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EVALUATION OF SOIL AND FOLIAR HERBICIDAL APPLICATIONS AT CAMELINA (*Camelina sativa* (L.) Crantz

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Abstract

Camelina is one of the underestimated oil crops with high potential for low input production. Main constrain during the cultivation is the weed infestation. A field trial for evaluation of the efficacy and the selectivity of several herbicides applied on three genotypes (variety Czenstochowska, local landrace BGR 436, and introduced accession CAM 265) was performed at the Agricultural University of Plovdiv, Bulgaria in 2022 and 2023. The herbicides Stomp Aqua (455 g/l pendimethalin) – 4.00 L ha^{-1} and Butisan 400 SC (400 g/l metazachlor) – 2.50 L ha^{-1} were applied after sowing before germination. The studied foliar herbicides were Lontrel 300 SL (300 g/l clopiralid) – 0.40 L ha^{-1} and Galera Super (240 g/l clopyralid + 80 g/l picloram + 40 g/l aminopyralid) – 0.20 L ha^{-1}. The products were sprayed at the growth stage when a single true leaf on 5th to 8th node was developed on the crop. The Lontrel 300 SL and Galera Super treatments showed higher weed control compared to Stomp Aqua and Butisan 400 SC, but had higher phytotoxixity as well that resulted in growth retardation and yields decrease.

Key words*: Camelina, herbicides, weeds, plant development, yields.*

INTRODUCTION

Camelina sativa origin is from south-eastern Europe and south-western Asia and is a member of the Brassicaceae family (Singh et al., 2015). *Camelina sativa* is also known as false flax or gold-of-pleasure (Luo et al., 2019). Camelina is one of the underestimated oil crops around the globe as well as in Bulgaria and neighbouring countries, but in the last decade is gaining great interest. The increased industrial search for alternatives to fossil fuels for jet fuel and biodiesel can be answered with this easy-to-grow and low-input crop well-adapted to each environment (Bakhshi et al., 2021; Mondor and Hernández-Álvarez, 2022). One of the greatest problematic issues during camelina growing is the weed infestation (Lenssen et al., 2012). One of the approaches for weed control in camelina is growing the crop as a mixed cropping system with legumes that leads to the suppression of some weeds (Saucke and Ackermann, 2006; Neshev et al., 2023). According to Codina-Pascual et al. (2022), the camelina can suppress the development of corn poppy and its seed production and may be considered a tool for IWM. In nowadays agriculture, weed management is based on herbicidal treatments (Simic et al., 2011; Mitkov et al., 2016, Jursík et al., 2017; Neshev et al., 2020). The weed management with herbicides has to be performed in the optimal crop growth stage (Simic et al., 2011). Therefore, a low number of herbicidal products are registered for application in the camelina fields. That makes weeds a difficult problem during the cultivation of the crop (Sobiech et al., 2020).

The application of the herbicides is not effective enough for full weed control and the crop is tolerant to a limited number of herbicides for broadleaf weed control (Berti et al., 2016; Obour, 2015). On the other hand, most of the herbicidal products applied before germination of the camelina led to injuries on the crop (Jha and Stougaard, 2013; Scheliga and Petersen, 2016).

Herbicide phytotoxicity can be observed in different situations as application of the herbicides in unsuitable weather conditions (waterlogging, drought, low or high temperatures, etc.) and herbicide drift; In case of technological mistakes by increasing the herbicidal rate; Application of herbicide on a sensitive by mistake; Due to insufficient selectivity; etc. (Hanks, 1995; Vischetti et al., 2002; Thistle, 2004; Neshev et al., 2022).

According to Dayan et al. (2015) and Dayan and Zaccaro (2012) if the detoxification of the herbicide sufficient different functional impairments appears in plants. The herbicidal toxicity is most often chronic, but in some situations, it may be lethal for the crop.

Prashant and Stougaard (2013) evaluated the tolerance of camellia to various herbicides such as quinclorac, S-metolachlor, dimethenamid-P, pendimethalin, and pyroxasulfone. Quinclorac applied before emergence did not cause significant damage to the camelina and had no negative effect on plant density, biomass, flowering, and yield. S-metolachlor caused less than 20% damage to the camelina. Dimethenamid-P applied at 630 g ai ha^{-1} did not affect camelina seeding density, nor biomass, flowering, and yield; however, at a rate of 1,260 g ha^{-1} the damage in sandy soils was up to 60%, flowering was delayed, and plant density and yield were reduced by 50 and 31%, respectively. Although it caused some visual damage to camelina, crop yield was not reduced by pendimethalin.

The results obtained in Russia by Serdyuk et al. (2021) are contradictory. The application of combinations of herbicides such as clopyralid, S-metolachlor, ethametsulfuron-methyl a significant reduction in plant density (by 18-32 plants m^2) and seed yield (by 0.33-0.52 t ha^{-1}) of camelina compared to the control was reported.

The ability to recover the herbicide-damaged plants depends on the degree of the occurred structural-functional impairment. Some studies have shown that chronic herbicide phytotoxicity can be overcome (to some extent or completely) by the application of biostimulants, foliar fertilizers, growth regulators, herbicide antidotes, etc. (Jablonkai, 2013; Balabanova et al., 2016; Colla et al., 2017; Balabanova, 2021; Soltani, 2015; Neshev et al., 2020; Neshev et al., 2021; Neshev et al., 2022).

There is still limited information about the herbicidal treatments' influence on the growth and development of camelina landraces. Therefore, this study aimed to evaluate the efficacy against the weeds of different herbicide products and evaluate the influence of the herbicidal treatments on camelina genotypes.

MATERIALS AND METHODS

The field study was carried out at the experimental field of the Agricultural University - Plovdiv, Bulgaria in 2022 and 2023. The experiment was done by the randomized block method in three repetitions. The size of the experimental plot was 10 m².

The plants were sown at a density of 500 germinated seeds/m² at the beginning of March, with a plot seeder. In both years of the research, the preceding crop of camelinas was sunflower. On the field of the trial deep ploughing, two times disc harrowing, and two times cultivation before sowing were done. After sowing before germination fertilization with 150 kg ha^{-1} with combined NPK fertilizer (15:15:15) was accomplished. No insecticides and fungicides were applied before or during the vegetation. No irrigation is provided for emergence or during the two growing seasons.

The herbicides Stomp Aqua and Butizan 400 SC were applied after sowing before germination (BBCH 00). The products Lontrel 300 SL and Galera Super were administered in the phenophase rosette (BBCH15-18). The treatments were performed with backpack sprayer SOLO model 417 (Solo, Germany). The size of the working solution was 250 L ha^{-1}.

Variants of the trial were:

1. Untreated control;
2. Stomp Aqua – 4.00 L ha^{-1};
3. Butizan 400 SC – 2.50 L ha^{-1};
4. Lontrel 300 SL – 0.40 L ha^{-1};
5. Galera Super – 0.20 L ha^{-1}.

Used herbicidal products:

- Stomp Aqua (455 g/l pendimethalin). Stomp® Aqua is a herbicide for the control of annual grass and broad-leaved weeds in a wide range of crops such as wheat, barley, rye, transplanted brassicas, carrots, onions, parsnips, combining peas, potatoes, sunflowers, triticale, etc. (https://www.agricentre.basf.co.uk/en/Products/Product-Search/Herbicides/Stomp-Aqua.html).
- Butizan 400 SC (400 g/l metazachlor). Butisan 400 SC is a selective herbicide for soil and early vegetation application against annual broadleaf and grass weeds. It is registered to be applied in cabbage, cabbage seedlings (beds), and oilseed rape (https://agroconsult-buinov.com/en/produkt/butisan-400-sc/).
- Lontrel 300 SL (300 g/l clopyralid) – 0.40 ml ha^{-1}. It is a post-emergence herbicidal product that can be applied in onions, grapevines, wheat, maize, mustard sugar beet, etc. It controls broadleaf weed species only

(https://www.agropataki.ro/en/herbicide/lontrel-300-ec-p19156.html).

- Galera Super (240 g/l clopyralid + 80 g/l picloram + 40 g/l aminopyralid) – 0.20 ml ha^{-1}. It is a foliar herbicide that controls annual and perennial broadleaf weeds in oilseed rape (https://www.nexles.com/eu/dow-agro-sciences-herbicide-galera-super-1-liter.html).

Herbicidal efficacy was assessed on the 10-score visual scale of EWRS (European Weed Research Society) on the 14th, 28th, and 42nd day after treatment (over 14 days). The efficacy is averaged for the three camelina genotypes since the herbicidal treatments are equal.

Herbicidal selectivity was assessed on the 9-score visual scale of EWRS on the 7th, 14th, 21st, and 28th day after crop post-emergence for the soil treatments (at 7 days) and on the 7th, 14th, 21st, and 28th day after treatment of the variants with foliar herbicides (in 7 days) as described below:

1. No effect (healthy plants);
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.

The natural weed species on the field were Fat-hen (*Chenopodium album* L.) – 21 specimens m^2 in 2022 and 17 specimens m^2 in 2023; Cleavers (*Galium aparine* L.) – 7 specimens m^2 in 2022 and 11 specimens m^2 in 2023; Forking larkspur (*Consolida regalis* Gray.) – 12 specimens m^2 in 2022 and 9 specimens m^2 in 2023; Spiny cocklebur (*Xanthium spinosum* L.) – 8 specimens m^2 in 2022 and 10 specimens m^2 in 2023; Green foxtail (*Setaria viridis* (L.) P. Beauv.) – 14 specimens m^2 in 2022 and 17 specimens m^2 in 2023; Annual ryegrass (*Lolium rigidum* Gaud.) – 16 specimens m^2 in 2022 and 19 specimens m^2 in 2023.

There is no registered camelina variety in Bulgaria, therefore three genotypes *of Camelina sativa* (L.) Crantz with different origins were chosen as test plants – landrace from Poland ("Czenstochowska"), Italy ("CAM 265"), and Bulgaria - local population ("BGR 436"). The "BGR 436" plants are part of a large collection collected through international scientific exchange with gene banks and scientists, within the framework of a project under the National Science Program "Healthy Biofoods for a Strong Economy and Quality of Life". The selection of the specific genotypes is based on different origins, phenological development, and morphological characteristics.

Several observations, biometrical, vegetative, and productive evaluations and measurements were performed:

- Symptoms of herbicidal damage;
- Plant height (PH) at the end of the vegetation (cm). The height of thirty plants per plot was measured (ninety plants total per treatment);
- Number of primary brunches plant^{-1} (NPB plant^{-1}) at the end of the vegetation. The number of primary branches of thirty plants per plot was measured (ninety plants total per treatment);
- Number of siliques plant^{-1} (NS plant^{-1}) at the end of the vegetation. The number of the siliques of thirty plants per plot was measured (ninety plants total per treatment);
- Seed yield plant^{-1} (SY), g. After manual harvesting, the seeds of thirty separate plants per plot were weighted individually on an electronic scale. The obtained results were summed and divided to thirty to recalculate the average seed yield plant^{-1}. Ninety plants total per treatment were analysed.

The analyses were performed separately for each of the three camelina landraces grown in the research.

The agrometeorological data during the experiments was taken from the automatic meteorological station "Meteobot® Pro". The presented data is for the average monthly minimum and maximum air temperatures (°C) as well as precipitation (mm) for the vegetation periods of camalinas (from March to June) during the two trial years.

The statistical analysis of the collected data for the plant height, number of primary branches plant^{-1}, number of siliques plant^{-1} at the end of the vegetation as well as the seed yield plant^{-1} was performed by Duncan's Multiple Range test (One-Way ANOVA) by the software program SPSS 26. As the efficacy and the selectivity were evaluated by visual rating no statistical analyses were done.

RESULTS AND DISCUSSIONS

Figure 1 shows the average temperatures, and Figure 2 presents the amount of precipitation during the vegetation period of the camelina genotypes. Temperatures were optimal for the crop development and no negative influence of temperatures on the growth and development of the studied camelina genotypes was found. It is seen that the amount of precipitation during the different months is a prerequisite for relatively good moisture storage and normal vegetation. Camellia was sown on dry soil in March. In both years there was a prolonged period of drought before sowing, but there was heavy rainfall at the end of March. Regarding the moisture during the growing season, in both experimental years, no period in which the camelina genotypes experienced a water deficit was established.

Based on the analysis of the meteorological data, we can point out the two experimental years as relatively favourable for the growth, development, and realization of the productive abilities of the grown camelina genotypes.

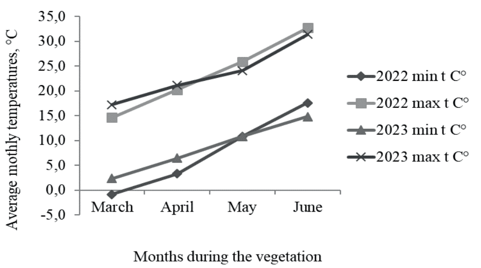

Figure 1. Average monthly minimum and maximum air temperatures, °C

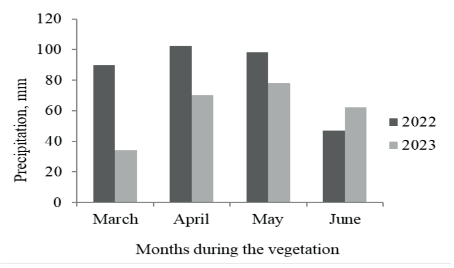

Figure 2. Average monthly precipitation, mm

All pesticides as well as herbicides require attention to meteorological factors such as temperatures and precipitation (World Meteorological Organization, 2010). There were no temperature values reported, which can contribute to a wrong assessment of the herbicidal substances' phytotoxic performances to the crop and the valuation of their efficacy against the weeds. If rain falls at the application time or immediately after that it may lead to washing away any unabsorbed amount of the herbicides applied (Tonev et al., 2011). The amount of precipitation during treatments in both years of the study did not affect the phytotoxic expressions and their overcoming by the camelina genotypes. The efficacy against the weeds was not influenced by the precipitation as well.

The efficacy of the soil-applied herbicide products Stomp Aqua and Butizan 400 SK against all weeds was lower on the first reporting date and increased by the third evaluation date. This is most likely due to several major factors influencing the action of soil-applicable herbicides such as the extent to which the herbicide is adsorbed to soil particles, the rate of absorption of the herbicide solution by plant roots, and the rate at which the herbicide decomposes, volatilizes or leaches from the soil (Osgerby, 1973). In contrast to the soil-applied herbicides, the efficacy of vegetatively applied Lontrel 300 SL and Galera Super against all weeds was lower on the first reporting date and increased by the third reporting date. This corresponds with results reported by different authors on other crop plants (Mitkov et al., 2017; Mitkov et al., 2018; Yanev et al., 2021).

Table 1 shows the efficacy of the evaluated herbicides against the weeds developing together with the camelina landraces.

For the weed Fat-hen (*Ch. album*) the soil-applied herbicides showed 88% efficacy on the 14th day after treatments. On the next reporting date, the efficacy decreased to 68-78% for variant 2 (Stomp Aqua – 4.00 L ha^{-1}) and variant 3 (Butizan 400 SC – 2.50 4.00 L ha^{-1}) respectively. On the 42nd day, the efficacy was lower - 48 - 55%.

In the case of the foliar herbicides, a higher initial efficacy (on the 14th day) was reported for variant 5 (Galera Super – 0.20 4.00 L ha^{-1}) – 65% on average for the two experimental years. The efficacy of Lontrel 300 SL – 0.40 4.00 L ha^{-1} (variant 4) was very low – 25%. At the next reporting date, the efficacy of Galera Super and

Lontrel increased to 45 and 78%, respectively. On the 42nd day, the efficacy of Lontrel 300 SL was 55%, indicating that the herbicide could not control the Fat-hen to a significant economic effect. The efficiency of Galera Super reached 88%, which effectively controlled the weed.

Table 1. Efficacy of the evaluated herbicides against the weeds, %

Treatments/Weeds/Year	2022	2023	Average for the period
Ch. album	(%)	(%)	(%)
1. Untreated control	-	-	-
2. Stomp Aqua – 4.00 L ha^{-1}	85.00	75.00	50.00
3. Butizan 400 SC – 2.50 L ha^{-1}	90.00	70.00	50.00
4. Lontrel 300 SL – 0.40 L ha^{-1}	20.00	40.00	50.00
5. Galera Super – 0.20 L ha^{-1}	60.00	75.00	85.00
G. aparine	(%)	(%)	(%)
1. Untreated control;	-	-	-
2. Stomp Aqua – 4.00 L ha^{-1}	80.00	65.00	50.00
3. Butizan 400 SC – 2.50 L ha^{-1}	85.00	70.00	50.00
4. Lontrel 300 SL – 0.40 L ha^{-1}	60.00	70.00	75.00
5. Galera Super – 0.20 L ha^{-1}	75.00	85.00	90.00
C. regalis	(%)	(%)	(%)
1. Untreated control	-	-	-
2. Stomp Aqua – 4.00 L ha^{-1}	70.00	50.00	30.00
3. Butizan 400 SC – 2.50 L ha^{-1}	80.00	60.00	40.00
4. Lontrel 300 SL – 0.40 L ha^{-1}	40.00	50.00	60.00
5. Galera Super – 0.20 L ha^{-1}	50.00	70.00	90.00
Xa. spinosum	(%)	(%)	(%)
1. Untreated control	-	-	-
2. Stomp Aqua – 4.00 L ha^{-1}	50.00	30.00	25.00
3. Butizan 400 SC – 2.50 L ha^{-1}	40.00	25.00	20.00
4. Lontrel 300 SL – 0.40 L ha^{-1}	45.00	70.00	90.00
5. Galera Super – 0.20 L ha^{-1}	40.00	50.00	60.00
S. viridis	(%)	(%)	(%)
1. Untreated control	-	-	-
2. Stomp Aqua – 4.00 L ha^{-1}	90.00	80.00	50.00
3. Butizan 400 SC – 2.50 L ha^{-1}	80.00	60.00	40.00
4. Lontrel 300 SL – 0.40 L ha^{-1}	0.00	0.00	0.00
5. Galera Super – 0.20 L ha^{-1}	0.00	0.00	0.00
L. rigidum	(%)	(%)	(%)
1. Untreated control	-	-	-
2. Stomp Aqua – 4.00 L ha^{-1}	65.00	45.00	25.00
3. Butizan 400 SC – 2.50 L ha^{-1}	65.00	50.00	30.00
4. Lontrel 300 SL – 0.40 L ha^{-1}	0.00	0.00	0.00
5. Galera Super – 0.20 L ha^{-1}	0.00	0.00	0.00

The efficacy of the tested herbicide against the weed Cleavers (*G. aparine*) was similar to those reported for the Fat-hen. The soil-applied herbicides showed average efficacy from 85 to 88% on the 14th day after application. On the next reporting date, the efficacy decreased to 70 and 73% for variant 2 (Stomp Aqua – 4.00 L ha^{-1}) and variant 3 (Butizan 400 SC – 2.50 L ha^{-1}) respectively. On the 42nd day, the efficacy of the herbicides was lower – 45%. On the 14th day, the foliar application of Galera Super – 0.20 L ha^{-1} (variant 5) reached 78% on average for the two years of the study and the efficacy of Lontrel 300 SL – 0.40 L ha^{-1} (variant 4) was 65%.

At the next reporting date, the efficacy of variants 4 and 5 increased to 73 and 88%, respectively. On the 42nd day after treatment, the efficacy of Lontrel was 80%, and that of Galera Super – 93%.

The efficacy of the evaluated herbicidal products against the weed Forking larkspur (*C. regalis*) was similar to that found in the Fat-hen and Cleavers. For the soil herbicides, the average efficacy on the 14th day after treatment was 75 to 85%. On the next reporting date, the efficacy decreased to 55 and 65% for variant 2 (Stomp Aqua – 4.00 L ha^{-1}) and variant 3 (Butizan 400 SC – 2.50 L ha^{-1}) respectively. On the 42nd day, the efficacy of the herbicides decreased to 35%.

Averaged over the two years, the efficacy of the foliar herbicides against the weed Forking larkspur on the 14th day after treatments was 48% for variant 5 (Galera Super – 0.20 L ha^{-1}).

The efficacy of Lontrel 300 SL – 0.40 L ha^{-1} (variant 4) was 45%. At the next reporting date, the efficacy of treatments 4 and 5 increased to 55 and 68%, respectively. On the 42^{nd} day, the efficacy of Lontrel 300 SL was 68%, and that of Galera Super reached 88%. The efficacy against the weed species Spiny cocklebur (*Xa. spinosum*) for the soil-applied herbicides was lower than that reported for the above-mentioned weed species. The average efficacy on the 14^{th} day was 43 to 45% for variant 3 (Butizan 400 SC – 2.50 L ha^{-1}) and variant 2 (Stomp Aqua – 4.00 L ha^{-1}) respectively. On the next reporting date, the efficacy decreased to 30%, and on day 42^{nd} to 20%.

Averaged over the two years, the efficacy of the foliar herbicides on the 14^{th} day after treatment was 43% for treatment 5 (Galera Super – 0.20 L ha^{-1}). The efficacy of Lontrel 300 SL – 0.40 L ha^{-1} (variant 4) was 45%. At the next reporting date, the efficacy of the treatments increased to 73 and 55%, respectively. On the 42^{nd} day after treatment, the efficacy of Lontrel 300 SL was the highest - 95%, and that of Galera Super was significantly lower - 65%. The efficacy against Green foxtail (*S. viridis*) and Annual ryegrass (*L. rigidum*) only for the soil-applied herbicide products was reported, as the foliar herbicides Lontrel 300 SL and Galera Super control only broadleaf weed species.

The average efficacy against Green foxtail on the 14^{th} day after treatment was 85% for treatment 3 (Butizan 400 SC – 2.50 L ha^{-1}) and treatment 2 (Stomp Aqua – 4.00 L ha^{-1}). At the next evaluation date, the efficacy decreased to 65% in variant 2 and 78% in variant 3. At day 42 after treatments, the efficacy decreased to 45% in both variants of the trial.

The efficacy of Stomp Aqua and Butizan 400 SC against the Annual ryegrass (*L. rigidum*) was lower than that reported against the weed Green foxtail. The reported average efficacy on the 14^{th} day for Butizan 400 SC – 2.50 L ha^{-1}) was 68%, and for Stomp Aqua – 4.00 L ha^{-1}) was 60%. At the next assessment date, efficacy decreased to 43% for treatment 2 and 48% for treatment 3. At day 42 the efficacy decreased to 28% for Stomp Aqua and to 30% for Butizan 400 SC.

The following Table 2 present the results of the observed visual phytotoxicity in the three camelina genotypes. Plants of the three landraces responded relatively equally to the herbicide intervention and exhibited almost identical symptoms of herbicidal stress. The phytotoxic symptoms were more severely pronounced on the first reporting date, after which it was overcome by the plants to some extent depending on the herbicide product applied.

Pendimethalin is a soil-applicable herbicidal active substance from the dinitroaniline chemical group. It has to be applied after sowing before germination of the crop (Smith et al., 1995). The phytotoxic symptoms are root growth retardation and stunning of the sensitive plants. Phytotoxicity of pendimethalin is reported on onions (Acar et al., 2022), pumpkins (Neshev et al., 2019), and camelina (Jha and Stougaard, 2013). In our study, herbicidal toxicity of pendimethalin (Stomp Aqua) was recorded only on the first reporting date (7 days after treatments) (Table 2). After that, the plants overcome the herbicidal stress and develop normally.

The other pre-emergence herbicide evaluated in the study was Butizan 400 SC which contains the active substance metazachlor. The herbicidal active ingredient is an inhibitor of the very long chain fatty acids biosynthesis (Boger, 2003). This herbicide belongs to the chemical group of pyrazoles. Metazachlor can be applied to several crops as winter oilseed rape (Dimitrova et al., 2014), cauliflower (Šuk et al., 2018), kohlrabi (Jursík et al., 2019), etc. In a study conducted by Serdyuk et al. (2021), it was concluded that the application of quinmerac + metazachlor showed no phytotoxic the camelina plants. In our trial, there were herbicidal stress symptoms after the application of Butizan 400 SC. Phytotoxic symptoms were found in all three camelina genotypes. The phytotoxicity recorded on the 7^{th} day after germination of the plants was more severely pronounced and was determined as score 4 (Table 2 and Figure 2). The symptoms of phytotoxicity were expressed in chlorosis (yellowing) and distortion of the leaf petiole and leaf blade. Plants appear stunted. On the second reporting date, the phytotoxicity decreased and reached a score of 2, as the plants overcame the herbicide toxicity. On the 21^{st} and 28^{th} days after emergence, the plants completely overcome the visible symptoms of phytotoxicity.

Clopyralid is the active substance from the group pyridine carboxylates and it is known as synthetic auxin (Busi et al., 2018). Clopiralid (the active substance of the herbicidal product Lontrel 300 SL) can be applied in oilseed rape (Blackshaw, 1989; Mitkov et al., 2018), strawberries (Dobre et al., 2018), winter wheat (Gallo and Pekár, 2001.), onions (Gidea, M., 2014), etc. The camelina landraces were more severely damaged by the application of the foliar herbicides and experienced the stress to a higher degree. It was also reported in a research conducted by Sobiech et al. (2020) where the application of clopyralid damaged the evaluated plants to a greater extent than the other studied herbicides (propaquizafop, quizalofop-p-ethyl, and picloram). For Galera Super, the other herbicidal product studied in our trial, information for its application in camelina was not found. The combination of the three active substances (clopyralid + aminopyralid + picloram) in the commercial formulation showed stronger phytotoxicity to the three camelina genotypes when compared to the other treatments. The herbicide is applied for weed control in oilseed rape (Mitkov et al., 2017).

Table 2. Visual phytotoxicity in the three camelina genotypes, scores by EWRS

Treatments/Years/Days after treatments	2022				2023			
	7 days	14 days	21 days	28 days	7 days	14 days	21 days	28 days
"Czenstochowska"								
1. Untreated control	-	-	-	-	-	-	-	-
2. Stomp Aqua – 4.00 L ha^{-1}	2	1	1	1	2	1	1	1
3. Butizan 400 SC – 2.50 L ha^{-1}	4	3	1	1	4	3	1	1
4. Lontrel 300 SL – 0.40 L ha^{-1}	5	4	2	2	5	4	2	2
5. Galera Super – 0.20 L ha^{-1}	6	4	3	2	6	4	3	2
"CAM 265"								
1. Untreated control	-	-	-	-	-	-	-	-
2. Stomp Aqua – 4.00 L ha^{-1}	2	1	1	1	2	1	1	1
3. Butizan 400 SC – 2.50 L ha^{-1}	4	2	1	1	4	2	1	1
4. Lontrel 300 SL – 0.40 L ha^{-1}	6	5	3	2	6	5	3	2
5. Galera Super – 0.20 L ha^{-1}	6	5	3	3	6	5	3	3
"BGR 436"								
1. Untreated control	-	-	-	-	-	-	-	-
2. Stomp Aqua – 4.00 L ha^{-1}	2	1	1	1	2	1	1	1
3. Butizan 400 SC – 2.50 L ha^{-1}	4	2	1	1	4	2	1	1
4. Lontrel 300 SL – 0.40 L ha^{-1}	5	4	2	2	5	4	2	2
5. Galera Super – 0.20 L ha^{-1}	6	4	3	2	6	4	3	2

In general, the Italian camelina genotype "CAM 265" was more sensitive to foliar-applied herbicides. The lowest phytotoxicity for the three camelina genotypes after the treatment with Stomp Aqua – 4.00 L ha^{-1} was found. In both experimental years, phytotoxicity score 2 was detected on the 7th day after germination, with symptoms expressed in a slight suppression of the growth of plants that were sown more shallowly. On the following reporting dates, phytotoxic symptoms were not reported and the phytotoxicity was score 1 (healthy plants).

The phytotoxicity recorded on the 7th day after germination of the plants was more severely pronounced for treatment 3 – Butizan 400 SC – 2.50 L ha^{-1} – score 4.

High phytotoxicity was reported after the application of the foliar herbicide Lontrel 300 SL – 0.40 L ha^{-1} and Galera Super – 0.20 L ha^{-1}. Despite the more effective weed control, the yields of all three camelinas were severely reduced by the subsequent herbicide stress after spraying.

In the treatment with Galera Super and Lontrel 300 SL on the 7th day after treatments, a phytotoxicity score of 5 was recorded for the Poland camelina genotype "Czenstochowska", and the Bulgarian camelina landrace "BGR 436". The symptoms of visual phytotoxicity are expressed in plant wilting, suppressing the growth of the vegetation tip and from there slowing down the growth and development of the plants. On the 14th day after treatment, the phytotoxicity decreased to score 4, and the symptoms described above were less pronounced. On the 21st and 28th days, the symptoms of phytotoxicity decreased to score 2. For the camelina "CAM 265", the symptoms of phytotoxicity were more serious and reached score 6 and score 5, respectively, on the 7th and 14th day after treatment. On the 21st and 28th days, phytotoxic symptoms were evaluated with a score of 3 and 2, respectively. A delay in the entry of plants into the flowering phenophase was reported as well.

After the treatment with Galera Super – 0.20 L ha^{-1}, the phytotoxicity was generally higher than that of the treatment with Lontrel 300 SL – 0.40 L ha^{-1}. On the 7th day after spraying, a phytotoxicity score of 6 for the Poland camelina genotype "Czenstochowska" and the Bulgarian landrace "BGR 436" was recorded. The symptoms of visual phytotoxicity were stronger stunting of the plants, stronger suppression of the growth of the vegetative tip, and growth retardation. On the 14th day after treatment, the phytotoxicity diminished to a score 4, and the symptoms described above were lowered. On the 21st and 28th days, the symptoms of phytotoxicity decreased to a score of 3 and 2, respectively. In *Camelina* genotype "CAM 265", the symptoms of phytotoxicity were more severe and reached scores 6 and 5 respectively on the 7th and 14th day after application. On the 21st and 28th days, the phytotoxic symptoms were evaluated with a score of 3. A greater delay in the entry of plants into the flowering stage was found as well.

Plant height in camelina varies from 65 to 110 cm and is strongly influenced by external factors such as growing season, nutritional regime, rainfall, etc. (Berti et al., 2011). Researchers around the globe have reported a disturbance in plant growth after plants' exposure to herbicidal stress (Varshney et al., 2015; Neshev et al., 2020, Marques et al., 2021).

It was re-confirmed in the present study where all three camelina landraces were influenced by the herbicidal treatments. The plants treated with Lontrel 300 SL and Galera Super led to an extension of the vegetation and elongation of the plants (Table 3).

Table 3. Plant height at the end of the vegetation (cm)

Treatments/Year	2022	2023	Average for the period
"Czenstochowska"	cm	cm	cm
1. Untreated control	69.40 bc	65.70 b	67.55
2. Stomp Aqua – 4.00 L ha^{-1}	70.70 bc	65.30 b	68.00
3. Butizan 400 SC – 2.50 L ha^{-1}	66.60 c	69.90 ab	68.25
4. Lontrel 300 SL – 0.40 L ha^{-1}	78.90 a	76.20 a	77.55
5. Galera Super – 0.20 L ha^{-1}	74.20 ab	70.60 ab	72.40
"CAM 265"	cm	cm	cm
1. Untreated control;	69.20 b	69.70 ab	69.45
2. Stomp Aqua – 4.00 L ha^{-1}	63.60 b	65.60 bc	64.60
3. Butizan 400 SC – 2.50 L ha^{-1}	69.80 b	67.30 abc	68.55
4. Lontrel 300 SL – 0.40 L ha^{-1}	76.50 a	72.30 a	74.40
5. Galera Super – 0.20 L ha^{-1}	69.40 b	73.40 a	71.40
"BGR 436"	cm	cm	cm
1. Untreated control	62.60 b	61.60 b	62.10
2. Stomp Aqua – 4.00 L ha^{-1}	66.30 ab	63.10 b	64.70
3. Butizan 400 SC – 2.50 L ha^{-1}	67.30 ab	73.40 a	70.35
4. Lontrel 300 SL – 0.40 L ha^{-1}	71.10 a	75.80 a	73.45
5. Galera Super – 0.20 L ha^{-1}	66.60 ab	62.20 b	64.40

[a] Means with different letters are with proved differences according to Duncan's Multiple Range test ($p < 0.05$).

The genotypes selected for evaluation in this study are relatively short and respond differently to the applied herbicides. The stems are weakly hairy, well-branched, become woody when mature, and no lodging was observed during both experimental years.

Table 3 presents the change in the height of the plants of the studied camelina genotypes under the influence of the applied herbicidal products and compared with the untreated control.

On average for the period, the lowest plants for the untreated control from genotypes "Czenstochowska" and "BGR 436" - 67.55 and 62.10 cm, respectively were measured. In camellia genotype "CAM 265", the lowest plants were measured in variant 2 (Stomp Aqua – 4.00 L ha^{-1}) - 64.60 cm average for the period. The herbicidal stress caused by the foliar treatment with Lontrel 300 SL – 0.40 L ha^{-1} and Galera Super – 0.20 L ha^{-1} (variants 4 and 5) led to an extension of the vegetation. Plants of the three camelina genotypes treated with these herbicidal products were taller than those of the other variants. The only exception is variant 5 of camelina genotype “BGR 436”, where the plants are shorter.

The number of primary branches plant^{-1} at the end of the vegetation was influenced by the herbicidal treatments as well. The number of branches was higher for the soil-applicable herbicides Stomp Aqua and Butizan when compared with Lontrel 300 SL and Galera Super. In Table 4 the established results for the number of primary branches plant^{-1} in the investigated camelina genotypes are shown. On average for the period, the plants of variant 3 (Butizan 400 SK – 250 ml/da) for genotypes “Czenstochowska” and “CAM 265”, as well as variant 2 (Stomp Aqua – 4.00 L ha^{-1}) for genotype “BGR 436” have the highest number of branches – 12.20, 13.10 and 9.80, respectively. The plants treated with Galera Super – 0.20 L ha^{-1} (variant 5) had the lowest number of primary branches - 6.95, 5.70, and 4.45 on average for the period for the three grown camelina genotypes respectively.

Table 4. Number of primary brunches plant^{-1} at the end of the vegetation

Treatments/Weeds/Year	2022	2023	Average for the period
“Czenstochowska”	plant^{-1}	plant^{-1}	plant^{-1}
1. Untreated control	11.10 b	7.00 b	9.05
2. Stomp Aqua – 4.00 L ha^{-1}	10.30 b	7.00 b	8.65
3. Butizan 400 SC – 2.50 L ha^{-1}	14.90 a	9.50 a	12.20
4. Lontrel 300 SL – 0.40 L ha^{-1}	10.50 b	7.50 b	9.00
5. Galera Super – 0.20 L ha^{-1}	6.80 c	7.10 b	6.95
“CAM 265”	plant^{-1}	plant^{-1}	plant^{-1}
1. Untreated control;	9.40 b	9.40 b	9.40
2. Stomp Aqua – 4.00 L ha^{-1}	9.10 bc	9.80 b	9.45
3. Butizan 400 SC – 2.50 L ha^{-1}	13.00 a	13.20 a	13.10
4. Lontrel 300 SL – 0.40 L ha^{-1}	9.00 bc	12.60 a	10.80
5. Galera Super – 0.20 L ha^{-1}	6.40 c	5.00 c	5.70
“BGR 436”	plant^{-1}	plant^{-1}	plant^{-1}
1. Untreated control	7.20 b	9.50 a	8.35
2. Stomp Aqua – 4.00 L ha^{-1}	9.70 a	9.90 a	9.80
3. Butizan 400 SC – 2.50 L ha^{-1}	7.00 b	6.20 b	6.60
4. Lontrel 300 SL – 0.40 L ha^{-1}	7.70 ab	10.00 a	8.55
5. Galera Super – 0.20 L ha^{-1}	4.30 c	4.60 c	4.45

[a] Means with different letters are with proved differences according to Duncan’s Multiple Range test ($p < 0.05$).

Studies of different genotypes showed a strong variation in the silique number formed by a plant. The silique number correlates positively with nitrogen fertilization and sowing density (Czarnic et al., 2018). On average, about 60 to 115 boxes develop on one plant, changing their colour from green to yellow-reddish when ripe and then drying to full maturity (Jankowski et al., 2019). In a previous experiment with oilseed rape, Neshev et al. (2021) recorded a decrease in the silique number developed from a plant after imitation of herbicide drift that caused stress to the crop. In the present experiment with camelina varieties, there was silique number per plant decreased as well (Table 5). The results, calculated for the number of pods from one plant, are presented in Table 5. On average for the period, the plants from variant 3 (Butizan 400 SC – 2.50 L ha^{-1}) at genotype “Czenstochowska” had the highest number of siliques - 361.90. Plants with genotypes “CAM 265” and “BGR 436” formed the highest silique number plant^{-1} after the application of Stomp Aqua - 4.00 L ha^{-1} (variant 2) - 236.95 and 222.70, respectively. The plants treated with Lontrel 300 SL - 0.40 L ha^{-1} (variant 4) had the lowest silique number plant^{-1} - 99.3, 98.60, and 94.95 on average for the period for genotypes “Czenstochowska”, “CAM 265”, “BGR 436” respectively. Plants from the untreated control formed a greater number of pods per plant compared to variant 4 (Lontrel 300 SL).

Table 5. Number of siliques plant^{-1} at the end of the vegetation

TreatmentsYear	2022	2023	Average for the period
"Czenstochowska"	plant^{-1}	plant^{-1}	plant^{-1}
1. Untreated control	255.20 b	195.80 b	225.50
2. Stomp Aqua – 4.00 L ha^{-1}	367.30 a	187.20 bc	277.25
3. Butizan 400 SC – 2.50 L ha^{-1}	419.00 a	304.80 a	361.90
4. Lontrel 300 SL – 0.40 L ha^{-1}	91.10 c	107.50 c	99.30
5. Galera Super – 0.20 L ha^{-1}	178.00 b	188.60 bc	183.30
"CAM 265"	plant^{-1}	plant^{-1}	plant^{-1}
1. Untreated control;	215.90 b	182.70 a	199.30
2. Stomp Aqua – 4.00 L ha^{-1}	328.80 a	145.10 c	236.95
3. Butizan 400 SC – 2.50 L ha^{-1}	304.80 a	142.90 c	223.85
4. Lontrel 300 SL – 0.40 L ha^{-1}	57.20 c	140.00 c	98.60
5. Galera Super – 0.20 L ha^{-1}	254.10 ab	165.30 b	209.70
"BGR 436"	plant^{-1}	plant^{-1}	plant^{-1}
1. Untreated control	156.10 b	172.70 a	164.40
2. Stomp Aqua – 4.00 L ha^{-1}	276.40 a	169.00 a	222.70
3. Butizan 400 SC – 2.50 L ha^{-1}	194.00 ab	144.00 b	169.00
4. Lontrel 300 SL – 0.40 L ha^{-1}	67.20 c	122.70 c	94.95
5. Galera Super – 0.20 L ha^{-1}	188.00 b	170.80 a	179.40

[a] Means with different letters are with proved differences according to Duncan's Multiple Range test ($p < 0.05$).

The herbicidal stress may lead to a severe yield decrease in crops (Deeds et al., 2006; Webster et al., 2016; Neshev et al., 2021). All three landraces had lower yields after experiencing herbicidal damages (Table 6). The lowest yield plant^{-1} for variant 5 (Galera Super – 0.20 L ha^{-1}) and for the three camelina genotypes – 0.64 g ("Czenstochowska"), 0.64 g ("CAM 265"), and 0.53 g ("BGR 436") average for the study years was reported. In variant 4 (Lontrel 300 SL – 0.40 L ha^{-1}) the yields from one plant were slightly higher when compared to those of variant 5. On average for the two research yes, the plants of variant 2 (Stomp Aqua – 4.00 L ha^{-1}) stand out with the highest yields for the three camelina genotypes - 2.20 g ("Czenstochowska"), 1.66 g ("CAM 265"), and 1.77 g ("BGR 436"). The seed yields of the control plants averaged 1.50 g ("Czenstochowska"), 1.22 g ("CAM 265"), and 1.16 g ("BGR 436").

Table 6. Seed yield plant^{-1}, g

Treatments/Weeds/Year	2022	2023	Average for the period
"Czenstochowska"	plant^{-1}	plant^{-1}	plant^{-1}
1. Untreated control	1.63 b	1.36 a	1.50
2. Stomp Aqua – 4.00 L ha^{-1}	3.07 a	1.33 a	2.20
3. Butizan 400 SC – 2.50 L ha^{-1}	1.66 b	0.91 ab	1.29
4. Lontrel 300 SL – 0.40 L ha^{-1}	0.82 c	0.93 ab	0.88
5. Galera Super – 0.20 L ha^{-1}	0.54 c	0.74 b	0.64
"CAM 265"	plant^{-1}	plant^{-1}	plant^{-1}
1. Untreated control;	1.56 b	0.88 b	1.22
2. Stomp Aqua – 4.00 L ha^{-1}	2.58 a	0.74 bc	1.66
3. Butizan 400 SC – 2.50 L ha^{-1}	1.60 b	0.85 b	1.23
4. Lontrel 300 SL – 0.40 L ha^{-1}	0.96 c	1.01 a	0.99
5. Galera Super – 0.20 L ha^{-1}	0.74 c	0.54 c	0.64
"BGR 436"	plant^{-1}	plant^{-1}	plant^{-1}
1. Untreated control	1.47 b	0.85 ab	1.16
2. Stomp Aqua – 4.00 L ha^{-1}	2.48 a	1.06 a	1.77
3. Butizan 400 SC – 2.50 L ha^{-1}	1.24 b	0.66 ab	0.95
4. Lontrel 300 SL – 0.40 L ha^{-1}	0.93 c	0.67 ab	0.80
5. Galera Super – 0.20 L ha^{-1}	0.54 c	0.52 b	0.53

[a]Means with different letters are with proved differences according to Duncan's Multiple Range test ($p < 0.05$).

CONCLUSIONS

More efficient weed control was found from the foliar applications of Galera Super and Lontrel 300 SL, but higher phytotoxicity was found after the application of these herbicides. The camelina genotype "CAM 265" was the most sensitive to the herbicide applications. The lowest plants were measured in the untreated control from genotypes "Czenstochowska" and "BGR 436". The plants treated with Butizan 400 SC developed the highest number of branches for genotypes "Czenstochowska" and "CAM 265", and the plants of genotype "BGR 436" developed the highest number of branches after treatment with Stomp Aqua. The lowest number of branches was counted for the plants treated with Galera Super. The plants of genotype "Czenstochowska" formed the highest number of siliques where Butizan 400 SC was sprayed. The plants in genotypes "CAM 265" and "BGR 436" formed had the highest silique number after the application of Stomp Aqua. The lowest seed yields per plant were recorded when Galera Super was applied, and the highest seed yield per plant - when Stomp Aqua was sprayed.

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