

POWDERY MILDEW (*BLUMERIA GRAMINS*) AND PEST OCCURRENCE REDUCTION IN SPRING CEREAL MIXTURES

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Abstract: In the three-year experiment (2006–2008) the impact of three different spring cereals (wheat, barley, oat) and their two- and three-component mixtures were tested. The studies were carried out at two sites. The impact of mixtures on disease reduction, pests occurrence and yield height compared with pure stands were evaluated. Observations on powdery mildew occurrence during the vegetation season were done every 7–10 days. In order to compare the disease occurrence levels on different cultivars in pure stands and on their mixtures the Area Under Disease Progress Curve (AUDPC) was evaluated. Based on the AUDPC values, the reduction of powdery mildew occurring in the mixtures due to epidemiological and ecological factors functioning in mixed stands were also evaluated.

The occurrence of these pests: *Aphidodea*, *Oulema* spp., *Agromyzidae*, in spring cereals was evaluated twice in the vegetation season.

Based on the obtained results, it can be stated that winter barley cultivar mixtures do reduce the powdery mildew incidence and pest occurrence compared to pure stands. Also from the results, it can be stated that winter barley cultivar mixtures can constitute an alternative way of growing winter barley, especially in low-input and ecological agriculture.

The aim of the studies was to evaluate the yield through growing spring cereal mixtures. Positive effects (up to 8 dt/ha yield increase in mixtures compared to pure stands) were observed.

On the base of obtained results it can be stated that spring cereal mixtures can constitute an alternative way of growing, especially in low-input and ecological agriculture.

Key words: spring cereal mixtures, powdery mildew, pests in cereals, disease/pest reductions

INTRODUCTION

In today's industrial agriculture a popular cultivation method is growing monocultures of species or cultivars, which are characterized by the fact that plants with identical or very similar genetic types of resistance to diseases are cultivated on vast growing areas. A high genetic homogeneity of cultivars and species of plants is a reason for the fast spreading of pathogens attacking the plants. (Wolfe and Barrett 1979; Czembor 1981; Łacicowa 1984). This means that more and more serious cereal disease epidemics and an instability of the cultivars resistance to diseases, leads to them being removed from production pre-maturely (Czembor and Gacek 1987).

Modern plant protection methods have to be compliant with the ideas of sustainable agriculture, whose premise is plant protection that is economically profitable, environmentally-friendly and accepted in the community. In light of that, contemporary systems of cultivated plant protection should incorporate any available method of pest control, while at the same time taking into account natural self-regulation processes in agro-ecosystems, as well as aiding those processes. Practical application of integrated plant protection involves, as much as possible,

any pest control method alternative to chemical control (Gacek 2000). Such integrated plant protection in this respect should involve: introducing cultivars resistant to diseases and pests, proper agricultural science and crop rotation, managing the chemical treatments, i.e. subjecting plants to treatments at optimum times, but also taking into account sowing of mixtures. Those include both inter-species mixtures, as well as inter-cultivar mixtures within the same species. In recent years about 17% of general growing area has been sown with mixtures (cereal and cereal-leguminous).

What contributes to the losses stemming from the decrease in quantity and quality of spring cereal yields, apart from unfavorable weather and soil conditions, is first and foremost an intensification in the occurrence of fungal diseases and pests.

One of the most harmful and most commonly observed pathogenic fungi is *Blumeria graminis*, which produces the same symptoms as powdery mildew (Borecki 2001; Fiedorow *et al.* 2004 a, 2004 b). Powdery mildew is observed throughout the entire country, but it causes the biggest losses in the south-east and south-west regions of Poland. Its occurrence depends on the type of grown cul-

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tivars, the growing area, the frequency of corresponding virulence in the pathogen populations, and the environmental conditions (Czembor and Gacek 1987). The pests observed on spring cereals include aphids (Aphidodea), leaf beetles (*Oulema* spp.) and leaf-mining flies (Agromyzidae).

The aim of the three-year-long research, conducted at two sites, was to analyze the occurrence of fungal diseases and the most important spring cereal pests in pure stands and mixtures.

MATERIALS AND METHODS

Throughout three growing seasons (2006, 2007 and 2008) experiments were conducted on three spring cereals, i.e. wheat of the Zadra cultivar (SW), barley of the Orthega cultivar (SB) and oats of the Polar cultivar (O), including any possible combinations (mixtures) between them (SW+SB, SW+O, SB+O, SW+SB+O). The experiments were conducted at two sites, which differed in terms of soil and weather conditions, i.e. in the years 2006 and 2007 at Hodowla Roślin Smolice – Grupa IHAR Bąków Division (Opole province) and at the Plant Protection Institute – National Research Institute, Research Station Winna Góra (Wielkopolska province) while in the year 2008 at the Hodowla Roślin Smolice – Grupa IHAR Bąków Division and the Research Station for Variety Testing Kościelna Wieś (Wielkopolska province). The experiments did not incorporate any chemical treatments against fungal diseases or pests.

The ratio of components was 1 : 1 for the 2-component mixtures or 1 : 1 : 1 for the 3-component mixtures. The experiments were conducted on 10 m² (Bąków) and 15 m² (Winna Góra and Kościelna Wieś) experimental plots, in four repetition cycles, using the split-plot structure.

An assessment of the intensification of occurrence of diseases and pests was conducted during the growing seasons, every 7–10 days on 30 stalks. In the case of powdery mildew, a 9-grade scale of plant susceptibility was used, where 1 signified full susceptibility, and 9 meant full resistance (no symptoms of the disease). The results obtained were transformed into percentage values of damage to the stalks by the disease of the cereal species and its mixtures, and then the AUDPC value was calculated using the following formula:

$$\text{AUDPC} = [x_1 \cdot y_0 + x_1 \cdot ((y_1 - y_0) / 2)] + [x_2 \cdot y_1 + x_2 \cdot ((y_2 - y_1) / 2)] + \dots + [x_n \cdot y_{n-1} + x_n \cdot ((y_n - y_{n-1}) / 2)]$$

where:

AUDPC – area under disease progress curve

X_i – number of days between observations

Y_n – the surface damaged by the powdery mildew during consecutive assessments.

The reduction percentage of the powdery mildew occurrence in the mixtures (RAUDPC) was calculated by comparing the average damage to the mixture, with the average damage to the mixture components in a pure stand.

The date of the assessment of the pests abundance fell on the same time of their development when a chemical

treatment would be recommended, and if their abundance would have reached a threshold of economic harmfulness, the treatment would have been justifiable. In each repetition, the number of aphids, leaf beetles and leaf-mining flies was recorded for 30 analyzed stalks or ears. In the case of pests that were more abundant, a percentage of abundance reduction was calculated with relation to pure stands.

The quantity of yield from each experimental plot was also assessed. After harvesting the crops from each plot with a plot combine harvester, the yield was weighed and calculated into dt/ha. The results were statistically evaluated.

RESULTS AND DISCUSSION

In terms of cereal diseases, in the inter-species cereal mixtures experiment during the years the research was conducted, the only disease that caused significant damage to the stalks was powdery mildew (*Blumeria graminis*). The incidence of other diseases recorded was insignificant.

In the first and second year of the experiments (2006 and 2007 seasons), the incidence of the disease (the AUDPC value) was considerably higher in Bąków than in Winna Góra (Table 1). In the 2008 growing season, meteorological and soil conditions of the Kościelna Wieś were more favorable to the development of powdery mildew than in Bąków. In all three years of research, among the pure stands, spring barley mainly was the species most affected by powdery mildew. Comparing the results obtained from Bąków in the 2006 and 2007 growing seasons to the third year of research, the occurrence of powdery mildew was lower (lower AUDPC), not only on spring barley. Such unfavorable conditions for the development of the pathogen (long-lasting drought from mid-April to June) were favorable for the development of aphids and resulted in an intensification. There were even up to 100 specimens per stalk. In the 2006 and 2007 growing seasons at both experiment sites a reduction of the disease occurrence was noted in the mixtures, as compared to pure stands. In the 2006 season the value was from 34.9 to 66.5% and in the 2007 season from 29.1 to 66.4%, with more significant reductions observed in Bąków. In the 2008 growing season, with the exception of one combination (SW+SB mixture in Bąków), there was a reduction in the disease occurrence. The reduction was between 13.5 to 66% compared to pure stands, with a more significant reduction observed in Kościelna Wieś. The biggest reduction in powdery mildew occurrence (of all years and sites) was noted in the 3-component mixture (the most varied genetically) – 48.9% (Table 1).

Similar results were obtained by other researchers (Gacek *et al.* 1996, 2000), who studied the reduction in damage done by powdery mildew in inter-species mixtures of spring cereals and the reduction was even up to 75% compared to pure stands.

Low temperatures prevailing for an extended period of time in the spring of 2006 contributed to the fact that the pests appeared on spring cereal crops later than usual. Their abundance did not exceed the economic harmful-

Table 1. Powdery mildew occurrence in spring cereal pure stands and mixtures

Place/ AUDPC/RAUDPC	Combinations						
	wheat [SW]	barley [SB]	oat [O]	[SW+SB]	[SW+O]	[SB+O]	[SW+SB+O]
2006 growing season							
Bąków – AUDPC	211.9 bc	261.6 c	137.9 ab	127.6 a	82.8 a	107.7 a	87.6 a
Bąków – RAUDPC				45.6	52.8	44.5	55.3
Winna Góra – AUDPC	75.2 a	125.1 b	40.2 a	58.5 a	38.2 a	38.8 a	26.9 a
Winna Góra – RAUDPC				40.5	34.9	53.5	66.5
2007 growing season							
Bąków – AUDPC	274.0 a	312.6 a	228.7 a	142.0 a	117.3 a	84.0 a	115.9 a
Bąków – RAUDPC				48.8	50.6	66.4	57.9
Winna Góra – AUDPC	117.2 b	131.5 b	64.3 b	62.8 b	47.4 a	62.8 b	59.6 ab
Winna Góra – RAUDPC				43.1	45.3	29.1	34.4
2008 growing season							
Bąków – AUDPC	85.4 a	205.4 c	65.3 a	158.4 bc	53.9 a	111.7 ab	101.4 a
Bąków – RAUDPC				–*	27.8	17.1	13.5
Kościelna Wieś – AUDPC	178.1 a	347.0 b	127.7 a	105.4 a	91.9 a	83.2 a	71.0 a
Kościelna Wieś – RAUDPC	–	–	–	60.6	32.1	62.2	66.0
Average reduction percentage in mixtures				39.8	40.6	45.4	48.9

*no reduction; different letters indicate statistical differences between combinations

Table 2. Powdery mildew occurrence in spring cereal pure stands and mixtures – statistical synthesis for years

Place/ AUDPC/RAUDPC	Combinations						
	wheat [SW]	barley [SB]	oat [O]	[SW+SB]	[SW+O]	[SB+O]	[SW+SB+O]
Bąków – AUDPC (3 years)	190.43 b	259.89 b	143.96 b	142.66 ab	84.67 a	101.11 a	101.65 a
Winna Góra – AUDPC (2 years)	96.22 bc	128.34 c	52.29 a	60.67 ab	42.82 a	50.82 a	43.26 a

Table 3. Cereal leaf beetle (*Oulema* spp.) occurrence/reduction at spring cereal pure stands and mixtures

Pure stands/mixtures	Cereal leaf beetle (<i>Oulema</i> spp.)			
	Winna Góra (2006–2007)/Kościelna Wieś (2008)		Bąków	
	number of larvae	reduction [%]	number of larvae	reduction [%]
2006 growing season				
Wheat (SW)	2.7		1.5	
Barley (SB)	2.0		0.5	
Oat (O)	5.0		1.5	
SW+SB	1.5	36.7	1.5	6.7
SW+O	3.0	11.2	2.0	*
SB+O	3.0	*	1.0	*
SW+SB+O	2.6	17.3	0.8	39.1
2007 growing season				
Wheat (SW)	6.5 b		4.7	
Barley (SB)	8.7 b		6.7	
Oat (O)	5.0 ab		6.2	
SW+SB	6.7 b	6.1	5.0	*
SW+O	7.0 b	*	4.0	27.6
BS+O	4.5 a	39.7	5.0	23.1
SW+SB+O	5.7 b	9.3	5.2	12.4
2008 growing season				
Wheat (SW)	13.7		4.5	
Barley (SB)	20.0		6.5	
Oat (O)	20.5		6.7	
SW+SB	11.7	20.8	5.5	*
SW+O	14.0	19.7	5.7	*
BS+O	17.0	12.7	5.2	17.4
SW+SB+O	11.7	32.4	4.7	14.8

*no reduction; different letters indicate statistical differences between combinations

Table 4. Aphid (Aphidodea) occurrence/reduction in spring cereal pure stands and mixtures

Pure stands/mixtures	Aphids (Aphidodea)					
	Winna Góra (2006–2007)/Kościelna Wieś (2008)		Bąków (2006–2008)			
	number of aphids	reduction [%]	number of aphids	reduction [%]		
2006 growing season						
Wheat (SW)	very low abundance of aphids recorded – single specimens	no basis for calculating reduction	25.7	*		
Barley (SB)			18.2			
Oat (O)			24.7			
SW+SB			29.7			
SW+O			17.7		9.7	
BS+O			9.2		17.5	
SW+SB+O			9.7		49.4	
2007 growing season						
Wheat (SW)	5.2	33.6	6.7	41.7		
Barley (SB)	5.5		4.5			
Oat (O)	10.7		8.2			
SW+SB	3.5		3.2			
SW+O	5.5		5.0		29.2	
BS+O	2.7		62.4		7.5	*
SW+SB+O	5.7		*		4.7	2.2
2008 growing season						
Wheat (SW)	69.5	6.95	547.5 c	5.21		
Barley (SB)	57.5		862.5 bc			
Oat (O)	405		562.5 b			
SW+SB	61.25		660.0 b		5.21	
SW+O	170.0		26.88		481.2 a	19.63
BS+O	288.7		*		692.5 bc	*
SW+SB+O	139.5		17.65		608.0 b	*

*no reduction; different letters indicate statistical differences between combinations

Table 5. Cereal aphid (*S. avenae*) occurrence/reduction in spring cereal ears of pure stands and mixtures

Pure stands/mixtures	Winna Góra 2006		Kościelna Wieś 2008			
	number of aphids	reduction [%]	number of aphids	reduction [%]		
Wheat (SW)	15.2	*	2.7 a	46.4		
Barley (SB)	4.5		1.0 a			
Oat (O)	16.2		132.7 d			
SW+SB	13.2		0.2 a			
SW+O	15.5		1.6		19.0 b	73.3
BS+O	6.7		34.0		27.2 c	56.2
SW+SB+O	8.6		15.5		11.0 b	77.6

*no reduction; different letters indicate statistical differences between combinations

ness thresholds. At both sites, a bigger abundance of the leaf beetles and aphids were on leaves and stems, while the ears of the crops suffered only in Winna Góra (Tables 3, 4, 5).

In the case of leaf beetles, no reduction of abundance was noted in mixtures as compared to pure stands in the spring barley and oat mixture in Winna Góra and the spring wheat and oat mixture, as well as the spring barley and oat mixture in Bąków (Table 3).

Aphids on leaves and stems in Bąków were less abundant in mixtures than in pure stands, apart from the spring wheat and spring barley mixture, where no reduction in abundance was recorded (Table 4). In Winna Góra the differences were so insignificant that there was no

basis for calculating the reduction at all. Cereal aphids, however, were slightly more abundant in Winna Góra. The spring wheat and spring barley mixture was the only one where no reduction was recorded (Table 5). In the experiments, stalks with damaged leaves had a below 1% average abundance of leaf-mining flies.

There was a mild winter and the spring came quickly in the 2007 growing period. For this reason the pests appeared on plantations earlier than usual, but in a relatively small abundance. The economic harmfulness thresholds were not exceeded at either site. The number of leaf beetle larvae was significantly higher than in the 2006 season. Reduction in their abundance was noted for all mixtures except for the spring wheat and oat mixture in

Table 6. Spring cereal yield increase in pure stands and mixtures in vegetation seasons 2006,2007 and 2008

Objects	Yield in dt/ha					
	Bąków			Winna Góra		Kościelna Wieś
	2006	2007	2008	2006	2007	2008
SW+SB pure stand average	52.5	31.9	28.9	22.9	30.0	34.9
Yield – mixture	53.3	31.8	34.3	24.2	38.0	38.2
Yield increase	+0.8	-0.1	+5.4	+1.3	+8.0	+3.3
SW+O pure stand average	40.6	27.4	18.2	22.6	31.0	33.1
Yield – mixture	43.1	27.9	21.4	24.4	33.5	36.2
Yield increase	+2.5	+0.5	+3.2	+1.8	+2.5	+3.1
SB+O pure stand average	44.6	25.6	21.9	17.5	29.6	29.7
Yield – mixture	47.3	28.2	28.1	17.8	26.6	31.5
Yield increase	+2.7	+2.6	+6.2	+0.3	-3.0	+1.8
SW+SB+O pure stand average	45.7	28.3	23.0	21.0	32.8	32.5
Yield – mixture	46.7	32.2	22.8	23.8	30.0	35.7
Yield increase	+1.0	+3.9	-0.2	+2.8	+2.8	+3.2

Table 7. Pure stands and mixtures yields of spring cereal in vegetation seasons 2006,2007 and 2008

Place/Year	Combinations						
	wheat [SW]	barley [SB]	oat [O]	[SW+SB]	[SW+O]	[SB+O]	[SW+SB+O]
Bąków – 2006	47.98 c	56.05 a	33.18 d	53.30 ab	43.15 c	47.28 c	46.70 c
Bąków – 2007	33.70 a	30.05 b	21.18 d	31.38 ab	27.93 c	28.25 bc	32.25 a
Bąków – 2008	25.18 cd	32.60 ab	11.25 e	34.33 a	21.38 d	28.08 bc	22.80 d
Winna Góra – 2006	28.03 a	17.79 c	17.24 c	24.22 b	24.46 ab	17.85 c	23.79 b
Winna Góra – 2007	39.21 a	36.49 ab	22.88 e	38.00 a	33.55 bc	26.58 de	30.03 cd
Kościelna Wieś – 2008	38.33	31.50	27.84	38.17	36.17	31.50	35.67

Different letters indicate statistical differences between combinations

Table 8. Yield of spring cereal pure stands and mixtures – statistical synthesis for years

Place/AUDPC/RAUDPC	Combinations						
	wheat [SW]	barley [SB]	oat [O]	[SW+SB]	[SW+O]	[SB+O]	[SW+SB+O]
Bąków – AUDPC (3 years)	35.62 a	39.57 a	21.87 b	39.67 a	30.82 ab	34.53 a	33.92 a
Winna Góra – AUDPC (2 years)	33.62 a	27.14 a	20.06 b	31.11 a	29.00 a	22.21 b	26.91 ab

Different letters indicate statistical differences between combinations

Winna Góra and the spring wheat and spring barley mixture in Bąków (Table 3). At both sites, may saw an occurrence of relatively high numbers of winged specimens of bird cherry aphid (*Rhopalosiphum padi*). The species did not develop dynamically, though, and before crop vegetation in the experiment ended, only single specimens or small colonies could be observed. The only two mixtures for which no reduction of abundance was observed as compared to pure stands were the three-component mixture in Winna Góra and the spring barley and spring oat mixture in Bąków. Due to the fact that grain aphid (*Sitobion avenae*) occurred in very small numbers, the reduction in its abundance was not calculated.

In the last year of the research experiment (2008) the leaf beetle larvae abundance in Kościelna Wieś was sig-

nificantly higher than in Bąków. In most of the mixtures the economic harmfulness thresholds were exceeded and all of them showed a reduction of the abundance of aphids as compared to pure stands. No reduction of the leaf beetle was observed in Bąków for the spring wheat and spring barley and the spring wheat and oat mixtures (Table 3).

Due to favorable weather conditions (a long period of warm rainless weather) at both sites, the abundance of aphids on leaves and stems were very high. Reductions in their abundance, as compared to pure stands, were observed in five out of eight mixture combinations (Table 4). In Kościelna Wieś, aphids were also observed on ears of the spring cereals. They appeared mainly on oat pure stands. In oat mixtures, the abundance of aphids was sig-

nificantly lower. Reductions in the abundance were observed in all mixture combinations (Table 5).

The grain yield in the mixtures was presented by calculating the expected yield – average yield from pure stands (components of a particular mixture) compared to the yield obtained from that particular mixture.

In given growing seasons, at both sites, it was possible to note an increase of yield as compared to yields obtained from pure stands. There was an exception, however, in the yield obtained in the 2007 season in Bąków from the spring wheat and spring barley mixture and the three-component mixture in the 2008 season, as well as the spring barley and oat mixture in the 2007 season in Winna Góra. The increase of yields oscillated between 0.8 dt/ha and 2.8 dt/ha in the 2006 season, 0.5 dt/ha and up to 8.0 dt/ha in the 2007 season and between 1.8 dt/ha and 6.2 dt/ha in the 2008 season. Due to a drought and a high abundance of aphids in the 2008 growing season, the yields from the Bąków plots were considerably lower (Tables 6, 7, 8).

Experiments regarding inter-species cereal mixtures conducted by other researchers (Gacek *et al.* 1996) have shown a similar increase in yields from mixtures as compared to pure stands. Additionally, they emphasize the yield stability from mixtures throughout the years.

CONCLUSIONS

1. Among the pure stands, spring barley was the species most damaged by powdery mildew (*Blumeria graminis* f. sp. *hordei*).
2. It was observed that growing mixtures of spring cereals contributes to the reduction of damage by powdery mildew (up to 66.5%) as compared to pure stands.
3. Most often a higher percentage in the reduction of powdery mildew occurrence was noted for mixtures that included spring barley.
4. The appearance and development of pests in particular seasons was dependent on meteorological conditions.
5. Reductions of the occurrence of the most important cereal pests were noted for 70–90% of the spring cereal mixture combinations as compared to pure stands.
6. It was noted that spring cereal mixtures brought about an increase in yields up to 8 dt/ha as compared to the yields obtained from pure stands.

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POLISH SUMMARY

OGRANICZANIE WYSTĘPOWANIA MĄCZNIAKA PRAWDZIWEGO (*BLUMERIA GRAMINS*) I SZKODNIKÓW W MIESZANKACH ZBÓŻ JARYCH

W ciągu trzech lat, w dwóch miejscowościach, przeprowadzono doświadczenia z dwu- i trójskładnikowymi jarymi mieszankami zbożowymi (jęczmień, pszenica i owies). Celem pracy było zbadanie wpływu zróżnicowanych genetycznie mieszanek zbożowych na występowanie chorób (mączniaka prawdziwego zbóż), szkodników oraz plon. Obserwacje porażenia mączniakiem prawdziwym prowadzono co 7–10 dni, w ciągu sezonu wegetacyjnego. W celu porównania porażenia gatunków w siewie czystym i mieszanym wyliczano wartość AUDPC – powierzchnia wykresu pod krzywą rozwoju choroby, a następnie redukcję AUDPC w mieszankach. W czasie prowadzonych badań, obserwowano takie szkodniki na zbożach, jak: mszyce (Aphidodea), skrzypionki (*Oulema* spp.) i miniarki (Agromyzidae).

Na podstawie uzyskanych wyników stwierdzono, że mieszanki zbóż jarych wpływają na redukcję występowania mączniaka prawdziwego oraz szkodników. Odnotowano mniejsze porażenia mieszanek oraz przyrost plonu w mieszankach zbóż jarych, w porównaniu do siewów czystych (nawet do 8 dt/ha). Badania wykazały, że mieszanki zbóż jarych mogą stanowić alternatywę uprawy – zwłaszcza w rolnictwie niskonakładowym i ekologicznym.