a specific working conditions. Two major factors, the vacuum pressure in the seeding drum and suck hole diameter were tested on cabbage seeds (Valentina cultivar) and plastic tray with 64 cells at three levels (–1, 0, +1) for each factor using the orthogonal central composite design (CCD) regression experiment. The effects of these factors on the single-seed rate (seed singulation), double-seed rate and empty-seed rate were investigated. The experimental results showed that major factor affecting single-seed rate, empty-seed rate and multi-seed rate was vacuum pressure, while suction hole diameter do not affect double-seed rate. It has been established that the round holes of the seeding drum conform to the round-shaped cabbage seeds to ensure high-quality seeding within the required agrotechnical indices — up to 96.0 % of single-seed sowing, and up to 4 % seeding of cells with double and empty-seed rate. The study determined the optimal parameters of vacuum pressure to be 2,9 kPa and 1,0 mm for suction hole diameter at a constant speed of conveyor belt 2,4 m/min. These parameters provided the basis for design and performance improvement of the tray vegetable seeding mechanism.*

***Keywords:*** *vacuum pressure, hole diameter, seed-metering performance, cabbage, seeding mechanism*

**Introduction.** The value of vegetables as an important article of daily human diet has come to be recognized all over the world in recent years. Many specific chemical substances needed by our body for growth, reproduction and for maintenance of health are obtained from vegetables.

Vegetable seedling production technology provide convenient way to look after the 'baby' seedling, provide favourable growth conditions, eliminates the problem of difficult soils, easy weed control, improved crop uniformity, more optimal use of hybrid seeds, shorter growing season and more efficient use of land, more accurate prediction of harvest date as well as higher yields [1].

Tray seeding technology has become one of the best techniques of raising vegetable seedlings in recent years. Precision cell tray seeder is mainly used to achieve precision seeding, and it is the key equipment to accomplish the goal of mechanized and automated seedling in the greenhouse. The cell seedlings planter can greatly improve the productivity of labour and reduce labour intensity at the same time. The seed metering mechanism is the core component of precision cell tray seeder. Its performance directly influences the production, the sowing quality and the cost [2].

Research on vacuum seeding technology is fast developing in Europe, America and Asia and other parts of the world [3], where different types of metering mechanisms are employed such as drum, needles, and plate types. Liao et al. [4–6] conducted several researches on horizontal plate precision meter for corn seed, putting forward the corresponding measures and methods on reducing the broken seeds rate. Similarly, Yu et al [7, 8] studied on corn precision metering device with concave metering inner-cell, with single seed rate of about 90% and empty seed rate less than 3,5 %. Seed size was required strict of these mechanical seed meter, and seed-filling was not high enough. Wu et al. [9] presented an automatic precision seeding system which has high automatic level, and the experimental result showed that the miss index and multiple index for corn seeds were 3,70 % and 4,62 % respectively. Xia et al. [10] used cabbage seeds for sowing performance test. Their single factor test results showed that with the increase of diameter of suction hole, single-seed rate began to increase and then decreased, multi-seed rate increased, empty-seed rate began to decrease and then increased.

Afify et al. [11] developed a mathematical model for predicting the optimum vacuum pressure of a precision vacuum seeder using onion seed properties. Vacuum characteristics and the hole geometry of seed plate. Results indicated that the developed model could satisfactorily describe the parameters affecting in determining the vacuum pressure in the hole with correlation coefficients ranged from 0,97 to 0,99. It is also showed that the final model could be used for predicting the optimum vacuum precision of a precision vacuum seeder of onion seeds with an efficiency of 0,99.

Gaikwad and Sirohi [12] developed a predicting plug tray seeder using indigenous materials and off-the-shelf available standard components. Experimental results indicated that the seeder worked satisfactorily at suction pressure of 4,91 and 3,92 kPa and nozzle diameters of 0,46 and 0,49 mm to achieve more than 90 % single seed sowing in the case of capsicum and tomato respectively.

A cell tray vegetable seeder with capacity of 200–300 trays/h which works with a vacuum seeding drum were designed and developed in Belarusian State Agrarian Technical University (Minsk). The cell tray vegetable precision seeder is made out of local material with a vacuum pump as source of vacuum for seeds suction. The main objective of the study was to investigate the seed-metering performance of the seeder with target of reducing double-seed rate and empty-seed rate as well as determining the optimal parameters.

**Material and method. Experimental device and operating principle.** The cell tray vegetable seeder shown in figure 1, is composed of seed hopper, seeding drum, dibbling/compaction cylinder, conveyor belt, frame, perlite/vermiculite hopper, transmission chain and switch control. The principle of operation was described by [13] as shown in figure 3.

The seeding mechanism consist of frame 1; the rack 2; dibbler with cone-shaped punches 3; chain transmission 4; seeding drum 5; seed hopper 6.

**Experimental materials and methods.** The combination factors affecting performance of seed-metering mechanism were based on the single factor preliminary experiments [14]. The seeds used in this test were cabbage known as valentina cultivar obtained

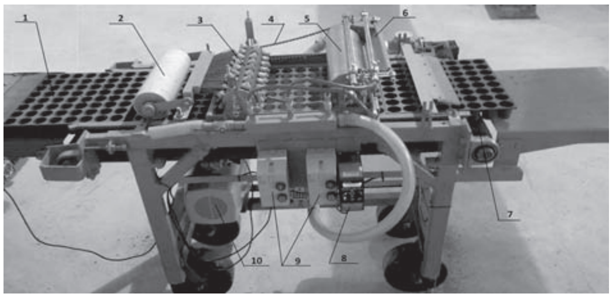


**Figure 1 — Experimental platform of the cell tray vegetable precision seeder**

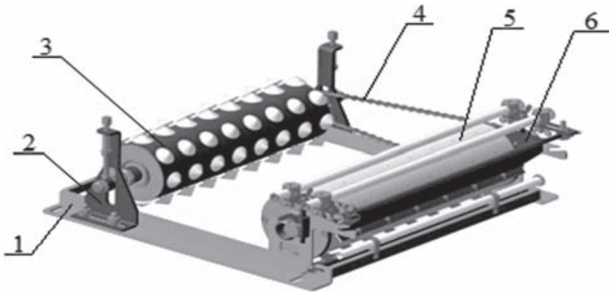



**Figure 2 — Cell tray vegetable precision seeder seeding mechanism:** 1 — frame; 2 — the rack; 3 — dibbler with cone-shaped punches; 4 — chain transmission; 5 — seeding drum; 6 — seed hopper

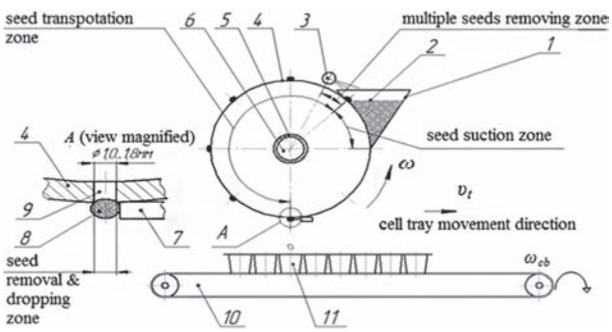



**Figure 3 — Schematic and operational diagram of the seeding mechanism:** 1 — seed hopper; 2 — vegetable seeds; 3 — multiple seeds blower; 4 — seeding drum; 5 — hollow axis of rotation; 6 — vacuum chamber; 7 — seed scraping mechanism; 8 — seed; 9 — suction hole; 10 — conveyor belt; 11 — cell tray

from Agro-industrial Complex “Zhdanovichi” in Minsk. The one-thousand kernel weight (TKW) of the seeds was 467 g, and there was friction angle of 21,22° with stainless steel material [15]. The study considered the vacuum pressure in the drum ($x_1$) and the suction hole diameter ($x_2$) as the experimental factors. The single-seed rate, double-seed rate and empty-seed rate were taken as indices using quadratic regression experimental design. The three levels were adopted basing on the results of a preliminary experiment to obtain a compromise solution. The coding of factor levels is presented in table 1.

Before the experiment, necessary preliminary checks were conducted and the speed of the conveyor belt was regulated by means of vector frequency converter to 2,6 m/min, while the motor speed became stable, 64 cells tray was then seeded for four replicates and the results were recorded.

**Table 1 — Code and level of factors**

| Code value | Vacuum pressure $x_1$ (kPa) | Suction hole diameter $x_2$ (mm) |
|---|---|---|
| Upper level (+1) | 1,0 | 1,0 |
| Zero level (0) | 2,5 | 1,4 |
| Lower level (–1) | 4,0 | 1,8 |

**Results and discussion. The experimental results.** By the initial experimental design, results of quadratic orthogonal regression experiment were presented in table 2. The recorded values are the average ones from four observations.

**Regression equation and secondary order of experimental factors.** The experimental data were analyzed using Microsoft Excel. The regression equations were determined between each experimental factor and performance index as shown below:

$$Y_1 = 61,19 + 1,04X_1 - 0,67X_2 + 0,63X_1X_2 - 0,71X_{12} + 0,17X_{22}; \quad (1)$$

$$Y_2 = 1,50 - 1,33X_1 + 0,54X_2 - 0,88X_1X_2 - 0,13X_{22}; \quad (2)$$

$$Y_3 = 1,31 + 0,29X_1 + 0,13X_2 + 0,25X_1X_2 + 0,71X_{12} - 0,04X_{22}, \quad (3)$$

where $Y1$ is single-seed rate, %; $Y_2$ is empty-seed rate, %; $Y_3$ is double-seed rate, %; $X_1$ is vacuum pressure; kPa; $X_2$ is suction hole diameter, mm.

In order to verify the significance of regression equation, the $F$ test was used for equations (1), (2) and (3). According to the lack-of-fit test, $F_{E1}$ = 1,24, $F_{E2}$ = 2,01 and $F_{E3}$ = 1,24 were all less than $F_{0,05}$ (4,27) = 5,56, the lack of fit was significant at the level of $\alpha$ = 0,05 and the equation fits well with the experimental data according to the $T$-test of the regression coefficients, reaching a significance level of 0,05. Eliminating the insignificant factors, the models between the experimental factors and performance index are as follows:

$$Y_1 = 61,19 + 1,04X_1 - 0,67X_2 + 0,63X_1X_2 - 0,71X_{12}; \quad (4)$$

$$Y_2 = 1,50 - 1,33X_1 + 0,54X_2 - 0,88X_1X_2; \quad (5)$$

$$Y_3 = 1,31 + 0,29X_1 + 0,71X_{12}. \quad (6)$$

The test of the regression equation coefficients of equations (4)–(6) indicated that the primary and secondary order of the factors affecting the single-seed rate and empty-seed rate were the vacuum pressure in the seeding drum and the suction hole diameter while the factor affecting double-seed rate was vacuum pressure.

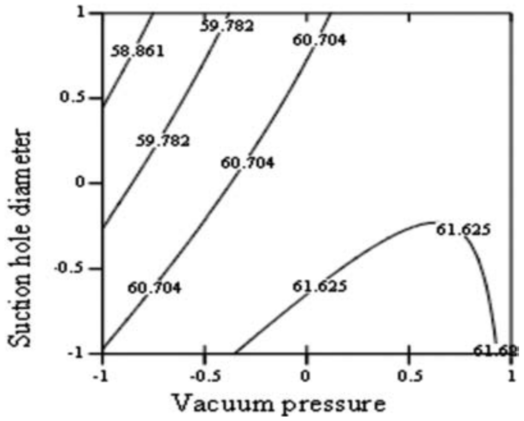
**Discussion on the effect of the two factors.** The relationship between single-seed rate, empty-seed rate, double-seed rate and the factors affecting performance index are shown using Mathcad 15.0 in figures 4–6 below.

Figure 4 elucidates the interaction of vacuum pressure and suction hole diameter on single-seed rate. A higher region of single-seed rate emerges when vacuum pressure is at the 0,5 level while suction hole diameter is approximately at zero level. When vacuum pressure in the seeding drum is fixed, the single-seed rate decreases with decrease in suction hole diameter; when the suction hole diameter is fixed, single-seed rate increases initially with increase in vacuum pressure and then decreases. The highest point of 61,6 cells (96%) appears when the vacuum pressure is at the 0,5 level. When the vacuum pressure is below 0,5 level, the single-seed rate increases with increase in vacuum pressure; when the suction hole diameter is above zero level, the single-seed rate decreases with increase in suction hole diameter. In case of vacuum pressure and suction hole diameter interaction, the vacuum pressure is the main factor that influence the seeding rate.

Figure 5 shows the interaction of the vacuum pressure in the seeding drum and suction hole diameter on empty-seed rate. The lower region of empty-seed rate is noticed when the vacuum pressure is at 0,5 level and the suction hole diameter is at approximately 0,5 level. When the suction hole diameter is fixed, the change of empty-seed rate decreases with increase in

**Table 2 — CCD experimental results**

| Serial number | Vacuum pressure $x_1$ (kPa) | Suction hole diameter $x_2$ (mm) | Single-seed rate, cells (%) | Empty-seed rate, cells (%) | Double-seed rate, cells (%) |
|---|---|---|---|---|---|
| 1 | 1,0 | 1,0 | 61,5 (96,1) | 1,0 (1,6) | 1,5 (2,8) |
| 2 | 4,0 | 1,0 | 62,3 (97,3) | 0,3 (0,5) | 1,5 (2,3) |
| 3 | 1,0 | 1,8 | 58,5 (91,4) | 4,3 (6,7) | 1,3 (2,0) |
| 4 | 4,0 | 1,8 | 61,8 (96,6) | 0,0 (0,0) | 2,3 (3,6) |
| 5 | 2,5 | 1,4 | 61,5 (96,1) | 1,3 (2,0) | 1,3 (2,0) |
| 6 | 1,0 | 1,4 | 59,8 (93,4) | 3,3 (5,2) | 1,0 (1,6) |
| 7 | 4,0 | 1,4 | 62,0 (96,9) | 0,3 (0,5) | 1,8 (1,5) |
| 8 | 2,5 | 1,0 | 62,0 (96,9) | 1,5 (2,3) | 0,5 (2,3) |
| 9 | 2,5 | 1,8 | 61,5 (96,1) | 1,8 (2,8) | 0,8 (1,6) |

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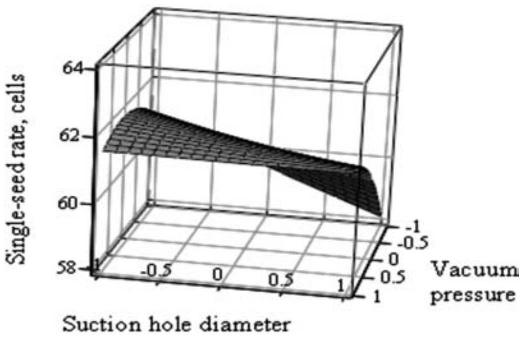


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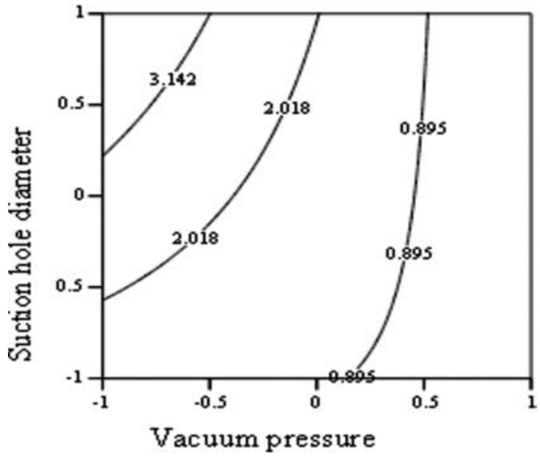
**Figure 4 — Interaction of vacuum pressure (*a*) and suction hole diameter on single-seed rate (*b*)**

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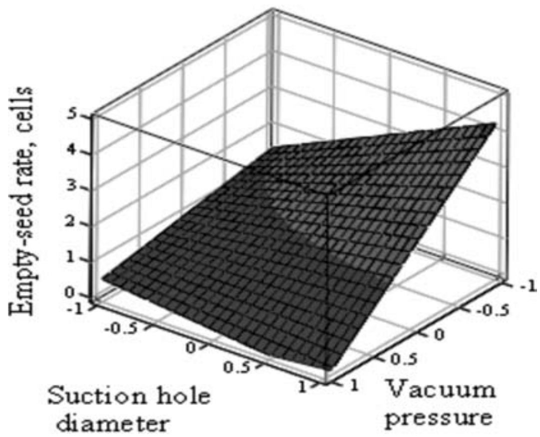



*b*

**Figure 5 — Interaction of the vacuum pressure in the seeding drum (*a*) and suction hole diameter on empty-seed rate (*b*)**

vacuum pressure. The lowest empty-seed rate 0,90 cell (1,4 %) is noticed when the vacuum pressure is approximately at zero level. When the vacuum pressure is below the zero level, the empty-seed rate increases with decrease in vacuum pressure; when the suction hole diameter is below 0,5 level empty-seed rate increases with increase in the suction hole diameter. During interaction of vacuum pressure and suction hole diameter, the vacuum pressure is the leading factor that influence the seeding rate.

Figure 6 indicates the interaction of the vacuum pressure in the seeding drum and suction hole diameter on double-seed rate. Lower region of double-seed rate appears when the vacuum pressure is approximately at 0,5 level. When the vacuum pressure is fixed, the change of double-seed rate with horizontal displacement of the cabbage seeds is almost negligible; when the suction hole diameter is fixed, double-seed rate increases with increase in vacuum pressure. When the vacuum pressure is approximately at 0,5 level, the double-seed rate is effectively at minimum 1,73 cells (2,7 %). When the vacuum pressure is below 0,5 level, double-seed rate disappears with increase in vacuum pressure. When vacuum pressure and the suction hole diameter are in interaction, suction hole diameter has no effect on double-seed rate.

**Performance index optimization.** According to precision cell tray seeder performance requirement, three regression equations for the performance index of single-seed rate, empty-seed rate and double-seed rate are taken as the index. A solver main objective method was used with Microsoft Excel to optimize the solution, achieving the improved parameter combination scheme under different objective functions.

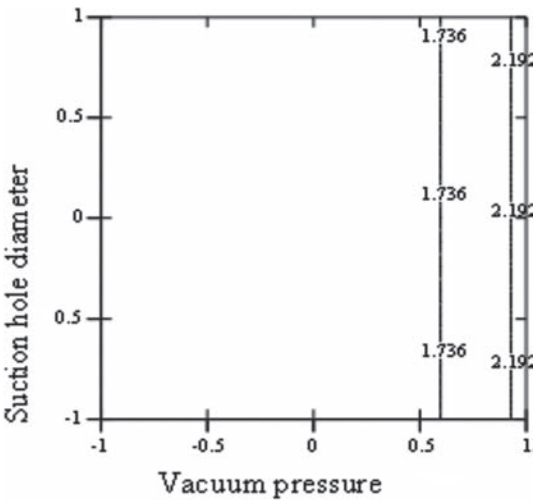
The optimum parameter combinations are presented in table 3.

To achieve maximum single-seed rate with minimum empty/double-seed rates, the optimum parameters are: the vacuum pressure is 2,9 kPa and the suction hole diameter is 1,0 mm.

**Experimental verification.** According to the aforementioned study, the performance indices are a single-seed rate of 96,0 %, an empty-seed rate of 1,4 % and a double-seed rate of 2,7% are found to be within the limit of cell tray precision seeder agrotechnical requirements.

**Table 3 — Optimum parameters of the seeding mechanism**

| Factors | Optimized values |
|---|---|
| Vacuum pressure, kPa | 2,9 |
| Suction hole diameter, mm | 1,0 |

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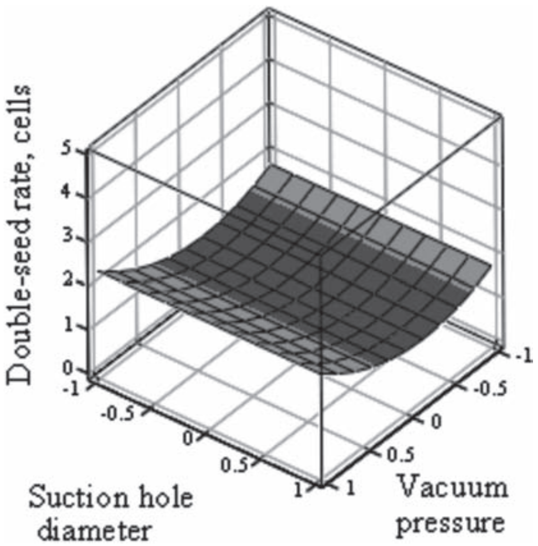


*b*

**Figure 6 — Interaction of the vacuum pressure in the seeding drum (*a*) and suction hole diameter on double-seed rate (*b*)**

**Conclusions.** An orthogonal central composite design (CCD) was used to establish a nonlinear regression model that illustrates the relationship between the vacuum pressure in the seeding drum, suction hole diameter and single-seed rate, empty-seed rate and double-seed rate. This enables a theoretical foundation for parameters improvement of the vegetable seeds cell tray precision seeder.

Vacuum pressure and suction hole diameter are the main factors affecting single-seed rate and empty-seed rate, while the only factor affecting double-seed rate is vacuum pressure. The optimal seeding mechanism parameters of the vegetable cell tray precision seeder in the study are the vacuum pressure in the seeding drum of 2,9 kPa and suction hole diameter of 1,0 mm.

The performance indices verified experimentally are the single-seed rate of 96,0 %, empty-seed rate of 1,4 % and a double-seed rate of 2,7 % which all meet the agrotechnical requirements with seeding instability ($Hy$) and non-uniformity ($H_p$) of 0,01 % and 1,4 % respectively.

Single-seed vegetable cell tray seeding techniques are important for reducing seeds wastage, ensuring germination rate and improving vegetable production, which is conducive to the promotion of rational use of human and material resources to achieve quality seedlings for vegetable-growing enterprises in Belarus.

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Мухаммад Белло ГАРБА, магистр техн. наук
аспирант[1]
E-mail: engrbello@bsatu.by

А.А. ШУПИЛОВ, канд. техн. наук, доц.
заведующий кафедрой «Стандартизация и метрология»[1]
E-mail: shypilov.a.a.sm@bsatu.by

[1]Белорусский государственный аграрный технический университет, г. Минск, Республика Беларусь

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# РЕЗУЛЬТАТЫ ИССЛЕДОВАНИЙ ПО ОПТИМИЗАЦИИ УСТАНОВКИ ДЛЯ ВЫСЕВА СЕМЯН ОВОЩНЫХ КУЛЬТУР В КАССЕТЫ

*Преведены результаты экспериментальных исследований по оптимизации параметров механизма высевающего аппарата установки для высева семян овощных культур в кассеты с целью адаптации к конкретным условиям работы. Два основных фактора: разряжение, создаваемое в высевающем барабане, и диаметр присасывающего отверстия — были проверены на семенах капусты (сорт Valentina) с использованием пластиковых кассет с 64 ячейками на трех уровнях (–1, 0, +1) при ортогональном центральном композиционном плане (ОЦКП) регрессионного эксперимента. Исследовано влияние факторов на однозерновой высев, высев с двойниками и пропусками. Результаты исследований показали, что основным фактором, влияющим на однозерновой высев, высев с пропускамии, высев с двойниками, является вакуумное давление, а диаметр присасывающего отверстия не влияет на высев с двойниками. Установлено, что круглые отверстия высевающего барабана соответствуют форме семян капусты для обеспечения качественного высева с требуемыми агротехническими показателями — до 96,0 % одинозернового высева и до 4 % высева ячеек с двойниками и пропусками. Определены оптимальные значения параметров: вакуумное давление — 2,9 кПа и диаметр всасывающего отверстия — 1,0 мм при постоянной скорости движения ленточного транспортера — 2,4 м/мин. Установлено, что эти параметры могут служить основой для разработки и повышения эффективности высевающего аппарата для высева семян овощных культур в кассеты.*

***Ключевые слова:** вакуумное давление, диаметр присасывающего отверстия, качество высева семян, капуста, высевающий аппарат*

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