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SELECTIVITY OF DIFFERENT IMAZAMOX-CONTAINING HERBICIDES AT CLEARFILED® AND CLEARFIELD PLUS® SUNFLOWER HYBRIDES

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Abstract

In the period of 2022-2023, a field experiment was conducted in the Plovdiv region on an alluvial-meadow type of soil. The phytotoxicity of four imazamox-containing herbicides at different application dose rates was evaluated in the sunflower hybrids SY Bacardi CLP and Coloris CL. The experiment includes the following treatment variants: 1. untreated control; 2. Pulsar 40 - 1.25 l ha $^{-1}$; 3. Pulsar Plus - 1.6 l ha $^{-1}$; 4. Pulsar Plus - 2.00 l ha $^{-1}$; 5. Saltus - 0.5 l ha $^{-1}$; 6. Saltus - 0.65 l ha $^{-1}$ and 7. Maza 4 SL - 1.25 l ha $^{-1}$. The highest phytotoxicity was recorded 7 days after treatment with the herbicide Saltus - 0.65 l ha $^{-1}$ in both sunflower hybrids. The seed yield in all treated variants of the two hybrids in the both crop years was lower than those of the check (untreated controls, maintained weed-free by hand). The highest oil content (41.5%) in the seeds on average for the experimental period is measured by the hybrid Coloris CL treated with Pulsar Plus - 1.6 l ha $^{-1}$.

Key words*: selectivity, phytotoxicity, imazamox, sunflower, seed yield, oil content.*

INTRODUCTION

In order to manage economically significant broadleaf and cereal weeds, particularly races of the upper flower parasite blue wrist of sunflower, imidazolinone herbicides, or IMIs, are frequently applied. IMI herbicides function by preventing the ALS enzyme from being synthesized, which is necessary for the cellular building components of plant cells-valine, leucine, and isoleucine (Traner & Wright, 2002; Hanson et al., 2007; Serban et al., 2019). Herbicide phytotoxicity can manifest in both overt (morphological abnormalities and alterations, delayed growth, chlorosis, necrosis, deformities, etc.) and covert ways (disorders in photosynthesis, respiration, water balance, etc.). In IMI-R sunflower hybrids, the herbicide imizamox may cause brief yellowing and development retardation; this occurs more frequently in stressful environmental circumstances. Sensitive plant leaves begin to show signs of toxicity, such as necrosis and chlorosis, a few days after imazamox is applied topically (Pfenning et al., 2008; Cobb and Reade, 2010; Sala et al., 2012). Further data regarding the photosynthetic efficiency of the herbicide-treated plants may be helpful for further developing the Clearfield technology, even if photosynthetic processes are not the main sites of imazamox activity, they may be altered (Balabanova et al., 2016).

One of the primary challenges restricting sunflower output in Eastern Europe is weeds, which result in significant yield losses (Kaya, 2014). A Clearfield® technique, based on the use of both the herbicide imazamox (imidazolinone herbicides) and resistant (IMI-R) sunflower hybrids, has been developed to address this challenge in the cultivation of sunflowers.

Efficient weed control is crucial for attaining elevated yields and optimizing the primary vegetation variables (Tonev, 2000; Delchev et al., 2015; Vozhehova et al., 2019). Prior to the key period for reducing the morphological characteristics being achieved, weed management at sunflower should be carried out during the crop's ideal phases (Simic et al., 2011).

Herbicides containing imidazolinone in combination with crops resistant to imidazolinone (IMI-R) offer a means of addressing the significant issue of weed presence in sunflower seedling growth stages.

The environmental conditions and the genetic traits of a hybrid play also an important role in achieving a hybrid's potential (Delibaltova et al., 2015; Neshev et al., 2017; Kharchenko et al., 2019).

The current study's objective is to assess the selectivity and efficacy of herbicides containing

imazamox at two sunflower's hybrids to be produced using the Clearfield® and Clearfield® Plus technologies.

MATERIALS AND METHODS

The field experiment was conducted on alluvial-meadow soils in the crop years 2022 and 2023 on the village of Voyvodinovo in central-south Bulgaria. Following a previous crop of wheat, the experiment was set up using the small plots parcel method with 8 treatments in four repetitions. Each plot has a 30 m^2 area and four rows spaced 70 cm apart along a 10 m length. The soil had the following pre-sowing treatments: thorough plowing to a depth of 30 cm, two cultivations, and the application of a mixed NPK fertilizer in a ratio of 15:15:15 prior to the second cultivation. In both years, the seeding rate was 55 000 plants per hectare. The second part of April is the sowing season. Using a working solution of 150 l/ha, the treatment of each variant was done using a boom back sprayer with a working width of 3 m. The experiment was performed of the randomized block design with 8 variants in four replications.

We evaluated the phytotoxicity of four herbicides containing imazamox at varying rates of application on two sunflower's hybrids: Coloris CL and SY Bacardi CLP. The following treatment variations are part of the experiment: One is the check (untreated control, maintained weed-free by hand); two is Pulsar 40 - 1.25 l ha^{-1}; three is Pulsar Plus - 1.6 l ha^{-1}; four is Pulsar Plus - 2.00 l ha^{-1}; five is Saltus - 0.5 l ha^{-1}; six is Saltus - 0.65 l ha^{-1}; and seven is Maza 4 SL - 1.25 l ha^{-1}.

The phytotoxicity of the sunflower crop was reported in percentage terms following the EWRS scale on days 7, 14, and 21, and the efficacy against weeds was recorded in percentage terms following the EWRS scale on the same days following the application of the post-emergence herbicides. The European Weed Research Society (EWRS) uses a nine-point rating system to assess the effectiveness and selectivity of herbicides. A score of one indicates that the herbicide is 100% effective and shows no signs of having phytotoxic effects on grown plants. On the scale, a score of 9 denotes total death and the herbicide effect of 29.9% to 0%. The EU's EPPO Standards served as the basis for the trials.

The indicators of oil content and seed yield were recorded. The Soxhlet method, as outlined by Ivanov and Popov (1994), was used to ascertain the oil content of the sunflower seeds.

RESULTS AND DISCUSSIONS

Table 1 displays the visual phytotoxicity for hybrid SY Bacardi CLP at 7, 14, and 21 days following treatment, while Table 2 displays the visual phytotoxicity for hybrid Coloris CL. Seven days after treatment, the signs of imazamox toxicity were most noticeable in both hybrids. The hybrid SY Bacardi CLP variant 7 (Saltus 0.65 l ha^{-1}) exhibited the highest phytotoxicity, with scores of 3 (2022) and 4 (2023) at 7 DAA.

There was visible phytotoxity appears with yellow blight at treatment 7. Sunflower plants treated with imazamox developed both leaf chlorosis and deformities in the young leaves. Little necrotic patches started to emerge in the leaves. The most damage were at 7 DAA. When sunflower plants were starting to elongation the stems, 14 days following spraying, observed budding.

Table 1. Visual phytotoxicity of SY Bacardi CLP hybrid reported at 7, 14 and 21 DAA, score

№ Trt.	Product Name	Formulation Concentration	Product rate L/HA	AI rate G/HA	7 DAA		14 DAA		21 DAA	
					2022	2023	2022	2023	2022	2023
1	Check									
2	Pulsar 40	40	1.25	50	2	3	1	2	1	1
3	Pulsar Plus	25	1.6	40	1	1	1	1	1	1
4	Pulsar Plus	25	2	50	2	2	1	1	1	1
5	Saltus	80	0.5	40	2	3	1	1	1	1
6	Saltus	80	0.65	52	3	4	2	3	1	1
7	Maza 4 SL	40	1.25	50	3	3	1	2	1	1

*Determined phytotoxicity using the EWRS 9-point phytotoxicity scale, where 1 represents no harm and 9 represents total crop mortality.

Based on the plants' response, the genotypes of sunflowers were analyzed in relation to the herbicide treatment. At 14 DAA, the plants developed new leaves devoid of visible phytotoxity symptoms, were only marginally apparent at 14 DAA, and even then, mainly on older leaves. Similar circumstances applied to hybrid Coloris CL, where the use of the herbicide Saltus at a dose of 0.65 l ha^{-1} again accentuated the phytotoxic symptomatology. When analyzing the effects of different herbicide dosages of Pulsar Plus, we found that the phytotoxicity of hybrid SY Bacardi CLP is significantly higher in the plants treated with the higher dose of imazamox (2 l ha^{-1}) and less noticeable in the plants treated with the lesser dose of the herbicide Pulsar Plus (1.6 l ha^{-1}). However, according to our observations, the Coloris CL hybrid was neither much more nor less phytotoxic when exposed to varying dosages of the herbicide Pulsar Plus.

Table 2. Visual phytotoxicity of Coloris CL hybrid reported at 7, 14 and 21 DAA, score

№ Trt.	Product Name	Formulation Concentration	Product rate L/HA	AI rate G/HA	7 DAA		14 DAA		21 DAA	
					2022	2023	2022	2023	2022	2023
1	Check									
2	Pulsar 40	40	1.25	50	1	1	1	1	1	1
3	Pulsar Plus	25	1.6	40	1	1	1	1	1	1
4	Pulsar Plus	25	2	50	1	1	1	1	1	1
5	Saltus	80	0.5	40	1	2	1	1	1	1
6	Saltus	80	0.65	52	2	3	1	1	1	1
7	Maza 4 SL	40	1.25	50	1	2	1	1	1	1

*Determined phytotoxicity using the EWRS 9-point phytotoxicity scale, where 1 represents no harm and 9 represents total crop mortality.

Herbicidal metabolism is influenced by various factors such as crop stage at application, use rate, adsorption, and translocation, which in turn affects crop response. Occasionally, after applying imazamox, crop plants may experience a brief yellowing or loss in height. If crops are growing in adverse environmental conditions (heat, drought, wet soils, etc.), these effects may be more noticeable. There is no documented evidence of drastic yield depressions, and the symptoms are transitory. In one to two weeks, normal development and look should return (Kudsk and Kristensen, 1992; Pfenning et al., 2008). The significant amount of rain that fell in 2023 following the application of the herbicides containing IMZ is what caused the more noticeable phytotoxicity in 2023 in both hybrids as opposed to 2022.

Depending on the sprayed imazamox-containing herbicides as well as the meteorological circumstances in each research year, the sunflower hybrid's yield changed over time.

Table 3 displays the yields of plants with and without phytotoxicity signs from imazamox-containing herbicides at the hybrid SY Bacardi CLP. The yields of hybrid Coloris CL plants with and without herbicide-induced phytotoxicity symptoms are shown in Table 4.

Table 3. Seed yield of SY Bacardi CLP hybrid, t/ha

№ Trt.	Product Name	Formulation Concentration	Product rate; L/HA	AI rate; G/HA	Yield, t/ha		Yield, %	
					2022	2023	2022	2023
1	Check*				2.218	1.421	100	100
2	Pulsar 40	40	1.25	50	2.097	1.186	94.5	83.5
3	Pulsar Plus	25	1.6	40	2.207	1.341	99.5	94.4
4	Pulsar Plus	25	2	50	2.154	1.235	97.1	86.9
5	Saltus	80	0.5	40	2.014	1.151	90.8	81.0
6	Saltus	80	0.65	52	1.886	1.005	85.0	70.7
7	Maza 4 SL	40	1.25	50	2.007	1.109	90.5	78.0

*The check is untreated controls, maintained weed-free by hand.

Variant 3 (Pulsar Plus - 1.60 l ha^{-1}) produced the best sunflower seed yield of all treated versions in 2022 for the hybrids SY Bacardi CLP and Coloris CL, with 2.207 t ha^{-1} and 2.186 t ha^{-1}. Variant 3 reports yield of 1.341 t ha^{-1} for the hybrid SY Bacardi CLP and 1.296 t ha^{-1} for the hybrid Coloris CL in 2023, which is comparable to the results of yields for the two hybrids. When compared to varieties treated with lower dosages of imazamox, those treated with greater rates have poorer yields. This was most likely brought on by the stress that the high herbicide rates had produced. This assertion aligns with the findings of a research conducted by Mitkov et al. (2019), which shown that the variations treated with twice imazamox rates yielded poorer yields when compared to those treated with recorded doses (Neshev et al., 2020).

Table 4. Seed yield of Coloris CL hybrid, t/ha

№ Trt.	Product Name	Formulation Concentration	Product rate; L/HA	AI rate; G/HA	Yield, t/ha		Yield, %	
					2022	2023	2022	2023
1	Check*				2.194	1.524	100	100
2	Pulsar 40	40	1.25	50	2.096	1.209	95.5	79.3
3	Pulsar Plus	25	1.6	40	2.186	1.296	99.6	85.0
4	Pulsar Plus	25	2	50	2.162	1.236	98.5	81.1
5	Saltus	80	0.5	40	2.014	1.102	91.8	72.3
6	Saltus	80	0.65	52	1.907	1.036	86.9	68.0
7	Maza 4 SL	40	1.25	50	1.982	1.128	90.3	74.0

*The check is untreated controls, maintained weed-free by hand.

Compared healthy plants of the check (untreated controls, maintained weed-free by hand), the seed production of symptomatic plants dropped, at the hybrid SY Bacardi CLP till 15% (2022) and 29.3% (2023) and at hybrid Coloris CL till 23.1% (2022) and 32% (2023). These findings demonstrate that IMI herbicide damages sunflower plants, resulting in both obvious damage and a drop in production. Our findings align with those of a study conducted in northern Serbia on IMI-herbicides (Maširević et al., 2010). They discovered that while most plants exhibiting signs of herbicide phytotoxicity recover, the course of treatment affects the plants' overall production. The output drops more as the number of these plants increases. According to Tichþ et al. (2018), a high amount of phytotoxicity also caused an increase in sunflower heads, stem branching, and a decrease in production.

The oil content of the hybrids under study, changed over the period of two years, ranging from 38.51% to 42.56%, as with the individual variants of treatment with imazamox containing herbicides, it varies in narrow limits. The results of the present study are presented in Figures 1 and 2.

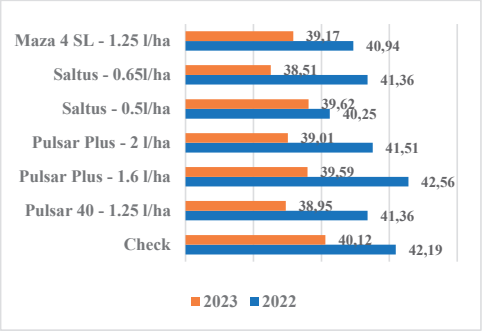

Figure 1. Oil Content of SY Bacardi CLP hybrid, %

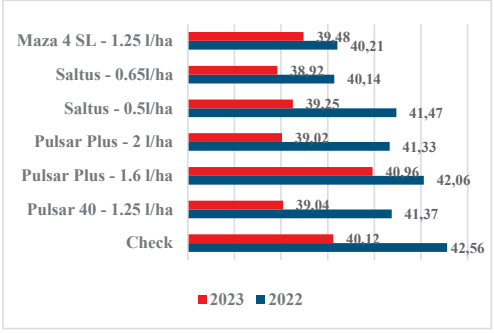

Figure 2. Oil Content of Coloris CL hybrid, %

In the two experimental years, the Check (untreated controls, maintained weed-free by hand) - those with no phytotoxic damage - realized the highest average yields of 1.820 t ha^{-1} and 1.859 t ha^{-1}, respectively (Table 5). Variant 6 (Saltus - 0.65 l ha^{-1}) had the lowest average seed yields of the two hybrids that were studied, measuring 1.446 t ha^{-1} for SY Bacardi CLP and 1.472 t ha^{-1} for Coloris CL. The highest concentrations of phytotoxicity indicators were displayed by both hybrids in this variant.

The yield and oil content of treatment with a higher dose of Pulsar Plus (2 l ha^{-1}) than the maximum recommended (1.6 l ha^{-1}) are affected. There was an average yield loss of 2.41% for the hybrid Coloris CL and 4.45% for the hybrid SY Bacardi CLP, according to the research. The corresponding decreases for the oil content indication were 3.13% and 1.95%, respectively (Table 5).

Table 5. Yield (t/ha) and oil contained (%), average for 2022/2023

№ Trt.	Product Name	SY Bacardi CLP		Coloris CL	
		Oil containt, %; average	Yield, t/ha; average	Oil containt, %; average	Yield, t/ha; average
1	Check	41.2	1.820	41.3	1.859
2	Pulsar 40 - 1.25 l ha^{-1}	40.2	1.642	40.2	1.653
3	Pulsar Plus - 1.6 l ha^{-1}	41.1	1.774	41.5	1.741
4	Pulsar Plus - 2 l ha^{-1}	40.3	1.695	40.2	1.699
5	Saltus - 0.5 l ha^{-1}	39.9	1.583	40.4	1.558
6	Saltus - 0.65 l ha^{-1}	39.9	1.446	39.5	1.472
7	Maza 4 SL - 1.25 l ha^{-1}	40.1	1.558	39.8	1.555

To determine the association between phytotoxicity resulting from the application of herbicides containing imazamox and the quantitative indicators of seed yield and oil containt in the Coloris CL and SY Bacardi CLP hybrids, a correlation analysis was carried out. The correlation matrices (Tables 6 and 7) show the correlation coefficients that express the relationship between the examined indicators.

Table 6. Correlation matrix of quantitative parameters and phytotoxicity in the hybrid SY Bacardi CLP

	Oil containt, %	Yield, t/ha	Phytotoxicity
Oil containt, %	1		
Yield, t/ha	0.906**	1	
Phytotoxicity	-0.827*	-0.962**	1

*Correlation is significant at the 0.05 level (2-tailed)
**Correlation is significant at the 0.01 level (2-tailed)

When expressing a specific numerical expression in natural measurements such as fractions (t/ha), percentages (%), etc., quantitative signals are measured in absolute terms. The phytotoxicity and the seed yield index showed a significant negative correlation in the hybrid SY Bacardi CLP (r = -0.962) and in the hybrid Coloris CL (r = -0.814). Obviously, phytotoxicity also has an adverse impact on oil content for the hybrids SY Bacardi CLP and Coloris CL cultivars, as evidenced by their respective correlation coefficients of (r = -0.827) and (r = -0.686).

Table 7. Correlation matrix of quantitative parameters and phytotoxicity in the hybrid Coloris CL

	Oil containt, %	Yield, t/ha	Phytotoxicity
Oil containt, %	1		
Yield, t/ha	0.851*	1	
Phytotoxicity	-0.686	-0.814*	1

*Correlation is significant at the 0.05 level (2-tailed)
**Correlation is significant at the 0.01 level (2-tailed)

CONCLUSIONS

The highest phytotoxicity in both hybrids SY Bacardi CLP and Coloris CL was recorded in the variant with Saltus, applied at a rate of 0.65 l ha^{-1}.

For both technologies (Clearfield and Clearfield Plus) the highest yields of all treated variants are achieved in treatment with herbicide Pulsar plus (1.6 l ha^{-1}) for hybrid Bacardi CL - 2.207 t ha^{-1} (2022) and 1.341 t ha^{-1} (2023), and in the case of hybrid Coloris CL - 2.185 t ha^{-1} (2022) and 2.196 t ha^{-1} (2023).

Research showed that the yield of seeds from plants treated with greater doses of herbicide was lower than that of plants treated with recommended dosages.

Phytotoxicity reflected on seed yield and oil content in the hybrid Coloris CL and SY Bacardi CLP, which was reflected in the negative correlation coefficients of these parameters.

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