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DYNAMIC ANALYSIS FOR VEGETABLE SEED SUCKING AND TRANSPORTING ON A TRAY VACUUM PRECISION SEEDING DEVICE

Abstract: Seeding of single seeds in tray cell is an important factor for seedlings production. The aim of this study was to theoretically investigate the factors affecting seeds at sucking and transporting stages. The analysis provided theoretical foundation for optimizing the operational and structural parameters of metering device for tray seedlings production.

Keywords: vegetable seed, sucking, transporting, dynamic, vacuum metering device

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АНАЛИЗ ДИНАМИКИ ПРИСАСЫВАНИЯ И ТРАНСПОРТИРОВКИ СЕМЯН ОВОЩНЫХ КУЛЬТУР В КАССЕТЫ ВАКУУМНЫМ ВЫСЕВАЮЩИМ АППАРАТОМ ТОЧНОГО ВЫСЕВА

Аннотация: Обеспечение однозернового высева семян в кассеты является значимым фактором получения качественной рассады. Цель исследования – анализ факторов, влияющих на процесс присасывания и транспортировки семян к месту высева. Результаты исследований могут служить теоретической основой для оптимизации конструктивно-технологических параметров высевающих аппаратов для промышленного производства рассады в кассетах.

Ключевые слова: семена овощных культур, присасывание, транспортировка, динамика, вакуумный высевающий аппарат

Introduction

Vegetables are considered as one of most important groups of food crops due to their high nutritive value, relatively higher yield and higher return. Vegetables are beneficial to one's health – they are the main sources of nutrients such as vitamins A and C, potassium, folic acid and dietary fiber. Dietary fiber from vegetables aids in reducing cholesterol levels, lowers the risk of heart disease and is also essential for digestion. At present, globally, vegetable production has grown intensively especially on a per capita basis, which is increasing annually. This trend is particularly strong in developing countries. Vegetables cover 1.1 percent of the world's total agricultural area, with the region of Europe and Central Asia contributing with 12 percent of the total global area, and with 14 percent of global production [1].

However, obtaining quality and healthy vegetable seedlings depends on sowing operation. Sowing ensures a proper stand establishment and is one of the most important factors affecting vegetable seedlings growth before transplanting which leads to crop yield. The advantages of vegetable seedlings grown in tray are enormous such as easily removal from the tray for transplanting and the growth check of transplants from tray cells is minimal when planted in the field compared to the use of other types of transplants. Seedlings from cell trays may be used in manual or automatic transplanters. Moreover, the main ways of sowing are, to a large extent, not fully mechanized and mostly manual, which is time-consuming and with low efficiency, and eventually limit the scale of vegetable seeds sowing. Presently, using semi-mechanized devices and manual seeding are the main methods in vegetable seeds sowing in tray while sowing process is labor intensive and time consuming work which brings a great demand to alternative seeding devices.

The majority of vegetable seedlings are from three crops namely, cabbage, tomatoes and peppers [2, 3] B.B. Gaikwad 2008, Vavrina & Summer-hill, 1992). While these seeds are highly expensive, it is important to achieve maximum germination rate and disease-free seedlings for transplanting in open fields. The raising of vegetable seedlings in cell trays is one of the methods that achieve these requirements. Therefore, mechanization of seeding operation in tray cells is necessary to increase the capacity of rapidly growing industries for vegetable seedlings.

In recent times, many seeding metering devices for cell tray seeding such as drum, needle, and plate types are designed or optimized to improve their seed singulation performances. Xia et al [4] 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.

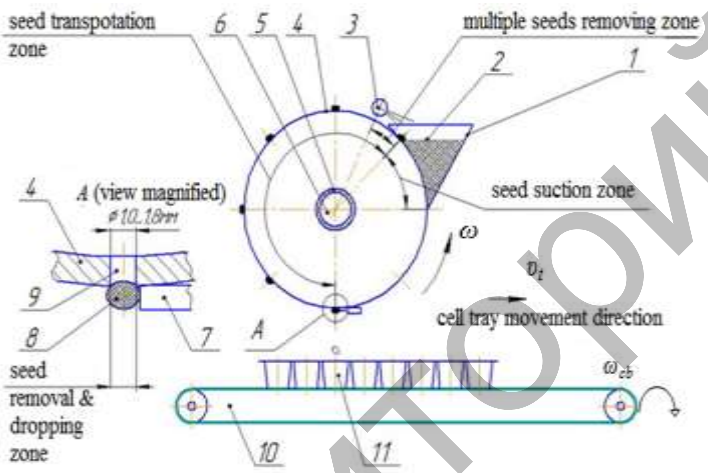
Gaikwad and Sirohi [2] developed a predicting plug tray seeder using indigenous materials and off-the-shelf available standard components/experimental results indicated that the seeder worked satisfactorily at suction pressure of 4.91 and 3.92 kPa and nozzle diameters of 0.46 and 0.49 mm to achieve more than 90% single seed sowing in the case of capsicum and tomato respectively.

Afify et al [5] 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%.

One advantage of the drum-vacuum seeding device is that different seeds (round, flat-shapes) can be seeded without damages and blockage of suction holes. Based on the dynamics and kinematics analyses of vegetable seeds motion around the seeding drum during sucking and transporting stages on a cell tray vacuum precision seeding device, the effect of vacuum pressure and suction hole diameter were investigated.

Structure and operating principle of tray vacuum precision seeding device

The cell tray vacuum precision seeding device is composed of seed hopper, seeding drum, dibbling/compaction cylinder, conveyor belt, frame, perlite/vermiculite hopper, transmission chain and switch control. A schematic diagram of the seeder is shown in figure 1 and a general view of the developed cell tray vacuum precision seeder in figure 2. The principle of operation was described by [6].



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

Figure 1 - Schematic and operational diagram of the seeding device

Figure 2 - Experimental platform of the cell tray vacuum precision seeder

The seeding process is accomplished in three stages starting with seeds suction created by the vacuum produced through vacuum pump, seeds transportation around the surface of the drum and finally seeds removal and dropping in the cells of the tray.

In suction stage, the forces acting on one seed can be denoted as gravitational force (G), normal force from the drum (N), centrifugal force (F_C), sucking force (F_{air}) and friction force (F_T). In addition, the seed sucking force in the hole by the aerodynamic flow will be influenced by the force (F_a).

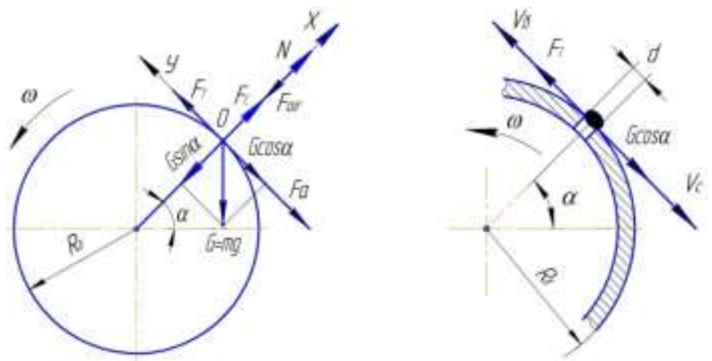


Figure 3 - Forces acting on the seed at the moment of seed suction to the drum suction hole

The position of the seed at the moment of capture into the hole is described by the equations:

$$\sum F_x = N + F_c - G\sin\alpha - F_{air} = 0$$
$$\sum F_y = F_T - G\cos\alpha - F_a = 0, \tag{1}$$

The theoretical force F_{air} necessary to suck the seed to the drum hole diameter is determined by the formula [1]:

$$F_{air} = k\Delta PS, \tag{2}$$

Where, ΔP is the vacuum pressure in the drum (in Pascal), k is drag coefficient ($k = 0.8 - 1.2$), S is projected seed suction hole area (m^2).

The relationship between friction force F_T and supporting normal force N can be expressed as:

$$F_T = fN, \tag{3}$$

then,

$$F_T = fN, \tag{4}$$

Where, f is dynamic coefficient of friction of seeds on the drum surface.

Substituting F_T from equation (3) to (4)

$$\sum F_x = N + F_c - G\sin\alpha - F_{air} = 0$$
$$\sum F_y = fN - G\cos\alpha - F_a = 0 \tag{5}$$

From equation (5):

$$N = \frac{G\cos\alpha + F_a}{f} \tag{6}$$

Substituting N from equation (6) in (5)

$$F_{air} = \frac{G\cos\alpha + F_a}{f} + F_c - G\sin\alpha \tag{7}$$

In order to suck seeds successfully to the hole of the rotating drum, following inequality should be fulfilled i.e. F_{air} should be larger in the first stage to overcome the weight and the force among seeds:

$$F_{air} \geq \frac{G\cos\alpha + F_a}{f} + F_c - G\sin\alpha \tag{8}$$

We define the vacuum force in the drum, at which equation (7) holds. To this end, we substitute the values and transform into equation (8), taking into account that

$$F_c = \frac{mV_б^2}{R_б}, \tag{9}$$

Where $V_б$ is velocity of the drum (m/s); $R_б$ is radius of the drum (m).

To determine the vacuum in the drum necessary for seed suction, after the transformation, inequality (2) takes the following form:

$$k\Delta PS \geq \frac{G\cos\alpha + F_a}{f} + \frac{mV_б^2}{R_б} - G\sin\alpha, \tag{10}$$

When $G = mg$ and $F_a = \frac{3mV_б^2}{d}$ (taking into account some assumptions which are not shown here). Thus,

$$\Delta P \geq \frac{G}{S \cdot k}\left[\frac{1}{f}\left(\cos\alpha + \frac{3V_б^2}{g \cdot d}\right) - \sin\alpha + \frac{V_б{}^2}{gR_б}\right]. \tag{11}$$

The above inequality (11) determines the vacuum required to suck the seeds to the holes in the drum under other conditions and the specified parameters of seeding into the tray which depends mainly on the mass of the sown seeds, the diameter of the suction holes, the peripheral speed of the drum (synchronized with conveyor belt speed), and the dynamic coefficient of friction of the seeds on the surface of the drum. With the increase in these parameters, the vacuum required for reliable suction of seeds increases.

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