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THE INFLUENCE OF ENVIRONMENTS ON THE EPISTATIC EFFECTS OF GENES CONTROLLING SOME TRAITS IN WINTER RYE

ABSTRACT

The aim of the study was to show epistatic effects of genes responsible for inheritance of important morphological traits in winter rye populations. Furthermore, the thesis that the environment plays very important role in epistatic effects in winter rye populations was verified. The study showed very significant epistasis for inheritance of the important yield components in 1985–1999 years. It was confirmed that epistasis increased or reduced values of the traits under study. It was also showed that epistasis depended on investigated varieties and environments (year of the study). The method described by Comstock and Robinson (1952), and Kearsey and Jinks (1968) consisting in crossing of selected populations with three different testers: T1 (SMH–49), T2 (SMH–75) and T3 (hybrid T1 × T2) was used. The obtained F1 hybrids were sown in 3–replications every year (1985–1999). The epistatic effects were estimated according to formula; $Ji = L_{1i} + L_{2i} - 2L_{3i}$, where J_i is the epistatic effects of i–th variety, L_{1i}, L_{2i}, $2L_{3i}$ are the mean values of characters for the hybrids obtained from the crossing between i–th variety and tester. The study concerned following traits: plant height, heading date, length of ear and uppermost internode of ear, grain yield per ear, grain number per ear, 1000–grain yield, grain yield per plot, test weight, falling number, protein content, resistance to brown rust and powdery mildew. Relationships between epistatic effects for selected traits and precipitation and temperature coefficient were evaluated according to Spaerman coefficient of correlation.

Key words: epistasis, environments, inheritance, winter rye, *Secale cereale*

INTRODUCTION

Our previous investigations (1985, 1989, 1993, 1996, 1999) showed very significant epistasis for inheritance of important yield components. Similar results obtained Jedyński and Kaczmarek (1989) and Kaczmarek and Bujak (1993). The studies confirmed that epistasis raised or reduced values of investigated traits. The thesis was also verified (1998) that epistatic effects in winter rye populations depended from investigated varieties and environment (years of study). Literature described various statistical methods for analysing genotype–environment interaction. But

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few works pointed at the influence of the environment on epistatic effects in plants. Jinks *et al*. (1973) confirmed that extreme environment conditions modified epistatic effects of genes for certain traits in *Nicotiana rustica*. He carried out one–year experiment with 82 tobacco lines sown densely in various time. Significant influence of year–trait interaction on the inheritance of yield, height and 1000 kernel weight in two–row and six–row barley progeny found Kjear and Jensen (1998). Studies on epistatic effects in winter rye confirmed that very significant problem is an influence of the environment. One–year experiments do not make good possibility to observe such influence, but multi–year experiments could allow to estimate and define role the environment can play in this gene action for traits in investigated populations of winter rye.

The aim of the study was to explain epistatic effects of genes responsible for inheritance of important morphological traits in winter rye populations. Furthermore, we showed that epistasis depended on investigated varieties and environments (year of the study).

MATERIAL AND METHODS

The study was carried out with 59 winter rye populations from 8 countries (Table 1) and 3 testers in 1985–1999. In each year 5 to 20 objects were tested in field experiment. In total, 186 objects were tested (Table 2). The varieties Dańkowskie Nowe, Dańkowskie Złote, Motto and Amilo were investigated respectively in 13, 12, 11 and 10 years, remained cultivars – in one to several years (Table 2). The objects of the study came from collections, breeding experiments and cultivar register of winter rye in Poland.

Table 1

Origin of tested rye populations

Country	Number of objects
Poland	43
Germany	5
Sweden	2
Portugal	1
Russia	2
Austria	2
Holland	1
Czech Republik	1

The method described by Comstock and Robinson (1952) and Kearsey and Jinks (1968) consisting in crossing of selected populations with three different testers: T1 (SMH–49), T2 (SMH–75) and T3 (hybrid T1xT2) was used. A randomised block design was applied. The obtained F1 hybrids were sown in 3–replications every year (1985–1999) at one location – Krakow. Each experimental plot was 0.5 m^2 and 60 viable kernels were

Table 2

The register of cultivar winter rye investigated in 1985-1999

No	Cultivar	Years of study	No.	Cultivar	Years of study
1.	PANCERNE	1	31.	SMH 50	4
2.	DAŃKOWSKIE NOWE	13	32.	RHEIDOL	3
3.	WOJCIESZYCKIE	4	33.	(LAD 185) AMILO	8
4.	ECHO KURZ	3	34.	DAŃKOWSKIE ZŁOTE	10
5.	PECURO	3	35.	(AND 289) ARANT	6
6.	CARO KURZ	3	36.	JEC 289	1
7.	PASTAR	3	37.	SMH 389	2
8.	DAŃKOWSKIE SELECKYJNE	6	38.	(SMH 590) WIBRO	8
9.	TEMPO	3	39.	SMH 109	1
10.	CHODAN	1	40.	CHD M–16	2
11.	TURBO	5	41.	WARKO	7
12.	GLORIA	2	42.	SMH 102	2
13.	BANDELIER	1	43.	SMH 104	1
14.	HALO	2	44.	SMH 106	1
15.	PEROS	3	45.	SMH 111	1
16.	OTELLO	2	46.	SMH 120	2
17.	SMH 285	5	47.	SMH 116	1
18.	SMH 183	2	48.	SMH 121	2
19.	BRENO	1	49.	MONTALEGRE	2
20.	MOTTO	11	50.	KR 50	3
21.	SMH 75–2	2	51.	RADZIMA	2
22.	SMH 57–1	2	52.	SYDAR	1
23.	JAROSŁAWNA	2	53.	SMH 115	1
24.	SMH 66	2	54.	SMH 117	3
25.	MERKATOR	3	55.	CHD 23	1
26.	ANNA	1	56.	ZDUNO	2
27.	SMH 64	2	57.	ADAR	2
28.	SMH 1–4–1	5	58.	SMH 1094	1
29.	TSCHERMARKS MARCHFELDER	2	59.	SMH 1195	1
30.	MADAR	8		TOTAL	186

sown per plot. In the study we concerned on following traits: plant height, heading date, length of ear and uppermost internode of ear, grain yield per ear, grain number per ear, 1000 grain yield, grain yield per plot, test weight, falling number, protein content, resistance to brown rust and powdery mildew. The epistatic effects were estimated according to for–mula:

$$J_i = L_{1i} + L_{2i} - L_{3i}$$

where;

J_i is the epistatic effects of i^{th} variety,

L_{1i}, L_{2i}, $2L_{3i}$ are the mean values of characters for the hybrids obtained from the crossing between i^{th} variety and tester.

Relationships between epistatic effects for the selected traits and pre–cipitation and temperature coefficient were evaluated according to Spearman correlation coefficient.

RESULTS

Analysis of variance, presented in Table 3a, 3b and 3c, revealed highly significant variability of mean squares for years of study, epistasis and interaction between epistasis and years for all investigated traits (ex–cluding brown rust and powdery mildew). It was also found that there was significant epistasis of two types: type "i" (interaction of homozy–gous with homozygous loci), and type "j,l" (interactions of homozygous with heterozygous and heterozygous with heterozygous loci) for four traits: plant height, 1000–grain weight, test weight and yield grain per plot (Table 3a, 3b and 3c). However, for 8 traits: yield and number of grains per ear, heading, ear length, internode length, number of ears per plot, falling number and protein content, significant epistasis was only for type "j,l" (Table 3a, 3b and 3c). Moreover, for all traits (excluding falling number) there was highly significant interaction between years and epistasis of type "j,l" (Table 3, 7). Tables 4, 5, 6 present estimation of epistatic effects for each investigated form.

For instance, epistasis considerably increased plant height in variety OTELLO (Table 4), grain yield for population CHD 23 (Table 5), number of ears per plot for variety KR–50 (Table 5), falling number for variety RHEIDOL and protein content for variety HALO (Table 6).

On a contrary, epistasis reduced grain yield per ear for variety ANNA (Table 4), grain yield per plot for strain SMH 104 (Table 5), falling num–ber for variety ADAR and protein content for variety PEROS (Table 6).

On the grounds of performed synthesis it was shown that for cultivar OTELLO epistasis increased greatly values of four traits (plant height, number of grains per ear, ear length and internode length), but for cultivar ADAR epistasis significantly reduced values of such traits as plant height, ear length, number of grains per ear and falling number (Table 4, 5, 6).

Similar results obtained Węgrzyn and Śmiałowski (1993, 1995, 1999), but in those investigations we have not done any synthesis. In this multi–year study it was shown that epistasis controlled significantly

Table 3a

The analysis of variance of epistatic effects for traits investigated in 1985–1999

Source of variance	D.F.	Plant height	Yield of grain per ear	Number of grain	Days to heading	1000 grain yield
		ms	Ms	Ms	Ms	ms
Years of study	14	173.8**	0.39**	142.4**	12.2**	53.6**
Epistasis	59	110.9**	0.17**	118.4**	5.8**	36.7**
type "i"	1	141.9**	0.1	21.3	3.4	53.7**
type"j,l"	58	110.4**	0.17**	120.1**	5.9**	36.4**
Epistasis × years	126	87.2**	0.25**	104.9**	6.3	47.2**
type "i" × years	14	89.7**	0.45**	103.9**	12.9**	54.2**
type "j,l"× years	112	86.9**	0.22**	105.0**	5.5**	46.3**
Error	974	26.3	0.05	19.1	1.5!	8.5!

! D. F. = 965 for days to heading; ! D. F. = 996 for 1000 grain weight

Table 3b

The analysis of variance of epistatic effects for traits investigated in 1992–1999

Source of variance	D. F.	Number ear per plot	Length of ear	Internode length	Test weight	Yield per plot
		ms	Ms	ms	ms	Ms
Years of study	7	2051.9**	3.04**	14.1**	17.1**	12622.6**
Epistasis	39	2951.1**	1.59**	19.4*	10.6**	6799.3**
type "i"	1	1.7	0.7	5.1	13.8**	9653.9**
type "j,l"	38	3028.7**	1.61**	19.8**	10.5**	6724.2**
Epistasis x years	68	2111.2**	1.5**	13.1*	10.7**	6518.5**
type "i" × years	7	2363.7**	3.81**	20.1**	17.7**	2058.6**
type "j,l" × years	61	2082.3**	1.23**	12.4**	9.9**	5882.7**
Error	561	487.9	0.44	2.53	2.7	1658.6

Table 3c

The analysis of variance of epistatic effects for traits investigated in 1985–1999

Source of variance	Falling number		Protein content		Leaf rust		Powdery mildew	
	D. F.	ms	D. F.	ms	D. F.	m s	D. F.	Ms
Years of study	7	2999.9**	4	12.4**	10	20.6	2	0.7
Epistasis	44	2414.3**	42	87.6**	56	22.2	27	0.8
type "i"	1	147.8	1	0.27	1	73.5	1	0.8
type "j,l"	43	2466.9**	41	89.7**	55	21.3	26	0.8
Epistasis × years	39	1898.9**	35	88.1**	85	18.2	7	0.2
type "i" × years	4	856.0	4	19.7**	10	25.6	2	0.1
type "j,l" × years	35	2017.9**	31	96.9**	75	17.2	5	0.2
Error	447	459.2	413	0.66	739	79.1	169	67.9

*,** – significant at P=0,05 and P=0,01, respectively

Table 4

The synthesis of the epistatic effect for varieties investigated in 1985–1999 years

Traits									
Plant height		Yield grain per ear		1000 grain yield		Number grain per ear		Days to heading	
Varieties	Epistatic effects	Varieties	Epistatic effects	Varieties	Epistati c effects	Varieties	Epistatic effects	Varieties	Epistatic effects
1	2	3	4	5	6	7	8	9	10
SMH 57–1	11.8**	SMH 398	0.6**	SMH 398	6.4**	JEC 289	17.3**	JEC 289	4.7**
OTELLO	15.0**	SMH 106	0.5*	PANCERNE	5.8*	SMH 117	16.5**	BANDEL.	3.3*
CHODAN	14.2*	JEC 289	0.5*	SMH 57–1	5.7*	PECURO	10.2**	SMH 1195	2.9*
SMH 75–2	13.3**	CHD M–16	0.4*	WOJCIESZ.	4.7**	OTELLO	9.9**	SMH 102	2.7**
BRENO	12.3*	MERKAT.	0.45*	SMH 115	4.67	TEMPO	8.7**	SMH 57–1	2.22*
SMH 117	8.7**	SMH 57–1	0.41*	D.SELEK.	4.5*	SMH 106	8.2	SMH 64	2.18*
SMH 389	7.9	SMH 10954	0.41	SMH 116	4.2	SMH 102	7.2*	SMH 398	2.17*
PECURO	7.2*	CHODAN	0.38	CHD M–16	3.9	SMH 75–2	7.1*	SMH 50	1.9*
BANDELIER	6.6	SMH 117	0.35*	SMH 1094	3.5	SMH 36	6.8**	MOTTO	1.8**
KR–50	5.9*	KR–50	0.19	EHO KURZ	2.7	MERKAT.	6.7*	ZDUNO	1.7
SMH 111	5.5	SMH 212	0.17	SMH 106	2.2	SMH 121	6.4*	SMH 109	1.7
PASTAR	5.5*	MOTTO	0.14	MERKAT.	2.2	T. MARCH.	4.6	SMH 1094	1.6
MONTALEGRE	5.5	OTELLO	0.13	SMH 109	2.0	CHD M–16	4.4	OTELLO	1.5
TEMPO	5.2	D.ZŁOTE	0.12	RHEIDOL	1.9	SMH 1094	3.9	WIBRO	1.23**
RADZIMA	4.9	MADAR	0.11	TURBO	1.8	SMH 120	3.7	CHD M–16	1.2
ADAR	4.6	TEMPO	0.11	PASTAR	1.7	PANCERNE	3.6	D. ZŁOTE	0.95*
DAŃKOWSKIE NOWE	4.5**	SMH 120	0.1	WARKO	1.6	EHO KURZ	3.2	CHD 23	0.7
PEROS	4.4	WIBRO	0.09	ADAR	1.6	KR 50	2.9	BRENO	0.6
SMH 1094	3.8	TURBO	0.08	MONTAL.	1.5	D.ZŁOTE	2.8*	SMH 1–4–1	0.4
SMH 66	2.9	E. KURZ	0.07	SMH 104	1.4	MOTTO	2.8*	ADAR	0.4

Table 4

The synthesis of the epistatic effect for varieties investigated in 1985–1999 years (continued)

1	2	3	4	5	6	7	8	9	10
SMH 50	2.8	WARKO	0.06	SMH 1–4–1	1.0	SMH 57–1	2.5	RADZIMA	0.4
GLORIA	2.6	AMILO	0.06	CHD 23	0.96	BANDEL.	2.4	ARANT	0.3
SMH 106	2.5	SMH 75–2	0.04	ARANT	0.7	D.NOWE	2.2	SMH 106	0.3
WIBRO	2.0	BANDELIER	0.02	SYDAR	0.3	BRENO	1.4	TURBO	0.3
HALO	1.97	TSCH.MARCHF.	0.01	AMILO	0.2	SMH 66	1.3	RHEIDOL	0.2
DAŃKOWSKIE .SELKCYJNE	1.89	D.SELEK.	–0.02	KR–50	0.1	MADAR	1.02	JAROSŁ.	0.01
SMH 116	1.88	D.NOWE	–0.02	MADAR	0.08	WARKO	–0.3	D. NOWE	0.01
JEC 289	1.8	SYDAR	–0.03	CHODAN	–0.14	GLORIA	–0.7	SMH 120	–0.12
MOTTO	1.7	MONTALEGRE	–0.03	D. ZŁOTE	–0.17	CHODAN	–0.8	SYDAR	–0.14
TURBO	1.7	RADZIMA	–0.04	SMH 285	–0.33	SMH 111	–1.1	SMH 66	–0.15
SMH 121	1.5	SMH 102	–0.04	BANDEL.	–0.6	TURBO	–1.1	GLORIA	–0.2
WARKO	1.2	SMH 115	–0.05	TEMPO	–1.1	D.SELEK.	–1.2	T. MARCH.	–0.2
CHD 23	0.8	ZDUNO	–0.05	RADZIMA	–1.2	SMH 50	–1.3	MADAR	–0.3
WOJCIESZYCKIE	0.4	ARANT	–0.08	D.NOWE	–1.2	RADZIMA	–1.4	MERKAT.	–0.3
SMH 183	–0.2	SMH 109	–0.08	PEROS	–1.2	SMH 183	–1.9	ANNA	–0.4
SMH 1–4–1	–0.4	CHD 23	–0.1	JAROSŁ.	–1.4	SMH 1–4–1	–2.1	D. SELEK.	–0.4
DANK.ZŁOTE	–0.6	RHEIDOL	–0.1	SMH 120	–1.5	SMH 64	–2.2	SMH 285	–0.4
MADAR	–0.9	SMH 66	–0.1	SMH 183	–1.7	AMILO	–2.2	MONTAL.	–0.5
SMH 285	–1.2	SMH 285	–0.13	SMH 64	–1.8	WIBRO	–2.2	KR 50	–0.6
TCHERMARKS MARFELDER	–2.1	PASTAR	–0.14	SMH 117	–1.88	SMH 285	–2.3	HALO	–0.7
RHEIDOL	–2.1	ADAR	–0.16	WIBRO	–1.9	SYDAR	–3.5	SM 111	–0.7

Table 4

The synthesis of the epistatic effect for varieties investigated in 1985–1999 years (continued)

1	2	3	4	5	6	7	8	9	10
CHD M–16	–2.2	SMH 104	–0.16	JEC 289	–1.96	ZDUNO	–3.8	PANCERNE	–0.8
AMILO	–2.6	PECURO	–0.17	MOTTO	–1.98*	PEROS	–4.2	TEMPO	–0.8
CARO KURZ	–2.9	SMH 111	–0.2	TSCH.MAR.	–2.0	RHEIDOL	–4.2	SMH 75–2	–0.99
ZDUNO	–3.6	SMH 1–4–1	–0.22	SMH 66	–2.7	SMH 1195	–5.3	SMH 183	–1.1
MERKATOR	–3.8	BRENO	–0.28	GLORIA	–2.7	HALO	–5.4	AMILO	–1.1*
SMH 1195	–5.8	SMH 64	–0.29	SMH 111	–2.8	PASTAR	–6.4**	SMH 117	–1.1
ARANT	–5.8*	SMH 183	–0.29	SMH 75–2	–2.9	SMH 104	–6.7	WARKO	–1.4*
ANNA	–5.97	GLORIA	–0.29	OTELLO	–3.04	MONTAL.	–7.7	SMH 115	–1.6
JAROSŁAWNA	–7.4	PEROS	–0.31*	SMH 1195	–3.8	ARANT	–8.4**	EHO KURZ	–1.6*
SMH 104	–7.8	SMH 1195	–0.32	ZDUNO	–3.9	ANNA	–9.3*	PASTAR	–2.1**
SMH 115	–8.2	SMH 116	–0.33	SMH 121	–4.6*	C. KURZ	–9.5**	PECURO	–2.3**
SMH 109	–8.2	SMH 50	–0.36*	BRENO	–4.9	SMH 115	–10.8*	SMH 104	–2.4
ECHO KURZ	–8.9*	WOJCIESZYCK.IE	–0.5**	SMH 102	–5.9*	WOJCIESZ.	–11.7**	PEROS	–2.5**
PANCERNE	–9.3	PANCERNE	–0.54*	SMH 50	–6.4**	JAROSŁAW	–12.6**	C. KURZ	–2.6**
SMH 120	–9.9*	HALO	–0.56**	HALO	–8.01*	CHD 23	–12.9*	CHODAN	–3.2*
ADAR	–12.8*	JAROSŁAWNA	–0.63**	C. KURZ	–9.5**	SMH 116	–13.1**	SMH 121	–3.9**
SMH 64	–12.89**	CARO KURZ	–0.88**	PECURO	–12.4**	SMH 109	–14.5**	WOJCIESZ.	–4.7**
SMH 102	–17.02**	ANNA	–1.28**	ANNA	–16.04**	ADAR	–19.7**	SMH 116	–4.7**
Mean	0.88		–0.02		–0.54		–0.34		–0.14
LSD	8.1		0.36		4.62		6.9		2.2

**,* – significant at P = 0,01 and P=0,05, respectively

Table 5

Synthesis of the epistasis effect for varieties of winter rye investigated in 1992–1999

No.	Traits									
	Number ear per plot		Length of ear		Internode length		Test weight		Grain yield	
	Varieties	Epistatic Effects	Varieties	Epistatic Effects	Varieties	Epistatic Effects	Varieties	Epistatic Effects	Varieties	Epistatic Effects
1	2	3	4	5	6	7	8	9	10	11
1	KR 50	97.9**	TURBO	2.5**	MONTAL.	13.6*	MERK.	5.4**	CHD 23	118.5**
2	CHD 23	85.9**	SMH 102	2.3**	OTELLO	11.9**	PASTAR	5.2**	KR 50	112.4**
3	ADAR	76.3**	OTELLO	1.36	SMH 109	5.2**	KR 50	4.1**	ADAR	94.3**
4	SMH 1195	70.7**	SMH 1094	1.34	SYDAR	5.3**	TURBO	2.7*	SMH 102	92.4**
5	RADZIMA	39.8**	SMH 106	1.29	SMH 115	4.5*	SMH 1094	2.6	RADZIMA	61.5
6	SMH 285	39.2*	RADZIMA	1.2	RADZIMA	4.4**	RHEIDOL	2.4	SMH 116	60.7
7	SMH 102	35.7*	HD 23	1.18	SMH 116	3.8*	ADAR	2.3	SMH 285	56.6
8	AMILO	28.5**	PASTAR	1.1*	TURBO	3.6**	SMH 116	2.1	SMH1195	51.9
9	ARANT	24.2*	MOTTO	0.73*	D. SELEK.	3.4	JEC 289	1.7	S–4–1	36.4
10	JEC 289	23.9	SM 117	0.7	SMH 1195	3.2	D. SEL.	1.5	SMH 109	30.1
11	ZDUNO	20.2	SMH 116	0.63	SMH 121	3.1*	SMH 111	1.2	SMH 389	21.7
12	MADAR	16.2	SMH 121	0.62	SMH 1094	1.7	CHD M16	0.99	JEC 289	21.0
13	SYDAR	10.7	S–4–1	0.6	D. NOWE	0.9	CHD 23	0.8	PASTAR	14.0
14	SMH 116	10.1	SMH 1195	0.58	AMILO	0.88	ARANT	0.7	ZDUNO	10.3
15	S–4–1	9.9	SYDAR	0.55	CH M–16	0.85	SYDAR	0.5	MADAR	7.4
16	SMH 106	8.7	WIBRO	0.53*	WIBRO	0.7	SMH 120	0.4	ARANT	5.9
17	SMH 389	4.9	ZDUNO	0.45	KR 50	0.66	S–4–1	0.04	RHEIDOL	4.8
18	TURBO	0.8	MONTA.L	0.2	MADAR	0.65	MADAR	0.03	D.NOWE	3.4

Table 5

Synthesis of the epistasis effect for varieties of winter rye investigated in 1992–1999 (continued)

1	2	3	4	5	6	7	8	9	10	11
19	RHEIDOL	–0.8	SMH 389	0.1	MOTTO	0.35	SMH 109	–0.16	TURBO	–0.1
20	DANK. NOWE	–0.9	K 50	0.1	WARKO	–0.02	WIBRO	–0.17	SMH 111	–2
21	SMH 111	–5.6	WARKO	0.04	D. ZŁOTE	–0.13	SMH 117	–0.17	SMH 1094	–2.1
22	PASTAR	–7.4	D.ZŁOTE	0.04	PASTAR	–0.13	SMH 106	–0.3	AMILO	–5.1
23	MONTALEGRE	–8.0	SMH 104	–0.04	RHEIDOL	–0.46	SMH 389	–0.4	WIBRO	–18.1
24	SMH 115	–13.9	SMH 115	–0.1	SMH 120	–0.6	WARKO	–0.4	OTELLO	–23.1
25	MOTTO	–14.7	D. NOWE	–0.2	SMH 104	–0.9	MOTTO	–0.9	WARKO	–33.6
26	WARKO	–14.8	MADAR	–0.2	ADAR	–0.91	SMH 104	–0.9	MERK.	–34.4
27	WIBRO	–15.2	SMH 120	–0.4	S–4–1	–1.19	SMH 50	–1.1	CHD M–16	–37.9
28	CHD M–16	–19.9	AMILO	–0.4	SMH 106	–1.3	AMILO	–1.1	SMH 117	–38.5
29	SMH 109	–23.3	RHEIDOL	–0.5	ARANT	–1.6*	D. NOWE	–1.4*	SYD.	–47.3
30	SMH 1094	–23.4	CHD M–16	–0.6	SMH 398	–1.76	SMH 102	–1.6	D. SEL.	–52.4
31	SMH 121	–25.5	D.SELE.K	–0.6	ZDUNO	–1.9	SMH 115	–1.6	SMH 115	–53.6
32	DANK. SELEK.	–26.3	ARANT	–0.7*	SMH 50	–1.9	SMH 121	–1.7	MOTTO	–53.8**
33	OTELLO	–30.6	SMH 111	–1.04	SMH 117	–2.8**	D. ZŁOTE	–1.8**	SMH 120	–60.1
34	SMH 50	–31.3	SMH 50	–1.2*	SMH 285	–2.8*	RADZIMA	–2.9*	D. ZŁOTE	–68.6**
35	SMH 117	–35.3*	ADAR	–1.4**	SMH 111	–3.5	OTELLO	–3.2	SMH 121	–69.1*
36	SMH 120	–37.1*	JEC 289	–1.5*	CHD 23	–4.5*	SMH 385	–3.4**	MONT.	–69.5
37	MERKATOR	–48.7	MERKAT	–1.7*	SMH 102	–5.7**	MONT.	–3.8*	SMH 109	–69.8
38	DANK. ZŁOTE	–55.7**	SMH 109	–2.1**	JEC 289	–7.5**	ZDUNO	–5.3**	SMH 50	–96.2**
39	SMH 104	–61.9*	SMH 285	–2.24**	MERKATOR	–7.6**	SMH 1195	–7.5**	SMH 104	–169**
Mean		0.16		0.08		0.22		–0.36		–9.5
LSD		42.9		1.22		3.16		3.15		68.98

, * – significant at P = 0,01 and 0,05, respectively

41% populations for internode length, 37% populations for ear length, and 36% for number of grains per ear (Table 7). Only 11% investigated populations was characterised by significant effects for protein content (Table 7). There was also studied if the epistasis depended from selected elements of environment (year of study). The analysis carried out for Dańkowskie Nowe variety (under study in period 1985–1999) (Fig. 1). Analysing the relationships between epistasis effects and certain environmental parameters, correlations were found between plant height epistasis and mean temperature (r = –0.21), total precipitation (r = 0.61), and also between grain number per ear and grain weight per ear epistasis and total precipitation (r = –0.21 and 0.38 respectively). Thus it should be concluded that influence of the environment on epistasis effects in winter rye varieties is very complicated phenomenon and depended from many environmental factors. There has not yet been data on environment–epistasis interaction in winter rye. Carrying out studies on this problem is a difficult task to be made in several year period. But solving of the problem may facilitate and accelerate creation new valuable genetic source material for breeders' need.

CONCLUSIONS

Epistasis significantly influenced inheritance of many important traits of winter rye. If epistasis occurred for many investigated traits, it is of the type "j,l" (due to interaction of homozygous with heterozygous and heterozygous with heterozygous loci).

Environmental factors played important role in the occurrence of epistatic effects for investigated traits. Important element of observed effects was also interaction between all types of epistasis and environment.

The study confirmed that interaction between epistasis and environments is a composite problem. So it is necessary to continue investigations on the influence of environmental factors on epistatic effects of genes in cereals.

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