International Journal of Agricultural Technology 2024 Vol. 20(5):1755-1764
Available online http://www.ijat-aatsea.com
ISSN 2630-0192 (Online)

The mechanical method of collecting the colorado potato beetle (*Leptinotarsa decemlineata* SAY, 1824, *Coleoptera, Chrysomelidae*) using a device with passive working elements

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Arendarenko, V., Semenov, A., Kharak, R., Padalka, V., Antonets, A., Liashenko, S., Opara, N., Barabolia, O., Prudkyi, T. and Drozhchana, O. (2024). The mechanical method of collecting the colorado potato beetle (*Leptinotarsa decemlineata* SAY, 1824, *Coleoptera, Chrysomelidae*) using a device with passive working elements. International Journal of Agricultural Technology 20(5):1755-1764.

Abstract An analysis of traditional and alternative methods for combating the Colorado potato beetle in potato cultivation was conducted. In this study, a device for mechanical collecting the Colorado potato beetle using passive elastic rods has been developed. As the device is moved through the potato rows, the elastic rods, when deflected, strike the stems and leaves of the plants. As a result of this shaking action, the beetles are fallen into collection trays. To test the method using the developed device, the field was divided into 12 plots, each with 6 rows. Three interchangeable plates with one, two, and three rows of elastic rods, made of organoplastic and measuring 150 mm in length, were used for shaking. The device's chamber is equipped with a mechanism for adjusting the inclination angle of the working plate. In the experiments, this angle was set at 50, 150, 250, 300, and higher. The conducted research was determined that at a machine-tractor unit speed of 6.8 km/h and an inclination angle of the working plate $\alpha = 250$, the maximum value of the Colorado potato beetle collection coefficient kc = 0.914 is achieved. The coefficient of leaf mass damage did not exceed 3.1 %.

Keywords: Collection coefficient, Elastic rods, Mechanical device, Potato cultivation, Colorado potato beetle

Introduction

Potatoes are grown on nearly every continent in the world and are a significant sector in agriculture in many countries (Çalişkan *et al.*, 2022). Some of these countries play a more significant role in global potato production, as it

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ranks among the top five crops worldwide. China and India are the largest potato producers, with their production volumes amounting to 148 million metric tons annually (Potato News Today, 2023).

In Ukraine, potatoes hold a prominent position in terms of their versatility for use in the food industry, with an annual production quantity of 21 million metric tons (Potato News Today, 2023).

One important agronomic practice in potato cultivation is combating the Colorado potato beetle (Kadoić-Balaško *et al*., 2020), a pest capable of causing significant damage to farms. Its harmfulness is manifested in a 50 % or more reduction in potatoes yield (Maharijaya and Vosman, 2015), as well as a decrease in tuber size, starch content, and protein content (Huseth *et al*., 2014; Alyokhin *et al*., 2015).

The use of pesticides has become the primary method of combating this notorious pest in recent years (Sablon *et al*., 2013). Throughout the entire growing season, potato fields undergo multiple chemical treatments. Insecticides are used for this purpose (Kadoić-Balaško *et al*., 2020), which are applied to the leaves and stems of the potato plants using sprayers. However, prolonged use of chemical substances leads to a decrease in their effectiveness due to the emergence of resistant populations of the beetle and its resistance and adaptation to insecticides (Pélissié *et al*., 2022). Excessive use of chemical insecticides has a negative impact on the environment, including soil, water, and air pollution (Khelifi *et al*., 2007).

Non-traditional methods include biological (Cingel *et al*., 2016), pneumatic (Reshad *et al*., 2009, Almady and Khelifi, 2021), and mechanical approaches, which are of interest in achieving environmentally friendly production and minimizing environmental impact.

Cingel *et al*. (2016) asserted that the diverse life cycle, phenotypic plasticity, adaptation to adverse conditions, and ability to tolerate toxins make the Colorado potato beetle (CPB) virtually "indestructible". The advancement in molecular biology has unfolded a biotechnological warfare in the battle against CPB. However, the authors emphasized that biotechnological methods alone cannot overcome the Colorado potato beetle. Such control methods compel the beetle to display its adaptability (Schoville *et al*., 2018). Its high capability for acclimatization is associated with specific genes (Cingel *et al*., 2016).

One of the environmentally friendly methods for pest control including the Colorado potato beetle is the use of insecticidal proteins (Žigon *et al*., 2021). Due to their biological function, insecticidal proteins hold significant potential in the development of transgenic plant resistant to insect pests and the formulation of new bioinsecticidal agents.

To combat pests using mechanical methods, inventors propose numerous devices and techniques. In the study, Reshad *et al*. (2009) stated that a portable pneumatic machine for collecting the Colorado potato beetle was developed. The design is based on an air-blowing unit to dislodge insects from plants and a collection unit placed opposite and on both sides of the potato plant rows. Evaluation was conducted at different speeds under field conditions: at 35 and 45 m s-1. Experimental results showed that a speed of 45 m/s achieved better insect displacement from the plants. A similar pneumatic device was discussed in Almady and Khelifi (2021). The authors considered pneumatic methods as an alternative to chemical insecticides. The pneumatic machine prototype was tested under field conditions using three air flow speeds (31, 35, and 38 m/s) and two machine speeds (5 and 6 km/h). There was indicated that air flow speed and machine speed did not significantly affect CPB displacement ($p = 0.0548$ and 0.7033, respectively). The most effective air flow speed resulted in the removal of most CPB larvae from potato leaves which found to be 35 m/s. Lacasse *et al*. (1998) proposed a vacuum-based system for collecting the Colorado potato beetle. The principle is involved in sucking the insects into nozzles using an airflow and collecting them in special containers. There was investigated the impact of different combinations of air flow speeds, width of the air flow, and machine speeds. The effectiveness of this system was evaluated in comparison to traditional approaches.

Vincent and Boiteau (2001) offered a diffusion-based suction device for collecting pests. They suggested device consisted of a chamber with a horizontal slit at the lower part, through which pests are sucked by the created low pressure generated by a centrifugal fan. As the apparatus is moved across the field, harmful insects are drawn into the airflow and transported to the collection container through the suction chamber nozzles. The pests are destroyed after accumulation. A drawback of this device is shown the inability to collect pests from the lateral surfaces of plants. A significant number of pests remain on the ground, due to shaking. There are also other methods and designs of air headers for Colorado beetle control (Rifai *et al*., 2004).

Boiteau and Misener (1996) investigated the response of the Colorado potato beetle (*Leptinotarsa decemlineata*) to vibrational stimuli under laboratory conditions. Beetles exposed to vibrations primarily dropped off within the first 2 seconds of exposure. It was demonstrated that the vibrational method can be quite effective in collecting beetles at frequencies of 20 Hz and over.

The analysis of mechanical and pneumatic devices for collecting and eliminating the Colorado potato beetle indicated that mechanical devices are show to be structurally simpler compared to pneumatic ones. They can be effectively used on small potato fields in farmer's and private farms.

The aim of this study was to develop and investigate a device with passive-type working elements for the mechanical method of collecting the Colorado potato beetle.

To achieve this goal, the following tasks need to be addressed, developed a device with passive-type working elements; investigated the effectiveness of Colorado potato beetle collection based on device parameters.

Materials and methods

Experimental studies on the collection of the Colorado potato beetle in a potato field were conducted at the Nadia Farm in Kremenchug district, Poltava region, Ukraine, in 2022 and 2023.

For field research, a plot of land with 54 rows and a row spacing of 70 ± 3 cm was selected. The potato plants were hilled, with an average ridge height of 25 cm. The length of the potato rows was 400 m. The field with potato plantings was divided into nine plots, each containing six rows. The ambient temperature during the research was 26 °C.

For the collection of the Colorado potato beetle, a single-row mechanical device with passive shaking working elements was used (Figure 1a). The device consists of a tunnel-shaped body (1) a plate that bends the potato stems into the collection tray (2), a variable textolite plate (3), a mechanism for adjusting the angle of inclination of the potato stems (4), a removable tray for collecting pests (5), and running wheels (6). The textolite plate is equipped with a set of elastic rods (7) that is made of organoplastic, each measuring 150 mm in length. Three types of textolite plates were used in the experiments on the first plate (Type A), the elastic rods were arranged in a single row; on the second plate (Type B), the elastic rods were arranged in two rows; and on the third plate (Type C), the elastic rods were arranged in three rows (Figure 1b).

The device is operated as follows. During the potato row movement plate number 2 bends the potato stems towards the tray number 5. Due to the translational speed of the device the elastic rods are made frequently impulse with impacts on the leaves and stems of the potato plant. As pests have a defensive instinct it detached themselves from their location in response to the oscillatory action and fall into the tray of the device. After passing through the row the tray with the pests was removed and the beetles that ended up in it, and were transferred to a container that weighed on electronic scales. The device was towed by a 14 kN tractor at a translational speed ranging from 6.4 to 8.1 km/h.

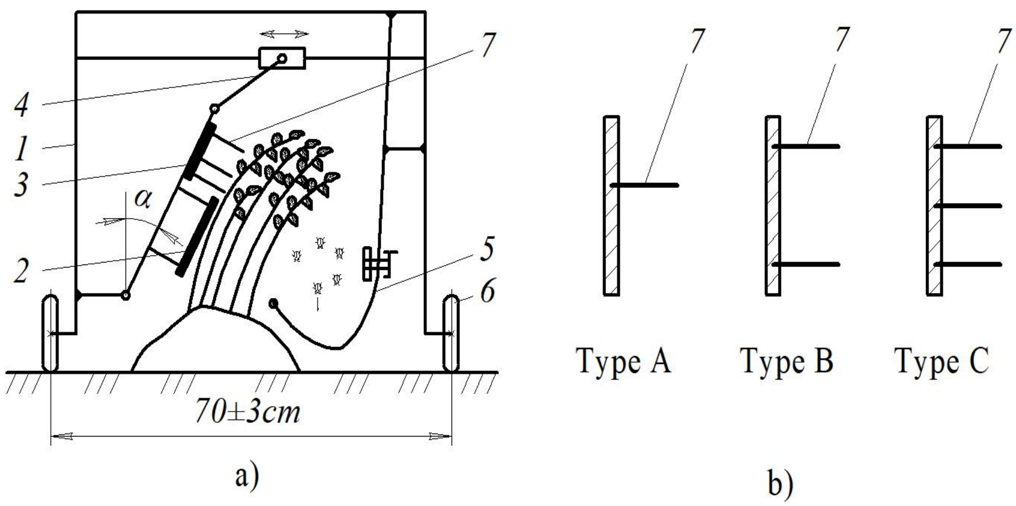

Figure 1. Device for collecting Colorado potato beetles: a) front view; b) types of interchangeable textolite plates with a set of elastic rods

The experiment with a single row of rods (Plate A) and an angle α = 50 was conducted on the first six rows. Then, using the adjustment mechanism, the angle was set to α = 150, and the pest collection was carried out on the next six rows. Similarly, beetle collection was performed with an angle α = 250.

After collecting the Colorado beetles on the eighteen rows the textolite plate was replaced. Plate A with a single row of rods was removed and Plate B with two rows of elastic rods was installed. The experiment on beetle collection with two rows of elastic rods followed the same scheme on the remaining eighteen rows. The subsequent experiment on beetle collection was conducted similarly to the first two. However, Plate B included three rows of rods. During the experiments on beetle collection the damage coefficient of the leaf and stem mass of the potato plants was simultaneously determined. The minimum acceptable value of the damage coefficient was kd = 5 %.

The processing of the results obtained from the experiments on Colorado beetle collection using the device with passive elastic rods was carried out using statistical methods and calculations of collection coefficients, variations, and damage.

Results

Potato beetles were collected in the tray after passing through the first plot consisting of six rows of potatoes with a stem inclination angle (α) of 50 degrees, 1036.8 grams of Colorado. The total mass of Colorado potato beetles on these rows, after manual collection, was 1626.2 grams. Calculations revealed that there were 15 to 21 pests per plant. The collection coefficient of Colorado potato beetles in this plot was kc = 0.638, and the damage coefficient did not exceed 2 %.

The stem inclination angle (α) was set to 150 degrees on the second plot which was also consisted of six rows. After passing through all six rows, 1244.5 grams of pests were collected in the tray. Additionally, a certain number of beetles were manually collected, resulting in a total mass of 1661.6 grams. The collection coefficient (kc) on this plot was kc = 0.749, and the damage coefficient did not exceed 2.4 %.

On the third experimental plot with an angle α = 250, 1397.5 grams of beetles were collected. The total weight of the beetles on this plot was 1812.9 grams. The collection coefficient (kc) was 0.771, and the leaf damage coefficient did not exceed 2.5 %.

The results of the subsequent experiments on plots 4-9 with angles α = 50, α = 150, α = 250 using plates B and C are presented in Table 1.

Field studies revealed that the population of Colorado potato beetles is higher at the outer sections of the potato field compared to the central sections. This can be attributed to the migration of the pests from other plantations.

Through the screening of the experimental data was determined that factors that have the greatest impact on the quality indicators of insect collection were identified. These factors include the angle of the working plate, the number of rows of elastic rods on the textolite plate, and the speed of the aggregate movement. The best results in beetle collection are achieved with an angle α = 250 and three rows of elastic rods (Table 1).

At a speed of 6.8 km/h for the mechanical transport aggregate and with an inclination angle of the working plate B α = 250, the maximum collection coefficient (kc) of 0.914 for Colorado potato beetles is achieved. The leaf damage coefficient does not exceed 3.1 %.

Table 1. The mechanical collection of Colorado potato beetles using passive vibrating working elements

Indexes	***Angle of inclination of the working plate relative to the vertical, degrees***		
	α = 5^0	*α* = 15^0	*α* = 25^0
One row of elastic rods (plate type A), *n* = 1			
Collection coefficient, k_c	0.638	0.749	0.771
Mean squared, σ	$3.48 \cdot 10^{-2}$	$1.25 \cdot 10^{-2}$	$2.31 \cdot 10^{-2}$
Coefficient of variation, V %	5.45	1.67	2.99
Damage coefficient, k_d	≤2.0 %	≤2.4 %	≤2.5 %
Two rows of elastic rods (plate type B), *n* = 2			
Collection coefficient, k_c	0.719	0.789	0.882
Mean squared, σ	$6.31 \cdot 10^{-3}$	$7.31 \cdot 10^{-3}$	$8.47 \cdot 10^{-3}$
Coefficient of variation, V %	0.86	0.926	0.96
Damage coefficient, k_d	≤2.1 %	≤2.6 %	≤2.8 %
Three rows of elastic rods (plate type B), *n* = 3			
Collection coefficient, k_c	0.736	0.803	0.914
Mean squared, σ	$3.58 \cdot 10^{-3}$	$4.27 \cdot 10^{-3}$	$4.71 \cdot 10^{-3}$
Coefficient of variation, V %	0.49	0.53	0,54
Damage coefficient, k_d	≤2.5 %	≤2.9 %	≤3.1 %

In the experiments on Colorado potato beetle collection the angle of inclination of the working plate with elastic rods was set in three positions. The first position was α = 50, the second was α = 150, and the third was α = 250. Further adjustment of the angle of inclination resulted in intensive damage to the stem and leaf mass of the plants. With an angle of α = 250, the damage coefficient did not exceed 3.1 %. However, when the angle of inclination was set to α = 300, the damage coefficient ranged from 7.6 % to 9.1 %. At an inclination angle of α = 350, the amount of damage increased by approximately 14 %.

Discussion

Based on the conducted analysis, the effectiveness of mechanical methods for controlling the population of the Colorado potato beetle in potato cultivation has been confirmed. Mechanical methods typically employ working elements of various configurations (Arendarenko *et al*., 2011), which shake the pests into device trays for subsequent destruction.

As shown by the analysis of mechanical methods, Colorado potato beetles can be collected using pneumatic devices that create an airflow (Reshad *et al*., 2009, Almady and Khelifi, 2021) or, conversely, vacuum suction (Lacasse *et al*., 1998). The pneumatic device used in study (Reshad *et al*., 2009) provided a beetle collection rate of 44 % at an airflow speed of 45 m s-1, but this rate dropped to 21.2 % when the speed was reduced to 35 m s-1. Such results do not ensure high potato yields, and the reuse of such a pneumatic system is economically disadvantageous. In another study (Almady and Khelifi, 2021), the authors experimented with a pneumatic device and settled on an airflow speed of 35 m s-1, while the mechanical transport unit operated at speeds ranging from 5 to 6 km h-1. However, the offered device requires large-scale testing to determine the necessary efficiency of pest collection and the extent of plant damage. Study (Lacasse *et al*., 1998) utilized a setup with a pneumatic system that created a vacuum in the working chambers. The speed of the equipment also did not exceed 6.0 km h-1, and the damage coefficient to leaf mass was insignificant, although there were more severe damages caused by tractor wheels. Like in previous studies, the collection coefficient of Colorado potato beetles was unsatisfactory, thus indicating the need for improvement in the vacuum pest displacement system. Pneumatic devices have significant drawbacks, as they are complex, energy-intensive, have low productivity, and do not ensure effective pest collection from plants (Vincent and Boiteau, 2001). The mentioned drawbacks of pneumatic devices can be easily overcome by using a device with passive working elements that provides mechanical shaking of Colorado potato beetles from plants with optimal productivity and efficiency.

Therefore, the proposed device with passive working elements, when operated within the specified parameters, ensures the collection of Colorado potato beetles at a high technological level.

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(Received: 7 June 2023, Revised: 9 July 2024, Accepted: 6 September 2024)