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Selectivity and stability of herbicides, herbicide tank mixtures and herbicide combinations on seed yield of Clearfield oilseed canola (*Brassica napus* L.)

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Abstract. *During the period 2018-2020 a field experiment was carried out with the winter Clearfield oilseed canola hybrid Phoenix CL (Brassica napus L). Factor A included the years of investigation. Factor B included untreated control, 2 combined herbicides: Cleranda SC and Cleravo SC; 6 herbicide tank mixtures: Electron 500 SC + Maza 4 SL, Springbok + Maza 4 SL, Tanaris + Maza 4 SL, Butisan max + Maza 4 SL, Cliofar 600 SL + Maza 4 SL and Galera super + Maza 4 SL; 6 herbicide combinations: Caliph 480 EC + Maza 4 SL, Caliph mega + Maza 4 SL, Bismark CS + Maza 4 SL, Nero EC + Maza 4 SL, Brasan 540 EC + Maza 4 SL and Colsor trio EC + Maza 4 SL. Herbicides Cleranda, Cleravo and Maza were used in addition with adjuvant Dash HC. Foliar-applied herbicides were treated during 2-4 leaf canola stage. Soil-applied combined herbicides were treated during after sowing before emergence period of the canola. It was found that: (i) the highest seed yields are obtained by use of combined herbicide Cleranda, followed by herbicide tank mixture Electron + Maza and combined herbicide Cleravo; (ii) the high canola yields are also obtained by herbicide tank mixtures Butizan max + Maza, Springbok + Maza, Tanaris + Maza, as well as by herbicide combinations Caliph mega + Maza, Brasan + Maza, Bismarck + Maza; (iii) technologically the most valuable are combined herbicide Cleranda, followed by herbicide tank mixture Electron + Maza and combined herbicide Cleravo; (iv) in terms of technology for growing winter Clearfield oilseed canola, herbicide tank mixtures Springbok + Maza, Butisan max + Maza and Tanaris + Maza, as well as herbicide combinations Caliph mega + Maza, Bismar + Maza and, Nero + Maza get high rating; herbicide tank mixtures Cliofar + Maza and Galera super + Maza and herbicide combinations Caliph + Maza and Colsor trio + Maza get low rating*.

Keywords: herbicides, herbicide tank mixtures, herbicide combinations, oilseed canola, selectivity, stability

Introduction

A number of authors in their research establish the efficacy of different herbicides, herbicide tank mixtures and herbicide combinations in weed control in canola crops and their positive impact on the yield of seed (Chaudhry et al., 2011; Werner, 2014; Zotz et al., 2016; Delchev, 2020, 2021). The concomitant use of several active substances greatly increases herbicide efficacy against weeds in winter oilseed canola (Majchrzak et al., 2008; Majchrzak and Jarosz, 2010).

With the conventional technology for oilseed canola growing some of the registered selective herbicides have no satisfactory efficacy against cruciferous weeds like *Sinapis arvensis* L., *Raphanus raphanistrum* L., *Capsella bursa-pastoris* L., *Descurainia sophia* Plantl., *Thlaspi arvense* L. The control of weeds from *Brassicaceae* family in many countries is carried out by the use of GMO canola hybrids which are banned on the territory of the European Union, including Bulgaria (McMullan et al., 1994). An alternative to solving this problem is the Clearfield technology for oilseed canola growing (Pfenning et al., 2012; Delchev, 2018). This technology uses imidazolinone-tolerant canola hybrids (Schönhammer et al., 2010; Ádámszki et al., 2010). Little attention is paid to the stability of herbicides in years different in climatic terms.

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The purpose of the investigation was to establish the selectivity and stability of some herbicides, herbicide tank mixtures and herbicide combinations on seed yield of winter Clearfield oilseed canola under the influence of different meteorological conditions.

Material and methods

The research was conducted during 2018-2020 with the imazamox-tolerant canola hybrid Phoenix CL (*Brassica napus* L). A field experiment was carried out as a block method in 4 repetitions, on a 15 m^2 harvesting area, on pellic vertisol soil type, after durum wheat predecessor. Factor A included the years of investigation. Factor B included untreated control, 2 combined herbicides: Cleranda SC and Cleravo SC; 6 herbicide tank mixtures: Electron 500 SC + Maza 4 SL, Springbok + Maza 4 SL, Tanaris + Maza 4 SL, Butisan max + Maza 4 SL, Cliofar 600 SL + Maza 4 SL and Galera super + Maza 4 SL; 6 herbicide combinations: Caliph 480 EC + Maza 4 SL, Caliph mega + Maza 4 SL, Bismark CS + Maza 4 SL, Nero EC + Maza 4 SL, Brasan 540 EC + Maza 4 SL and Colsor trio EC + Maza 4 SL. The active substances, doses and periods of treatments of the investigated herbicides, herbicide tank mixtures and herbicide combinations are given in Table 1. Foliar-applied herbicides were treated during 2-4 leaf canola stage. Treatment with soil-applied combined herbicides was done after sowing before emergence period of the canola. All variants are applied with working solution consumption 200 l/ha. The mixing of the tank mixtures is done in the sprayer tank. Due to the low adhesion of the herbicides Cleranda, Cleravo and Maza, they were used in addition with adjuvant Dash HC – 1 l/ha.

Table 1. Investigated herbicides, herbicide tank mixtures and herbicide combinations

No	Variants	Active substance	Doses	Treatment period
1	Control – untreated	-	-	-
		Herbicides		
2	Cleranda SC	metazachlor + imazamox	2 l/ha	2-4 leaf
3	Cleravo SC	quinmerac + imazamox	1 l/ha	2-4 leaf
		Herbicide tank mixtures		
4	Electron 500 SC + Maza 4 SL	metazachlor + quinmerac imazamox	2 l/ha 1.25 l/ha	2-4 leaf 2-4 leaf
5	Springbok + Maza 4 SL	metazachlor + dimethenamid-P imazamox	2.5 l/ha 1.25 l/ha	2-4 leaf 2-4 leaf
6	Tanaris + Maza 4 SL	dimethenamid-P + quinmerac imazamox	1.5 l/ha 1.25 l/ha	2-4 leaf 2-4 leaf
7	Butisan max + Maza 4 SL	metazachlor + quinmerac + dimethenamid-P imazamox	2.5 l/ha 1.25 l/ha	2-4 leaf 2-4 leaf
8	Cliofar 600 SL + Maza 4 SL	clopyralid imazamox	250 ml/ha 1.25 l/ha	2-4 leaf 2-4 leaf
9	Galera super + Maza 4 SL	clopyralid + picloram + aminopyralid imazamox	250 ml/ha 1.25 l/ha	2-4 leaf 2-4 leaf
		Herbicide combinations		
10	Caliph 480 EC + Maza 4 SL	clomazone imazamox	200 ml/ha 1.25 l/ha	ASBE 2-4 leaf
11	Caliph mega + Maza 4 SL	clomazone + metazachlor imazamox	3 l/ha 1.25 l/ha	ASBE 2-4 leaf
12	Bismark CS + Maza 4 SL	clomazone + pendimethalin imazamox	1.5 l/ha 1.25 l/ha	ASBE 2-4 leaf
13	Nero EC + Maza 4 SL	clomazone + petoxamide imazamox	3 l/ha 1.25 l/ha	ASBE 2-4 leaf
14	Brasan 540 EC + Maza 4 SL	clomazone + dimethachlor imazamox	2 l/ha 1.25 l/ha	ASBE 2-4 leaf
15	Colsor trio EC + Maza 4 SL	clomazone + dimethachlor + napropamide imazamox	4 l/ha 1.25 l/ha	ASBE 2-4 leaf

*Herbicides Cleranda, Cleravo and Maza were used in addition with adjuvant Dash HC – 1 l/ha;ASBE – after sowing, before emergence.

The selectivity of herbicides, herbicide tank mixtures and herbicide combinations has been established through their influence on seed yield. The math processing of the data was done according to the method of analyses of variance (Shanin 1977; Barov, 1982; Lidanski 1988). The stability of herbicides, herbicide tank mixtures and herbicide combinations for seed yield with relation to years was estimated using the stability variances σ_i^2 and S_i^2 of Shukla (1972), the ecovalence W_i of Wricke (1962) and the stability criterion YS_i of Kang (1993).

Results and discussion

The seed yields obtained by treatment with the respective herbicides, herbicide tank mixtures and herbicide combinations were evaluated (Table 2). The results show that there is a positive correlation between their biological efficacy against weeds and seed yields.

The lowest seed yields are obtained in the untreated control, as a result of the high weed infestation with broadleaved and graminaceous weeds and self-sown plants of *Triticum durum* Desf., *Coriandrum sativum* L. and *Silybum marianum* Gaertn. The highest seed yields are obtained by use of combined herbicide Cleranda - 20.6 % above the untreated control.

Almost the same seed yields are obtained by use of herbicide tank mixture Electron + Maza – 20.2% above the control. Obviously, the combination of three active substances - metazachlor and quinmerac (from herbicide Electron) and imazamox (from herbicide Maza) leads to high herbicide efficiency of the tank mixture, without any manifestations of phytotoxicity on canola plants. These results are confirmed by studies of Schönhammer and

Freitag (2014). The authors tested the herbicides Vantiga D and Cleravis SC, which contain three active substances - metazachlor, quinmerac and imazamox. They also found high herbicidal efficacy and selectivity of the tested combined herbicides. Unfortunately, these herbicides have not yet been registered in Bulgaria.

Table 2. Influence of some herbicides, herbicide tank mixtures and herbicide combinations on seed yield of canola (2018-2020)

Factor B / Factor A	2018		2019		2020		Mean (Factor B)	
	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%
Control – untreated	3933	100	3630	100	3505	100	3689	100
Herbicides								
Cleranda	4727	120.2	4345	119.7	4276	122.0	4449	120.6
Cleravo	4688	119.2	4283	118.0	4245	121.1	4405	119.4
Herbicide tank mixtures								
Electron + Maza	4722	120.1	4320	119.0	4260	121.5	4434	120.2
Springbok + Maza	4672	118.8	4276	117.8	4213	120.2	4387	118.9
Tanaris + Maza	4590	116.7	4207	115.9	4171	119.0	4322	117.2
Butisan max + Maza	4657	118.4	4283	118.0	4206	120.0	4382	118.8
Cliofar + Maza	4330	110.1	3968	109.3	3926	112.0	4075	110.5
Galera super + Maza	4334	110.2	3822	105.3	3961	113.0	4040	109.5
Herbicide combinations								
Caliph + Maza	4370	111.1	4156	114.5	4000	114..2	4175	113.2
Caliph mega + Maza	4641	118.0	4273	117.7	4210	120.1	4375	118.6
Bismark + Maza	4602	117.0	4207	115.9	4171	119.0	4326	117.2
Nero + Maza	4491	114.2	4102	113.0	4080	116.4	4224	114.5
Brasan + Maza	4602	117.0	4214	116.1	4167	118.9	4328	117.3
Colsor trio + Maza	4370	111.1	3866	106.5	4000	114.2	4079	110.6
Mean (Factor A)	4515	-	4130	-	4093	-	-	
LSD, kg/ha:								
Factor A	p≤5%=68	p≤1%=87	p≤0.1%=109					
Factor B	p≤5%=126	p≤1%=166	p≤0.1%=215					
AxB	p≤5%=216	p≤1%=286	p≤0.1%=370					

Very high seed yields are obtained by use of combined herbicide Cleravo - 19.4% above the untreated control. These yields are slightly lower than those of herbicide Cleranda and tank herbicide mixture Electron + Maza, due to the shorter duration of action of Cleravo due to the absence of the active substance metazachlor in this combined herbicide.

Very high canola yields were also obtained by herbicide tank mixtures Springbok + Maza and Butizan max + Maza, 18.9% and 18.8% above the control, respectively. High results from the combination of the active substances metazachlor, dimethenamid-P, quinmerac and imazamox have also been reported by Schönhammer et al. (2018). These authors combine herbicide Butizan combi (metazachlor + dimethenamid-P) with herbicide Clentiga SC (quinmerac + imazamox).

High seed yields are obtained by herbicide combinations Caliph mega + Maza, Brasan + Maza, Bismarck + Maza and by herbicide tank mixture Tanaris + Maza – from 17.2% to 18.6% above the untreated control.

Lower seed yields are obtained by herbicide combinations Nero + Maza, Caliph + Maza, Colsor trio + Maza and by herbicide tank mixtures Cliofar + Maza and Galera super + Maza. In all these variants, seed yields were also higher than in the untreated control. The reason for lower yields of Nero + Maza, Caliph + Maza and Cliofar + Maza is the lower herbicide efficacy of these variants. The reason for lower yields of Colsor trio + Maza and Galera super + Maza is their stronger phytotoxicity to oilseed canola. In herbicide tank mixture Galera super + Maza, the probable cause is the mixing of active substances clopyralid, aminopyralid and picloram, on the one hand, with active substance imazamox, on the other hand. In herbicide combination Colsor trio + Maza, the probable cause is the mixing of active substances clomazone, dimethachlor and napropamide, on the one hand, with active substance imazamox, on the other hand.

Through the applied variance analysis concerning seed yield (Table 3) it was found that the effect of the tested variants is 90.2% of the total data variation, proven at p≤0.1%. Years have the strongest effect on seed yield – 81.2% of that of the variants. The effect of years is very well proven at p≤0.1%. It is accounted for by the unequal response of variants to changes in environmental conditions. The reason for that are the big differences in weather conditions over the three years of the study. The power of influence of herbicides, herbicide tank mixtures and herbicide combinations is 6.9%. Their effect is well proven at p≤1%. There is interaction of herbicides with year conditions (A x B) – 2.1%. It has been proven at p≤5%.

Table 3. Analysis of variance for seed yield

Source of variation	Degrees of freedom	Sum of squares	Influence of factor, %	Mean squares	Fisher's criterion	Level of significance
Total	134	997965	100	-	-	-
Tract of land	2	679988	7.1	33997.6	17.1	***
Variants	44	906944	90.2	20738.7	33.3	***
Factor A - Years	2	852473	81.2	43210.0	27.2	***
Factor B - Variants	14	33737	6.9	2345.6	1.4	**
A x B	28	2781	2.1	98.5	0.2	*
Pooled error	88	15102	2.7	172.3	-	-

*p≤5%; **p≤1%; ***p≤0.1%

Based on the proven interaction year x variant, the stability of the manifestations of each variant has been evaluated in terms of seed yield of winter oilseed canola (Table 4). Stability variances σ_i^2 and S_i^2 have been calculated by Shukla, W_i ecovalence by Wricke and stability criterion YS_i by Kang.

Table 4. Stability parameters for the herbicides, herbicide tank mixtures and herbicide combinations for seed yield with relation to years

Variants	$\bar{x}$	σ_i^2	S_i^2	W_i	YS_i
Control - untreated	3689	207.6*	40.4	1161.8	-5
		Herbicides			
Cleranda	4449	42.5	-1.6	101.7	16+
Cleravo	4405	50.2	7.0	107.4	14+
		Herbicide tank mixture			
Electron + Maza	4434	33.3	-1.8	81.6	15+
Springbok + Maza	4387	34.5	48.1	73.1	13+
Tanaris + Maza	4322	22.5	21.9	58.4	11+
Butisan max + Maza	4382	45.5	58.1	83.1	13+
Cliofar + Maza	4075	44.8	41.5	54.8	8
Galera super + Maza	4040	173.5	733.7*	1147.2	6
		Herbicide combinations			
Caliph + Maza	4175	-6.1	1.6	3,2	9
Caliph mega + Maza	4375	-4.9	1.4	14.8	12+
Bismark + Maza	4326	-2.5	-1.9	18.4	11+
Nero + Maza	4224	-0.6	-1.7	12.3	10+
Brasan + Maza	4328	-1.7	-3.0	21.2	11+
Colsor trio + Maza	4079	183.1	704.9*	1130.8	7
Mean	4246				9.6
LSD (p=0.05)	126				

Stability variances (σ_i^2 and S_i^2) by Shukla accounting for the linear and non-linear interactions, respectively, assess unidirectionally the stability of variances. Those variants that show lower values are assessed as more stable because they interact less with the environmental conditions. The negative values of parameters σ_i^2 and S_i^2 are considered to be 0. In reliably high values of any of the two parameters - σ_i^2 and S_i^2, the variants are considered unstable. In the ecovalence W_i by Wricke, the higher the values of the parameter, the more unstable the respective variant.

On this basis, using the first three stability parameters, it has been established that the most unstable is the untreated control, followed by herbicide tank mixture Galera super + Maza and herbicide combination Colsor trio + Maza. In these three variants the values of the stability variance σ_i^2 and S_i^2 by Shukla and the ecovalence W_i by Wricke are the highest and mathematically proven. In the control, instability is of linear type - proven values of σ_i^2. The reason for this instability is the wide variation in seed yields throughout the years of the experiment. In herbicide tank mixture Galera super + Maza and herbicide combination Colsor trio + Maza instability is of non-linear type - proven values of S_i^2. The reason for this high instability is the high phytotoxicity of these two variants in regard to winter Clearfield oilseed canola. The other variants show high stability during the three years of the study.

In order to fully assess the effectiveness of each variant one should take into consideration both its impact on seed yield of winter oilseed Clearfield canola and its stability - the reaction of the crop to that variant throughout the various years. Very valuable information on the technological value of the variants is provided by the parameter YS_i by Kang for simultaneous assessment of production and stability, based on the reliability of differences in yield and the variance of interaction with the environment. The overall criterion for stability YS_i by Kang, taking into account both the stability and value of yield gives a negative assessment solely of the untreated control, characterizing it as the most unstable and low yielding.

According to that criterion technologically the most valuable are combined herbicide Cleranda, followed by herbicide tank mixture Electron + Maza and combined herbicide Cleravo. These combinations combine high seed yields and high stability of that parameter over the various years.

In terms of technology for growing winter Clearfield oilseed canola, herbicide tank mixtures Springbok + Maza, Butisan max + Maza and Tanaris + Maza, as well as herbicide combinations Caliph mega + Maza, Bismar + Maza and, Nero + Maza get high rating. In these tank mixtures and combinations relatively good seed yields are combined with high stability throughout the years of the study.

Herbicide tank mixtures Cliofar + Maza and Galera super + Maza and herbicide combinations Caliph + Maza and Colsor trio + Maza get low rating. Cliofar + Maza and Caliph + Maza receive a low rating due to their lower herbicide efficacy. Galera super + Maza and Colzor trio + Maza receive a low rating due to their higher phytotoxicity in regard to winter Clearfield oilseed canola.

Conclusion

The highest seed yields form the imazamox-tolerant canola hybrid Phoenix CL (*Brassica napus* L) are obtained by use of combined herbicide Cleranda, followed by herbicide tank mixture Electron + Maza and combined herbicide Cleravo. High canola yields are also obtained by herbicide tank mixtures Butizan max + Maza, Springbok + Maza, Tanaris + Maza, as well as by herbicide combinations Caliph mega + Maza, Brasan + Maza, Bismarck + Maza. Technologically the most valuable are combined herbicide Cleranda, followed by herbicide tank mixture Electron + Maza and combined herbicide Cleravo. In terms of technology for growing winter Clearfield oilseed canola, herbicide tank mixtures Springbok + Maza, Butisan max + Maza and Tanaris + Maza, as well as herbicide combinations Caliph mega + Maza, Bismar + Maza and, Nero + Maza get high rating. Herbicide tank mixtures Cliofar + Maza and Galera super + Maza and herbicide combinations Caliph + Maza and Colsor trio + Maza get low rating.

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