

The assessment of grain quality of maize cultivars depending on the way and term of herbicides application

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Abstract. Accessibility of stably-yielding maize cultivars with different degrees of earliness, as classified in the FAO system, has created the possibility of maize production across the whole area of Poland. An extensive area under maize cultivation is possible due to a favourable economic situation and wide utilization of grain both in the production of fodder mixtures and by many branches of industry. Among cereals, maize is characterized by the highest energy value and high digestibility of nutrients resulting from high content of starch and fat, as well as low content of protein and crude fibre. These properties are influenced by environmental conditions, accessibility of water and nitrogen and also by plant protection chemicals, including herbicides. The herbicides applied are not always selective for particular cultivars and, therefore, they can negatively affect the course of plant growth and development (inhibition of seedling sprouting, discoloration and deformations of leaves, or retardation of plant growth), as well as disturb assimilate production in the course of photosynthesis which led to reduction in yield and to deterioration of yield components and crop quality.

The study demonstrated that from among investigated cultivars Lg 3225 and Anjou 249 gave the highest yields. However, from among the herbicides used only Mustang 306 SE applied in BBCH 16 had significantly lowered grain yields.

Although no phytotoxicity effect was recorded, application of Maister in divided doses brought about a significantly lower content of starch and fat in the cultivar Salgado.

In the cultivars Lg 3225 and Anjou 249 treated with the herbicide Mustang 306 SE phytotoxicity symptoms of injuries and decrease of grain and dry matter yield, and reduction in the thousand grain weight were observed.

The cultivar Anjou 249 treated with the herbicide Mustang 306 SE in the 5th leaf stage, contained significantly decreased amounts of protein, fat, starch and fibre in comparison to the non-treated control, due to a strong phytotoxic effect.

Tolerant cultivars, like: Ronaldinio, Hexxer, PR 39T45 did not show any morphological and qualitative changes, regardless

of the application date and the manner in which the herbicide was applied.

key words: herbicides, phytotoxicity, cultivar of maize, qualitative parameters

INTRODUCTION

Among cereals, maize is characterized by the highest energy value and high digestibility of nutrients as it contains considerable amounts of starch and fat (Normy..., 1993; Normy..., 2005). Maize grain is not known for providing protein, as it features disadvantageous balance of exogenic amino-acids composition, yet it constitutes an important nutrient in total fodder balance because of its high yielding potential (Podkówka, Podkówka, 2002). Qualitative properties, depending on such parameters as genotype (Rothkaehl, 2000), type of grain – glassy or floury form, as well as grain structure – well developed endosperm, easy separation of seed embryo and the kind of starch (amylopectin, amylose), make maize grain a marketable commodity. These properties can be modified by climate, soil and cultivation technology factors as well as by the use of plant protection preparations, including herbicides (Gołębiowska, Rola, 2008). A long-term study undertaken in the 1990s by the scientists of the Ecology and Weed Control Department in Wrocław on the response of maize cultivars to herbicides proved that reduced selectivity of herbicides often results from interaction between genotype properties of a particular cultivar, weather and environmental conditions, as well as the mode of herbicide activity (Rola, Gołębiowska, 2003; Praczyk, 2002). Thus herbicides introduced in the course of the plant growing period can disturb a number of plant vital activities which results in morphological changes (e.g. necrosis, coloration, growth retardation), or irregular course of photosynthesis, blocking of amino-acids synthesis (Rola, Gołębiowska, 2003). However, it has not been known so far if and to

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what extent herbicides affect grain technology value and the content of nutrients. Therefore, there does exist the necessity of doing complex qualitative examination, especially justified in the case of new cultivars and new-generation preparations being introduced into practice.

The aim of this study was the assessment of the effect of Maister OD and Mustang 306 SE herbicides on the qualitative properties of grain of six maize cultivars as affected by the date and manner of herbicide application.

MATERIAL AND METHODS

The study was conducted in the years 2005–2007. Field experiments were done in private farms in the region of Wrocław. Full description of environmental conditions prevailing during the experiments with maize cultivars was shown in Table 1.

Field experiments were established according to split-plot balanced blocks design in three replications, at sites

Table 1. Characteristics of environmental conditions.

Preceding crop	Winter wheat
Type of soil	Black earth formed from medium loam belonging to very good and good wheat complex
FAO classification	Haplic Phaeozems
Class	I–II, IIIa
pH	6.3–6.8
Organic matter content	3.3–3.6%
Fertilisation [kg ha ⁻¹]	
N	157–173
P ₂ O ₅	63–71
K ₂ O	65–85
Type of cultivation	Based on ploughing

free from weeds, with a herbicide as a primary factor and a cultivar as a secondary one. The whole field was provided with full range fertilization to meet current requirements of the plant cultivated. The experiments involved herbicides of different mode of activity and causing characteristic injury symptoms described in Table 2.

Maize was seeded in conformance with cultivation technology recommendations for the region of Lower Silesia. Herbicides were applied across the seeded maize plots using Unimog sprayer with a boom span of 6 m carried on a Mercedes chassis. In the experiment hybrids of single-cross type, featuring similar FAO earliness and utilization-related traits: Ronaldinio, Hexxer, PR 39T45, Lg 3225, Anjou 249, Salgado, were used. Their description was shown in Table 3. The assessment of the phytotoxic effect of the herbicide preparations on selected maize cultivars was done 1, 2 and 3 weeks after herbicide application, according to scale 1:9. The methods used were in accordance with EPPO Standards – PP 1/135, PP 1/152, PP1/181, PP 1/214 oraz 1/50(2) (EPPO 1995).

Grain yield and thousand grain weight (TGW) values were measured at 15% moisture content. Yield components were also subjected to evaluation. Grain of the examined maize cultivars, collected from control treatment, as well as that originating from herbicide-treated plots were analyzed for the following parameters: thousand grain weight, dry matter at 105°C – according to gravimetric method, contents of protein, starch, fat and fibre – using INSTALAB 600 device making use of near infra-red technique LSD.

The data were subjected to analysis of variance for randomized blocks design. Significance of differences was tested using Tukey's confidence semi-interval and the smallest significant difference was estimated for confidence level of 0.05.

Calculations were done using AWAR 2.0 computer software.

Table 2. Mode of action of active substances of herbicides used in the experiments and symptoms of phytotoxicity injuries in maize cultivars.

Mode of action	Herbicides	Active substance	Term of application BBCH	Symptoms of injuries
Inhibitors of amino-acid synthesis	Mustang 306 SE	florasulam + 2,4-D triazolopyrimidiny +growth regulator	<i>Postemergence</i> BBCH 12 BBCH 16	Sp spotting GR growth retardation Df deformation of leaves and young plants Ld lodging
	Maister OD	foramsulfuron + jodosulfuron methyl sodium + izoksadifen ethyl + adjuvant	<i>Postemergence</i> BBCH 12 + BBCH 16	Ch leaves chlorosis Sp spotting Gr growth retardation

BBCH 12 – 2–3-leaf stage of maize development

BBCH 16 – 5–6-leaf stage of maize development

Table 3. Characteristics of maize hybrids in field experiments.

Maize hybrids/cultivar	Type of hybrid	Year of hybrid registration	Utilization trend [#]			Breeder	Earliness of maize hybrids FAO
			G	CCM	S		
Ronaldinio		2003	X	X	-	KWS	FAO 260
PR 39T45		2004	X	X	X	PIONEER	FAO 240
Hexxer	SC	2002	X	X	-	RAGT	FAO 240
Lg 3225	Single hybrid	2002	X	X	-	LIMAGRAIN	FAO 230
Anjou 249		2002	X	X	-	MAIS ANGEVIN	FAO 250
Salgado		2003	X	X	X	KWS	FAO 240

[#]G – grain, CCM – corn-cob mix, S – maize silage

RESULTS AND DISCUSSION

Phytotoxic effect of herbicides on maize hybrids

Mode of action of the herbicide Maister OD active ingredient consists in inhibition of the synthesis of enzymes which are necessary for forming amino-acids in plant cells. Among maize hybrids treated with this herbicide only Salgado responded by showing symptoms of phytotoxicity typical for these compounds – coloration of leaves and growth retardation (Table 4), as well as growth retardation, which occurred to be temporary and disappeared three weeks later. The symptoms of those injuries were observed in each plant growing season, yet with different intensity, depending on weather conditions.

A similar mode of action is shown by florasulam, one of the active ingredients in the herbicide Mustang 306 SE, while another component, 2,4-D in some hybrids can cause leaf curling which makes tasseling difficult, delays dusting and retards plant growth (Table 4). As a result tiny grains of decreased TGW can occur in hybrids that show low tolerance of these substances. In our study characteristic symptoms of injuries were recorded in Lg 3225 and Anjou 249. Mustang 306 SE applied in early stages of plant development, showed a mild effect and caused temporary, 3-week-lasting injuries in those cultivars. The same preparation, however, when applied in older plants resulted in considerable retardation of plant growth, leaf deformation and lodging. Unfavorable weather conditions in the plant growing season of 2005 intensified the occurrence of the symptoms.

The effect on grain yield, thousand seed weight and dry matter

From among the investigated cultivars the lowest yields were recorded in Lg 3225 and Anjou 249. However, out of the herbicides tested only Mustang 306 SE applied in BBCH 16 had a significant negative effect on yields. All cultivars responded with an increase in dry matter after application of herbicides (Table 5).

No significant differences were observed in growth and development of the five cultivars resulting from introduction of Maister OD herbicide, nor were any marked differences recorded for maize yields, dry matter and thousand grain weight since the values of those parameters resembled those of the control (non-sprayed treatment).

Phytotoxic activity of the herbicide Mustang 306 SE on Lg 3225 and Anjou 249 (BBCH 16) had a significant negative impact on grain yield when compared to the yields in the control treatment. Differences in the yields between those cultivars and the control treatment were statistically proved. Lg 3225 and Anjou 249 treated with that herbicide also responded by considerably diminishing grain dry matter whereas in Lg 3225 only the thousand seed weight was affected (Tables 6 and 7).

The effect of herbicides on the contents of protein, fat, starch and fibre

Among the investigated cultivars Hexxer was noted for the lowest crude protein content, PR 39T45 was lowest in crude fat and Anjou 249 had the lowest starch content (Tables 8, 9, and 10). Crude fibre was the lowest in Ronaldinio and PR 39T45. From among the herbicides used none had a negative effect on the value of those qualitative parameters.

With regard to the qualitative properties of the grain of the cultivars treated with the herbicide Maister OD in BBCH 12 + BBCH 16 (split-split doses), significantly decreased content of starch was found only in Salgado and of fat – in Anjou 249. The remaining cultivars did not show any reduction in the values of the examined parameters when treated with this herbicide.

Low selectivity of the herbicide Mustang 306 SE towards the cultivar Anjou 249 had a negative impact on the qualitative properties of the grain: protein, starch and fibre content as compared to the control treatment (Table 11). The preparation tested was safe in relation to the remaining cultivars and differences in the content of protein, starch, fat and fibre were not statistically proved.

Among cereals, maize features the highest energy value and high digestibility of nutrients, as a result of its high

Table 4. Phytotoxic effect of herbicides on growth and development of maize hybrids – symptoms of injuries.

Maize hybrids/cultivar	Term of application BBCH ^s	F – phytotoxicity – plants sensitivity to herbicides in 1:9 scale [#]					
		Ronaldinio	Hexxer	PR 39T45	Anjou 249	Salgado	Lg 3225
Untreated object	-	1 no injuries	1 no injuries	1 no injuries	1 no injuries	1 no injuries	1 no injuries
Mustang 306 SE 0,6 l ha ⁻¹	BBCH 12	1 no injuries	1 no injuries	1 no injuries	3 Gr, Df	1 no injuries	4 Gr, Df, Sp
Mustang 306 SE 0,6 l ha ⁻¹	BBCH 16	1 no injuries	1 no injuries	2 Gr, Df	5 Gr, Df	1 no injuries	5-6 Gr, Df, Ld, Sp
Maister OD + Maister OD 0,5 + 0,5 l ha ⁻¹	BBCH 12 + BBCH 16	1 no injuries	1 no injuries	1 no injuries	1 no injuries	2 Gr, Sp	1 no injuries

1 – no reaction, 9 – crop damage

Df – deformation of leaves and young plants; Sp – spotting; Gr – growth retardation; Ld – lodging

Table 5. Effect of herbicides on grain yield of maize hybrids [t ha⁻¹].

Treatment	Term of application BBCH ^s	Maize hybrids/cultivar						Mean values for herbicides
		Ronaldinio	Hexxer	PR 39T45	Anjou 249	Salgado	Lg 3225	
Control Untreated object	-	12.16	11.74	11.9	10.27	10.24	11.08	11.23
Mustang 306 SE 0.6 l ha ⁻¹	BBCH 12	12.56	12.12	11.89	10.69	11.68	10.00	11.49
Mustang 306 SE 0.6 l ha ⁻¹	BBCH 16	12.74	11.89	11.72	9.09	11.74	8.63	10.97
Maister OD + Maister OD 0.5 + 0.5 l ha ⁻¹	BBCH 12 + BBCH 16	12.43	12.26	11.86	11.2	11.4	10.92	11.68
Mean values for cultivars		12.47	12.00	11.84	10.31	11.27	10.16	11.34
LSD (0.05) for:								
cultivars		1.22						
herbicides								1.05
interaction cultivars × herbicides					0.986			

^s see Table 2

Table 6. Effect of herbicides on dry matter of maize hybrids grain [%].

Treatment	Term of application BBCH ^s	Maize hybrids/cultivar						Mean values for herbicides
		Ronaldinio	Hexxer	PR 39T45	Anjou 249	Salgado	Lg 3225	
Control Untreated object	-	80.95	77.17	76.31	79.92	79.21	79.21	78.13
Mustang 306 SE 0.6 l ha ⁻¹	BBCH 12	82.55	82.44	80.12	82.56	79.59	79.11	81.06
Mustang 306 SE 0.6 l ha ⁻¹	BBCH 16	83.51	82.24	80.13	63.92	76.17	61.22	74.53
Maister OD + Maister OD 0.5 + 0.5 l ha ⁻¹	BBCH 12 + BBCH 16	80.6	80.2	80.26	82.06	81.74	81.74	81.10
Mean values for cultivars		80.90	80.51	79.21	77.12	79.18	75.32	
LSD (0.05) for:								
cultivars		3.75						
herbicides								78.71
interaction cultivars × herbicides					4.22			

^s see Table 2

Table 7. Effect of herbicides on weight of thousand grains (TGW) of maize hybrids [g].

Treatment	Term of application BBCH ^s	Maize hybrids/cultivar						Mean values for herbicides
		Ronaldinio	Hexxer	PR 39T45	Anjou 249	Salgado	Lg 3225	
Control Untreated object	-	362.7	380.6	389.6	331.7	418.2	354.4	372.87
Mustang 306 SE 0.6 l ha ⁻¹	BBCH 12	365	390.3	399.6	332.1	401.2	335.6	370.63
Mustang 306 SE 0.6 l ha ⁻¹	BBCH 16	367.6	384.8	407.2	326.2	406.8	315.6	368.03
Maister OD + Maister OD 0.5 + 0.5 l ha ⁻¹	BBCH 12 + BBCH 16	374.5	383.3	403.9	331.1	407.9	345.6	374.38
Mean values for cultivars		367.45	384.75	400.08	330.28	408.53	337.80	371.48
LSD (0.05) for:								
cultivars		28.56						
herbicides								15.67
interaction cultivars × herbicides					17.367			

^s see Table 2

Table 8. Effect of herbicides on crude protein content [%] in grain.

Treatment	Term of application BBCH ^s	Maize hybrids/cultivar						Mean values for herbicides
		Ronaldinio	Hexxer	PR 39T45	Anjou 249	Salgado	Lg 3225	
Control Untreated object	-	8.6	8.6	9.9	9.7	9.3	8.2	9.05
Mustang 306 SE 0.6 l ha ⁻¹	BBCH 12	8.6	8.5	9.6	9.6	9.5	9.4	9.20
Mustang 306 SE 0.6 l ha ⁻¹	BBCH 16	8.6	8.5	9.8	8.1	9.6	8.7	9.22
Maister OD + Maister OD 0.5 + 0.5 l ha ⁻¹	BBCH 12 + BBCH 16	8.7	8.7	9.5	9.7	9.2	8.1	8.98
Mean values for cultivars		8.63	8.58	9.70	9.27	9.40	8.60	9.11
LSD (0.05) for:								
cultivars		1.32						
herbicides								0.894
interaction cultivars × herbicides					0.977			

^s see Table 2

Table 9. Effect of herbicides on crude fat content [%] in grain.

Treatment	Term of application BBCH ^s	Maize hybrids/cultivar						Mean values for herbicides
		Ronaldinio	Hexxer	PR 39T45	Anjou 249	Salgado	Lg 3225	
Control Untreated object	-	3.4	4.0	2.6	4.1	4.5	3.2	3.80
Mustang 306 SE 0.6 l ha ⁻¹	BBCH 12	3.3	3.8	2.9	4.5	4.8	3.3	3.62
Mustang 306 SE 0.6 l ha ⁻¹	BBCH 16	3.2	3.6	3.3	4.2	4.0	3.3	3.60
Maister OD + Maister OD 0.5 + 0.5 l ha ⁻¹	BBCH 12 + BBCH 16	3.6	3.8	3.5	3.0	3.9	3.5	3.87
Mean values for cultivars		3.38	3.80	3.08	4.20	4.30	3.58	3.72
LSD (0.05) for:								
cultivars		0.958						
herbicides								0.659
interaction cultivars × herbicides		0.672						

^s see Table 2

Table 10. Effect of herbicides on starch content [%] in grain.

Treatment	Term of application BBCH ^s	Maize hybrids/cultivar						Mean values for herbicides
		Ronaldinio	Hexxer	PR 39T45	Anjou 249	Salgado	Lg 3225	
Control Untreatment object	-	73.4	72.1	71.9	69.6	71.6	70.7	71.55
Mustang 306 SE 0.6 l ha ⁻¹	BBCH 12	73.1	71.2	71.5	70.2	72.2	70.25	71.41
Mustang 306 SE 0.6 l ha ⁻¹	BBCH 16	73.4	71.9	71.1	62.1	71.2	70.9	71.12
Maister OD + Maister OD 0.5 + 0.5 l ha ⁻¹	BBCH 12 + BBCH 16	72.2	71.2	71.3	68.2	69.2	70.6	71.77
Mean values for cultivars		73.03	71.60	71.45	70.03	71.05	70.61	71.46
LSD (0.05) for:								
cultivars		1.069						
herbicides								5.69
interaction cultivars × herbicides		1.47						

^s see Table 2

Table 11. Effect of herbicides on crude fibre content [%] in grain.

Treatment	Term of application BBCH ^s	Maize hybrids/cultivar						Mean values for herbicides
		Ronaldinio	Hexxer	PR 39T45	Anjou 249	Salgado	Lg 3225	
Control Untreated object	-	2.30	3.20	2.10	2.90	3.50	3.20	2.87
Mustang 306 SE 0.6 l ha ⁻¹	BBCH 12	2.40	2.90	2.10	2.90	3.40	3.00	2.63
Mustang 306 SE 0.6 l ha ⁻¹	BBCH 16	2.20	3.20	2.40	2.50	3.20	3.10	2.75
Maister OD + Maister OD 0.5 + 0.5 l ha ⁻¹	BBCH 12 + BBCH 16	2.30	3.60	2.60	3.30	3.20	3.20	2.87
Mean values for cultivars		2.30	3.23	2.30	2.63	3.32	3.12	2.78
LSD (0.05) for:								
cultivars		1.01						
herbicides								0.196
interaction cultivars × herbicides		1.0539						

^s see Table 2

content of starch and fat, and low content of crude protein and crude fibre. The most important source of energy in maize grain is starch whose contribution reaches 70%. The most concentrated source of energy is fat and it is in maize that it occurs in the highest quantity. Maize fat is characterized by high content of essential unsaturated acids and linolic acid.

Maize protein, since it is deficient in exogenic amino-acids, has low biological value. Amino-acids composition of maize protein is not balanced due to lysine and tryptophan deficit. Total protein content in maize grain, as well as its amino-acids composition, are not constant values and they can be affected by variable climate con-

ditions in the course of plant growing period, cultivation technique, fertilization, as well as application of pesticides and genetic factors, which was stressed by Panamarioviene and Tamulis (1997) in their studies. So far neither the herbicides of the 2,4-D and MCPA group nor those of the triazine group have been shown to have a negative impact on photochemical activity of chloroplasts, as well as on breathing processes in some maize cultivars (Hwang et al., 1996). Similarly, the mode of action of the sulfonyl-urea herbicides, with their typical blocking of synthesis of amino-acids chain, can disturb regular plant development in sensitive cultivars, which was demonstrated in this study.

CONCLUSIONS

1. From among investigated maize cultivars the lowest yields were recorded in Lg 3225 and Anjou 249, however from among used herbicides only Mustang 306 SE significantly depressed yields of cultivars applied in BBCH 16.
2. All investigated cultivars responded with an increase of dry mass after application of herbicides.
3. In spite of the lack of phytotoxic effect of the herbicide Maister OD, the cultivar Salgado showed a significantly lower content of starch and fat.
4. In the cultivars Lg 3225 and Anjou 249 treated with the herbicide Mustang 306 SE phytotoxicity symptoms of injuries and decrease of grain yield and dry matter were observed. In the cultivar Lg 3225 a significant decrease of the weight of thousand grains was observed.
5. Low selectivity of Mustang 306 SE herbicide towards the cultivar Anjou 249 significantly lowered values of grain qualitative properties – protein, fat, starch and fibre content as compared to the control treatment.
6. Tolerant cultivars Ronaldinio, Hexxer, PR 39T45 did not show any morphological and qualitative changes, regardless of the herbicide applied.

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