Theor Appl Genet (1992) 85: 33–45

THEORETICAL AND APPLIED GENETICS

Genetic linkage map of rye (*Secale cereale* L.)

G. Melz[1], **R. Schlegel**[2] **and V. Thiele**[3]

[1] Bundesanstalt für Züchtungsforschung an Kulturpflanzen, Institut für Züchtungsmethodik, O-2551 Gross Lüsewitz, Federal Republic of Germany
[2] Institut für Genetik und Kulturpflanzenforschung, O-4325 Gatersleben, Federal Republic of Germany
[3] Landesamt für Umwelt und Natur, O-2601 Gülzow, Federal Republic of Germany

Received January 10, 1992; Accepted January 27, 1992
Communicated by G. Wenzel

Key words: Rye – Gene location – Genetic map

Rules of Gene Symbolization

The rules of gene symbolization were adapted from the International Rules of Genetic Nomenclature, from the rules recommended for wheat (Hart and Gale 1988; McIntosh 1988), and from the Recommendation of the International Workshop on Rye Chromosome Nomenclature and Homoeology Relationships (Sybenga 1983).

1) In naming hereditory factors, the use of the language of higher internationality is given preference.
2) Symbols of hereditory factors derived from their original names are written in italics.
3) When unambigous, the name and symbol of a dominant allele begins with a capital letter and those of a recessive with a small letter.
4) All letters and numbers used in symbolization are written on one line.
5) Two or more genes having phenotypically similar effects are designated by a common basic symbol. Nonallelic loci (mimics, polymeric genes, etc.) are designated in accordance with two procedures:
   5.1) In sequential polymeric series, an Arabic numeral immediately follows the gene symbol; e.g., *ct2*.
   5.2) In homologous chromosomes the basic symbol is followed by a hyphen ("-") followed by the locus designation in the form of the accepted genome symbol of rye (R) and a homoeologous set number represented by an Arabic numeral: e.g., *Adh-R1* designates the R-genome member of the first Adh set. Different alleles, or alleles of independent mutational origin, are designated by a low-case Roman letter following the locus number designation; e.g., *Pm1* a.
   5.3) Temporary symbol designation. Where linkage data are not available, provision has been made for temporary symbols. These shall consist of the basic symbol followed by an abbreviation for the genotype or stock and an Arabic number referring to the gene; e.g., *YrKi2, YrKi3* refer to two genes for reaction to Yellow rust in genotype 'King II'. It is recommended that official records of temporary designations be kept, but it is not essential that subsequent numbers from other laboratories be checked against earlier numbers either phenotypically or genetically.
6) Inhibitors, suppressors, and enhancers are designated by the symbols *I, Su,* and *En,* or by *i, su,* and *en* if they are recessive, followed by a space and the symbol of the allele affected.
7) Whenever convenient, lethals are designated by the letter *l* or *L*, and sterility and incompatibility genes by *s* or *S*.
8) In rye and related wilds, linkage groups and corresponding chromosomes are designated by an Arabic numeral (1–7) followed by the genome designated by a capital Roman R. Whenever it appears necessary to indicate from which *Secale* species a certain chromosome (or chromosome arm) is derived, a superscript of three letters is added. Thus, $1R^{mon}$ (L) indicates the long arm of chromosome 1 of the species *S. montanum.* Telocentric chromosomes are designated S (short) and L (long), respectively.
9) Genetic formulae are written as fractions, with the maternal alleles given first. Each of the fractions corresponds to a single linkage group.
10) Chromosomal aberrations are indicated by the abbreviations Tr (for translocation) and Tp (for transposition).

Correspondence to: G. Melz

11) The zygotic number of chromosomes is indicated by 2n, the gametic number by n, and the basic number by x.
12) Symbols for extra-chromosomal factors are enclosed within brackets and precede the genetic formula.

References

Hart GE, Gale MD (1988) Guidlines for nomenclature of biochemical/molecular markers. Proc. 7th Int Wheat Genet Symp, Cambridge (England), pp 1215–1221

McIntosh RA (1988) Catalogue of gene symbols for wheat. Proc 7th Int Wheat Genet Symp, Cambridge (England), pp 1225–1323

Sybenga J (1983) Rye chromosome nomenclature and homoeology relationships. Z Pflanzenzücht 90:297–304

Gene map

Chromosome 1R

Gene location	Gene	Reference
1RS-SAT[a]	*CTer-1RS-syn pSchet1*	6, 96
	Gpi1 syn Pgi	16, 53, 132
	Lr1 syn Lr26	10, 11, 97, 172
	Pr3	16
	Sec1	20, 79, 141, 142
	Sec1a	16
	Sec1b	16
	SrR	145
	Sr1 syn Sr31	10, 59, 97, 171
	XcslH69.10	12
	XcslH69.13	12
	Xpsr161	165
	Xpsr393	165
1RS	*Gbr*	92, 168
	l(as)2 syn Si2 syn Asi	54, 67
	Nor1	78, 80
	Per7-leaf syn Per-R1,	3, 55, 83, 166
	Per13/15,	139
	L1Per1	39
	Pm1 syn Pm8	10, 64, 82, 97, 171
	rd	56
	rDNA[b]	5, 90
	5S-rDNA[b]	5, 90, 99, 123
	Wsm	92
	XGlu3	165
	XNor1	80, 165
	Xpsr168	165
	XSec1a syn XGli1	165
	XTri	12
	Yr1 syn Yr9	19, 97, 171
1RL	*Alp1*	40
	Alp3	40
	Dnr1	114
	fs	56
	Glu1	16
	Mdh1-leaf	16, 38, 135, 162
	Mdh2a-leaf syn Mdh4	16, 39, 135
	Pgd3-leaf syn Pgd1a.2	19, 38, 39, 41, 78, 166
	S1 syn S	170
	Sec3	79, 142
	Thi	137
	XAdh	165
	XcslH69.11	12
	XcslH69.12	12
	XcslH69.14	12
	XEm1	165
	XLec1	165
	XPgk1	165
	XPpdk1	165
	Xpsr158	165
	Xpsr159	165
	Xpsr161	165
	Xpsr325	165
	Xpsr330	165
	Xpsr391	165
	XSec3 syn XGlu1	165
1R	*an1-1R*	101
	dw4	101
	Ha4	100
	Pm7	65
	Sf1	105, 106
	Xiag79	169
	Xiag95	169
	Xiag138 (1)	169
	Xiag138 (2)	169
	Xiag138 (3)	169
	Xiag140	169

[a] The satellite does not include the NOR which is involved in the short arm mapping

[b] Approximately 4200 RNA genes are present in rye. Within the cereals these are basically two loci for 5S DNA: one is identified by repetitive units 320–468 bp on chromosome 1; the other with repetitive sequence 469–500 on chromosome 5

Gene order

Gene order	Reference
Gpi1–centromere–Mdh2a–Mdh1–Pgd3	39
Nor1–(Gpi1–Sec1–5S-rDNA)–Sr1/Lr26/Yr9–telomere	70, 146
Per7–Gpi1–Pgd3	166
Per7–Gpi1–Xiag	169
Pgd3–Sec3–centromere–Pr3–Sec1b–Sec1a	16
Pgd3–Sec3–centromere–Nor1	78
Pgd3–Sec3–centromere–Nor1–Gpi1–Sec1	78

Linkages

Linked genes	Value of linkage	Reference
Alp1–Alp3	11.1 ± 4.0	40
Alp1–Per7	21.4 ± 7.8 cM	39
Centr.–Glu1	4.6 ± 1.0	144
Centr.–Nor1	2.7 cM	78, 165
Centr.–Sec1	26.1 ± 4.3 cM	145, 146
	11.5 ± 4.0 cM	146
Centr.–Sec3	4.6	16, 78, 144
Centr.–Xpsr161, 393	8.2 cM	165
Gpi1–Mdh1	25.0	38
	36.7 ± 3.6 cM	162
	32.4 ± 3.6 cM	39
Gpi1–Mdh2a	35.4 ± 5.9 cM	39
Gpi1–Nor1	7.6 ± 1.8	78

Linkages

Linked genes	Value of linkage	Reference
Gpi1–Per17	12.0±1.6	166
	28.0±1.8	166
	25	169
Gpi1–Pgd3	20.7±3.1	78
	37.0±2.8	166
	28.6±3.1 cM	162
Gpi1–Sec1b	21.8 cM	78
Gpi1–Sec3	13.4±2.4	78
Gpi1–XGli1	19.8 cM	165
Gpi1–Xiag95	20	169
Gpi1–XNor1	42.0 cM	165
Lr26–Sec1	5.4±1.7	145
Mdh1–Mdh2a	5.2	38
	5.2±2.3 cM	39
Mdh1–Pgd3	30.8	38
	25.9±3.4 cM	162
Mdh2a–Pgd3	28.0	38
	28.0±6.3 cM	39
Nor1–Pgd3	14.0±2.4	78
Nor1–Sec1	9.0±2.4	78
	26.5±7.4	78
	30.0	156
Nor1–Sec3	7.2±1.8	78
Per7–Pgd3	34.0±2.6	166
	14.0±2.2	166
Per7–S1(S)	1	169
	0–0.2	45
Per7–Xiag95	37	169
Per7–Xiag138	10	169
Pgd3–Pr3	36.4±2.9	16
Pgd3–Sec1a	37.1±2.9	16
	55.0 cM	16, 165
Pgd3–Sec1b	36.8±2.9	16
	44.0 cM	165
Pgd3–Sec3	25.4±2.6	16
	7.2±1.8	78
	0–9	156
Pgd1–Xiag138	8	169
Pr3–Sec1a	10.6±1.8	16
Pr3–Sec1b	10.2±1.8	16
Pr3–Sec3	19.4	16
Sec1–Sec3	10.7	156
	36.0±4.6	78
	36.0±4.1	25
	40.8±3.8	142
Sec1–Lr1, Sr1, Yr1	5.4±1.7 cM	146
Sec1–SrR	7.0±3.1 cM	146
Sec1–term. C-band	2.5	156
Sec1a–Sec1b	0.35±0.35	16
Sec1a–Sec3	24.4±2.5	16
Sec1b–Sec3	24.0±2.5	16
SrR–telomeric C-band		
	16.0±4.8 cM	146
XAdh–XGli1	106.0 cM	165
XAdh–Xpsr62	19.6 cM	165
Xiag79–Xiag138	16	169
Xiag79–Xiag140	8	169
Xiag138–Xiag140	18	169
XLec1, XGlu1–Xpsr330		
	1.0 cM	165
XLec1, XGlu1–Xpsr158, XPpdk1, XEm1		
	1.7 cM	165
XNor1–Xpsr161, 393	2.0 cM	165
Xpsr325–Xpsr158, XPpdk-1R, XEm1		
	7.1 cM	165
Xpsr158, XPpdk1, XEm1–Xpsr330, XLec1, XGlu1		
	2.7 cM	165
Xpsr330, XLec1, XGlu1–Xpsr162		
	5.0 cM	165

Chromosome 2R

Gene location	Gene	Reference
2RS	*Gdh1*	130
	l(as)1 syn Si1 syn Asi	54,67
	mo	19,32
	Per1–leaf syn Perl1	131
	Per2–leaf syn Perl2,	131
	L2Per2	16
	Per3–leaf syn Perl3,	131
	L2Per3a,	19, 41
	L2Per3b	19, 41
	Per4–leaf syn Perl4,	41, 131
	L2Per4	16, 19, 21
	Rfc1	57
	Sec2	37, 142
2RL	*Est7–leaf* 'Imperial',	
	'King II'	86
	H1	43
	Mdh1–leaf	41
	Pgd4–leaf syn Pgd2a.3	19, 41, 130
	Pm2	35, 82, 97, 126
	tg	103
	Yr2	11, 26
2R	*al syn el*	148
	l(Amy)	93, 129
	an1-2R	101, 152
	An1-2R	30, 152
	An3	101
	β-Amy2–leaf	140
	β-Glu1 syn Glu1	95, 139, 166
	dw2	32, 101
	Est2–leaf	139
	Est4–leaf	166
	Lr2	35, 97
	Me	48
	Per1–scutellum syn Cpxs1, 'Dakold'	131
	Per2–scutellum syn Cpxs2, 'Dakold'	131
	Pm8	65
	Ps	32
	S3 syn Z	50
	Sod	61, 112
	Ssp1	42
	Tyr	174
	Xβ-Amy-2R	140
	XEmbp-2R	31

Gene order

Gene order	Reference
mo–Ps–dw2	32
Ps–L2Per3b–mo–L2Per2 or *Ps–mo–L2Per3b–L2Per2*	19
dw2–Ps–(L2Per3a, L2Per3b, mo)–L2Per2	19

Linkages

Linked genes	Value of linkage	Reference
al–mo	32.3 ± 3.5	148
al–S3	13.2	50
β-Glu–Est4	35.0 ± 3.7	166
β-Glu–S3	14.4 ± 3.3	45
dw2–mo	31.5 ± 12.3	32
	37.1 ± 20.4	19
dw2–Ps	2.2 ± 1.3	32
mo–L2Per2	36.8 ± 3.8	19
mo–Ps	29.7 ± 3.5	32
	26.1 ± 6.5	148
	31.0 ± 3.6	19
L2Per2–L2Per3b	36.2 ± 5.4	19
L2Per3a–L2Per3b	0.3 ± 0.3	41
L2Per3b–L2Per4	26.0 ± 4.0	41
L2Per3b–Ps	26.2 ± 4.0	19
Mdh1–Pgd4	16.0	41

Chromosome 3R

Gene location	Gene	Reference
3RS	*Dnr2*	114
	Mal1	84
	Ndh4 'Imperial', 'King II'	87
	Pm3	82, 126
	Sec4	37, 46, 116
	Sr2	91, 97
3RL	*Aat3–leaf syn Got3, Got4*	34, 132, 139, 157 166
	Est1–leaf	41, 136
	Mdh2b(2)–leaf	16, 41, 135, 162
	Tpi1	118, 167
3R	*Adh4*	53
	α-Amy7–seeds	134
	Alt2	4
	An6	101
	dw3	32, 101
	Est1–seeds	9, 136
	l(et)	54
	Lr3	146
	ms2	102
	P(cp)	81, 108
	Per4–leaf syn Lper4	162
	vb	56
	XiagA03	169
	ys	56

Gene order

Mdh2b–Est1(2)–Aat3	38
Mdh2b–Aat3–Tpi1	167

Linkages

Linked genes	Value of linkage	Reference
Aat3–Centromere	20.6 ± 2.4	16
Aat3–Est1(2)	5.6 ± 3.1	38
	15.4	16, 41
Aat3–Mdh2(b)	5 ± 2.0	167
	16 ± 3.0	167
	16.6 ± 1.7	162
	21.0	16, 41
Aat3(Got4)–Tpi1	18	169
	7 ± 2.0	167
Est1(2)–Mdh2b	7.4 ± 2.9	38
	5.6	16, 41
LPer4–Mdh2	30.7 ± 5.8	162
Mdh2b(2)–Tpi1	5	169
	9 ± 1.6	167
Mdh2b(2)–XiagA03	22	169

Chromosome 4R

Gene location	Gene	Reference
4RS	*Adh1–seeds*	7, 60, 139, 157
	Amp2 syn Lap2	62, 98, 157
	Dia2	166
	Ep2	34, 71, 139
	Ndh1 'Imperial', 'King II'	87
	Nca1	164
	Pgm1	14, 166
	Rfc2	57
4RL	*Aat4–leaf syn Got1*	34, 166
	an1–4R	72, 101, 172, 173
	EstB–leaf	76
	Est10–leaf	166
	lg1	32
	Pc	107
	Per1–endosperm syn Cpxe1, EPer1	131 162
	Per2–endosperm syn Cpxe2, EPer2	131 162
	Per3–endosperm syn Cpxe3, EPer3	131 162
	Per4–endosperm syn Cpxe4	131
	Pgd1–leaf syn Pgd1a	121, 130, 166
	Pgd1–seeds	58
	Sec7	37, 46
	Ssp2	42
4R	*Alt3*	4
	br2	101
	Cat	15
	Dnr3	114
	dw5	101
	fv	143
	gr2	56
	Ha2	100
	Ldh1	159
	Ldh2	159
	Per1–embryo syn Pere1	131
	Per2–embryo syn Pere2	131
	Per3–leaf syn LPer3	166
	Per4–leaf syn LPer4	166
	Per5–leaf syn LPer5	166
	Per6–leaf syn LPer6	166
	ms1	102
	Nar1	63
	Pm6	82
	Sf3	105
	va	56
	wa3	56
	XEmbp-2R	31
	Xpsr108	89
	Xpsr110	89
	Xpsr119	89

Gene location	Gene	Reference
	Xpsr139	89
	Xpsr147	89
	Xpsr152	89
	Xpsr153	89
	Xpsr166	89

Linkages

Linked genes	Value of linkage	Reference
Aat4–Dia1	13.0±2.1	166, 167
Aat4–Est10	36.0±3.8	166, 167
Aat4–LPer6	17.0±3.4	166
Centromere–Pgm1	14.9±2.3	38
(EPer1–EPer3)–Pgm1	36.7±3.9	162
EPer2–Pgm1	18.4±8.2	162
Est10–LPer3	8.0±1.7	166
Est10–LPer4	18.0±3.0	166
Est10–LPer5	29.0±3.1	166
Est10–LPer6	29.0±2.4	166
Est10–Pgm1	22.0±4.1	166, 167
LPer3–LPer4	0.0±6.9	166
LPer3–LPer5	26.0±3.7	166
LPer4–LPer5	33.0±7.6	166
LPer5–LPer6	0.0±6.7	166

Chromosome 5R

Gene location	Gene	Reference
5RS	*α-Amy4–seeds*	134
	br1	32
	Gpd	130
	Skd	69
	ti	32, 56
	5S-rDNA2[b]	99, 123
5RL	*Aadh1 syn Adh2–leaf*	18, 52, 139
	Aco1(2)	27, 166
	α-Amy2–seeds	134
	α-Amy3–seeds	134
	α-Amy7/18/20–seeds	139
	β-Amy1–seeds	2, 7, 20, 77, 139
	Ce	47, 49
	ct2	32, 151
	Est1–leaf	166
	Est2–leaf	166
	Est3–leaf	166
	Est4–leaf	139, 166
	Est5–leaf	166
	Est6–leaf	166
	Est7–leaf	166
	Gai1a	22, 23
	Gai1b	22, 23
	Gai1c	22, 23
	gr1	32
	Ha1, syn Hs syn Hp	97, 100, 115
	Ibf1	85
	I(et)2	66
	Nca2	138
	Ner1	124
	Pm4	82, 126
	Sp1 syn Vnr	32, 101, 169
	Su(cp)	127
	Xα-Amy3	94
	Xβ-Amy5R	140
	Xksu8	89
	Xksu26	89
	Xpsr81	89
	Xpsr120(1–4)	89
	Xpsr360	119, 89
	Xpsr426	119, 89
	Xpsr806	119
	Xpsr906	119
5R	*an1-5R*	101
	An4	101
	An5	101
	Ddw1 syn Dw1	150
	dw6	101
	Hma	109
	Lys	37
	Mas	109
	S2	50, 128
	Sf2	105, 106
	Tpi2	118
	wa2	56, 111
	XEmbp-2R	31
	Xiag10	169
	Xiag23	169
	Xiag167	169
	Xiag170	169
	Xiag200	169
	Xpsr109	89
	Xpsr118	89
	Xpsr145	119
	Xpsr164	89

[b] See footnote b for chromosome 1R

Gene order

An5–Ddw1–ct2/Gai1b	101
Ha1–Est1–Est2–Est3–Est5,6,7	166
Centromere–Xpsr120(II)–Xpsr360–Xpsr906–Xpsr806–Xpsr120(I)–Sp1–Xpsr426–ct2	119

Linkages

Linked genes	Value of linkage	Reference
Aco1–Est1	11.0±1.0	166
Aco1–Est2	16.0±6.2	166
Aco1–Est3	26.0±3.0	166
Aco1–Est5,6,7	27.0±1.8	166
Aco1–Ha1	26.0±3.5	166
Aco1(2)–Xiag10	10	169
An5–Ddw1	25.9±2.6	148
br–ti	0.0	32
Centromere–Ha1	44.1...49.5	26
ct2–An5	42.1±2.6	148
ct2–Ddw1	30.9±6.7	101
ct2–Gai1b	0.0	22, 23
ct2–S2	39.9	50
ct2–Sp1	11.7±3.5	32
ct2–Xpsr426	28 cM	119
Est1–Est2	14.0±2.2	166
Est1–Est5,6,7	25.0±1.5	166
Est1–Est3	26.0±1.8	166
Est1–Ha1	29.0±13.5	166
Est2–Est3	21.0±2.4	166

Linkages

Linked genes	Value of linkage	Reference
Est2–Est5,6,7	14.0±6.4	166
Est2–Ha1	39.0±12.5	166
Est2–Sp1 syn Vnr	5	169
Est2–Xiag167	8	169
Est3–Est5,6,7	0.0	166
Est5,6,7–Xiag10	27	169
Ha1–Sp1	32.3	154
Ha1–wa2	18.8	111
Ha1–Xiag10	26	169
Ibf1–Xpsr120(1)	7 cM	89
Ibf1–Xpsr426	13 cM	89
Sp1–Xpsr120(I)	18 cM	119
Sp1–Xpsr426	8 cM	119
Xiag23–Xiag167	13	169
Xiag23–Xiag200	18	169
Xksu8–Xpsr120(3)	19 cM	89
Xksu8–Xpsr360	15 cM	89
Xksu8–Xksu26	19 cM	89
Xksu26–Xpsr120(1)	16 cM	89
Xpsr81–β-amy1	6 cM	89
Xpsr81–Xpsr1426	15 cM	89
Xpsr120(1)–Xpsr120(3)	16 cM	89
Xpsr120(I)–Xpsr806	11 cM	119
Xpsr120(2)–Xpsr360	0.3 cM	119
Xpsr120(2)–Xpsr120(4)	4 cM	89
Xpsr120(4)–Xpsr360	4 cM	89
Xpsr360–Xpsr906	0.2 cM	119
Xpsr806–Xpsr906	26 cM	119

Chromosome 6R

Gene location	Gene	Reference
6RS	*Alt1*	4
	Amp1 syn Lap1	18, 139, 157
	co	107
	wh	32
6RL	*Aadh2 syn Adh3–leaf*	7, 18, 53, 139
	Aat2–leaf syn Got2(3)	18, 133, 139, 157, 166
	Aco2(1)	27, 166
	α-Amy1–malt	2
	α-Amy1-1-1	94
	α-Amy1-1-2	94
	α-Amy1-2	94
	Cre1	8
	Dia1	166, 167
	Est6–endosperm	18, 136
	Est7–endosperm	136
	Est8–endosperm	18, 136, 139
	Est9–endosperm	136
	Est10–endosperm	139
	Est13–endosperm	139
	Est6–leaf	136
	Est7–leaf	136
	Est8–leaf	136, 166
	Est9–leaf	136, 166
	Est10–leaf	136
	EstA–leaf	7, 76
	gd	104
	H2	43
	Ha3	104
	Ep1–leaf	18, 34, 139
	Ndh3 'Imperial', 'King II'	87
	Per1–scutellum syn Cpxs1, 'Imperial', 'King II'	131
	Per2–scutellum syn Cpxs2, 'Imperial', 'King II'	131
	Pgd2–leaf syn Pgd1b	18, 121, 130, 166
	Pgd2–seeds	58
	Pm5	82, 107
	Reg	107, 125
	Rog	107
	Yr3	107
	Xα-Amy1-1-1	94
	Xα-Amy1-1-2	94
	Xα-Amy1-2	94
	Xpsr106(2)	94
	Xpsr149	94
	Xpsr154	94
6R	*an1-6R*	101
	Anu	160
	β-Gal1	169
	Cbt1	33
	dw7	56, 101
	Est6	62
	Est11–leaf	169
	ms3	102
	Per–embryo	18
	Pro	37
	RNAase1	169
	rr	56
	Sec6	37
	Sf4	105, 106
	Xiag111	169

Gene order

Aco1–Dia1–Est8	167
Amp1–centromere–Aco1, Est8–Est6–Ep1	18

Linkages

Linked genes	Value of linkage	Reference
Aat2(3)–Aco2(1)	18	169
Aco2–Amp1	33.7±3,8	18
Aco2(1)–β-Gal1	9	169
Aco2–Dia1	16.0±3.8	166, 167
	29.0±4.1	166
Aco2–Est6	30.4±4.1	18
Aco2–Est8	33.0±3.7	166, 167
	29.6±4.1	18
Aco2(1)–RNAase1	11	169
β-Gal1–Dia1	8	169
Dia1–Est8/9	8±2.7	167
Dia1–Est8/9	22.0±1.6	166, 167, 169
Est6–Ep1	30.7±3.6	18
Est6–Est8	0.5±0.5	18
Est8–Ep1	31.3±3.6	18
Est8–Est12	0.3±0.3	16
Est8/9–Est11	10	169
Est11–Xiag111	16	169
EstA–Ep1	9.9±2.0	75

Linkages

Linked genes	Value of linkage	Reference
Xα-Amy1-2–Xα-Amy1-1-1		
	3 cM±1.0	94
Xα-Amy1-2–Xpsr149		
	15 cM	94
Xα-Amy1-1-1–Xpsr154		
	17 cM	94
Xpsr154–Xpsr106(2)		
	27 cM	94

Chromosome 7R

Gene location	Gene	Reference
7RS	*Acp2–embryo syn phs2*	132
	Acp3–embryo syn phs3	132
	Acp4–embryo syn phs4	132
	Acp6–embryo syn phs6	132
	Acp3–endosperm syn eph3	132
	Acp4–endosperm syn eph4	132
	Acp5–endosperm syn eph5	132
	Acp7–endosperm syn phe7	132
	Acp8–endosperm syn phe8	132
	Acp9–endosperm syn phe9	132
	Acp2–leaf syn phlr1, Phos2	132, 162, 166
	Acp3–leaf syn phlr3, Phos3	132, 162, 166
	Acp4–leaf syn phlr8	132, 166
	Alp2	40
	Alp4	40
	Alp5	40
	Ndh2 'Imperial', 'King II'	87
	Per5–endosperm syn Cpxe5	131
	Per6–endosperm syn Cpxe6	131
	Sec5	37, 116
	Wsp	88
7RL	*Aat1–leaf syn Got1(2)*	122, 133, 157, 166
	Acp1–embryo syn sph1	132
	Acp1–leaf syn cPh1	132, 139, 157, 166
	Adk1 'Imperial', 'King II'	17
	α-Amy2–green	2
	α-Amy2-1	94
	α-Amy2-2	94
	α-Amy5–green	134
	an1-7R	32, 101
	ct1	32, 101
	Ep1	53, 71
	Gai1a	22, 23
	Gai1b	22, 23
	Ner2	124
	Xα-Amy2-1	94
	Xα-Amy2-2	94
7R	*An1-7R*	101
	an2	153
	Cbt2	33
	Ddw2 syn Dw2	101
	Dnr4	114
	Per2–endosperm syn LPer2	19
	Per4–endosperm syn LPer4	19
	Per5–endosperm syn LPer5	19
	Per6–endosperm syn LPer6	19
	wa1	101
	XEmbp-2R	31
	XFed	28
	Xiag85	169
	Xiag111	169
	XPepc	89
	Xpsr65	89
	Xpsr104	89
	Xpsr115	89
	Xpsr117	89
	Xpsr129	89
	Xpsr157	89
	Xpsr163	89
	Xpsr169	89
	Xpsr580	89

Gene order

Alp2–Alp4–Alp5	40
Acp1–Aat1–Acp2	166
Acp1–Alp2–Alp3–Alp5	39

Linkages

Linked genes	Value of linkage	Reference
Aat1–Acp1	0.0±0.0	167
	5.0±2.4	166, 167
Aat1–Alp2	6.0±2.6	166, 167
Aat1–an1-7R	9.1±1.4	122
Aat1(Got2)–Xiag85	9	169
Acp1–Acp2	8.0±3.1	166, 167
Acp1–Alp2	20.0±8.9 cM	39
	6.9±4.7 cM	39
Acp1–Alp3	19.1±4.8 cM	39
Acp2–Acp3	0.0	166, 167
	25.0±5.2	162
Alp2–Alp4	9.5±3.7	40
Alp2–Alp5	21.9±0.1	40
	34.4±8.4 cM	39
Alp4–Alp5	11.0±0.1	40
an1-7R–an2	5.7	153
an1-7R–ct1	0.0	32
ct1–wa1	40.0±6.0	101
Ddw2–wa1	32.6±5.1	101
EPer2–EPer4	17.8±3.6	19, 44
	13.8±7.6	44
EPer2–EPer5	1.0±7.1	19, 44
	10.3±5.3	44
EPer2–EPer6	1.0±8.3	19, 44
EPer4–EPer5	4.7±3.0	19, 44
EPer4–EPer6	15.8±8.0	19, 44
EPer5–EPer6	2.8±0.7	19, 44
EstA–Ep1	9.9±2.0	76
Xα-Amy2-1–Xα-Amy2-2		
	5 cM±2.0	94
Xiag85–Xiag111	5	169
Xpsr115–Xpsr580	24.6±3.8 cM	89

Genes without localization

Gene	Referene	Gene	Reference
asc	120	*lu syn cl*	36
au	24	*on*	74
Be syn firm	161	*or*	110
Bg	13	*pe*	148
bn	155	*re*	148
bs syn br	148	*rs*	117
De syn N	148	*sl syn sp*	148
dr syn sr	155	*td*	149
Er	161	*vi syn vt*	24
Fr	163	*wg syn es*	148
Hg syn V	148	*whg*	147
la	73	*xa*	113

Linked genes without localization

Linked genes	Value of linkage	Reference
EPer3–EPer5	1.0 ± 10.0	44
EPer4–EPer5	10.8 ± 3.5	44
SPer5–SPer6	11.5 ± 4.2	19
Xiag23–Xiag27	8	169
Xiag27–Xiag120	6	169
Xiag27–Xiag32	3	169
Xiag32–Xiag170	9	169

Summary of symbols

Aat syn Got	Aspartate aminotransferase
Aco	Aconitase
Acp	Acid phosphatase
Adh syn Aadh	Alcohol dehydrogenase/ aromatic alcohol dehydrogenase
Adk	Adenylate kinase isomerase
al syn el	Absent ligule
Alp	Alkine phosphatase
Alt	Aluminium tolerance
Amp syn Lap	Aminopeptidase
Amy	Amylase
I(Amy)	Amylase inhibitor
an1	Anthocyaninless
an2	Anthocyaninless leaf base
An1	Anthocyanin (green seeds)
An3,4,6	Anthocyanin (purple seeds)
An5	Anthocyanin (purple leaf base)
Anu	Antinutritive component
I(as) syn Si syn Asi	α-amylase/subtilisin inhibitor
asc	Asynaptic chromosome pairing
au	Aurea
Be syn firm	Brittle ear
bg	Brown glumes
bn	Bent lowest internode
br	Brittle stem
bs syn br	Branched stem
Cat	Catalase
Cbt	Carnal bunt resistance
Ce	Copper efficiency
Co	Corroded
P(cp)	Homoeologous pairing promotor
Su(cp)	Homoeologous pairing supressor
Cre	Resistance to *Heterodera avenae*
ct	Short straw mutant (compact spike)
CTer	Terminal DNA sequence, terminal locus probe DNA clone pSchet
Ddw	Dominant dwarf
De syn N	Dark ear
Dia	Diaphorase
Dnr	Resistance to *Diuraphis noxia* (Mordvilko)
dr syn sr	Secondary root system defective
dw	Dwarf
Ep	Endopeptidase
Er	Early ripening
Est	Esterase
I(et)	Major endosperm trypsin inhibitor
Fr	Fusarium resistance
fs	Fine stripe
fv	Flavovirescent
Gai	Gibberellic acid insensitivity
Gal	Galactosidase
Gbr	Green bug resistance
gd	Grass dwarfness
Gdh	Glutamate dehydrogenase
Glu	β-glucosidase
Gpd	Glucose-6-phosphate dehydrogenase
Gpi syn Pgi	Glucose phosphate isomerase
gr	Grassy plant habit
Ha syn Hp syn Hs	Hairy leaf sheath/peduncle
H	Hessian fly resistance
Hg syn V	Hairy glume
Hma	3-hydroxymugineic acid synthetase
Ibf	Iodine binding factor
la	Leafy awn
Ldh	Lactate dehydrogenase
lg	Light-green leaf color
Lr	Leaf rust resistance
lu syn cl	Lutescent
Lys	Lysine
Mal	Malic enzyme
Mas	Mugineic acid synthetase
Mdh	Malate dehydrogenase
Me	Manganese efficiency
mo	Monstrous growth habit
ms	Male sterility
Nar	Nitratreductase
Nca	Neocentric activity
Ndh	NADH dehydrogenase
Ner	Hybrid necrosis
Nor	Nucleolar organizer region
ol	Onion accrected leaves
or	Orange
Pc	Purple culm
pe	Perennial growth habit
Per	Peroxidase
Pgd	6-Phosphogluconate dehydrogenase
Pgm	Phosphoglucomutase
Pm	Powdery mildew resistance
Pr3	55-k-seed protein
Pro	Proline
Ps	Purple seeds
rd	Reed growth habit
re	Reduced ear
Reg	Red grain
Rf	Male sterility restorer
RNAse	RNAse
Rog	Round grain
rr	Red rachis

rs	Reduced seed set
S syn Z	Self-incompatibility
Sec	Secalin
Sf	Self-fertility
Skd	Shikimate dehydrogenase
sl syn sp	Spreading leaf
Sod	Superoxide dismutase
Sp syn Vnr	Spring growth habit
Sr	Stem rust resistance
Ssp	Salt-soluble protein
td	Disturbed tetrade formation
tg	Tulip growth habit
Thi	Thionin
ti	Tigrina
Tpi	Triose phosphate isomerase
Tyr	Tyrosinase
va	Viridoalbina
vb	Viridis
vi syn vt	Virescent
wa	Waxless plant
wg syn es	Waxless glume
wh	White
whg	White glume
Wms	Wheat streak mosaic virus resistance
Wsp	Water-soluble proteins
xa	Xantha
XAdh	DNA clone p3NTR, function: untranslated region of *Adh1A*, copy number: 1
Xα-Amy1	cDNA clone of wheat gene *α-Amy1* (AMY-46)
Xα-Amy2	cDNA clone of wheat gene *α-Amy*2 (AMY-4848)
Xα-Amy3	cDNA clone of wheat gene *α-Amy*3 (AMY-33)
Xβ-Amy	cDNA clone pc βc51 of barley
Xcs...	DNA clones
XEm1	DNA clone p1015, function: early-methionine-labelled polypeptide, copy number: 3
XEmbp	cDNA clone pGC19, function: bZIP protein
XFed	Ferredoxin
XGlu3	DNA clone pTag544, function: low-molecular-weight glutenin, copy number: 1
Xiag...	DNA clones
Xksu8, 26	gDNA clones
XLec1	DNA clone PNVRI, function: lectin, copy number: 4
XNor1	DNA clone pTA71, function: ribosomal DNA, copy number: multiple
XPgk1	DNA clone P7, function: chloroplast phosphoglycerate kinase, copy number: 1
XPpdk1	DNA clone PPDK4, function: pyruvate orthophosphate dikinase, copy number: 1
Xpsr81, 106, 115, 120, 149, 154, 158, 159, 161, 168	cDNA clones, copy number: 1
Xpsr360, 325, 330, 391, 393, 426, 580	gDNA clones, copy number: 1
XSec1a	DNA clone pTag1436, function: gamma-gliadin, copy number: 3
XSec3	DNA clone pTag1290, function: high-molecular-weight glutenin, copy number: 2
XTri	DNA clone
Yr	Yellow rust resistance
ys	Yellow stripe

References

1. Ainsworth CC, Miller TE, Gale MD (1986) The genetic control of grain esterases in hexaploid wheat 2. Homoeologous loci in related species. Theor Appl Genet 72:219–226
2. Ainsworth CC, Miller TE, Gale MD (1987) α-Amylase and β-amylase homoeoloci in species related to wheat. Genet Res 49:93–105
3. Ainsworth CC, Johnson HW, Jackson EA, Miller TE, Gale MD (1984) The chromosomal locations of leaf peroxidase genes in hexaploid wheat, rye and barley. Theor Appl Genet 69:205–211
4. Aniol A, Gustafson JP (1984) Chromosome location of genes controlling aluminium tolerance in wheat, rye and triticale. Can J Genet Cytol 26:7101–7106
5. Appels R, Driscoll CJ, Peacock WJ (1978) Heterochromatin and highly repeated DNA sequences in rye (*Secale cereale* L.) Chromosoma 70:67–89
6. Appels R, Reddy P, McIntyre CL, Moran LB, Frankel OH, Clarke BV (1989) The molecular-cytogenetic analysis of grasses and its application to studying relationships among species of *Triticeae*. Genome 31:122–133
7. Artyomova NV (1982) Chromosomal control of alcohol dehydrogenase, esterase and β-amylase isozymes in different rye cultivars. Genetika 18:661–668
8. Asiedu R, Fisher JM, Driscoll CJ (1990) Resistance to *Heterodera avenae* in the rye genome of triticale. Theor Appl Genet 79:331–336
9. Barber HN, Driscoll CJ, Long PM, Vickery RS (1969) Gene similarity of the *Triticinae* and the study of segmental interchanges. Nature 22:897–898
10. Bartos P, Bares I (1971) Leaf and stem rust resistance of hexaploid wheat cultivars 'Salzmünder', 'Bartweizen' and 'Weique'. Euphytica 20:435–440
11. Bartos P, Stuchlikova E, Kubova R (1984) Wheat leaf rust epidemics in Czechoslovakia in 1983. Cereal Rusts Bull 12:40–41
12. Baum M, Appels R (1991) The cytogenetic and molecular architecture of chromosome 1R – one of the most widely utilized sources of alien chromatin in wheat varieties. Chromosoma 101:1–10
13. Berkner G, Meyer K (1927) Morphologische Studien an Roggenähren aus Anatolien. Z Pflanzenzücht 16:229–245
14. Benito C, Figueiras AM, Gonzalez-Jean MT (1984) Phosphoglucomutase – a biochemical marker for group 4 chromosomes in the *Triticinae*. Theor Appl Genet 69:555–559
15. Benito C, Figueiras AM, Gonzalez-Jean MT, Salinas J (1985) Biochemical evidence of homoeology between wheat and barley chromosomes. Z Pflanzenzücht 94:307–321
16. Benito C, Frade IM, Orellana J, Carrillo JM (1990) Linkage and cytogenetic maps of genes controlling endosperm storage proteins and isozymes in rye (*Secale cereale* L.). Theor Appl Genet 79:347–353
17. Benito C, Gallego FJ, Frade IM, Zaragoza C, Figueiras AM (1990) Chromosomal location of adenylate kinase isozymes in *triticea* species. Theor Appl Genet 79:157–161
18. Benito C, Gallego FJ, Zaragoza C, Frade JM, Figueiras AM (1991) Biochemical evidence of a translocation between 6RL/7RS chromosome arms in rye (*Secale cereale* L.). Theor Appl Genet 82:27–32
19. Benito C, Zaragoza C, Gallego FJ, de la Pena A, Figueiras AM (1991) A map of rye chromosome 2R using isozyme and morphological markers. Theor Appl Genet 82:112–116
20. Bernard M, Autran JC, Joudrier P (1977) Use of biochemical markers to identify rye chromosomes. Ann Amelior Plant 27:355–362

21. Bosch A, Figueiras AM, Gonzalez-Jaen MT, Benito C (1986) leaf peroxidases – a biochemical marker for the group 2 chromosomes in the *Triticinae*. Genet Res 47:103–107
22. Börner A (1990) Genetical studies of gibberellic acid insensitivity in rye (*Secale cereale* L.). Plant Breed 106:53–57
23. Börner A, Melz G (1988) Response of rye genotypes differing in plant height to exogenous gibberellic acid application. Arch Züchtungsforsch 18:71–74
24. Brewbaker H (1926) Studies of self-fertilization in rye. Univ Minn Agric Exp Stn Tech Bull 40
25. Carillo JM, Vazquez YF, Orellana J (1990) Linkage relationships between the loci *Sec1* and *Sec3* in rye (*Secale cereale* L.). Heredity 64:125–131
26. Chang TD (1975) Mapping of the gene for hairy peduncle (*Hp*) on rye chromosome 5R. Can J Genet Cytol 17:127–128
27. Chenicek KJ, Hart GE (1984) Identification and chromosomal locations of aconitase gene loci in *Triticeae* species. Theor Appl Genet 74:261–269
28. Chinoy CN, Devos KM, Bringloe D, Gray JC, Gale MD, Dyer TA (1991) Chromosomal location of the genes for ferredoxin in wheat, barley and rye. Theor Appl Genet 82:1–2
29. Chojecki AJS, Gale MD (1983) Genetic control of glucose phosphate isomerase in wheat and related species. Heredity 49:237–247
30. Chrzastek M, Miazga AD (1988) Studies on the cv 'Grana' wheat lines with the Dankowskie Zlote rye chromosome addition II. An estimate of important qualitative traits. Genet Pol 29:21–26
31. Devos KM, Atkinson MD, Chinoy CN, Guiltinan MJ, Quatrano RS, Gale MD (1991) Chromosomal location and variability in wheat, barley and rye of a wheat gene encoding a bZIP protein (*EmBP-1*). Theor Appl Genet 82:665–667
32. De Vries JN, Sybenga J (1984) Chromosomal location of 17 monogenically inherited morphological markers in rye (*Secale cereale* L.) using the translocation tester set. Z Pflanzenzücht 92:117–139
33. Dhaliwal HS, Multani DS, Singh BB (1987) Identification of rye and barley chromosomes carrying resistance to karnal bunt of wheat (*Neovossia indica*). Cereal Res Commun 15:191–194
34. Drefahl S, Buschbeck R (1991) Gene localization of aspartate aminotransferase and endopeptidase isozymes in wheat and rye using developmental and organ specific patterns. Plant Breed 107:218–225
35. Driscoll CJ, Jensen NF (1963) A genetic method for detecting induced intergeneric translocations. Genetics 48:459–468
36. Dumon AG, Laremans R (1963) De overerning van het chlorofyl bej *Secale cereale* L. Agricultura 11:91–105
37. Evans LE, Scoles DJ (1980) Cytogenetics, plant breeding and agronomy. In: Roz proisvodstvo, chimia i technologia. Moscow, pp 16–36
38. Figueiras AM, Elorrieta MA, Benito C (1989) Association of four isozyme loci with a reciprocal translocation between 1R/4R chromosomes in cultivated rye (*Secale cereale* L.). Theor Appl Genet 78:224–229
39. Figueiras AM, Elorrieta MA, Benito C (1991) Genetic and cytogenetic maps of chromosomes 1R, 4R and 7R in cultivated rye (*Secale cereale* L.). Genome 34:681–685
40. Figueiras AM, Gonzalez-Jaen MT, Benito C (1987) Genetics of rye phosphatases: evidence of a duplication. Theor Appl Genet 73:683–690
41. Figueiras AM, Gonzalez-Jaen MT, Salinas J, Benito C (1985) Association of isozymes with a reciprocal translocation in cultivated rye (*Secale cereale* L.). Genetics 109:177–193
42. Fra-Mon P, Salcedo G, Aragoncillo C, Garcia-Olmedo G (1984) Chromosomal assignment of genes controlling salt-soluble proteins (albumins and globulins) in wheat and related species. Theor Appl Genet 69:167–173
43. Friebe B, Hatchett IH, Sears RG, Gill BS (1990) Transfer of Hessian fly resistance from 'Chaupon' rye to hexaploid wheat via a 2BS/2RL wheat-rye chromosome translocation. Theor Appl Genet 79:385–390
44. Garcia P, Perez de la Vega M, Benito C (1982) The inheritance of rye seed peroxidases. Theor Appl Genet 61:341–351
45. Gertz A, Wricke G (1989) Linkage between the incompatibility locus Z and a β-glucosidase locus in rye. Plant Breed 102:255–259
46. Gomez L, Sanchez Monge R, Salcedo G (1988) Chromosomal location of gene encoding low molecular weight prolamins from rye endosperm. Theor Appl Genet 75:674–678
47. Graham RD (1978) Tolerance of triticale, wheat and rye to copper deficiency. Nature 271:542–543
48. Graham RD (1987) Triticale: A cereal for micro nutrient deficients soils. Int Triticale Topics 1:6–7
49. Graham RD, Pearce DT (1979) The sensitivity of hexaploid and octoploid triticale and their parent species to copper deficiency. Aust J Agric Res 30:791–799
50. Gunkov YP (1985) Linkage of incompatibility genes with certain marker genes in rye. Issled otdalen gibridiz rast, pp 147–152
51. Gustafson PJ, Butler E, McIntyre CL (1990) Physical mapping of a low-copy DNA sequence in rye (Secale cereale). Proc Natl Acad Sci USA 87:1899–1902
52. Hart GE (1978) Chromosomal location of *Adh-R2* and an acid phosphatase structural gene in 'Imperial' rye. Cereal Res Commun 6:123–135
53. Hart GE, Tuleen NA (1983) Introduction and characterization of alien genetic material. In: Tanksley SD, Orton TJ (Eds.) Isozymes in plant genetics and breeding. Elsevier Publ, Amsterdam, pp 103–120
54. Hejgaard J, Björn SE, Nielsen G (1984) Rye chromosomes carrying structural genes for the major grain protease inhibitors. Hereditas 101:257–259
55. Höhler B, Schlegel R, Blüthner WD (1979) Das Muster von Peroxidase Isoenzymen in 1R(1B)-Weizen-Roggen-Substitutions- bzw. 1B-1R Translokationslinien. Biochem Physiol Pflanz 174:838–843
56. Hoppe J (1985) Lokalisierung von Genen beim Roggen (*Secale cereale* L.) mit trisomen Linien der Sorte 'Heines Hellkorn'. PhD thesis. TU Berlin
57. Hossain MA, Driscoll CJ (1983) Fertility compensation of Cornerstone male sterility of wheat by rye. Genetics 104:181–187
58. Hsam SLK, Zeller FJ, Huber W (1982) Genetic control of 6-phosphogluconate dehydrogenase (6-PGD) isozymes in cultivated wheat and rye. Theor Appl Genet 62:317–321
59. Hu CC, Roelfs AP (1986) Postulation of genes for stem rust resistance in 13 Chinese wheat cultivars. Cereal Rusts Bull 14:68–74
60. Irani BN, Bhatia CR (1972) Chromosomal location of alcohol dehydrogenase gene (s) in rye using wheat-rye addition lines. Genetica 43:195–220
61. Jaaska V (1982) Isoenzymes of superoxide dismutase in wheats and their relatives. Alloenzyme variation. Biochem Physiol Pflanz 177:747–755
62. Jouve N, Diaz F (1990) Genetic control of esterase-6 isozymes in hexaploid wheat and rye. Euphytica 47:165–169

63. Kleinhofs A, Chao S, Sharp PJ (1988) Mapping of nitrate reductase genes in barley and wheat. In: Miller TE, Koebner RMD (eds) Proc 7th Int Wheat Genet Symp. Cambridge, pp 541–546
64. Knits TMC van (1986) Mildew of wheat. UK Cereal Pathogen Virulence Survey Annu Rep, pp 7–12
65. Koebner RMD (1986) Introduction into wheat of disease resistance from related species. Annu Rep PBI Cambridge, pp 69–70
66. Koebner RMD (1987) Genetic control of a novel series of tripsin inhibitors in wheat and its relatives. Biochem Genet 25:591–602
67. Koebner RMD (1990) Subtilisin inhibitor – a polymorphic protein produced by a gene on the short arms of wheat homoeologous group 1 chromosomes. J Genet Breed 44:49–52
68. Koebner RMD, Martin PK (1989) Chromosomal control of the aminopeptidase of wheat and its close relatives. Theor Appl Genet 78:657–665
69. Koebner RMD, Shepherd KW (1982) Shikimate dehydrogenase – a biochemical marker for group 5 chromosomes in the *Triticinae*. Genet Res 41:209–213
70. Koebner RMD, Sheperd KW, Appels R (1986) Controlled introgression to wheat of genes from rye chromosome arm 1RS by induction of allosyndesis 2. Characterization of recombinants. Theor Appl Genet 73:209–218
71. Koebner RMD, Miller TE, Snape JE, Law CN (1988) Wheat endopeptidase: genetic control, polymorphism, intrachromosomal gene location and alien variation. Genome 30:186–193
72. Koller OL, Zeller FJ (1976) The homoeologous relationships of rye chromosomes 4R and 7R with wheat chromosomes. Genet Res 28:177–188
73. Kubicka H (1988) New form of winter rye (*Secale cereale* L.) with leaf awns. Simp selek rzhi Tez Dokl Leningrad 27, p 76
74. Kubicka H, Kubicki B (1986) A form of winter rye (*Secale cereale* L.) with onion accreted leaves. Genet Pol 27:213–219
75. Kudryakova NV (1987) Genetic analysis of endopeptidase in rye: Inheritance and chromosomal control. Cytol Genet 21:349–352
76. Kudryakova NV (1987) Mapping of EstA and EstB genes controlling the synthesis of esterase isozyme in rye grains. Soviet Genet 23:1139–1145
77. Kudryakova NV, Khorena VI, Kobylyanski VD, Lapikov NS (1988) Genetics of amylases and resistance of rye to sprouting in the ear. Simp selek. rzhi 4–9 iyulya 1988 Tez Dokl Leningrad 29, p 78
78. Lawrence GJ, Appels R (1986) Mapping the nucleolus oranizer region, seed protein loci and isozyme loci on chromosome 1R in rye. Theor Appl Genet 71:742–750
79. Lawrence GJ, Shepherd KW (1981) Chromosomal location of genes controlling seed proteins in species related to wheat. Theor Appl Genet 59:25–31
80. Leitch IJ, Leitch AR, Heslop-Harrison JS (1991) Physical mapping of plat DNA sequences by simultaneous hybridization of 2 differently labelled florescent probes. Genome 34:329–333
81. Lelley T (1976) Introduction of homoeologous pairing by genes of rye suppressing chromosome 5B effect. Can J Genet Cytol 18:485–489
82. Lind V (1982) Analysis of the resistance of wheat-rye addition lines to powdery mildew of wheat (*Erysiphe graminis* F. *sp. tritici*). Tagungsber Akad Landwirtschaftswiss DDR 198:509–520
83. Lindner A, Melz G, Müller HW, Buschbeck R (1984) Genetic analysis of rye (*Secale cereale* L.). Leaf peroxidase isoenzymes in trisomic and telotrisomics of chromosome 1R. Genet Pol 25:345–348
84. Liu CJ, Gale MD (1988) Three new marker system iodine binding factor (*Ibf1*), malic enzyme (*Mal1*) and malate dehydrogenase (*Mdh3*) in wheat and related species. In: Miller TE, Koebner RMD (eds). Proc 7th Int Wheat Genet Symp. Cambridge, pp 555–560
85. Liu CJ, Gale MD (1989) *Ibf1* (Iodine binding factor) a highly variable marker system in the *Triticeae*. Theor Appl Genet 77:233–240
86. Liu CJ, Gale MD (1970) *Est7*, a set of genes controlling green tissue esterases in wheat and related species. Theor Appl Genet 79:781–784
87. Liu CJ, Gale MD (1991) The chromosomal location of genes encoding NADH dehydrogenase isozymes in hexaploid wheat and related species. Genome 34:44–51
88. Liu CJ, Chao S, Gale MD (1989) *Wsp-1*, a set of genes controlling water-soluble proteins in wheat and related species. Genet Res 54:173–181
89. Liu CJ, Atkinson MD, Chinoy CN, Devos KM, Gale MD (1992) Non-homoeologous translocations between group 4, 5 and 7 chromosomes of wheat and rye. Theor Appl Genet 83:305–313
90. Long EO, Dawid IB (1980) Repeated genes in eukaryotes. Annu Rev Biochem 49:727
91. Luig NH, Watson IA (1976) Strains of *Puccinia graminis* virulent on wheat plants carrying gene *Sr27* derived from 'Imperial' rye. Phytopathology 66:664–666
92. Martin TJ, Harvey TL, Livers RW (1976) Resistance to wheat streak mosaic virus and its vector *Aceria tulipae*. Phytopathology 66:346–349
93. Masojc P (1989) Polimorfizm inhibitora α-amylazy z bielma zyta X. Zjazd Polsk. Tow. Genet Wroclaw, p 211 (Abstr)
94. Masojc P, Gale MD (1991) α-Amylase structural genes in rye. Theor Appl Genet 82:771–776
95. May CE, Appels R (1978) Chromosome 2R substitution and translocation lines in hexaploid wheat. Cereal Res Commun 6:231–234
96. May CE, Wray F (1991) A rapid technique for the detection of wheat-rye translocation chromosomes. Genome 34: 486–488
97. McIntosh RA (1983) A catalogue of gene symbols for wheat (1983 edition). In: Sakamoto S (ed). Proc 6th Int Wheat Genet Symp. Kyoto, Japan, pp 1197–1254
98. McIntosh RA, Hart GE, Gale MD (1991) Catalogue of gene symbols. Annu Wheat Newsl 37:200–216
99. McIntyre CL, Reddy P, Appels R (1988) The *5S-DNA* loci in the *Triticeae*. In: Miller TE, Koebner RMD (eds). Proc 7th Int Wheat Genet Symp. Cambridge, pp 769–773
100. Melz G (1987) Genetical analysis of rye (*Secale cereale* L.). IV. Localization of genes of hairy leaf sheath and hairy peduncles. Genet Pol 28:319–325
101. Melz G (1989) Beiträge zur Genetik des Roggens (*Secale cereale* L.) PhD thesis, B, Berlin
102. Melz G (1991) Genetic analysis of rye (*Secale cereale* L.). Genetics of male sterility of the G-type. Theor Appl Genet 82:761–764
103. Melz G (unpublished)
104. Melz G, Dill P (1988) Genetic analysis of rye (*Secale cereale* L.). Genetics and location of the genes *gd* and *Ha3* of the mutant 'grass dwarfness'. Arch Züchtungsforsch 18:363–367
105. Melz G, Kaczmarek J, Szigat G (1989) Genetical analysis of rye (*Secale cereale* L.). Location of self-fertility genes in different inbred lines. Genet Pol 31:1–7

106. Melz G, Melz GU, Winkel A (1987) Genetic analysis of rye (*Secale cereale* L.). 3. Self-fertility of the mutant 'vd'-Inheritance and gene location. Genet Pol 28:1–8
107. Miller TE (1984) The homoeologous relationship between the chromosomes of rye and wheat. Can J Genet Cytol 26:578–589
108. Miller TE, Reader SM, Gale MD (1983) The effect of homoeologous group 3 chromosomes on chromosome pairing and crossability in *Triticum aestivum*. Can J Genet Cytol 25:634–641
109. Mori S, Kishi-Nishizawa N, Fujigaki J (1990) Identification of rye chromosome 5R as a carrier of the genes for mugineic acid synthetase and 3-hydroxymugineic acid synthetase using wheat-rye additions. Jpn J Genet 65:343–352
110. Müntzing A (1963) A case of preserved heterozygosity in rye in spite of long continued inbreeding. Hereditas 50:347–413
111. Nalepa S (1983) A genetical investigation of hexaploid triticale. III. The inheritance of some characters in hexaploid triticale and linkage between them. Hodowla Rosl Aklim Nasienn 27:39–50
112. Neuman PR, Hart GE (1984) Genetic control of the mitochondrial form of superoxide dismutase in hexaploid wheat. Biochem Genet 24:435–446
113. Nilson-Ehle (1913) cited by Laube W, Quadt F (1959) Roggen (*Secale cereale* L.). In: Handbuch der Pflanzenzüchtung, vol 3, 2nd edn. P. Parey, Berlin Hamburg, pp 68
114. Nkongolo KK, Quick JS, Peairs FB, Meyer WL (1990) Gene location for Russian aphid resistance of 'Imperial' rye using wheat-rye addition lines. Cereal Res Commun 18:307–313
115. O'Mara JG (1951) Cytogenetic studies in triticale. II. The kinds of intergeneric chromosome addition. Cytologia 16:225–232
116. Owen MRL, Larter EN (1983) The effect of telomeric heterochromatin on prolamin (secalin) synthesis in inbred *Secale cereale* L. Agron Abstr 74–75
117. Pammer G (1905) Über Veredlungszüchtung mit einigen Landsorten des Roggens in Niederösterreich. Z Landwirtsh Versuchsw Österreich 8:1015–1053
118. Pietro ME, Hart GE (1985) The genetic control of triose phosphate isomerase of hexaploid wheat and other *Triticeae*. Genet Res 45:127–142
119. Plaschke J, Börner A, Koebner R, Schlegel R, Gale MD (1992) RFLP markers for mapping of genes affecting growth habit and plant height in rye. In: Book of Poster Abstracts, XIII Eucarpia Congr. Angers, pp 713–715
120. Prakken R (1943) Studies of asynapsis in rye. Hereditas 29:475–495
121. Rao IN, Rao PVM (1980) Evidence for duplicated genes coding for 6-phosphogluconate dehydrogenase in rye. Genet Res 35:309–312
122. Rebordinos L, Perez de la Vega M (1988) Gene duplication in the structural gene for a glutamate oxaloacetate transaminase zone (*Got1*) in *Secale*. J Hered 79:78–80
123. Reddy P, Appels R (1989) A second locus for the 5s multigene family in *Secale* L.: sequence divergence in two lineages of the family. Genome 32:456–467
124. Ren ZL, Lelley T (1990) Chromosomal location of genes in the R genome causing hybrid necrosis in rye and triticale. Genome 33:40–43
125. Riley R, Chapman V (1958) The production and phenotypes of wheat-rye chromosome addition lines. Heredity 12:301–315
126. Riley R, Macer RFC (1966) The chromosomal distribution of genetic resistance of rye to wheat pathogens. Can J Genet Cytol 8:640–653
127. Riley R, Chapman V, Miller TE (1973) The determination of meiotic chromosome pairing. In: Sears ER, Sears LMS (eds). Proc 4th Int Wheat Genet Symp. Univ Missouri, Columbia, Mo., pp 731–738
128. Romanova NP (1982) Ispolsovanie metoda opredelenija zeplenija faktorov samenesovmestimosti morfologitscheskimi markerami u rzi. Sesd Vsesoj Obsch Genetikov i Selek Kishinev 4, p 142
129. Sadowski J, Daussant J (1988) Application of immunoblotting for chromosomal localization of non-enzymatic protein structural genes: α-amylase inhibitor gene of rye. Genet Pol 29:281–285
130. Salinas J, Benito C (1983) Chromosomal location of genes controlling 6-phosphogluconate dehydrogenase, glucose-6-phosphate dehydrogenase and glutamate dehydrogenase isozymes in cultivated rye. Euphytica 32:783–790
131. Salinas J, Benito C (1983) Chromosomal location of peroxidase structural genes in rye (*Secale cereale* L.). Z Pflanzenzücht 93:291–309
132. Salinas J, Benito C (1984) Phosphate isozymes in rye. Genetic control and chromosomal location. Z Pflanzenzücht 93:115–137
133. Salinas J, Benito C (1985) Chromosomal locations of phosphoglucomutase, phosphoglucose isomerase and glutamate oxaloacetate transaminase structural genes in different rye cultivars. Can J Genet Cytol 27:105–113
134. Salinas J, Benito C (1985) Chromosoml location of α-amylase structural genes in rye (*Secale cereale* L.). Experientia 41:1180–1181
135. Salinas J, Benito C (1985) Chromosomal location of malate dehydrogenase structural genes in rye (*Secale cereale* L.). Z Pflanzenzücht 94:208–218
136. Salinas J, Benito C (1985) Esterase isozymes in rye – Characterization, genetic control and chromosomal location. Theor Appl Genet 71:136–140
137. Sanchez-Monge R, Delibes A, Hernandez-Lucas C, Carbonero P, Garcia-Olmedo F (1979) Homoeologous chromosomal location of the genes encoding thionins in wheat and rye. Theor Appl Genet 54:61–63
138. Schlegel R (1987) Neocentric activity in chromosome 5R of rye revealed by haploidy. Hereditas 107:1–6
139. Schmidt JC, Seliger P, Schlegel R (1984) Isoenzyme als biochemische Markerfaktoren für Roggenchromosomen. Biochem Physiol Pflanz 179:197–210
140. Sharp PJ, Kreis M, Shewry PR, Gale MD (1988) Location of β-amylase sequences in wheat and its relatives. Theor Appl Genet 75:286–290
141. Shepherd KW, Jennings AG (1971) Genetic control of rye endosperm protein. Experientia 27:88–98
142. Shewry PR, Bradberry D, Franklin J, White RP (1985) The chromosomal locations and linkage relationships of structural genes for the prolamin storage proteins (secalins) of rye. Theor Appl Genet 69:63–71
143. Shilko TS, Kedrov-Zichman OO (1982) The linkage group of the pseudonormal trisomic of winter rye. Sesd Vsesoj Obsch Genetikov i Selek Kishinev 4:267 (in Russian)
144. Singh NK, Shepherd KW (1984) Mapping of the genes controlling high-molecular-weight glutelin subunits of rye on the long arm of chromosome 1R. Genet Res 44:117–123
145. Singh NK, Shepherd KW, McIntosh RA (1990) Linkage mapping of genes for resistance to leaf, stem and stripe rusts and omega-secalins on the short arm of rye chromosome 1R. Theor Appl Genet 80:609–616
146. Singh SJ, McIntosh RA (1990) Linkage and expression of genes for resistance to leaf rust and stem rust in triticale. Genome 33:115–118

147. Sirks MJ (1929) Über einen Fall vererbbarer Lichtempfindlichkeit des Chlorophylls beim Roggen (*Secale cereale* L.). Genetica 11:375–386
148. Smirnov WG, Sosnichina SP (1984) Genetika rzi. University report, Leningrad
149. Sosnichina SP, Smirnov WG, Sabirova ER (1980) Genetic control of chromosome behaviour in meiosis in diploid rye, *Secale cereale* L. – Inbred lines. Genetika 16:677–683
150. Sturm W, Engel KH (1980) Trisomenanalyse des Alles *HI* für Kurzstrohigkeit bei *Secale cereale* L. Arch Züchtungsforsch 10:31–35
151. Sturm W, Müller HW (1982) Localization of the recessive gene of the Moscow dwarf mutant short-stalk character in *Secale cereale* L. Citol i Genet Kiev 16:13–17
152. Sturm W, Neumann H, Melz G (1981) Trisomenanalyse für das Merkmal Anthocyanfärbung bei *Secale cereale* L. Arch Züchtungsforsch 11:49–53
153. Surikov IM (1971) Inheritance of two chlorophyll aberrations in rye. Tr Prikl Bot Genet Sel Ser 2 46:122–130 (in Russian)
154. Surikov IM, Romanova NP (1978) A contribution to factoral genetics of rye. *Secale cereale* L. II. Inheritance of differences in such characters as pubescence of leaf sheath and winter or spring habit of growth. Genetika 14:397–405 (in Russian)
155. Sybenga J, Prakken R (1962) Gene analysis in rye. Genetica 33:95–105
156. Sybenga J, Parmar S, van Eden J, Shewry P (1990) Mapping seed storage protein loci *Sec1* and *Sec3* in relation to five chromosomal rearrangements in rye (*Secale cereale* L.). Theor Appl Genet 79:201–208
157. Tang KS, Hart GE (1975) Use of isozymes as chromosome markers in wheat-rye addition lines and triticale. Genet Res 26:187–201
158. Tanner DG, Reinbergs E (1982) Genetic analysis of the trypsin inhibitor activity of triticale and rye. Z Pflanzenzücht 88:177–185
159. Thiele V, Melz G (1991) Chromosomal location of genes controlling lactate dehydrogenase in rye, wheat and barley. Genome 35:32–34
160. Thiele V, Melz G, Flamme W (1989) Genetic analysis of rye (*Secale cereale* L.). Location of gene *Anu* controlling an anti-nutritive factor. Arch Züchtungsforsch 19:239–242
161. Tschermak E (1906) Über Züchtung neuer Getreiderassen mittels künstlicher Kreuzung. II. Kreuzungsstudien an Roggen. Z Landwirtsch Versuchsw Österreich 9:699–743
162. Vaquero F, Rebordinos L, Vences FJ, Perez de la Vega M (1990) Genetic mapping of isozyme loci in *Secale cereale* L. Theor Appl Genet 80:88–94
163. Veselovski V (1971) Resistenzzüchtung des Roggens gegen Schneeschimmel. Genet a Slecht 7:11–18
164. Viinikka Y (1985) Identification of the chromosomes showing neocentric activity in rye. Theor Appl Genet 70:66–77
165. Wang ML, Atkinson MD, Chinoy CN, Devos KM, Harcourt RL, Liu CJ, Rogers WJ (1991) RFLP-based genetic map of rye (*Secale cereale* L.). Chromosome 1R. Theor Appl Genet 82:174–178
166. Wehling P (1986) Genetische Analyse und chromosomale Lokalisation von Isoenzymloci beim Roggen. PhD thesis, University of Hannover
167. Wehling P (1991) Inheritance, linkage relationship and chromosomal localization of the glutamate oxaloacetate transaminase, acid phosphatase and diaphorase isozyme genes in *Secale cereale* L. Theor Appl Genet 82:569–576
168. Wood EA, Sebesta EE, Starks KJ (1974) Resistance of 'Gaucho' triticale to *Schizaphis graminum*. Environ Entomol 3:720–721
169. Wricke G (1991) A molecular marker linkage map of rye for plant breeding. Vortr Pflanzenzücht 20:72–78
170. Wricke G, Wehling P (1985) Linkage between an incompatibility locus and a peroxidase isozyme locus (*Prx7*) in rye. Theor Appl Genet 71:289–292
171. Zeller FJ (1972) Cytogenetics of some rust resistant wheat cultivars. In: Proc Eur Med Cereal Rust Conf. Prague, pp 297–301
172. Zeller FJ (1973) 1B/1R wheat-rye chromosome substitutions and translocations. In: Sears ER, Sears LMS (eds). Proc 4th Int Wheat Genet Symp. Univ Missouri, Columbia, Mo., pp 209–221
173. Zeller FJ, Koller OL (1981) Identification of a 4A/7R and a 7B/4R wheat-rye chromosome translocation. Theor Appl Genet 59:33–37
174. Zeven AC (1972) Identification of chromosome carrying a locus for a gene conditioning the production of tyrosinase. Wheat Inf Serv 35:3–8