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Original Paper

Management of Harmful Mordellidae (Coleoptera: Mordellidae) in Hemp Crops of the Left-Bank Forest-Steppe of Ukraine

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Protection of agricultural crops from harmful organisms is an important component in the plant production system, a significant reserve for increasing plant productivity and improvement of crop quality. Today, along with specialized species of phytophages, insects from the Mordellidae family are increasingly harmful in hemp crops, which is dangerous due to the biology of hemp and the hidden lifestyle of the harmful larval stage of these insects. The purpose of the research is to determine the effectiveness of biological and chemical insecticides against insect phytophages of the Mordellidae family in hemp crops. The species composition of harmful tumbling flower beetles (Mordellidae) in the hemp agrocenosis of the Left-Bank Forest-Steppe of Ukraine was represented by three species – *Mordellistena parvula* Gyll. (4.72%), *M. connata* Erm. (0.58%) and *M. variegata* Fabr. (0.03%) with a total share in the harmful entomocomplex of 5.33%. The highest effectiveness of insecticidal protection of hemp from Mordellidae was provided by the double application of chemicals Voliam flexi 300, SC (0.3 l/ha) and Coragen 20, SC (0.2 l/ha), which had the best technical efficiency (81.4% and 79.4% in the phenophase «fully ripe, beginning of fruit abscission» (BBCH 89), respectively) and economic efficiency (seed yield reached 1.73 t/ha, straw yield – 4.20 t/ha and 1.71 t/ha and 4.13 t/ha) due to the long-term protective action.

Keywords: agrocenosis, insects, phytophages, insecticides, efficiency

1 Introduction

Protection of agricultural crops from harmful organisms is an essential component of plant production systems, serving as a significant reserve for increasing plant productivity and improving crop quality (Pisarenko et al., 2020; Kalogiannidis et al., 2022; Zheng & Xu, 2023). Among the factors that hinder the realization of the genetic potential of hemp plants (*Cannabis sativa* L.) and degrade the quality indicators of hemp production, phytophagous insects play a significant role (Cranshaw et al., 2019). Alongside specialized species, in recent years, the harmfulness of insects from the Mordellidae family has increased in hemp fields, which, considering the peculiarities of hemp plant biology and the concealed lifestyle of the harmful larval stage of these phytophages, poses an extremely dangerous threat (Pivtoraiko et al., 2022; Pivtoraiko, 2022). Modern approaches to optimizing the phytosanitary condition of hemp crops, regardless of the zone and cultivation conditions of the crop, require integrated protection, which is a complex technological process implemented through a sequential series of measures. This includes selecting more resistant varieties to pests, implementing agronomic practices, and using highly effective and low-toxicity chemical and biological agents (Bakro et al., 2018; Küçüktopçu et al., 2020).

Due to the peculiarities of cultivation and the difficulties in protecting hemp crops from harmful tumbling flower beetles, which arise in the second half of the crop's vegetation period, there is a need for effective prevention of hemp production losses based on making timely, specific decisions regarding the implementation of various protective measures. Therefore, there is an urgent need to study the development characteristics of tumbling flower beetles in hemp agrocenosis to search for effective, environmentally safe methods to reduce their harmfulness. Developing and justifying a system

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of measures based on the use of low-toxic biological and chemical agents (as components of an integrated hemp protection system) will allow for the maximum realization of the crop's genetic potential and the production of safe products for human consumption, which is currently a highly relevant issue. The objective of the research is to determine the effectiveness of using biological and chemical insecticides against phytophagous insects from the family Mordellidae in hemp cultivation.

Plant protection from insect pests is ensured by combining techniques of various spectra and mechanisms of action, forming a system that enables reducing damage from phytophages and thereby ensuring significant crop preservation and improvement in its quality (Deguine et al., 2021; Angon et al., 2023). The increase in the average annual air temperature, the concentration of continuous thick-stemmed crop plantings (especially sunflower) (Demenko et al., 2019; Skendžić et al., 2021; Moroz & Fokin, 2021) has led to the increase in the population size and spread to new regions of populations of common intra-stem phytophagous insects shared with hemp, particularly tumbling flower beetles (Mordellidae), which are currently dangerous and already causing noticeable crop losses. Effective measures to reduce the harmfulness of this group of phytophages are not studied, including the absence of insecticides permitted for use in hemp crops against representatives of Mordellidae (Pivtoraiko et al., 2020; Pivtoraiko & Kabanets, 2020; Pivtoraiko, 2022).

The Mordellidae is a highly diverse family of Coleoptera order. Currently, the global fauna comprises 2.308 species from 115 genera. Representatives are ubiquitous, except for the polar and subpolar zones (Liu et al., 2018). According to recent data, the fauna of Ukraine includes 87 species of the Mordellidae family, belonging to 12 genera and two subfamilies, making it the most studied in Europe. In terms of geographic distribution, the increase in the species diversity of tumbling flower beetles is observed from north to south, which can be explained by the thermophilic nature of these insects (Odnosum, 2010).

Tumbling flower beetles are abundant active pollinators of entomophilous vegetation at the imago stage. They are found in various habitats, including broad-leaved forests, well-lit forest clearings, meadows, fields, and other stations where they feed on the pollen of many flowering plants. Tumbling flower beetle larvae are widely represented in entomocomplexes of xylo-, myceto-, and hortobionts. For example, *Mordella* sp., *Variimorda* sp., *Tomoxia* sp., and some *Mordellistena* sp. develop in tree stems, while others (*Curtimorda* sp.) inhabit the sporocarps of *Polyporaceae fungi*. *Mordellistena* sp. and *Mordellistenula* sp. are found in the stems of various herbaceous plants, among which a significant proportion of species are pests of technical, essential oil, and medicinal crops. Trophic specialization links most representatives to weedy vegetation, while some are associated with plants of the genera *Cannabis* L. and *Helianthus* L. In some cases, tumbling flower beetle larvae may also act as predators of other insects (mostly larvae of *Diptera* and *Lepidoptera*) or be inquilines in termite colonies (Odnosum, 2010; Selnekovič et al., 2019). In particular, it is noted that larvae of *Mordellistena parvula* Gyll. are a constant and widely distributed pest of sunflower in Ukraine (Mrynskii, 2020; Fokin & Moroz, 2021). The species *M. micans* Germ. is indicated as a phytophagous insect of hemp (Odnosum, 2010; Pivtoraiko, 2020). Additionally, in recent years, researchers have emphasized the increase in the population of *M. parvuliformis* Stsheg.-Bar. in southern regions of Ukraine and the massive infestation of significant areas of sunflower with larvae of this phytophagous insect, reaching 100% in some cases (Gornovska, 2021; Fedorenko et al., 2021).

Under modern conditions, the most effective method capable of protecting hemp crops from insect pests is the application of insecticides (Visković et al., 2023). Scientific literature mentions protection only against certain species of tumbling flower beetles that have significant economic importance. In particular, researchers have found that when protecting sunflower crops from *M. parvuliformis* Stsheg.-Bar., the contact-systemic chemical insecticide Engio 247 SC, exhibited maximum biological effectiveness when applied at the beginning of larval mass resurgence. It is noted that the mortality of the larval stage of the phytophagous insect reached 70% at the application rate of 0.18 l/ha and 74% at 0.25 l/ha, with a protective period lasting up to two months. The technical effectiveness of other chemical insecticides (Karate Zeon 050 CS – 0.3 l/ha and Actara 25, WG – 0.14 kg/ha) ranged from 22% to 58% (Lytvyn et al., 2012).

It is also necessary to note that in the «List of Pesticides and Agrochemicals Authorized for Use in Ukraine» current for the year 2022 (Koretskyi, 2022), the following chemical insecticides are registered for controlling the population of tumbling flower beetles in sunflower crops: Decis f-Lux 25, EC (deltamethrin, 25 g/l) – 0.3–0.5 l/ha, Engio 247 SC (lambda-cyhalothrin 106 g/l + thiamethoxam, 141 g/l) – 0.18 l/ha, Inazuma, WG (acetamiprid, 100 g/kg + lambda-cyhalothrin, 30 g/kg) – 0.2–0.4 g/ha, Coragen 20, SC (chlorantraniliprole, 200 g/l) – 0.15 l/ha. The application of the aforementioned preparations is recommended during the vegetation period of sunflower plants. However, currently, no registered preparations are available for protecting industrial hemp plants from harmful species of tumbling flower beetles.

2 Material and Methods

2.1 Location Characteristics

The research was conducted at the scientific-experimental base of the Institute of Agriculture of the Northeast of National Academy of Agrarian Sciences of Ukraine during the growing seasons of hemp plants from 2019 to 2021. The research site is located in the northeastern part of the Left-Bank Forest-Steppe of Ukraine (Sumy region, Sumy district, village Sad) at the geographical coordinates of 50.8846º N, 34.6961º E. The climate is moderately continental with warm long summers, moderately cold winters, and frequent thaws. The average annual air temperature is +7.4 °C, precipitation is 593 mm, and relative air humidity is 77%. Monitoring of the entomocomplex was carried out in seed fields of industrial hemp of Ukrainian selection variety "Hlesiya". Hemp was grown with a row spacing of 45 cm for dual use. The seeding rate was 1.0 million seeds per hectare. The predecessor crop was winter wheat.

2.2 Reaearch Procedure

The study of the species composition and seasonal dynamics of tumbling flower beetles in the grass stand of industrial hemp agrocenosis was conducted using entomological sweeping net method, which was performed every ten days from 10:00 AM to 15:00 AM (Kyiv time). The observations began from the phenological phase «2 true leaf pairs» of hemp (BBCH 12) and continued throughout the vegetation period of the crop. The identification and counting of the detected insects were carried out in laboratory conditions. The emergence larvae of tumbling flower beetle was determined from the time of flowering in the crop («first individual flower buds of male flowers visible», BBCH 51). For this purpose, 100 stems were collected consecutively (5 in 20 locations) at equidistant points along two diagonals of the plot. In the laboratory, all crop stems were split open with a knife, thoroughly examined, and the number larvae of tumbling flower beetles was counted (Omeliuta, 1986). The accuracy of species identification of tumbling flower beetles was confirmed by experts from Institute of Zoology named after I.I. Schmalhausen of the National Academy of Sciences of Ukraine (Kyiv).

The effectiveness of insecticidal protection of hemp against harmful tumbling flower beetles was assessed according to commonly accepted plant protection methods (Tribel, 2001). The study involved determining the effectiveness of chemical insecticides: Inazuma, WG (acetamiprid, 100 g/kg, + lambda-cyhalothrin, 30 g/kg) – 0.3 kg/ha; Anticolorad Max, SC (imidacloprid, 300 g/l, + lambda-cyhalothrin, 100 g/l) – 0.15 l/ha; Coragen 20, SC (chlorantraniliprole, 200 g/l) – 0.2 l/ha; Voliam flexi 300, SC (thiamethoxam, 200 g/l, + chlorantraniliprole, 100 g/l) – 0.3 l/ha; and biological preparations: Bitoxibacillin-BTU, r (viable cells of bacteria *Bacillus thuringiensis* var. *thuringiensis*, endospores – titer $1.0 \cdot 10^9$ CFU/cm^3, and biologically active products of bacteria: protein crystals (endotoxin) and thermostable exotoxin) – 6.0 l/ha; Actofit, EC (aversektyn C, 0.2%) – 4.0 l/ha.

The treatment of hemp with the above-mentioned preparations was carried out according to the following scheme:

1. spraying plants at the stage «first individual flowers open» (BBCH 60), coinciding with the mass flight of tumbling flower beetles (number of treatments, times – 1);
2. spraying plants at the «full flowering» stage (BBCH 65) upon the appearance larvae of tumbling flower beetle (number of treatments, times – 1);
3. spraying crops during the period of mass flight of beetles (at the «beginning of flowering of male flowers» stage in hemp plants, BBCH 60) and repeated spraying after 14th days from the first treatment, upon the appearance larvae of tumbling flower beetle (at the stage of hemp plants «full flowering: 50% of flowers open», BBCH 65) (number of treatments, times – 2).

The area of experimental plot was 50 m^2. The experiment was conducted with four replications. The placement of variants was randomized. Treatment of hemp crops with the test preparations was carried out using a backpack sprayer «Forte OG-12 M», with a spray solution rate of 250 l/ha. Counts of imago tumbling flower beetles were conducted before spraying hemp plants, and on 3rd, 7th, 14th days afterward. Counts of larvae were conducted before treatment, and on 3rd, 7th,14th, 21th days after the application of the treatments and before harvesting the seeds of hemp, from 10:00 AM to 15:00 AM (Kyiv time).

2.3 Efficiency Analysis of Insecticides

The technical efficiency of the insecticides was determined by the difference in the number of pests in the control and experimental variants (Formula 1).

$$E = \frac{100(A - B)}{A} \qquad (1)$$

where: E – efficacy of insecticide, %; A – number of pests in the control variation, individuals/m^2, plant; B – number of insects in the experimental treatments individuals/m^2, plant

The economic efficiency of tested insecticides was determined according to the current Ukrainian State

Standards (DSTU 7695:2015. Hemp seeds. Technical specifications; DSTU 8422:2015. Hemp straw. Technical specifications; DSTU 8423:2015. Hemp retted straw. Technical specifications). In the phase of biological ripeness of hemp plants (for ripening 75% of seeds on plants), four sheaves were selected from each treatments on sections of a line 2.2 meters long, which, with a row width of 45 cm, was 1 m2. Manual threshing of hemp plants was carried out, and seed cleaning from a heap was done using metal sieves with round holes of diameters 4.5, 2.5, and 1.5 mm. Then, the straw and seeds were weighed separately, and the yield of products per unit area was determined. Fiber separation was done manually with subsequent calculation of its content.

2.4 Data Analysis

Mathematical and statistical calculations, as well as data visualization, were conducted using Microsoft Office Excel 2016 software package.

3 Results and Discussion

Three species of tumbling flower beetles (Mordellidae) were found in the grass stand of industrial hemp in Left-Bank Forest-Steppe of Ukraine – *M. parvula* Gyll. (4.72%), *M. connata* Erm. (0.58%), and *M. variegata* Fabr. (0.03%), with a total share in harmful entomocomplex of 5.33% (Fig. 1). Phenological observations have revealed that infestation of hemp field by harmful Mordellidae beetles occurs in late May to early June – during the «5–7 true leaf pairs» growth stage of the crop (BBCH 15–17), with peak flight activity of imago observed in the second half of June, coinciding with the phase in hemp «first individual flowers open» (BBCH 60). The emergence of the first larvae is noted at the end of June, during the phase «full flowering: 50% of flowers open» (BBCH 65), with mass appearance recorded in early July – during the technical maturity, phase of plants «10% of fruits have reached final size and coloration» (BBCH 71). The maximum number of harmful larval stages is observed during the phase of the crop «fully ripe, beginning of fruit abscission» (BBCH 89), just before hemp seed harvest.

Thus, initial insecticide treatment was carried out at the beginning of mass imago flight. It was found that in a control treatment, before the application of treatments, the number of imagoes was 2.54 individuals/m^2. During assessments on the 3rd and 7th days, their number increased to 4.09 and 6.12 individuals/m^2. The density of tumbling flower beetles decreased to 4.32 individuals/m^2 by 14th day, which can be explained primarily by the mortality of males after mating and the natural completion of the imago stage life cycle. Additionally, the application of all investigated insecticides led to a reduction in the density of tumbling flower beetles (Table 1).

The highest starting efficacy against tumbling flower beetles (called as «knockdown effect») was observed with the use of chemical insecticide Inazuma, WG, which was 85.6% on 3rd day after spraying. A longer period of hemp protection was noted with the use of insecticide Voliam flexi 300, SC, where on the 14th day the effectiveness

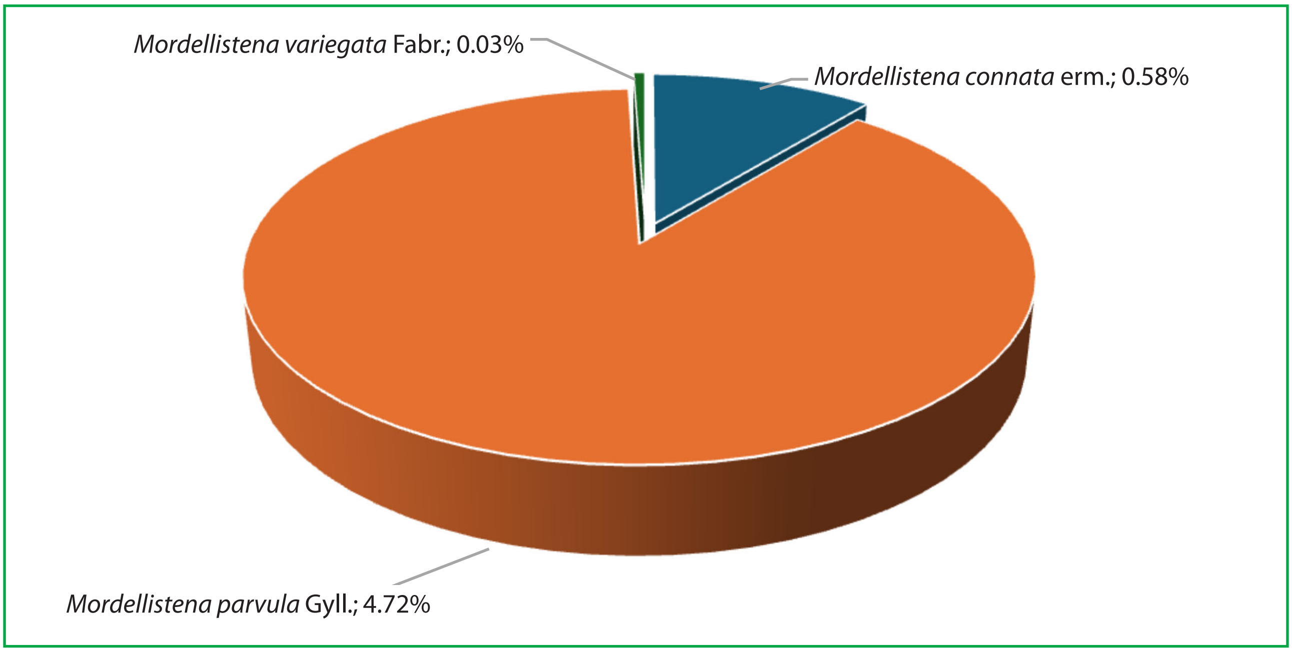

Figure 1 Harmful Mordellidae in the entomofauna of hemp field (IANE NAAS, mowing with the entomological net, Hlesiya variety, in total for 2019–2021)

Table 1 Technical effectiveness of insecticides during the spraying of hemp plants during the mass flight of imago tumbling flower beetles (IANE NAAS, Hlesiya variety, average for 2019–2021)

Treatment	Quantity of imago, individuals/m²				Technical efficiency (%)		
	before spraying	days after spraying					
		3	7	14	3	7	14
Control (water)	2.54	4.09	6.12	4.32	0	0	0
Inazuma, WG	2.72	0.59	1.17	1.58	85.6	80.9	63.4
Anticolorad Max, SC	3.12	0.73	1.56	1.92	82.2	74.5	55.6
Coragen 20, SC	2.87	0.72	0.96	1.49	82.4	84.3	65.5
Voliam flexi 300, SC	2.94	0.66	0.79	1.43	83.9	87.1	66.9
Bitoxibacillin-BTU, r	2.88	2.64	3.64	3.57	35.5	40.5	17.4
Actofit, EC	2.93	2.51	3.86	3.69	38.6	36.9	14.6
LSD_{05}	1.28	0.77	0.86	0.94	–	–	–

LSD – Least Significant Difference

of insecticide was 66.9%. The use of plant protection products of biological origin was not very effective for controlling the number of imago.

Considering that larvae are a harmful stage of tumbling flower beetles for hemp plants, research provides for the study of the effectiveness of chemical and biological means of controlling the number of larval stage of phytophagous development by a single continuous spraying of crop. As a result of the research, it was established that before the treatment of hemp with insecticides, the occupancy of plants by tumbling flower beetles larvae in the control was 0.90 individuals/plant. When counting on 3rd, 7th, 14th, 21th days and before harvesting seeds, their number gradually increased and amounted to 1.23, 1.92, 2.59, 3.13 and 3.20 individuals/plant. At the same time, as a single spraying of hemp with research insecticides provided a significant decrease in the density of tumbling flower beetles larvae compared to the control. The most effective among chemical insecticides was Voliam flexi 300, SC, the technical efficiency of which was 48.8%, on the 3rd day after spraying. The density of larvae was 0.63 individuals/plant. By counting on 7th day after spraying, its effectiveness increased to 64.6%, and the density of living larvae was 0.68 individuals/plant. On 14th day, the effectiveness of insecticide was at the level of 72.2%, for the number of larvae – 0.72 individuals/plant. On 21th day after application, the insecticide had the highest efficiency indicator – 75.7%, which provided a 4.1-fold lower number of tumbling flower beetles larvae (0.76 individuals/plant) than in the control. The efficacy of the preparation before harvesting the seeds of the crop

Table 2 Technical effectiveness of insecticides for spraying hemp plants during the period of appearance of tumbling flower beetles larvae (IANE NAAS, Hlesiya variety, average for 2019–2021)

Treatment	Number of larvae, individuals/plant						Technical efficiency, %				
	days after spraying										
	before spraying	3	7	14	21	before harvesting	3	7	14	21	before harvesting
Control (water)	0.90	1.23	1.92	2.59	3.13	3.20	0	0	0	0	0
Inazuma, WG	0.86	0.73	0.80	0.84	0.98	1.24	40.7	58.3	67.6	68.7	61.3
Anticolorad Max, SC	0.79	0.76	0.87	0.92	1.06	1.38	38.2	54.7	64.5	66.1	56.9
Coragen 20, SC	0.78	0.67	0.72	0.78	0.83	1.07	45.5	62.5	69.9	73.5	66.6
Voliam flexi 300, SC	0.81	0.63	0.68	0.72	0.76	1.01	48.8	64.6	72.2	75.7	68.4
Bitoxibacillin-BTU, r	0.92	0.86	1.24	1.52	1.89	2.12	30.1	35.4	41.3	39.6	33.8
Actofit, EC	0.88	0.83	1.15	1.54	2.01	2.27	32.5	40.1	40.5	35.8	29.1
LSD_{05}	0.37	0.28	0.39	0.41	0.58	0.64	–	–	–	–	–

LSD – Least Significant Difference

was also the highest in the experiment and amounted to 68.4% (Table 2).

Slightly lower technical efficiency indicators were provided by the use of Coragen 20, SC, in particular, when accounting on 3rd day – 45.5%, the number of live larvae of tumbling flower beetles was 0.67 individuals/plant. On 7th day after spraying, the efficacy of the insecticide increased to 62.5%, and the number of larvae was 0.72 individuals/plant. On 14th day, the effectiveness of the insecticide was at the level of 69.9% for the quantity of larvae 0.78 individuals/plant. Calculating on 21th day after spraying, the effectiveness of the insecticide increased to 73.5%, and the number of tumbling flower beetle larvae was almost 3.8 times lower than the control and amounted to 0.83 individuals/plant. Before harvesting the seed part of plants, the effectiveness of the insecticide decreased to 66.6%. Other chemicals insecticides (Inazuma, WG and Anticolorad Max, SC) had less technical efficiency. The use of insecticide of biological origin (Actofit, EC and Bitoxibacillin-BTU, r) against tumbling flower beetles larvae did not provide the expected effectiveness, which was several times lower compared to chemical insecticides. Thus, a single use of all studied insecticides against tumbling flower beetle imago or their larvae reduced the population density, also turned out to be insufficient for full control of tumbling flower beetles in hemp agrocenosis.

So, for increasing the efficiency and the duration of insecticidal action, especially biologics, the possibility of dual use of insecticides was studied, in particular, the first spraying – at the beginning of the mass flight of imago, the second – 14th day after the first treatment, or at the beginning of the revival of tumbling flower beetle larvae. The number of imago tumbling flower beetles in the control before the use of insecticides was 2.55 individuals/m^2. Its number increased to 3.98 and 6.08 individuals/m^2 in the following calculations on 3rd and 7th days. On the 14th day, the number of beetles decreased to 4.30 individuals/m^2, which is associated with the peculiarities of phytophagous biology. It was found that spraying hemp with insecticides reduced the population size of beetles in all variants compared to controls (Table 3).

However, in treatments with chemical protection, the number of imago was significantly lower compared to insecticides of biological origin. The highest insecticidal effect was observed with the use of Inazuma, WG, where on the 3rd day after spraying the number of beetles was 0.56 individuals/m^2, and the efficiency reached 85.9%. According to calculations for 7th and 14th days, the highest technical efficiency was obtained in the version with Voliam flexi 300, SC – 88.0 and 71.6% for the number of beetles 0.73 and 1.22 individuals/m^2. Insecticide Coragen 20, SC on 7th day after spraying had a technical efficiency of 85.2%.

The number larvae of tumbling flower beetles in the control was 0.76 individuals/plant before the second spraying. In the next calculations on 3rd, 7th, 14th, 21th days and in the end of hemp vegetation, the occupancy of plants by larvae gradually increased to 1.15, 1.82,

Table 3 Technical effectiveness of insecticides for spraying hemp plants during the mass flight of imago tumbling flower beetles and the appearance of their larvae (IANE NAAS, Hlesiya variety, average for 2019–2021)

Treatment	Number of imago (individuals/m^2)				Technical efficiency (%)			Number of larvae (individuals/plant)						Technical efficiency (%)				
	before spraying	days after spraying						before spraying	days after spraying									
		3	7	14	3	7	14		3	7	14	21	before harvesting	3	7	14	21	before harvesting
Control (water)	2.55	3.98	6.08	4.30	0	0	0	0.76	1.15	1.82	2.52	3.02	3.11	0	0	0	0	0
Inazuma, WG	3.01	0.56	1.15	1.54	85.9	81.1	64.2	0.58	0.44	0.59	0.70	0.75	0.78	61.7	67.6	72.2	75.2	74.9
Anticolorad Max, SC	2.73	0.70	1.50	1.85	82.4	75.3	57.0	0.61	0.49	0.65	0.73	0.83	0.85	57.4	64.3	71.0	72.5	72.7
Coragen 20, SC	2.49	0.68	0.90	1.34	82.9	85.2	68.8	0.55	0.37	0.50	0.58	0.63	0.64	67.8	72.5	77.0	79.1	79.4
Voliam flexi 300, SC	2.73	0.63	0.73	1.22	84.2	88.0	71.6	0.53	0.35	0.45	0.48	0.55	0.58	69.6	75.3	81.0	81.8	81.4
Bitoxibacillin-BTU, r	2.80	2.59	3.62	3.17	34.9	40.5	26.3	0.62	0.56	0.76	0.92	1.05	1.26	51.3	58.2	63.5	65.2	59.5
Actofit, EC	2.81	2.48	3.85	3.21	37.7	36.7	25.3	0.65	0.58	0.79	0.98	1.26	1.38	49.6	56.6	61.1	58.3	55.6
LSD_{05}	1.21	1.02	1.19	1.24	–	–	–	0.24	0.28	0.34	0.42	0.51	0.55	–	–	–	–	–

LSD – Least Significant Difference

2.52, 3.02 and 3.11 individuals per plant. The highest effectiveness of action was noted with the double use of the insecticide Voliam flexi 300, SC. So, the technical effectiveness of insecticide was 81.4% in the number of larvae 0.58 individuals/plant before hemp harvesting, which is almost 5.4 times less than the control. Also quite effective against larvae of tumbling flower beetles was Coragen 20, SC – 79.4%, and their amount in the phase of biological ripeness of the crop was 0.64 individuals/plant. Other chemical plant protection products were less effective. The technical effectiveness of studied biological insecticides for double spraying did not have a significant difference. But slightly higher values were obtained in the version with the treatment of hemp with the insecticide Bitoxibacillin-BTU, r – 65.2% on 21th day after implementation and 59.5% – before harvesting, and the number of larvae in the end of vegetation was almost 2.5 times less than in the control. So, the highest technical efficiency against tumbling flower beetles (imago and larvae) was provided by chemical insecticides – Voliam flexi 300, SC and Coragen 20, SC.

Along with high technical efficiency, the use of insecticides had a positive effect on increasing the yield of hemp products. So, in the experiment with the use of insecticides at the beginning of the mass flight of tumbling flower beetles, the yield in the control was 1.39 t/ha – seeds, 3.75 t/ha – straw with a mass of 1,000 seeds – 19.20 g (Table 4).

The highest yield of hemp was obtained in a variation using Voliam flexi 300, SC – 1.50 t/ha of seeds and 3.87 t/ha of straw with a single spraying during the mass flight of beetles. The quantity of saved harvest was significantly higher relative to the control and was: seeds – 0.11 t/ha and straw – 0.12 t/ha. The weight of 1,000 seeds in this variation was the largest in the experiment – 19.30 g. The use of insecticides Inazuma, WG and Coragen 20, SC also made it possible to obtain a significant increase in seed yield to control – 0.10 and 0.09 t/ha. The straw yield, a weight of 1,000 seeds and fiber content in these variants increased, but not significantly. Spraying with Anticolorad Max, SC provided some increase in performance indicators of hemp, but was inferior to other insecticides of chemical origin. Single treatment with biological preparations (Bitoxibacillin-BTU, r and Actofit, EC) against imago tumbling flower beetles did not lead to a significant increase in the yield of hemp products. Single treatment with insecticides during period of larvae appearance was more effective. The yield in the control variation was 1.38 t/ha – seeds, 3.70 t/ha – straw, with a weight of 1,000 seeds 19.25 g and a fiber content of 29.8% (Table 5).

The greatest value of saved hemp harvest was in the variation with spraying with insecticide Voliam flexi 300, SC. The yield of seeds was 1.61 t/ha, straw – 4.06 t/ha, which is 0.23 and 0.36 t/ha higher than those in the control at LSD_{05} – 0.14 and 0.28. Also, the use of this insecticide increased the weight of 1,000 seeds by 0.4 g (up to 19.65 g). Spraying plants with the insecticide Coragen 20, SC also contributed to the higher collection of hemp products per unit area. A significant increase compared to the control was noted by the yield of seeds – by 0.21 t/ha, straw – by 0.32 t/ha and weight of 1,000 seeds – by 0.35 g. Less economic efficiency was found after spraying hemp with Inazuma, WG. Thus, the yield of seeds compared to the control variation increased to 1.55 t/ha, straw – to 3.98 t/ha, a weight of 1,000 seeds – to 19.54 g. The use of insecticide Anticolorad Max, SC was the least effective among chemicals insecticides of crop protection. Treatment of hemp against of larvae tumbling flower beetles with biological insecticides

Table 4 Economic effectiveness of insecticides during the mass flight of imago tumbling flower beetles (IANE NAAS, Hlesiya variety, average for 2019–2021)

Treatment	Yield				Weight of 1,000 seeds		Fiber content (%)
	seeds		straw				
	t/ha	±to control, t/ha	t/ha	±to control, t/ha	g	±to control, g	
Control (water)	1.39	0	3.75	0	19.20	0	29.7
Inazuma, WG	1.49	+0.10	3.86	+0.11	19.29	+0.09	30.1
Anticolorad Max, SC	1.46	+0.07	3.83	+0.08	19.26	+0.06	29.9
Coragen 20, SC	1.48	+0.09	3.85	+0.10	19.28	+0.08	30.0
Voliam flexi 300, SC	1.50	+0.11	3.87	+0.12	19.30	+0.10	30.3
Bitoxibacillin-BTU, r	1.43	+0.04	3.78	+0.03	19.20	0.00	29.8
Actofit, EC	1.42	+0.03	3.77	+0.02	19.19	-0.01	29.7
LSD_{05}	0.08	–	0.12	–	0.09	–	0.69

LSD – Least Significant Difference

Table 5 Economic effectiveness of insecticides during the larvae appearance (IANE NAAS, Hlesiya variety, average for 2019–2021)

Treatment	Yield				Weight of 1,000 seeds		Fiber content (%)
	seeds		straw				
	t/ha	±to control, t/ha	t/ha	±to control, t/ha	g	±to control, g	
Control (water)	1.38	0	3.70	0	19.25	0	29.8
Inazuma, WG	1.55	+0.17	3.98	+0.28	19.54	+0.29	30.0
Anticolorad Max, SC	1.53	+0.15	3.91	+0.21	19.47	+0.22	30.1
Coragen 20, SC	1.59	+0.21	4.02	+0.32	19.60	+0.35	30.2
Voliam flexi 300, SC	1.61	+0.23	4.06	+0.36	19.65	+0.40	30.2
Bitoxibacillin-BTU, r	1.47	+0.09	3.82	+0.12	19.44	+0.19	30.1
Actofit, EC	1.45	+0.07	3.79	+0.09	19.41	+0.16	30.0
LSD_{05}	0.14	–	0.28	–	0.26	–	0.78

LSD – Least Significant Difference

showed significantly less economic efficiency compared to chemicals. The increase in yield in variations with spraying Bitoxibacillin-BTU, r and Actofit, EC was observed, but was not significant.

Double spraying of hemp with the studied insecticides provided a further increase in the realization of the genetic potential of plants. In the control variation, the yield was: seeds – 1.38 t/ha, straw – 3.67 t/ha for the weight of 1,000 seeds 19.31 g and fiber content 29.7%. The highest economic efficiency in the experiment was demonstrated by the insecticide Voliam flexi 300, SC, where a significant increase was noted in all indicators. Thus, the yield of seeds reached a level of 1.73 t/ha, straw – 4.20 t/ha, which is 0.35 and 0.53 t/ha more compared to the control. The weight of 1,000 seeds and the fiber content also increased and amounted to 19.77 g and 30.3%. Double treatment of plots with Coragen 20, SC was also a highly effective measure. The yield of seeds was – 1.71 t/ha, straw – 4.13 t/ha, which is 0.33 and 0.46 t/ha higher than such indicators at the control with LSD_{05} – 0.12 and 0.15. Also, spraying with this insecticide significantly increased the weight of 1,000 seeds – by 0.43 g to 19.74 g. According to the fiber content, no significant difference was noted (Table 6).

Double treatment of hemp with insecticide Inazuma, WG led to a slightly smaller amount of saved hemp crop compared to the two previous insecticides, and also was a highly effective measure for controlling tumbling flower beetles in the hemp field. Thus, the yield of seeds was 1.64 t/ha, straw – 4.06 t/ha, and the weight of 1,000 seeds – 19.68 g. Although an increase in the fiber content was observed, it was not significant. Lower economic efficiency was noted after two-times treatment of plants with insecticide Anticolorad Max, SC. Compared

Table 6 Economic effectiveness of insecticides during the mass flight of imago tumbling flower beetles and the appearance of its larvae (IANE NAAS, Hlesiya variety, average for 2019–2021)

Treatment	Yield				Weight of 1,000 seeds		Fiber content (%)
	seeds		straw				
	t/ha	±to control, t/ha	t/ha	±to control, t/ha	g	±to control, g	
Control (water)	1.38	0	3.67	0	19.31	0	29.7
Inazuma, WG	1.64	+0.26	4.06	+0.39	19.68	+0.37	30.2
Anticolorad Max, SC	1.60	+0.22	3.95	+0.28	19.59	+0.28	30.1
Coragen 20, SC	1.71	+0.33	4.13	+0.46	19.74	+0.43	30.1
Voliam flexi 300, SC	1.73	+0.35	4.20	+0.53	19.77	+0.46	30.3
Bitoxibacillin-BTU, r	1.57	+0.19	3.85	+0.18	19.52	+0.21	30.2
Actofit, EC	1.54	+0.16	3.83	+0.16	19.49	+0.18	30.1
LSD_{05}	0.12	–	0.15	–	0.16	–	0.55

LSD – Least Significant Difference

with the control, a significant increase was revealed by the yield of seeds – by 0.22 t/ha, straw – by 0.28 t/ha and the weight of 1,000 seeds – by 0.28 g with LSD_{05} – 0.12, 0.15 and 0.16. Two-times use of insecticides of biological origin showed less economic efficiency compared to chemicals, but significant relative to the indicators in the control. So, when spraying hemp plants with Actofit, EC and Bitoxibacillin-BTU, r, the yield of seeds was 1.54 and 1.57 t/ha, straw – 3.83 and 3.85 t/ha, which is 0.16 and 0.19 t/ha and 0.16 and 0.18 t/ha exceeded such indicators in control, with LSD_{05} – 0.12 and 0.15. The weight of 1,000 seeds also increased significantly – by 0.18 and 0.21 g per LSD_{05} – 0.16. Thus, the highest economic efficiency in the study was obtained in versions with double spraying of insecticides Voliam flexi 300, SC (0.3 l/ha) and Coragen 20, SC (0.2 l/ha).

Therefore, an important reserve for increasing the productivity of industrial hemp, and a stable increase in the volume of high-quality seeds and fiber is the optimization of elements of varietal technology for growing crops. Earlier studies by Kabanets & Pivtoraiko (2019) noted that with modern hemp production in the Left-Bank Forest-steppe of Ukraine, the harmful entomocomplex of hemp agrocenosis is increasingly being supplemented with new, more adapted to trophic and climatic conditions species that previously did not have an economically tangible value and now require a search for measures to control their numbers. Firstly, these are harmful representatives of the Mordellidae family nowadays. In addition, in the works of Selnekovič et al. (2019), Mrynskii (2020) it is noted that the hortobiont species of tumbling flower beetles are very similar to each other in biological and phenological features, and are common phytophages of some thick-stemmed crops (sunflower, hemp, etc.). Since the «List of insecticides and agrochemicals approved for use in Ukraine» (Koretskyi, 2022) does not register a single insecticide for the protection of industrial hemp from harmful tumbling flower beetles species, during the study we tested chemical insecticides that are recommended for use against these phytophages in sunflower crops.

In this research, the results on the insecticidal protection of hemp from harmful tumbling flower beetles are generally consistent with the data of other researchers and relatively have similar indicators of the technical effectiveness of chemicals insecticides. In particular, scientists Gornovska (2021) and Fedorenko et al. (2021) found that by spraying sunflower crops the most effective against tumbling flower beetle *M. parvuliformis* Stsheg.-Bar. is a chemical insecticide Coragen 20, SC (0.2 l/ha). It is noted that the mortality of imago after 5th day after the use of this insecticide was 96.4%. The technical effectiveness against larvae two months after the use of the insecticide was at 70%. The efficacy of other chemicals against the imago, Engio 247 SC (0.2 l/ha) and Decis f-Lux 25, CE (0.5 l/ha) was in the range of 90.8–93.2%.

The protection of industrial hemp from harmful tumbling flower beetles (Mordellidae) until recently remained a problematic issue, since the study of the effectiveness of insecticides against this group of insects was not carried out.

4 Conclusions

In Left-Bank Forest-Steppe of Ukraine conditions in 2019–2021 the species composition of harmful Mordellidae in hemp agrocenosis was determined, the features of their phenology were investigated and the technical and economic effectiveness of the use of insecticides was established. Three species of tumbling flower beetles have been identified – *M. parvula* Gyll. (4.72%), *M. connata* Erm. (0.58%) and *M. variegata* Fabr. (0.03% of all phytophagous insects) with a total share of 5.33%. It was found that the settlement the grass stand of hemp by imago tumbling flower beetles occurs in late May – early June – in the phenophase «5–7 true leaf pairs» of the culture (BBCH 15–17), and the peak of flight activity of imago is observed in the second half of June and coincides with the phase in hemp «first individual flowers open» (BBCH 60). The appearance larvae of tumbling flower beetles was seen in late June – in the phase of mass flowering «full flowering: 50% of flowers open» (BBCH 65), and the mass revival was recorded in early July – in the technical ripeness, phenophase of plants «10% of fruits have reached final size and coloration» (BBCH 71). The maximum number of harmful, larval stage is observed in the phenophase of the «fully ripe, beginning of fruit abscission» of the crop (BBCH 89).

During the mass flight of tumbling flower beetles, the most effective was single spraying with insecticides Inazuma, WG – 0.3 kg/ha (85.6% on 3rd day after application) and Voliam flexi 300, SC – 0.3 l/ha (66.9% on 14th day after spraying). During the period of larvae tumbling flower beetles appearance, the most effective was the single treatment of hemp with Voliam flexi 300, SC 0.3 l/ha and Coragen 20, SC 0.2 l/ha (68.4 and 66.6% before harvesting the seeds of the crop). The highest efficiency of insecticidal protection of hemp from tumbling flower beetles (imago and larvae) in the experiment provided two-times use of chemical Voliam flexi 300, SC (0.3 l/ha) and Coragen 20, SC (0.2 l/ha), which had the best technical (81.4 and 79.4% in the phase «fully ripe, beginning of fruit abscission», BBCH 89), economic (seeds yield reached 1.73 t/ha, straw – 4.20 t/ha and 1.71 t/ha and 4.13 t/ha) effectiveness along with long-term protective action and they are low toxic to useful insects.

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Conflict of Interest

The authors declare that there is no conflict of interest.

Author Contributions

V.P.: Investigation, Methodology, Data curation, Formal analysis, Visualization, Writing – original draft. V.K.: Conceptualization, Supervision, Resources, Validation, Writing – review & editing

AI and AI-Assisted Technologies use Declaration

No generative AI tools/AI-assisted technologies were used during the preparation of the manuscript.

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