ISAE 2023

The 6th International Symposium on Agricultural Engineering, 19th – 21st Oct 2023, Belgrade–Zemun, Serbia

EFFECTIVENESS OF INSECTICIDES IN THE CONTROL OF CEREAL LEAF BEETLE *(OULEMA MELANOPUS)* USING AN UNMANNED AERIAL VEHICLE

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Abstract: *Modern management of sustainable agriculture requires fast information about the condition of cultivated plants and a quick response to unwanted phenomena such as the appearance of pests in crops. According to the areas on which it is grown wheat occupies the first place in Serbia while the European Union is the world's largest producer of wheat. However, the technology of wheat production is demanding, especially in extreme climatic conditions such as large oscillatory changes in temperatures and rainfall during the year. The appearance of insects in wheat crops can cause significant crop damage and yield reduction, especially if protection measures are not implemented in a quality manner, in a timely manner, i.e. in the initial stages of insect development. A pest that can cause a significant reduction in wheat yields is the cereal leaf beetle (Oulema melanopus). The cereal leaf beetle feeds on leaves that remain bitten in the form of stripes while the larvae bite only the upper layer, which leads to the appearance of white elongated lines. Due to the decrease in leaf mass, there is also a decrease in the yield of wheat. In Serbia, chemical protection of wheat is most often applied using field sprayers, which recently often show insufficient effectiveness in protecting wheat. Modern pesticide application techniques involve the use of unmanned aerial vehicles (UAVs). Their main advantage compared to conventional field sprayers is the achievement of higher performance as well as better distribution of pesticides on the targeted surface, which results in greater efficiency and flexibility. The aim of this research was to examine the effectiveness of insecticides in controlling the cereal leaf beetle using two different techniques, unmanned aerial vehicles and field sprayer. The insecticide that was used in this research with an unmanned aerial vehicle showed a good efficiency, namely 3 DPT - 49.86%, that is, 72.17% - 9 DPT.*

Keywords: *unmanned aerial vehicle (UAV), knapsack sprayer, cereal leaf beetle, efficiency chemical protection, modern techniques, insects.*

INTRODUCTION

Wheat (*Triticum aestivum*) is one of the main agricultural crops used in the food industry of Serbia, and also one of the most important food products worldwide. According to the data of the Republic Institute of Statistics, the total area sown under wheat in Serbia for the year 2022 was 665,718 ha, which is 6.1% more than in 2021 (RZS, 2023), while in Europe in the mentioned period the areas under wheat amounted to 62,823,491 ha (FAOSTAT, 2023). Ensuring high and stable wheat yields is one of the important factors for solving the problems of poverty and hunger in the world. During the growing season, wheat is attacked by a large number of pathogens and pests. The grain leech (*Oulema melanopus*) is one of the most economically significant insect pests that can directly affect the yield and quality of wheat grains (Milovac and Franeta, 2016). Damage is caused by adult insects and larvae feeding on the leaves of winter wheat. The greatest damage occurs if the flag leaf is damaged, which according to data from the Netherlands can result in a yield reduction of up to 95%, while that percentage is slightly lower in Central Europe (70%) (Császár at el., 2021). In the case of a stronger attack of this pest, there may be damage in the form of smaller or larger oases on the plots, and eventually drying of the entire list mass. Mass reproduction of grain leech is favored by wet and warm weather.

Suppression of grain leech can be carried out by various preventive agrotechnical measures, which include the cultivation of resistant varieties, the destruction of plant residues by deep cultivation of the soil, the application of crop rotation, as well as the optimal application of nitrogen fertilizers. However, the most common way to control grain leech is the application of chemical measures, which include the use of insecticides. These measures act on both the adults and the larvae of this pest. The damage threshold for adults is from 8 to 15 larvae per m^2, while for larvae the damage threshold is from 5 to 10 larvae per m^2, i.e. 1-2 larvae per plant (Milovac and Franeta, 2016). Of the insecticides for these purposes, compounds from the parathyroid group are most often used. The timely and high-quality application of insecticides is of great importance for the successful control of grain leech. Suppression of the imago is carried out when its number reaches the specified damage threshold in order to prevent massive egg laying. However, the use of insecticides is usually aimed at controlling the larvae when they are in the younger larval stages. Insecticides are applied using agricultural sprayers, which can be backpack sprayer, tractor-mounted boom sprayer and self-propelled. Nevertheless, based on the conducted tests of sprayers used in our country, it was shown that they largely do not meet the prescribed technical parameters. Malfunctions that occur on these sprayers, which significantly affect the quality of pesticide application, are the flow of the pump and nozzle, as well as the correctness of the manometer. The flow rate of the pump and nozzle is often either higher or lower than prescribed, most often due to the long use span of the sprayer (Bošković et al., 2019). On the other hand, manometers often show pressures that deviate from the set values (Bošković et al., 2021). According to the agricultural census from 2012, the percentage representation of sprayers older than ten years in relation to the total number of sprayers in the Republic of Serbia is 82% (RZS, 2012), which indicates the stated problem of sprayer weariness. In addition to the correct selection of appropriate pesticides, it is necessary to pay attention to the adequate time of application and its correct application that is, the selection of appropriate technical systems for application (Pajić et al., 2019).

In recent years, the unmanned aerial system (UAV) for crop protection has developed rapidly in the world, not only technically but also in the field of practical application. Also, the safety and accuracy of UAVs has improved significantly with the introduction of obstacle avoidance and terrain tracking technology. As one of the main advantages of pesticide application using unmanned aerial vehicles, an increase in work efficiency of about 0.8 - 2.8 ha h^{-1} is stated (Zhang et al., 2021). Another important advantage of such a system is the absence of operator exposure to the harmful effects of pesticides.

Previous research has mainly focused on examining the influence of the operating parameters of the UAV on the effectiveness in controlling diseases and harmful insects such as aphids, while there is almost no data on the effectiveness of insecticides applied by UAV in the control of grain leech. The objective of this study was to investigate the effectiveness of insecticides in controlling *O. melanopus* using an UAV.

MATERIAL AND METHODS

The experiment was conducted at the location of Busije (Zemun municipality) (GPS: 44° 54′ 58″ N, 20° 13′ 34″ E, altitude: 66 m). Basic tillage was done on the plot to a depth of 20 cm, with the addition of NPK mineral fertilizer formulation 6:24:12 in the amount of 300 kg ha^{-1}. After the basic one, additional tillage of the soil was done, followed by pre-sowing preparation and finally the marking of the experimental field. Wheat sowing was done with a pneumatic seeder, on October 21st, 2022. The sowing rate was 240 kg ha^{-1}, while the pre-crop was corn. The wheat variety was Sofru-RWA. The wheat crop was supplemented with mineral fertilizers three times during the experiment.

In the experiment, a total of six treatments were set up in which the effects of two insecticide application techniques were examined, i.e. the application of insecticides using an UAV at different heights and speeds, as well as the application of insecticides using a conventional tractor sprayer. Table 1 shows data on treatments and applied technical systems.

Table 1. Overview of treatments tested in the trial

Treatment	Technical system	Work parameters
T1	UAV	h= 1 m; v= 3 m s^{-1}
T2	UAV	h=1 m; v= 5 m s^{-1}
T3	UAV	h= 2 m; v= 3 m s^{-1}
T4	UAV	h= 2 m; v=5 m s^{-1}
T5	Field sprayer	b = 21 m; v=5 m s^{-1}
T6A** and T6B	Control	Without chemical protection

*h – flight height; v – movement speed; b – spray width

**A – control for an unmanned aircraft; B – control for the field sprayer

The experiment was set up according to a partially adapted EPPO method (EPPO STANDARDS, 2005) for testing the effectiveness of insecticides in controlling grain leech (*Oulema spp.*) on winter wheat grains (PP 1/236 (1)). The size of the experimental field was 10,200 m^2, while the area of one experimental plot was 1,200 m^2 (20 m x 60 m). A buffer zone of 10 m was left between treatments as a protective zone to avoid the occurrence of drift effects (Wang, 2019). The insecticide used in the experiment was Deltamethrin (Decis Expert, 100 g l^{-1} a.i., Bayer, Germany) in the amount of 0.075 l ha^{-1} with the addition of the wetting agent Inex (fatty alcohol ethoxylate 20.3%, polydemethylsiloxane 1.0%) in the amount of 1 ml per 1 l of water. The treatment rate was 30 l ha^{-1} for the UAV, or 200 l ha^{-1} for the field sprayer. Treatments were carried out in the flowering phase of wheat (BBCH 61), more precisely with a field sprayer on May 9th, 2023, and with an UAV on May 16th, 2023.

The field sprayer (Kubota - iXtrack T3) used in the experiment has a working width of 21 m and a tank volume of 2,600 l. Lechler IDKT 12005 sprayers were used on the field sprayer. The working parameters of the sprayer were: speed of movement 5 m s^{-1}; system operating pressure 0.8 MPa; treatment rate 200 l ha^{-1}. The UAV sprayer (DJI T30, Shenzhen DJI Innovation Technology Co., Ltd., China) used in the experiment has a working width of 6 m and a tank volume of 30 l. The Jeet XR11001 nozzle was used on the UAV sprayer. The operating parameters of the UAV sprayer were: flight speed (v = 3 m s^{-1}; v = 5 m s^{-1}); flight altitude (h = 1 m; h = 2 m); system operating pressure 0.5 MPa; treatment rate 30 l ha^{-1}. Table 2 gives a detailed description of the technical characteristics of the UAV. The flight parameters of the unmanned aerial vehicle (altitude and speed) in the test were optimized based on previous research.

Table 2. Technical characteristics of the unmanned aerial vehicle

Characteristics	**Parametres**
Dimensions (mm)	2858 × 790 × 2685
Number of sprayer	16
Tank capacity (l)	30
Working width (m)	4 – 9 (5)
Type of the sprayer	TJeet XR11001
Flow (l/min)	7,2
Droplet diameter (µm)	130-250
Flight time with empty tank (min)	20,5
Flight time with full tank (min)	7,8

Figure 1. Unmanned aerial vehicle in operation

Effectiveness of insecticides - The effectiveness of insecticides was determined based on the number of grain leech larvae in the treatments. Assessments of the number of larvae were performed in three terms: immediately before treatment (NPT), three days after treatment (3 DPT) and nine days after treatment (9 DPT). In all evaluation periods, 100 upper leaves of wheat were examined by random selection within the experimental plot and the number of grain leech larvae was determined. The effectiveness of the insecticide was determined according to the Henderson-Tilton formula.

Meteorological conditions - During the experiment, meteorological parameters were monitored, which included the measurement of temperature and air humidity (Voltcraft DL-140TH), as well as wind speed (Testo 410i Smart Probe). The mentioned devices were placed at the height of the flight of an UAV, i.e. at 1 m and 2 m above the crops, in order to be in harmony with the height of the flight of of an UAV (table 4 and 5).

Yield monitoring - The analysis of yield parameters (morphological characteristics and yield) was carried out in laboratory conditions by taking 20 samples in five repetitions, a total of 100 samples from each experimental plot, where the sample was represented by wheat plants from an area of 1 m^2**.**

RESULTS AND DISCUSSION

Table 3 shows the values of average temperature and amount of precipitation for April, May and June 2023 for the area of Busija. Based on these data, it can be seen that during the month of May there was slightly more precipitation with optimal air temperatures, which favored the accelerated development of grain leech.

Table 3. Average values of meteorological parameters for the period April - June (2023)

	April	**May**	**June**
Average temperature (^oC)	11,2	17,4	21,8
Amount of precipitation (mm)	79	92,8	75,6

*****(RHMZ)

Table 4. Values of meteorological parameters at the time of treatment with a field sprayer

Date	Temperature (℃)	Wind speed (m/s)	Air humidity (%)
16.05.2023.	22	3	85

Tables 4 and 5 show the mean values of meteorological parameters that were monitored during chemical treatments. During the period of chemical protection with an UAV, the temperatures were slightly higher than the recommended temperatures for chemical protection, but the wind speed was optimal for the application of the mentioned insecticide. The meteorological parameters that were monitored during chemical protection with the filed sprayer were within the limits recommended for the performance of chemical protection and the successful adoption of insecticides.

Table 5. Values of meteorological parameters at the time of performing the treatment with an UAV

Measurement hight(m)	Temperature (℃)	Wind speed (m/s)	Air humidity (%)
1	30,2	0,96	44,9
2	30	1,05	46

Table 6: The numerosity of grain leech larvae NPT, 3DPT and 9DPT and the effectiveness of the applied insecticide (May 2023)

Treatments	Evaluation time	Average number of larvae per leaf	Efficiency (%)
	NPT	**1.57**	**-**
T1 (UAV) (h= 1 m; v= 3 m s^{-1})	**3DPT**	**1.06**	**49,86**
	9DPT	**0.67**	**72,17**
	NPT	**0,96**	**-**
T2 (UAV) (h= 1 m; v= 5 m s^{-1})	**3DPT**	**0.78**	**39,67**
	9DPT	**0,45**	**69,43**
	NPT	**0,94**	**-**
T3 (UAV) (h= 2 m; v= 3 m s^{-1})	**3DPT**	**0,82**	**35,22**
	9DPT	**0,43**	**70,17**
	NPT	**0,8**	**-**
T4 (UAV) (h= 2 m; v= 5 m s^{-1})	**3DPT**	**0,76**	**29,46**
	9DPT	**0,38**	**69,02**
	NPT	**0,87**	**-**

T5 Field sprayer	**3DPT**	**0,96**	**25, 05**
	9DPT	**1.0**	**36,34**
T6a control for UAV	**NPT**	**0,75**	**-**
	3DPT	**1.01**	**-**
	9DPT	**1,15**	**-**
T6b control for field sprayer	**NPT**	**0,72**	**-**
	3DPT	**1,06**	**-**
	9DPT	**1,3**	**-**

The number of grain leech larvae in control treatments immediately before treatment (NPT) ranged from 0.72 to 0.75 per plant. In the other investigated treatments, the number of larvae in the assessment before treatment was between 0.87 and 1.13 larvae per plant. The results of the experiment indicate that the application of insecticides using an UAV gave better effects in suppressing the grain leech compared to the application with a field sprayer. Thus, in the 3DPT evaluation, the efficiency of deltamethrin applied by means of UAV at a height of 1 m and a speed of movement of 3 m s^{-1} (T1 treatment) was 49.86%, while the 9DPT efficiency was 72.17% (Graph 1). In the second treatment where deltamethrin was applied using a UAV at a height of 1 m and a speed of 5 m s^{-1} 3DPT achieved an efficiency of 39.67%, while 9DPT efficiency increased significantly and reached 69.43%. The same insecticide applied using a UAV at a height of 2 m and a speed of 3 m s^{-1} (treatment T3) 3DPT had an efficiency of 35.22%, while after the second assessment, i.e. 9DPT, the efficiency was 70.17%. In the treatment where deltamethrin was applied by UAV at a height of 2 m and a speed of movement of 5 m s^{-1} (T4 treatment), the efficiency ranged from 29.46% (3DPT) to 69.02% (9DPT). On the other hand, application with a field sprayer was significantly less effective in controlling *O. melanopus* compared to application with an UAV vehicle in both evaluation periods. Thus, the efficiency of deltamethrin applied with a field sprayer in the 3DPT evaluation was 25.05%, while the 9DPT efficiency was only 36.34%, which indicates that there is a problem with this technical system.

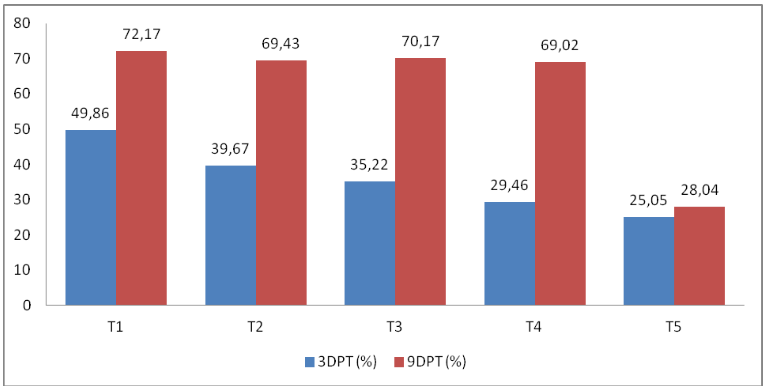

Figure 2. Effectiveness of insecticide applied by different technical systems

Many studies have shown that the application of pesticides using UAV has achieved good effectiveness in controlling harmful insects. Thus, Lou et al. (2018) found that the effectiveness of insecticides in controlling aphids was 63.7% and 61.3%, respectively, in controlling mites on cotton when the flight height was 1.5 and 2 m. Also, Wang at el. (2019) state that the effectiveness of insecticides in controlling aphids on wheat applied by UAV system is about 70.9%. On the other hand, Malschi (2003) states that the effectiveness of deltamethrin in controlling *O. melanopus* ranged from 93-96.6%. Trials conducted in 2008, 2009 and 2010, the effectiveness of insecticides from the pyrethroid group in controlling grain leech ranged from from 70.3 to 87.2% (Kaniuczak, 2013).

In general, the effectiveness of the applied preparationwas not satisfactory, so that, from a practical point of view, its application does not ensure complete protection of the wheat crop from grain leech. As one of the reasons that can contribute to a slightly lower efficiency are the favorable meteorological conditions that contribute to the rapid and unhindered development of grain leech during the spring. In addition, one of the reasons stated can be the intensive application of agrotechnical measures, first and foremost, supplementing with mineral fertilizers in order to ensure a high yield, which at the same time influence the intensive development of the pest. However, the effectiveness of the insecticide can be affected by the technical parameters of the treatment device itself, such as droplet size, distribution, deposition, drift, etc. For now, the mentioned parameters have not been tested for the devices that were used in the trial, so it is necessary to test the mentioned parameters in the following period. In their research, Zhang et al. (2021) proved that the height and speed of flight affect the uniformity of droplet deposition. In addition, for UAVs with multiple rotors (multi rotors), the influence of height and flight speed on the width and speed of droplet penetration was investigated, and it was proven that the flight speed significantly affects the effective width of the drone. Also, the best deposition of droplets at the base of rice plants was at a flight speed of 5 m s^{-1} and a height of 1.5 m. In order to achieve better effects in controlling pests in wheat crops, Wang et al. (2019) suggest the use of larger droplets as well as a higher rate of treatment. Finally, the potential development of resistance of grain leech populations to insecticides may be the reason for the poor efficiency. Considering the long history of application of parathyroid-based compounds in wheat crops, it should be investigated whether there has been a change in the sensitivity of *O. melanopus* populations to the mentioned group of insecticides.

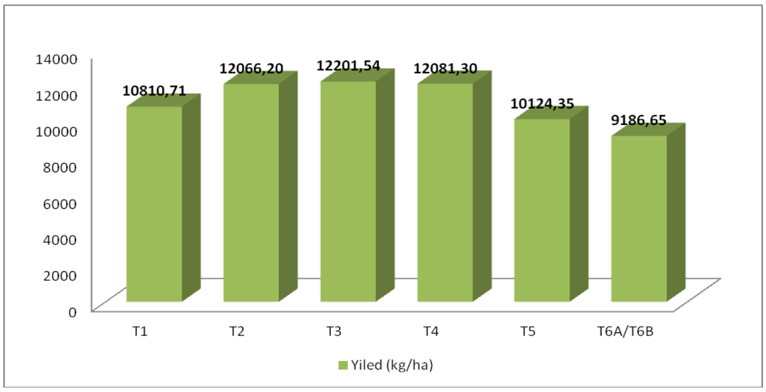

Figure 3. Wheat yield by treatments based on grain mass calculated at 14% moisture

In terms of yields (Figure 2), a significant difference can be observed in the yields achieved in the treatments where chemical protection was performed compared to the control (T6A/B). The highest yield, 12201.54 kg ha^{-1} was achieved in the T3 treatment, while the lowest yield was measured in the control and was 9186.65 kg ha^{-2}, i.e. in the T3 treatment the yield was higher by 24.7% compared to the T6A/B treatment. After the control, the lowest yield was achieved in the T5 treatment, 10124.35 kg ha^{-1}. In treatments T2 and T4, approximately the same yield was achieved, 12066.20 kg ha^{-1} and 12081.30 kg ha^{-1}, respectively, which is 23.86% and 23.95% more than in the control treatments. In treatment T1, the yield was 10810.70 kg/ ha^{-1}. The reason for the lower yield achieved in treatment T1 may be a slightly higher number of larvae immediately before treatment compared to the other treatments, which resulted in greater damage to the leaf and reflected on the yield itself.

CONCLUSION

The results of the research in this study show that there is a tendency for the efficiency of pesticides to increase with the application from the UAV system, but that it is first necessary to examine the influence of the operating parameters on the final efficiency. The above results show that the application of insecticides using an UAV achieved better effects in protecting wheat from grain leech compared to the conventional application using a field sprayer. In order to achieve the best protection effects, it is necessary to choose the appropriate operating parameters of the UAV system depending on the type of crop and the phenophase of development, then the type and developmental stage of the harmful agent and the conditions of the external environment.

According to our results, the best effectiveness in suppressing grain leech larvae was achieved by applying insecticides using an UAV at a height of 1 m and a flight speed of 3 m s^{-1}. Also, it can be concluded that the better efficiency of the insecticide was achieved at a flight speed of 3 m s^{-1}, while the height had no significant effect. However, the obtained results are applicable only for the type of UAV used in this research. Different types of UAVs may have different characteristics (such as single and multi-rotor UAVs), which may affect the quality and effectiveness of chemical protection, therefore systematic research should be conducted to determine the optimal combination of parameters. Future research should be focused on the relationship between the operating parameters of the UAV system, the crop structure and the air current of the UAV system and their influence on the effect of deposition and distribution of droplets.

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