Original article

Study on the herbicide Praxim (500 g L^{-1} metobromuron) applied for weed control in coriander (*Coriandrum sativum* L.)

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Summary

Weed control is an important part of coriander's production. The uncontrolled weed flora can lead to severe yield losses of the crop. During three vegetation seasons (2018, 2019, and 2020) a field trial with coriander 'Mesten drebnoploden' variety was performed. The study was stated on the agricultural land of Voyvodinovo village, Bulgaria. Our study aimed to evaluate the performance of the herbicidal product Praxim (500 g L^{-1} metobromuron) in increasing rates (1.50, 2.50, and 3.50 L ha^{-1}). The untreated plot (treatment 1) was used as a control. Treatment 2 represented the economical weed-free control. The herbicide application was performed in BBCH 12–13 (2nd–3rd true leaf unfolded). The selectivity of the herbicide for coriander and the efficacy against the existing weeds, and also the structural elements of the yield as plant height, number of branches and umbels $plant^{-1}$, 1,000 seed mass, as well as the seed yields were evaluated. The seed essential oil content was also analyzed. The observations showed that the metobromuron application caused phytotoxic symptoms on coriander expressed as growth retardation at the high rate of 3.50 L ha^{-1}. On the contrary, on those plants where the herbicide rate of 2.50 L ha^{-1} was applied no phytotoxic symptoms were observed and the obtained results of all studied parameters were comparable to those of the weed-free control treatment.

Keywords
weeds, efficacy, selectivity, yields, essential oil

Significance of this study

What is already known on this subject?

- Weeds occurring on coriander fields are one of the most limiting factors concerning crop development, its yield, and the quality of the production. Highly effective, and crop-safe weed management programs with proper herbicidal products must be accomplished.

What are the new findings?

- Our research findings have shown that the herbicidal product Praxim (500 g L^{-1} metobromuron) applied in a rate of 2.50 L ha^{-1} is safe and can be used in the early development stages of the crop for satisfactory control of different broadleaf weed species. Higher rates (3.50 L ha^{-1}) of the product are harmful to coriander and despite their high efficacy, they can decrease coriander's development, yield, and quality.

What is the expected impact on horticulture?

- The study has implications for more appropriate weed control by applying metobromuron (Praxim) at the rate of 2.50 L ha^{-1} at the early development stages of coriander. This application is enough to control broadleaf weeds such as *M. chamomilla, S. arvensis*, *S. nigrum* and *A. retroflexus*, and is safe enough for coriander for achieving high and stable yields and high in essential oil as well.

Introduction

Coriander (*Coriandrum sativum* L.) is an important essential-oil plant, belonging to the Apiaceae family. The technology for coriander growing overtime needs to be updated, as a result of ever-changing weather and growing conditions. Specified crop rotations, improved tillage operations, new sowing and harvesting periods are needed to be studied (Delibaltova et al., 2012). This could lead to changes in weeds development, to the emergence of resistant or new weed species. The weeds occurring in coriander crops are mainly from the group of the winter-spring and early-spring species. The most frequent winter-spring weeds are: *Alopecurus myosuroides* L., *Apera spica-venti* (L.) P.Beauv., *Bromus arvensis* L., *Avena ludoviciana* Durien., *Lolium multiflorum* L., *Anthemis arvensis* L., *Chamomilla recutita* Rauchert, *Consolida regalis* Gray, *Viola tricolor* L., *Lithospermum arvense* L., *Centaurea cyanus* L., *Papaver rhoeas* L., *Agrostemma githago* L. The most frequent early spring weeds are *Avena fatua* L., *Galium aparine* L., *Sinapis arvensis* L., *Falopia convolvulus* Leve, *Myagrum perfoliatum* L. (Mitchell and Abernethy, 1993; Atanasova and Gospodinov, 2005).

The broadleaf weeds are found to be the most dominant in coriander fields (Nagar and Jain, 2017). Efficient weed control is an important condition for fully realizing the biological potential of the crop and to obtaining high yields (Lugo and Santiago, 1996; Zheljazkov and Zhalnov, 1995), because seed yields can be severely reduced depending on the weed density and weed species (Thakral et al., 1989; Sagarka et al., 2005). Chemical weed control is, therefore, an important practice in many countries around the globe.

A successful herbicide should be safe for the crop and have high efficacy against the weeds. The use of herbicides, especially before crop emergence, protects the cultivated plants from the early developing weed species (Rao, 2000).

According to Tewari et al. (2005), the application of pendimethalin at 1.0 kg ha^{-1} and pretilachlor at 1.5 kg ha^{-1} before crop emergence showed high control of the weeds in coriander. In a study carried out by Kothari et al. (1989) the applications of pendimethalin and fluchloralin at 0.75 and 1.00 kg ha^{-1}, lead to 76.5 and 71.9% efficacy respectively. After these treatments, the seed and oil yields were comparable to the weed-free control. Similar results with pendimethalin were published by Mitchell et al. (1994). Results obtained by Pickett and Zheljazkov (2016) suggested that the active substances sethoxydim, isoxaben, linuron, trifluralin, and pendimethalin can be successfully applied for weed control in coriander.

Nevertheless, there is a lack of registered herbicides for weed control in coriander and the herbicide application options are limited.

Therefore, the issue of weed control is still relevant and leading us to evaluate the efficacy of the herbicide metobromuron (not registered for weed control in coriander) to identify more herbicidal options for weed management in this crop.

Materials and methods

Soil conditions

The soil of the experimental field is classified as Fluvisols and it has neutral pH (7.1) with low organic matter content (1.12%). The N_{min} (NH_4 + NO_3) is low (31.23 mg kg^{-1}), the P_2O_5 content is medium (17.24 mg 100 g^{-1}), and K_2O content is high (28.73 mg 100 g^{-1}).

Experimental plots

During the vegetation periods of three consecutive years (2018, 2019, and 2020) a field trial with coriander 'Mesten drebnoploden' variety was conducted. The study took place on the agricultural land of Voyvodinovo village (42°11'19.9"N, 24°46'53.3"E), Bulgaria. A randomized block design with 3 replications was used. The size of the experimental plot was 20 m^2 (60 m^2 total). The trial was performed under non-irrigated conditions.

Winter wheat was grown as preceding crop of the coriander in the three years of the investigation. Deep plowing, followed twice by a disc harrow and twice by a rotary tiller were performed before sowing. Basic combined fertilization with 250 kg ha^{-1} NPK (15:15:15) and spring dressing with 200 kg ha^{-1} NH_4NO_3 was applied. The sowing norm was 250 germinating seeds m^{-2}. The sowing was performed at the beginning of spring (in late March – 24.03.2018; 28.03.2019; 21.03.2020). Harvesting was done in September.

Treatments

The experiment included 5 treatments. An untreated plot (Treatment 1) was accepted as a control. Treatment 2 represented the weed-free control plot where the weeds were constantly removed by hand weeding. The treatments from 3 to 5 represented increasing rates of the herbicide metobromuron (commercial product Praxim containing 500 g L^{-1} metobromuron). Metobromuron is a pre-emergence herbicide. It is moderately soluble in water, is quite volatile, and there is a moderate risk that it may leach to groundwater. It has low mammalian toxicity but has a high potential to bioaccumulate. It is classified as an irritant. It is moderately toxic to birds and most aquatic organisms and earthworms. (http://sitem.herts.ac.uk/aeru/ppdb/en/Reports/464.htm). The evaluated herbicide rates included 1.50 L ha^{-1}, 2.50 L ha^{-1}, and 3.50 L ha^{-1}. The herbicide product Praxim is registered for application in potatoes, but not coriander (http://belchim.co.uk/products/praxim/).

The herbicide spraying was accomplished in April, in BBCH 12–13 of coriander (2nd–3rd true leaf unfolded) via electrical backpack sprayer SOLO model 417 (Solo, Germany) with a volume of the working solution of 300 L ha^{-1}. The herbicidal treatments were done before noon in calm weather without inappropriate wind speed that may lead to herbicide drift.

Table 1. Weed density in BBCH 69 – weed number m^{-2} for 2018, 2019 and 2020.

2018						
Treatments/weeds	*M. chamomilla*	*G. aparine*	*S. arvensis*	*S. nigrum*	*A. retroflexus*	*C. arvensis*
1. Untreated control	22	18	22	20	16	7
2. Weed-free control	0	0	0	0	0	0
3. Praxim 1.50 L ha^{-1}	6	10	6	6	6	5
4. Praxim 2.50 L ha^{-1}	4	4	3	3	3	3
5. Praxim 3.50 L ha^{-1}	2	2	1	2	1	2
2019						
Treatments/weeds	*M. chamomilla*	*G. aparine*	*S. arvensis*	*S. nigrum*	*A. retroflexus*	*C. arvensis*
1. Untreated control	19	20	16	17	14	8
2. Weed-free control	0	0	0	0	0	0
3. Praxim 1.50 L ha^{-1}	5	8	5	7	6	5
4. Praxim 2.50 L ha^{-1}	3	4	2	2	2	4
5. Praxim 3.50 L ha^{-1}	2	2	0	1	1	3
2020						
Treatments/weeds	*M. chamomilla*	*G. aparine*	*S. arvensis*	*S. nigrum*	*A. retroflexus*	*C. arvensis*
1. Untreated control	17	23	19	15	12	9
2. Weed-free control	0	0	0	0	0	0
3. Praxim 1.50 L ha^{-1}	5	11	6	6	5	6
4. Praxim 2.50 L ha^{-1}	3	5	2	2	2	5
5. Praxim 3.50 L ha^{-1}	1	2	1	1	1	3

Agrometeorological data

The agrometeorological data for the region of Voyvodinovo village, where the experiment was conducted, is provided by the department of "Botany and Agrometeorology" at the Agricultural University of Plovdiv, Bulgaria. The data is for the average monthly minimum and maximum air temperatures (°C) as well as precipitation (mm) for the vegetation periods of coriander (from March till August) during the three study years (2018, 2019, and 2020). A separate figure with the meteorological data concerning the period seven days before, seven days after, as well as on the day of herbicidal treatment is presented.

Sampling

Plant height (cm) was measured before the harvest of coriander. The height of 20 plants per plot was measured (in total 60 plants per treatment). The number of branches plant^{-1} and the number of umbels plant^{-1} before crop's harvests were also measured. For these two indicators, 20 plants per plot were evaluated (in total 60 plants per treatment). The number of seeds umbel^{-1} on 10 plants per plot was counted at harvest (in total 30 plants per treatment). The coriander seed yield was recorded by harvesting whole plots of each replication per treatment. The harvesting was done with a harvester for field plot trials "Wintersteiger". The data from each plot was recalculated for establishing the seed yields per hectare. The mass of 1,000 dry seeds was measured using an analytical balance (precision 0.01 g). For each replication of the treatments, we measured three batches of 1,000 seeds. The value for each replication was recalculated by dividing the results of the three batches of 1,000 seeds by 3 resulting in an average sample for each plot (3 × 3 = 9 batches of 1,000 seeds per treatment). The results are expressed in grams (g).

Weed species, herbicide efficacy, and herbicide phytotoxicity

The weed count was recorded species-wise using a 1 m × 1 m square sample for each replication of each plot where the weeds within the square sample were counted, recorded, and expressed in number m^{-2}. The weed density was recorded in BBCH 69 – end of the flowering stage of coriander.

The existing natural weed infestation in the three years of the research was represented by the species *Matricaria chamomilla* L. from the winter-spring group of weeds, *Galium aparine* L. and *Sinapis arvensis* L. represented the early-spring weeds, *Solanum nigrum* L. and *Amaranthus retroflexus* L. were the weeds from the late spring group of weeds, and the weed *Convolvulus arvensis* L. was the existing perennial species. The weed density is presented in Table 1.

The weed control efficacy was reported in BBCH 69, too. The following formula was used as described by Ofosu-Budu et al. (2014):

$$WCE\% = \frac{WD_C - WD_T}{WD_C} \times 100$$

where: WCE = weed control efficacy (%);
WD_C = weed biomass (kg m^{-2}) in the untreated control plot;
WD_t = weed biomass (kg m^{-2}) in the treated plot.

The phytotoxicity of the applied herbicidal treatments was reported once on the 7th day after application. The 9-score visual scale of the European Weed Research Society (EWRS) as described below was used:

1. No effect;
2. Very slight effects; some stunting and yellowing just visible;
3. Slight effects; stunting and yellowing, effects reversible;
4. Substantial chlorosis and or stunting, most effects probably reversible;
5. Strong chlorosis/stunting; thinning of stand;
6. Increasing severity of damage;
7. Increasing severity of damage;
8. Increasing severity of damage;
9. Total loss of plants and yield.

Essential oil content analysis

The seed essential oil content is determined by the method of water distillation in Clevenger type apparatus. To speed up the process and reveal the essential oil receptacle, the mature coriander seeds were crushed before processing. The distillation time is two hours, calculated from the appearance of the first drop of essential oil (ISO 6571:2008). Three samples for each treatment were processed.

Statistical analysis

The statistical analysis of the collected data was performed by Duncan's Multiple Range Test (One-way ANOVA) by the software program SPSS 26.

Results

Meteorological data

In Figures 1 and 2, the data for the average daily temperatures and precipitation during the coriander's vegetation in the three experimental years (2018, 2029, and 2020) is presented. According to the meteorological data for the in-

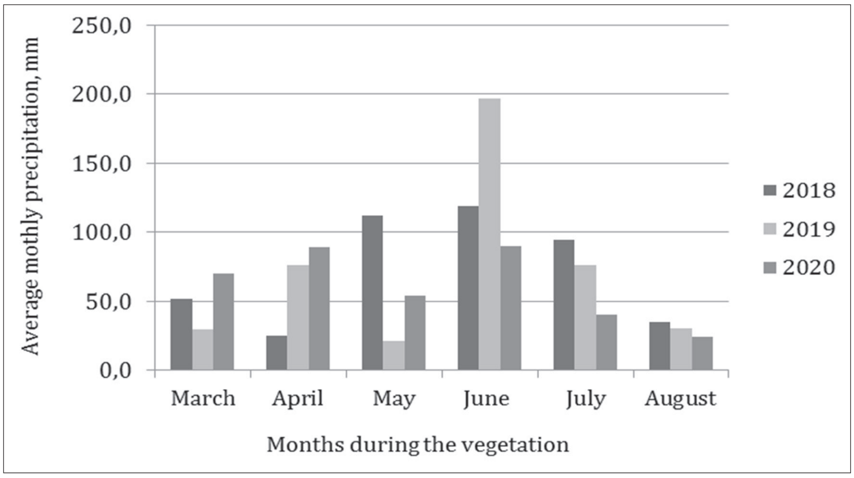

Figure 1. Average monthly precipitation (mm) for the vegetation periods of coriander (from March till August) during the three study years (2018, 2019 and 2020).

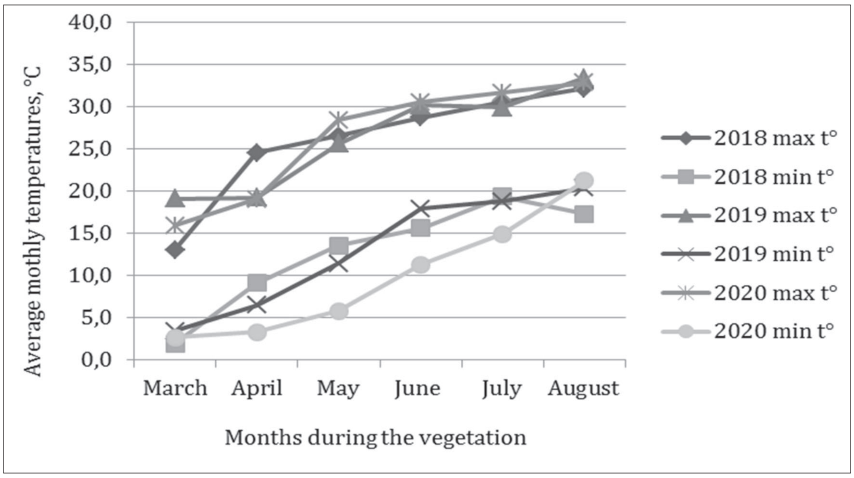

Figure 2. Average minimum and maximum air temperature (°C) for the vegetation periods of coriander (from March till August) during the three study years (2018, 2019 and 2020).

dividual years, it can be assessed how climatic conditions affected the herbicide efficacy, as well as the growth and development of the plants.

The precipitation was not equally distributed during the coriander's vegetation in the three years of research but was enough for the plant's growth and development. No water stress was observed during the investigation period. Only in June 2019, the precipitation reached 197.6 mm, but no negative effect on coriander was reported.

The average minimum and maximum air temperatures differed during the growing seasons of coriander. The air temperatures were suitable for coriander growing. Throughout the three study years, no extreme values affecting the crop were recorded.

Neither negative influences of the precipitation or air temperatures to the herbicidal efficacy nor selectivity of the studied herbicide product were observed.

Table 2. Weed control efficacy of the studied treatments compared to the untreated control, % (Ofosu-Budu et al., 2014).

			2018			
Treatments/weeds	*M. chamomilla*	*G. aparine*	*S. arvensis*	*S. nigrum*	*A. retroflexus*	*C. arvensis*
Untreated control	0.0 e	0.0 e	0.0 d	0.0 d	0.0 e	0.0 e
Weed-free control	100.0 a	100.0 a	100.0 a	100.0 a	100.0 a	100.0 a
Praxim 1.5 L ha^{-1}	72.7 d	55.6 d	72.7 c	70.0 c	62.5 d	42.9 d
Praxim 2.5 L ha^{-1}	81.8 c	77.8 c	86.4 b	85.0 b	81.2 c	57.1 c
Praxim 3.5 L ha^{-1}	91.0 b	88.9 b	95.5 ab	96.0 b	93.7 b	71.4 b
			2019			
Treatments/weeds	*M. chamomilla*	*G. aparine*	*S. arvensis*	*S. nigrum*	*A. retroflexus*	*C. arvensis*
Untreated control	0.0 d	0.0 e	0.0 d	0.0 e	0.0 e	0.0 e
Weed-free control	100.0 a	100.0 a	100.0 a	100.0 a	100.0 a	100.0 a
Praxim 1.5 L ha^{-1}	73.7 c	42.9 d	68.8 c	64.7 d	57.1 d	37.5 d
Praxim 2.5 L ha^{-1}	84.2 b	71.1 c	87.5 b	88.2 c	85.7 c	50.0 c
Praxim 3.5 L ha^{-1}	89.5 b	85.7 b	100.0 a	94.1 b	92.9 b	62.5 b
			2020			
Treatments/weeds	*M. chamomilla*	*G. aparine*	*S. arvensis*	*S. nigrum*	*A. retroflexus*	*C. arvensis*
Untreated control	0.0 e	0.0 e	0.0 d	0.0 de	0.0 e	0.0 e
Weed-free control	100.0 a	100.0 a	100.0 a	100.0 a	100.0 a	100.0 a
Praxim 1.5 L ha^{-1}	63.3 d	52.2 d	68.4 c	60.0 c	50.0 d	33.3 d
Praxim 2.5 L ha^{-1}	78.6 c	78.3 c	89.5 b	86.7 b	83.4 c	44.4 c
Praxim 3.5 L ha^{-1}	93.8 b	91.3 b	95.8 a	98.7 a	91.7 b	66.6 b
			Average for the period 2018–2020			
Treatments/weeds	*M. chamomilla*	*G. aparine*	*S. arvensis*	*S. nigrum*	*A. retroflexus*	*C. arvensis*
Untreated control	0.0 e	0.0 e	0.0 d	0.0 e	0.0 e	0.0 e
Weed-free control	100.0 a	100.0 a	100.0 a	100.0 a	100.0 a	100.0 a
Praxim 1.5 L ha^{-1}	69.9 d	50.2 d	69.8 c	64.9 c	56.5 d	37.9 d
Praxim 2.5 L ha^{-1}	81.5 c	75.7 c	87.8 b	86.6 b	83.4 c	50.5 c
Praxim 3.5 L ha^{-1}	91.4 b	88.6 b	97.1 a	96.2 a	92.8 b	66.8 b

* Means with different letters are with proved differences according to Duncan's Multiple Range test ($p < 0.05$). The statistical analysis of the results for each separate year is performed by using the data from each replication. The statistical analyses average for the period is done by using the data from each experimental year.

Weed control efficacy and herbicidal phytotoxicity

The results are expressed for each separate year and as average for the whole period of the study. The results regarding the efficacy of treatment 2 (weed-free control) are always 100.0%. The weeds for that treatment were constantly removed and the plots were free of unwanted weedy plants during the vegetation period. A similar tendency in efficacy was achieved over the three experimental years (Table 2).

The lowest examined rate of 1.50 L ha^{-1} for the herbicide product Praxim did not show satisfactory efficacy against the existing weed flora. The efficacy results reached 69.9% (against *M. chamomilla*), 50.2% (against *G. aparine*), 69.8% (against *S. arvensis*), 64.9% (against *S. nigrum*), 56.5% (against *A. retroflexus*), and 37.9% (against *C. arvensis*) averaged over the period of the study (Table 2).

The rate of 2.5 L ha^{-1} was efficient against the annual weed species as *M. chamomilla* (81.5%), *S. arvensis* (87.8%), *S. nigrum* (86.6%), and *A. retroflexus* (83.4%) but not effective enough to control the weed *G. aparine*. The efficacy against this weed was 75.5%. The recorded efficacy against the perennial weed *C. arvensis* was very low (50.5%), too.

High efficacy was reported for the highest studied rate of Praxim (3.50 L ha^{-1}). The efficacy was excellent varying from 88.6 to 96.2% against the different annual weed species. As before, also the rate of 3.50 L ha^{-1} was not efficient enough to control *C. arvensis*. This perennial weed appeared to be the most difficult-to-control species in our trial (Table 2).

TABLE 3. Phytotoxicity of the applied herbicidal rates of Praxim (by the visual 9-score scale of EWRS).

Variants	2018	2019	2020
1. Untreated control	–	–	–
2. Weed-free control	–	–	–
3. Praxim 1.5 L ha^{-1}	1	1	1
4. Praxim 2.5 L ha^{-1}	1	1	1
5. Praxim 3.5 L ha^{-1}	3	4	4

No phytotoxic symptoms were observed for the herbicidal rates of 1.50 and 2.50 L ha^{-1} of the herbicide product Praxim. On the contrary, the plants where the rate of 3.50 L ha^{-1} was sprayed, phytotoxic symptoms from score 3 (in 2018) and score 4 (in 2019 and 2020) were observed. The phytotoxic symptoms in 2018 were slight and expressed by stunting and growth retardation but the effects were reversible. In the next two years of the study, the phytotoxicity was stronger and was determined as score 4 (Table 3; Figure 3).

Biometrical parameters

We have studied three parameters: plant height, branches $plant^{-1}$, and umbels $plant^{-1}$ (data shown in Table 4). The results express the influence of the weed flora on the crop as well as the selectivity of the studied herbicidal product. The plant height was lowest for the untreated, weedy con-

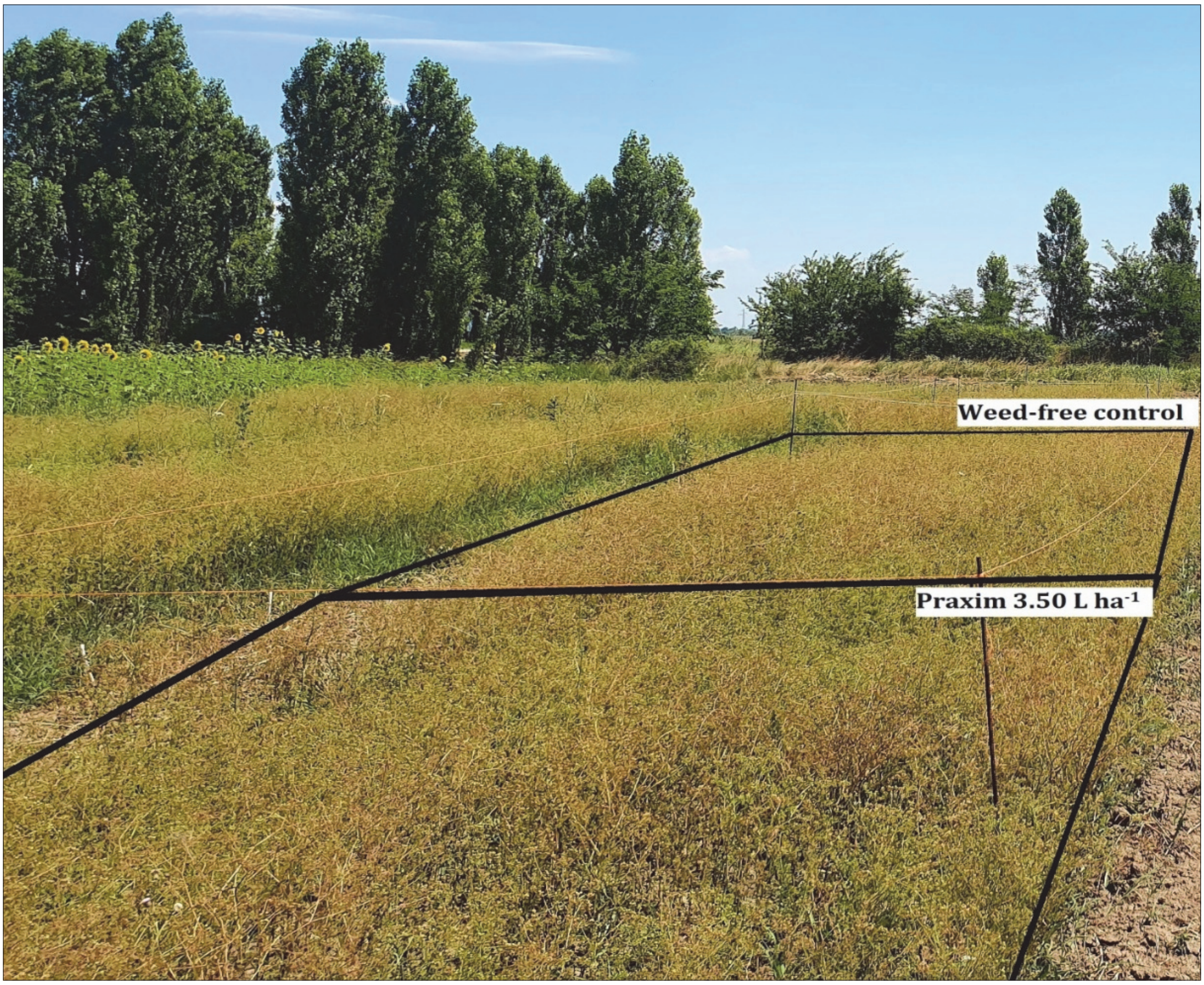

FIGURE 3. Plots with weed-free control (above) and growth reduction of Praxim 3.5 L ha^{-1} (below) in 2018.

trol and treatment 5 (Praxim 3.50 L ha^{-1}), with 71.31 and 72.10 cm, respectively. For the other treatments (2. weed-free control; 3. Praxim 1.50 L ha^{-1}, and 4. Praxim 2.50 L ha^{-1}) the plant height varied from 85.27 to 91.74 cm. The differences between these variants were not statistically significant ($p < 0.05$).

The untreated control and treatments 3 and 5 had the lowest number of branches plant^{-1} with – 4.67, 5.73, and 5.83, respectively, showing no significant differences. The weed-free control and treatment 4 had the highest number of branches plant^{-1} – 7.03 and 7.23, respectively, showing a significant difference to the other treatments.

Table 4. Biometrical parameters (plant height, branches plant^{-1}, and umbels plant^{-1}) in each year of the study and average for the period.

Treatments	2018	2019	2020	Average for the period
Plant height (cm)				
1. Untreated control	75.50 b	68.22 c	70.22 c	71.31 b
2. Weed-free control	88.05 a	90.37 a	96.33 a	91.58 a
3. Praxim 1.50 L ha^{-1}	88.53 a	81.00 b	86.29 b	85.27 a
4. Praxim 2.50 L ha^{-1}	90.58 a	89.82 a	94.81 a	91.74 a
5. Praxim 3.50 L ha^{-1}	78.00 b	65.99 c	72.30 c	72.10 b
Branches plant^{-1}				
1. Untreated control	4.60 c	4.40 c	5.00 c	4.67 c
2. Weed-free control	6.90 a	6.30 a	7.90 a	7.03 a
3. Praxim 1.50 L ha^{-1}	5.50 b	5.40 b	6.30 b	5.73 b
4. Praxim 2.50 L ha^{-1}	7.10 a	6.80 a	7.80 a	7.23 a
5. Praxim 3.50 L ha^{-1}	6.10 a	5.60 c	5.80 b	5.83 b
Umbels plant^{-1}				
1. Untreated control	13.10 d	12.50 e	13.50 d	13.03 d
2. Weed-free control	18.60 b	17.80 b	19.40 a	18.60 a
3. Praxim 1.50 L ha^{-1}	15.80 c	15.10 d	16.40 b	15.77 c
4. Praxim 2.50 L ha^{-1}	19.30 a	18.60 a	19.90 a	19.27 a
5. Praxim 3.50 L ha^{-1}	16.50 c	17.30 c	16.90 b	16.90 b

* Means with different letters are with proved differences according to Duncan's Multiple Range test ($p < 0.05$). The statistical analysis of the results for each separate year is performed by using the data from each replication. The statistical analyses average for the period is done by using the data from each experimental year.

Table 5. Coriander seed yield, absolute seed mass, and seed essential oil content in each year of the study and average for the period.

Variants	2018	2019	2020	Average for the period
Coriander seed yield (t ha^{-1})				
1. Untreated control	1.12 d	0.88 c	1.30 c	1.10 c
2. Weed-free control	2.03 a	1.75 a	2.20 a	1.99 a
3. Praxim 1.50 L ha^{-1}	1.72 b	1.44 b	1.81 b	1.66 b
4. Praxim 2.50 L ha^{-1}	2.04 a	1.77 a	2.32 a	2.01 a
5. Praxim 3.50 L ha^{-1}	1.27 c	1.32 b	1.51 bc	1.37 bc
Absolute seed mass (g)				
1. Untreated control	4.70 c	4.18 c	4.45 c	4.44 c
2. Weed-free control	5.79 a	5.33 a	5.60 a	5.57 a
3. Praxim 1.50 L ha^{-1}	5.30 b	4.81 b	5.09 b	5.07 ab
4. Praxim 2.50 L ha^{-1}	5.60 a	5.23 a	5.85 a	5.56 a
5. Praxim 3.50 L ha^{-1}	5.26 b	4.38 b	4.65 c	4.76 bc
Seed essential oil content (%)				
1. Untreated control	0.91 c	1.13 b	0.99 b	1.01 b
2. Weed-free control	1.28 a	1.44 a	1.32 a	1.35 a
3. Praxim 1.50 L ha^{-1}	1.30 a	1.40 a	1.25 a	1.32 a
4. Praxim 2.50 L ha^{-1}	1.32 a	1.41 a	1.30 a	1.34 a
5. Praxim 3.50 L ha^{-1}	1.12 b	1.24 b	0.92 b	1.09 b

* Means with different letters are with proved differences according to Duncan's Multiple Range test ($p < 0.05$). The statistical analysis of the results for each separate year is performed by using the data from each replication. The statistical analyses average for the period is done by using the data from each experimental year.

The untreated control, as well as treatments 3 and 5, had the lowest number of umbels plant^{-1} – 13.03, 15.77, and 16.90 average for the period. Besides, the differences between the values of the results are statistically proved. The weed-free control and treatment 3 (Praxim 1.50 L ha^{-1}) showed the highest results concerning this parameter – 18.60 and 19.27 umbels plant^{-1} averaged over the period. Both results are statistically proven according to the used statistical test ($p < 0.05$).

Seed yield, absolute seed mass, and seed essential oil content

Coriander seed yield, absolute seed mass, and seed essential oil content were also influenced by the weed infestation, herbicidal efficacy, and herbicide selectivity (Table 5).

The plants received 3.50 L ha^{-1} of the product yielded (1.37 t ha^{-1}) similar to the untreated control (1.10 t ha^{-1}), which was the lowest. Medium yields were obtained after the application of the rate of 1.50 L ha^{-1} of Praxim (treatment 3) – 1.66 t ha^{-1}. The yields of the weed-free control and treatment 4 (2.50 L ha^{-1}) – 1.99 and 2.01 t ha^{-1} respectively, were the highest in the study. These differences were statistically significant.

The absolute seed mass also differed among the treatments. The lowest values were found in the untreated control giving 4.44 g averaged over the period, followed by treatment 5 (Praxim 3.50 L ha^{-1}) – 4.76 g. The absolute seed mass for the weed-free control (treatment 2) as well as for treatment 4 was the highest in the research – 5.57 and 5.56 g, respectively, averaged over the trial period. Treatment 3 (Praxim 1.50 L ha^{-1}) showed medium results – 5.07 g.

As for the other studied indicators, differences in the seed essential oil content were found. The seeds of the untreated control had the lowest essential oil content – 1.01% average over the period. The average results of treatment 5 were low, too – 1.09%. The essential oil content of the other treatments (weed-free control, Praxim 1.50 and Praxim 2.50 L ha^{-1}) was significantly higher – 1.35, 1.32, and 1.34%, respectively.

Discussion

The herbicide-active substance metobromuron belongs to the group of urea herbicides, known to be photosynthesis inhibitors (Mortland, 1980). The herbicide controls annual broadleaf and grass weeds (belchim.co.uk). The herbicide can be applied pre- or post-emergence of the crop. However, post-emergence application in tank mixture (with metolachlor) might be lethal for some crops like cowpea (O'Makinwa and Akinyemiju, 1990). Herbicidal products containing the active ingredient metobromuron have been studied for weed control in potatoes (Zimdahl, 1971; Habib et al., 1989; Dobozi and Lehoczky, 2002; Dobozi et al., 2003, 2004; Vacher, 2016) and bean (Park and Hamill, 1993; McNaughton et al., 2004). Szempliński et al. (2018) applied 1,500 g ha^{-1} metobromuron (product unknown) pre-emergence when studying the response of coriander to different levels of agronomic factors.

Still, there is a lack of information about the effect of metobromuron application at different rates in the early vegetation stages of the crop. In the current study, the performance of the herbicide product Praxim was evaluated in three consecutive years (2018, 2019, and 2020). The obtained results were compared with untreated weedy control and weed-free control treatments. The herbicidal efficacy of the rate of 1.50 L ha^{-1} was insufficient to control the existing weeds. The control of the perennial weed *C. arvensis* was negligible at all rates applied. In research conducted in India by Savaliya et al. (2017) the application of pendimethalin – 1.0 kg ha^{-1} pre-emergence + quizalofop-P-ethyl – 0.04 kg ha^{-1} at 20 days after sowing led to the highest efficacy (79.30%), when comparing with hand weeding twice during the vegetation (85.27%).

The 2.50 L ha^{-1} application rate of Praxim led to higher efficacy against the weeds in the study that reached satisfactory values, above 80%. Among the weeds insufficiently controlled by the rate of 2.50 L ha^{-1} were the annual *G. aparine* and the perennial *C. arvensis* (below 80.0%). The herbicide rates of 1.50 and 2.50 L ha^{-1} applied in BBCH 12–13 of coriander were safe for the crop, no phytotoxic symptoms of any kind were reported. For *G. aparine* control, Delchev and Barakova (2017) studied the herbicidal products Silba SC (312.5 g L^{-1} s-metolachlor + 187.5 g L^{-1} terbuthylazine) – 3.5 L ha^{-1}, Sharpen 33 EC (330 g L^{-1} pendimethalin) – 5.0 L ha^{-1}, Merlin flex 480 SC (240 g L^{-1} isoxaflutole) 0.42 kg ha^{-1}, Smerch 24 EC (240 g L^{-1} oxyfluorfen) – 1.0 L ha^{-1}, and Raft 400 SC (400 g L^{-1} oxidiargil) – 1.0 L ha^{-1} applied after sowing before emergence (ASBE) of coriander as well as Lontrel 300 EC (300 g L^{-1} clopyralid) – 0.5 L ha^{-1} in rosette stage of the crop. The obtained efficacy against the weed was 100% for each of these treatments. The authors reported 0% efficacy against the perennial weed *C. arvensis.*

The highest efficacy was achieved after the application of 3.50 L ha^{-1} of the herbicide product. In reverse, this high rate led to phytotoxic consequences for coriander. The plants of the concrete treatment were stunted in growth and development. When the tolerance of cultivated plants to the absorbed herbicide is not enough to destroy them, the result is herbicide stress leading to various structural and functional impairments. In some cases, the phytotoxicity may show no visible symptoms, but inevitably growth retardation will be reported (Vischetti et al., 2002). No other signs of visual phytotoxicity were observed.

The studied parameters as plant height branches plant^{-1} and umbels plant^{-1} were influenced by the weed infestation and the herbicide rates. The obtained results are a reflection of the herbicidal efficacy and selectivity. Pendimethalin applied at 1.0 kg ha^{-1} + hand-weeding at 40 days after sowing was effective in increasing the growth and yield attributes of coriander (Yadav et al., 2013). Where the herbicide metobromuron was applied increased stem length was recorded. Also, a higher number of branches and umbels were formed (Szempliński et al., 2018). These findings correspond with our obtained results. The weed infestation in the untreated plots decreased the plant height, as well as the branches and umbels plant^{-1}. In our trial, the herbicide stress caused by the high metobromuron rate received from the coriander plants decreased these parameters, which reached the results of the untreated control. The rate of 2.50 L ha^{-1} reached the results of the weed-free control. These findings show that this examined rate has achieved enough weed control levels and the herbicide amount received is safe for the crop.

The weed concurrence is capable to decrease coriander seed yields (Thakral et al., 1989; Tewari et al., 2005; Carrubba and Marcello, 2013; Patil et al., 2020). The coriander seed yield was the lowest for the untreated weedy control. The highest productivity was found to be for the weed-free control and for the plants that received the 2.50 L ha^{-1} of the herbicidal product Praxim.

According to Georgiev et al. (2014), the indicator absolute seed mass is crucial for the formation of the yields. The absolute seed mass of the coriander seeds also differed among the treatments. The lowest results were found to be for the untreated control and treatment 5 (Praxim 3.50 L ha^{-1}). The absolute seed mass for the weed-free control and treatment 4 (Praxim 2.50 L ha^{-1}) was the highest.

The essential oil content of coriander's seed was also influenced by the weed flora and the herbicide's efficacy and selectivity. The weed infestation decreased the seed essential oil content the most, which is a parameter for quality. The herbicide rate of 3.50 L ha^{-1} also decreased the essential oil content in the seeds. The essential oil content for the other treatments like weed-free control, Praxim 1.50, and Praxim 2.50 L ha^{-1} was higher and did not differ significantly.

Conclusions

1. The mean efficacy of *M. chamomilla*, *G. aparine*, *S. arvensis*, *S. nigrum*, *A. retroflexus* and *C. arvensis* control was the lowest when applying the rate of 1.5 L ha^{-1}.
2. Satisfactory herbicidal efficacy against *M. chamomilla*, *S. arvensis*, *S. nigrum* and *A. retroflexus* was found for the rate of 2.50 L ha^{-1}.
3. The efficacy of the herbicide's rate of 3.50 L ha^{-1} was high, but together with the efficacy, visual phytotoxic symptoms from score 3 (in 2018) and score 4 (in 2019 and 2020) were observed. No phytotoxic symptoms were recorded for the lower two herbicidal rates.
4. The studied indicators (plant height, branches $plant^{-1}$, umbels $plant^{-1}$, seed yield, absolute seed mass, and seed essential oil content) were influenced by the existing weeds, herbicidal efficacy, and herbicidal selectivity. The plants that received the highest evaluated rate of 3.50 L ha^{-1} of the herbicidal product Praxim had the lowest results of the studied parameters among the treated variants. The plants of the untreated weedy control had the lowest results in the study. This in term shows how dangerous the weed infestation in coriander can be.

The weeds appearing in coriander fields have to be controlled in order to obtain high, stable, and high-quality seed yields. Our research findings have shown that the herbicidal product Praxim (500 g L^{-1} metobromuron) at the rate of 2.50 L ha^{-1} is safe and can be applied in the early development stages of the crop for satisfactory control of *Matricaria chamomilla* L., *Sinapis arvensis* L., *Solanum nigrum* L., *Amaranthus retroflexus* L. Higher rates (3.50 L ha^{-1}) of the product are harmful to coriander and despite their high efficacy they can decrease coriander's development, yields and quality.

Acknowledgments

This experiment was carried out with the support of Project 17-12 at The Centre of Research, Technology Transfer and Protection of Intellectual Property Rights at the Agricultural University of Plovdiv, Bulgaria.

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Received: May 21, 2021
Accepted: Mar. 19, 2022

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