Molecular breeding

Using the UK reference population Avalon×Cadenza as a platform to compare breeding strategies in elite Western European bread wheat

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Table S1 GY QTL detected by multi-environment QTL analysis in the Avalon×Cadenza DH population

QTL locus	Position	Flanking markers	LOD	PVE (%)	PVE(A)	PVE(AbyE)	Add	AbyE_05	AbyE_06	AbyE_07	AbyE_08
qGY-psr-1A	10	*BS00064205-Tagluten*	6.77	2.74	2.72	0.02	-0.19	0	0.01	-0.02	0.01
qGY-psr-1D.1	2	*BS00011947-BS00126040*	3.86	1.69	1.24	0.45	0.13	-0.05	-0.07	-0.01	0.13
qGY-psr-1D.2	6	*BS00113456-BS00158980*	4.28	1.76	1.27	0.49	0.13	-0.07	-0.06	0	0.13
qGY-psr-2A.1	40	*BS00011593-BS00094817*	8.53	3.46	3.39	0.07	0.21	-0.04	0.04	-0.02	0.01
qGY-psr-2A.2	155	*BS00032383-BS00091763*	5.49	2.05	1.98	0.07	0.16	0.04	0.01	-0.03	-0.02
qGY-psr-2B	184	*BS00070104-BS00004405*	3.31	1.4	1.11	0.28	-0.12	0.05	0.06	-0.07	-0.04
qGY-psr-2D.1	36	*gwm261-BS00043985*	35.21*	14.53	10.44	4.08	-0.37	-0.3	0.32	0.08	-0.09
qGY-psr-2D.2	60	*BS00147940-BS00022210*	3.84	1.95	0.77	1.17	-0.1	0.07	-0.21	0.07	0.08
qGY-psr-3A.1	73	*cfd79A-BS00022029*	4.59	1.79	1.12	0.67	-0.12	-0.02	0.03	-0.13	0.12
qGY-psr-3A.2	87	*BS00039925-BS00022631*	8.35	3.8	2.9	0.91	-0.19	0.08	0.12	-0.07	-0.14
qGY-psr-3B.1	86	*BS00059416-BS00111311*	3.4	1.28	1.17	0.12	0.12	0.04	0.02	0.01	-0.07
qGY-psr-3B.2	188	*BS00100706-BS00003596*	9.6	3.49	3.14	0.35	0.2	0.11	-0.06	0	-0.05
qGY-psr-4A	0	*BS00010582-BS00064269*	5.54	2.39	1.91	0.49	0.16	-0.05	-0.1	0.08	0.07
qGY-psr-4B.1	16	*BS00022055-BS00012006*	3.61	1.37	1.1	0.27	-0.12	-0.01	0.07	-0.09	0.03
qGY-psr-4B.2	41	*BS00002637-BS00074787*	3.02	1.22	0.38	0.84	-0.07	-0.06	0.18	-0.07	-0.06
qGY-psr-4D	0	*BS99999968-BS00108601*	3.94	1.46	1.14	0.32	-0.12	-0.04	0.11	-0.01	-0.05
qGY-psr-5D	182	*BS00067650-BS00179234*	6.08	2.8	2.43	0.37	0.17	-0.04	0.11	-0.07	0

PVE: phenotypic variation explained by the QTL; PVE (A): phenotypic variation explained by additive effect; PVE (AbyE): phenotypic variation explained by additive by environment effect; Add: additive effect; AbyE_05: additive effect of QTL in 2005; AbyE_06: additive effect of QTL in 2006; AbyE_07: additive effect of QTL in 2007; AbyE_08: additive effect of QTL in 2008.

Asterisk (*) means QTL by environment effect is significant.

Table S2 TGW QTL detected by multi-environment QTL analysis in the Avalon ×Cadenza DH population

QTL locus	Position	Flanking markers	LOD	PVE (%)	PVE(A)	PVE(AbyE)	Add	AbyE_07	AbyE_08
qTGW-psr-1D	20	*BS00130675-BS00022633*	3.62	1.76	1.44	0.32	-0.65	0.31	-0.31
qTGW-psr-2A	78	*BS00052043-BS00011945*	4.62	2.47	2.29	0.18	0.82	-0.23	0.23
qTGW-psr-3B	39	*BS00037871-wmc326*	4.15	4	3.22	0.78	0.97	0.48	-0.48
qTGW-psr-4B.1	0	*BS00023204-BS00023051*	4.31	5.18	2.88	2.3	-0.92	-0.82	0.82
qTGW-psr-4B.2	30	*BS00012006-BS00100151*	6.48	3.6	3.43	0.16	-1	0.22	-0.22
qTGW-psr-4D	25	*BS00099053-BS99999977*	4.53	3.69	3.45	0.24	-1.01	-0.27	0.27
qTGW-psr-5A.1	5	*BS00051181-BS00087453*	17.56*	10.78	10.1	0.68	-1.72	0.45	-0.45
qTGW-psr-5A.2	108	*BS00041063-BS00105208*	7.89	5	4.99	0.01	1.21	-0.05	0.05
qTGW-psr-5B	160	*BS00003637-gwm408*	3.02	2.43	2.26	0.17	-0.83	-0.23	0.23
qTGW-psr-6A.1	65	*BS00022947-BS00046964*	7.42*	3.55	1.34	2.21	0.63	-0.81	0.81
qTGW-psr-6A.2	80	*bArc171-BS00011034*	5.46	6.66	3.35	3.32	0.99	0.99	-0.99

PVE: phenotypic variation explained by the QTL; PVE (A): phenotypic variation explained by additive effect; PVE (AbyE): phenotypic variation explained by additive by environment effect; Add: additive effect; AbyE_07: additive effect of QTL in 2007; AbyE_08: additive effect of QTL in 2008.

Asterisk (*) means QTL by environment effect is significant.

Table S3 GN QTL detected by multi-environment QTL analysis in the Avalon×Cadenza DH population

QTL locus	Position	Flanking markers	LOD	PVE (%)	PVE(A)	PVE(AbyE)	Add	AbyE_07	AbyE_08
qGN-psr-1A	11	*BS00064205-Tagluten*	5.08	3.76	3.75	0.01	-495.87	-21.38	21.38
qGN-psr-1D	6	*BS00113456-BS00158980*	3.6	2.99	2.91	0.08	436.74	70.92	-70.92
qGN-psr-2A	153	*BS00009295-BS00032383*	3.4	2.59	2.57	0.02	411.68	36.3	-36.3
qGN-psr-2D	33	*gwm261-BS00043985*	13.63	11.24	11.11	0.13	-856.47	90.85	-90.85
qGN-psr-3A	95	*wPt-9215-wmc264*	7.16	5.18	4.75	0.44	-558.36	169.33	-169.33
qGN-psr-4A	0	*BS00010582-BS00064269*	3.44	2.47	2.46	0.01	400.7	-27.02	27.02
qGN-psr-4D	39	*BS99999977-BS00107639*	9.66	7.97	7.96	0	725.89	16.28	-16.28
qGN-psr-5A.1	12	*gwm293b-BS00022500*	3.64	2.8	2.74	0.06	422.79	62.54	-62.54
qGN-psr-5A.2	122	*BS00105208-BS00082218*	7.32	5.57	5.33	0.24	-589.87	124.62	-124.62
qGN-psr-6A	87	*BS00010730-BS00038646*	4.85	3.37	2.88	0.49	-435.86	178.97	-178.97
qGN-psr-7A	24	*BS00073988-BS00023207*	4.25	3.82	3.15	0.67	-453.59	-209.28	209.28

PVE: phenotypic variation explained by the QTL; PVE (A): phenotypic variation explained by additive effect; PVE (AbyE): phenotypic variation explained by additive by environment effect; Add: additive effect; AbyE_07: additive effect of QTL in 2007; AbyE_08: additive effect of QTL in 2008.

Table S4 GRW QTL detected by multi-environment QTL analysis in the Avalon ×Cadenza DH population

QTL locus	Position	Flanking markers	LOD	PVE (%)	PVE(A)	PVE(AbyE)	Add	AbyE_07	AbyE_08
qGRW-psr-1D	20	*BS00130675-BS00022633*	4.69	2.54	2.36	0.18	-0.02	0.01	-0.01
qGRW-psr-3D	63	*BS00067163-BS00117841*	3.58	2.36	2.36	0	-0.02	0	0
qGRW-psr-4B.1	0	*BS00023204-BS00023051*	3.88	4.55	2.54	2.01	-0.03	-0.02	0.02
qGRW-psr-4B.2	30	*BS00012006-BS00100151*	5.82	3.15	2.98	0.17	-0.03	0.01	-0.01
qGRW-psr-4D	26	*BS00099053-BS99999977*	4.5	3.76	3.42	0.34	-0.03	-0.01	0.01
qGRW-psr-5A.1	17	*BS00034704-BS00000645*	7.38*	3.87	3.31	0.56	-0.03	0.01	-0.01
qGRW-psr-5A.2	97	*BS00051765-BS00071402*	9.7	5.92	5.82	0.1	0.04	-0.01	0.01
qGRW-psr-6A.1	65	*BS00022947-BS00046964*	8.64*	4.25	1.79	2.45	0.02	-0.03	0.03
qGRW-psr-6A.2	80	*bArc171-BS00011034*	8.08	9.97	4.88	5.08	0.04	0.04	-0.04

PVE: phenotypic variation explained by the QTL; PVE (A): phenotypic variation explained by additive effect; PVE (AbyE): phenotypic variation explained by additive by environment effect; Add: additive effect; AbyE_07: additive effect of QTL in 2007; AbyE_08: additive effect of QTL in 2008.

Asterisk (*) means QTL by environment effect is significant.

Table S5 GRL QTL detected by multi-environment QTL analysis in the Avalon×Cadenza DH population

QTL locus	Position	Flanking marker	LOD	PVE (%)	PVE(A)	PVE(AbyE)	Add	AbyE_07	AbyE_08
qGRL-psr-2A	6	*BS00022024-BS00003735*	4.71	2.07	2.04	0.03	0.04	0.01	-0.01
qGRL-psr-2D	84	*BS00154619-BS00031475*	7.06	3.11	3.1	0.01	0.05	0.00	0.00
qGRL-psr-3A	94	*wPt-9215-wmc264*	19.64	9.07	8.97	0.11	0.09	-0.01	0.01
qGRL-psr-3B	97	*BS00022512-BS00022025*	11.45	4.8	4.71	0.09	0.06	-0.01	0.01
qGRL-psr-4A	22	*wPt-7807-BS00106888*	4.09	1.74	1.73	0.00	0.04	0.00	0.00
qGRL-psr-4B.1	39	*BS00076033-BS00037020*	5.21	1.88	1.27	0.60	-0.03	0.02	-0.02
qGRL-psr-4B.2	59	*BS00022258-BS00021984*	4.27	2.57	1.5	1.07	-0.04	-0.03	0.03
qGRL-psr-5A.1	13	*gwm293b-BS00022500*	43.29	24.89	24.72	0.17	-0.15	-0.01	0.01
qGRL-psr-5A.2	121	*BS00105208-BS00082218*	12.85	6.66	6.59	0.07	0.08	0.01	-0.01
qGRL-psr-5B.1	109	*BS00092630-BS00022542*	4.80*	1.71	0.62	1.09	0.02	-0.03	0.03
qGRL-psr-5B.2	112	*BS00049793-bArc74*	3.95	2.38	1.19	1.19	0.03	0.03	-0.03
qGRL-psr-5B.3	160	*BS00003637-gwm408*	3.51	1.59	1.55	0.04	-0.04	-0.01	0.01
qGRL-psr-6A	154	*BS00011404-cos7Tb*	8.85	3.42	2.85	0.57	-0.05	0.02	-0.02
qGRL-psr-6B	55	*BS00075795-BS00022480*	3.22	1.74	1.23	0.51	0.03	0.02	-0.02
qGRL-psr-7A	3	*BS00023951-BS00022119*	5.4	2.24	2.23	0.02	0.04	0.00	0.00
qGRL-psr-7D	94	*BS00081870-BS00024032*	4.15	1.68	1.67	0.00	-0.04	0.00	0.00

PVE: phenotypic variation explained by the QTL; PVE (A): phenotypic variation explained by additive effect; PVE (AbyE): phenotypic variation explained by additive by environment effect; Add: additive effect; AbyE_07: additive effect of QTL in 2007; AbyE_08: additive effect of QTL in 2008.

Asterisk (*) means QTL by environment effect is significant.

Table S6 PH QTL detected by multi-environment QTL analysis in the Avalon×Cadenza DH population

QTL name	Position	Flanking markers	LOD	PVE (%)	PVE(A)	PVE(AbyE)	Add	AbyE_05	AbyE_06	AbyE_07	AbyE_08
qPH-psr-1A.1	65	*BS00003851-BS00080438*	6.13	1.2	1.12	0.08	1.15	-0.26	0.48	0.05	-0.28
qPH-psr-1A.2	69	*I-10-2W1-BS00022172*	6.38	1.26	1.16	0.09	1.17	-0.3	0.52	0.06	-0.28
qPH-psr-1B.1	24	*BS00022030-BS00024037*	3.36	0.59	0.56	0.04	0.81	0.25	-0.01	-0.31	0.07
qPH-psr-1B.2	43	*BS00022648-BS00022324*	6.28	1.09	0.98	0.11	1.08	0.28	-0.08	-0.57	0.37
qPH-psr-1B.3	61	*BS00095568-BS00076504*	6.25	1.09	0.94	0.15	1.06	0.2	-0.13	-0.6	0.53
qPH-psr-1B.4	76	*BS00022779-BS00022626*	5.31	0.92	0.81	0.11	0.99	0.35	-0.23	-0.47	0.36
qPH-psr-1B.5	83	*BS00010436-BS00012029*	5.58	0.97	0.84	0.12	1.01	0.3	-0.43	-0.32	0.46
qPH-psr-2A.1	44	*BS00094817-BS00070798*	21.53	4.42	4.22	0.2	2.23	0.1	0.57	0.1	-0.76
qPH-psr-2A.2	121	*wmc181A-BS00024921*	3.45	0.63	0.6	0.03	0.85	-0.06	-0.17	-0.11	0.34
qPH-psr-2A.3	152	*BS00022150-BS00009295*	5.35	1	0.99	0.01	1.09	-0.03	0.02	-0.12	0.13
qPH-psr-2B	84	*BS00045163-BS00022493*	3.43	0.68	0.65	0.02	0.88	-0.16	-0.01	0.27	-0.1
qPH-psr-2D	37	*BS00043985-BS00122127*	82.64	20.52	20.3	0.22	-4.92	0.18	0.33	-0.88	0.37
qPH-psr-3A	77	*BS00022029-bArc19*	70.98	17.04	16.8	0.24	-4.45	0.21	0.63	-0.84	0
qPH-psr-3B.1	9	*BS00071108-BS00011898*	25.33	5.08	4.98	0.1	2.42	0.41	-0.52	-0.06	0.17
qPH-psr-3B.2	90	*BS00059416-BS00111311*	6.75	1.31	1.28	0.03	1.23	0.01	0.12	-0.31	0.18
qPH-psr-3B.3	104	*BS00060073-BS00110445*	9.06	1.65	1.63	0.02	1.39	0.02	0.04	-0.23	0.16
qPH-psr-3B.4	110	*BS00025644-BS00049437*	8.98	1.63	1.62	0.01	1.38	0.09	0.05	-0.19	0.05
qPH-psr-3B.5	117	*BS00022219-BS00022051*	7.47	1.38	1.37	0.01	1.27	0.01	0.11	-0.22	0.1
qPH-psr-3B.6	126	*BS00024090-BS00003708*	7.37	1.35	1.35	0	1.27	-0.04	0.02	-0.01	0.03
qPH-psr-3B.7	175	*BS00004108-gwm493*	3.24	0.58	0.56	0.03	0.82	0.14	-0.08	-0.26	0.2
qPH-psr-3B.8	191	*bArc75-wPt-1081*	3.91	0.71	0.65	0.06	0.88	0.16	0.05	-0.45	0.24
qPH-psr-4A.1	0	*BS00010582-BS00064269*	8.19	1.52	1.49	0.04	1.33	-0.06	-0.31	0.17	0.2
qPH-psr-4A.2	28	*BS99999979-BS00107766*	6.87	1.32	1.27	0.04	1.23	-0.31	-0.05	0.33	0.03

qPH-psr-4B.1	23	*BS00022055-BS00012006*	4.61	0.81	0.75	0.06	-0.94	-0.31	0.08	0.39	-0.15
qPH-psr-4B.2	70	*BS00073315-BS00022534*	5.72	1.08	1.06	0.01	-1.12	-0.05	-0.08	-0.1	0.23
qPH-psr-4B.3	110	*BS00065800-BS00011038*	3.73	0.68	0.67	0.01	-0.89	-0.12	-0.06	0.19	-0.01
qPH-psr-4D	48	*BS00107639-wMAS000002_Rht-D1*	71.06	16.77	16.49	0.28	-4.42	-0.15	-0.58	0.95	-0.22
qPH-psr-5A.1	5	*BS00051181-BS00087453*	16.11	3.28	3.16	0.12	-1.93	0.05	-0.5	-0.12	0.57
qPH-psr-5A.2	87	*BS00001736-BS00097996*	3.11	0.6	0.47	0.13	0.75	0.14	0.03	0.46	-0.62
qPH-psr-5A.3	107	*BS00041063-BS00105208*	3.3	0.63	0.54	0.09	0.8	0.16	0.17	0.24	-0.57
qPH-psr-5A.4	150	*BS00066675-BS00028802*	8.52	1.65	1.38	0.27	1.28	-0.14	-0.85	0.38	0.61
qPH-psr-5B.1	26	*BS00023008-BS00099534*	5.28	1.03	0.93	0.1	1.05	-0.16	0.58	-0.13	-0.29
qPH-psr-5B.2	91	*BS00081132-BS00034021*	3.1	0.6	0.48	0.12	-0.76	0.14	-0.49	0.52	-0.17
qPH-psr-5B.3	100	*BS00091302-BS00107906*	3.59	0.69	0.58	0.11	-0.83	0.1	-0.49	0.5	-0.11
qPH-psr-5B.4	144	*BS00022408-BS00023216*	6.25	1.2	1.17	0.04	-1.19	0.15	-0.35	0.15	0.05
qPH-psr-5B.5	153	*BS00068710-BS00024074*	6.02	1.14	1.11	0.03	-1.17	0.15	-0.3	0.18	-0.03
qPH-psr-5B.6	160	*BS00003637-gwm408*	6.21	1.17	1.13	0.03	-1.18	0.15	-0.19	0.25	-0.21
qPH-psr-5B.7	163	*BS00084089-BS00010573*	6.29	1.17	1.14	0.03	-1.19	0.1	-0.15	0.28	-0.23
qPH-psr-5B.8	172	*BS00049213-BS00049403*	5.2	0.94	0.88	0.06	-1.04	-0.14	-0.1	0.47	-0.23
qPH-psr-6A.1	68	*BS00054054-BS00105973*	12.13*	2.6	0.8	1.8	0.98	-0.71	-0.97	-0.85	2.53
qPH-psr-6A.2	75	*BS00024005-BS00086046*	10.79*	1.86	0.6	1.25	0.86	2.13	-0.77	-0.71	-0.65
qPH-psr-6A.3	82	*BS00022553-BS00023092*	6.46*	1.55	0.4	1.16	0.69	-0.64	-0.83	2.03	-0.56
qPH-psr-6A.4	86	*BS00002205-BS00047388*	5.85*	1.33	0.34	0.99	0.63	-0.63	1.88	-0.61	-0.64
qPH-psr-6B.1	3	*BS00023042-BS00076101*	4.41	0.77	0.72	0.05	-0.92	-0.36	0.26	0.16	-0.06
qPH-psr-6B.2	44	*BS00022081-BS00027771*	4.82	0.88	0.86	0.02	-1.01	-0.13	-0.13	0.22	0.04
qPH-psr-6B.3	92	*BS00087179-BS00046906*	9.51	1.77	1.74	0.03	-1.45	0	-0.31	0.17	0.14
qPH-psr-6B.4	104	*BS00023972-BS00024084*	8.26	1.56	1.52	0.04	-1.35	0.06	-0.37	0.19	0.11
qPH-psr-6B.5	134	*wPt-8814-BS00010403*	4.16	0.77	0.72	0.05	-0.93	0.02	0.23	0.13	-0.39
qPH-psr-6D.1	10	*bArc54-BS00042153*	5.08	0.98	0.9	0.08	1.03	-0.46	0.22	-0.11	0.35

qPH-psr-6D.2	81	*BS00022206-BS00168534*	3.95	0.73	0.65	0.08	0.87	0.16	-0.53	0.25	0.12
qPH-psr-7B	73	*BS00004376-BS00004403*	3.37	0.65	0.63	0.02	0.86	0.01	-0.01	0.24	-0.23
qPH-psr-7D.1	0	*BS00122154-BS00132860*	7.65	1.5	1.45	0.05	-1.31	0.38	-0.1	-0.3	0.03
qPH-psr-7D.2	22	*BS00062644-BS00094533*	3.45	0.61	0.57	0.04	-0.82	-0.18	0.3	0.14	-0.25

PVE: phenotypic variation explained by the QTL; PVE (A): phenotypic variation explained by additive effect; PVE (AbyE): phenotypic variation explained by additive by environment effect; Add: additive effect; AbyE_05: additive effect of QTL in 2005; AbyE_06: additive effect of QTL in 2006; AbyE_07: additive effect of QTL in 2007; AbyE_08: additive effect of QTL in 2008. Asterisk (*) means QTL by environment effect is significant.

Table S7 EM QTL detected by multi-environment QTL analysis in the Avalon×Cadenza DH population

QTL locus	Position	Flanking markers	LOD	PVE (%)	PVE(A)	PVE(AbyE)	Add	AbyE_05	AbyE_06	AbyE_07	AbyE_08
qEM-psr-1B.1	80	*BS00022530-BS00022392*	7.66	2.21	1.61	0.6	1.2	-0.41	0.04	1.16	-0.79
qEM-psr-1B.2	147	*BS00109526-BS00107837*	14.7	3.96	2.97	0.98	-1.61	-0.04	-0.38	-1.06	1.48
qEM-psr-1B.3	162	*BS00022153-BS00104270*	5.77	1.13	0.83	0.3	-0.86	0.52	-0.52	0.51	-0.51
qEM-psr-1D.1	2	*BS00011947-BS00126040*	30.24*	9.21	3.93	5.28	1.87	0.49	-1.93	3.34	-1.9
qEM-psr-1D.2	33	*wPt-8960-BS00119035*	3.38	0.67	0.65	0.02	0.75	0.05	-0.14	0.2	-0.1
qEM-psr-2B.1	138	*BS00074661-BS00011187*	4.55	0.95	0.72	0.23	0.79	0.34	0.54	-0.54	-0.33
qEM-psr-2B.2	142	*BS00004433-BS00011229*	6.81	1.8	1.36	0.45	1.09	-0.14	-0.18	1.02	-0.7
qEM-psr-2D	70	*BS00147940-BS00022210*	3.67	0.83	0.79	0.03	0.84	-0.1	0.13	0.21	-0.23
qEM-psr-3A	77	*BS00022029-bArc19*	24.11*	7.33	3.66	3.67	-1.79	-0.73	-2.6	1.57	1.76
qEM-psr-3B.1	84	*BS00105878-BS00059416*	5.98	1.37	1.29	0.08	-1.07	0.34	-0.35	-0.12	0.13
qEM-psr-3B.2	110	*BS00025644-BS00049437*	5.72	1.31	1.24	0.07	-1.04	0.28	-0.35	-0.07	0.15
qEM-psr-3B.3	117	*BS00022219-BS00022051*	5.03	1.2	1.09	0.11	-0.98	0.33	-0.5	-0.02	0.19
qEM-psr-3D.1	2	*BS00129989-BS00149712*	4.28	0.9	0.82	0.09	-0.85	0.25	-0.42	0.25	-0.08
qEM-psr-3D.2	31	*BS00183559-BS00021920*	3.34	0.8	0.73	0.07	-0.8	0.2	-0.42	0.05	0.17
qEM-psr-4A.1	24	*BS99999979-BS00107766*	3.96	1.47	0.5	0.97	0.66	-0.68	1.59	-0.45	-0.46
qEM-psr-4A.2	38	*BS00011628-BS00001241*	9.63*	2.2	1.02	1.18	0.95	-1.3	-0.58	1.38	0.49
qEM-psr-4A.3	45	*BS00022125-BS00065607*	4.42*	0.72	0.31	0.41	0.52	0.98	0.02	-0.5	-0.5
qEM-psr-4B	56	*wmc89b-BS00022576*	3.1	0.46	0.39	0.07	0.58	0.32	-0.25	-0.24	0.17
qEM-psr-4D	56	*BS99999984-BS00023942*	6.74*	0.99	0.62	0.37	0.74	0.79	-0.35	-0.7	0.27
qEM-psr-5A	120	*BS00105208-BS00082218*	23.83	7.4	5.78	1.62	2.25	-1.22	1.59	0.71	-1.08
qEM-psr-5B.1	26	*BS00023008-BS00099534*	4.7	1.12	1.01	0.11	-0.94	0.46	-0.33	-0.22	0.09
qEM-psr-5B.2	127	*BS00049659-BS00009607*	4.2	0.9	0.68	0.22	-0.78	0.09	-0.61	0.63	-0.11
qEM-psr-5B.3	142	*BS00022408-BS00023216*	5.24	1.03	0.85	0.18	-0.87	0	-0.5	0.61	-0.12

qEM-psr-5B.4	171	*BS00080474-BS00049213*	4.49	0.99	0.76	0.23	-0.83	0.11	-0.67	0.61	-0.05
qEM-psr-5B.5	184	*BS00049997-BS00028492*	3.48	0.68	0.57	0.11	-0.72	0	-0.38	0.5	-0.12
qEM-psr-5B.6	193	*BS00037023-BS00032082*	3.34	0.79	0.67	0.12	-0.78	0.22	-0.55	0.27	0.06
qEM-psr-6A.1	65	*BS00022947-BS00046964*	11.79*	3.19	1.46	1.73	-1.14	-0.67	-1.7	1.18	1.2
qEM-psr-6A.2	79	*BS00086046-bArc171*	12.13*	2.56	1.38	1.18	-1.11	1.02	1.01	-1.26	-0.76
qEM-psr-6B.1	53	*BS00075795-BS00022480*	4.91	1.11	1.07	0.05	-0.98	0.19	-0.32	-0.05	0.19
qEM-psr-6B.2	70	*gwm219-BS00010993*	7.33	1.62	1.56	0.06	-1.18	0.25	-0.33	-0.12	0.2
qEM-psr-6B.3	109	*BS00023972-BS00024084*	8.59	1.84	1.77	0.06	-1.26	0.16	-0.24	-0.21	0.3
qEM-psr-7A.1	105	*BS00022959-BS00023993*	7.39	1.94	1.12	0.82	-0.99	0.08	-1.28	1.11	0.08
qEM-psr-7A.2	120	*BS00009978-BS00039009*	13.28*	3.61	2.15	1.46	-1.37	0.42	1.1	-1.9	0.37

PVE: phenotypic variation explained by the QTL; PVE (A): phenotypic variation explained by additive effect; PVE (AbyE): phenotypic variation explained by additive by environment effect; Add: additive effect; AbyE_05: additive effect of QTL in 2005; AbyE_06: additive effect of QTL in 2006; AbyE_07: additive effect of QTL in 2007; AbyE_08: additive effect of QTL in 2008.

Asterisk (*) means QTL by environment effect is significant.

Table S8 SS QTL detected by multi-environment QTL analysis in the Avalon×Cadenza DH population

QTL locus	Position	Flanking markers	LOD	PVE (%)	PVE(A)	PVE(AbyE)	Add	AbyE_05	AbyE_06
qSS-psr-1B.1	0	*BS00010592-BS00030768*	3.08	0.85	0.8	0.06	-2.07	0.54	-0.54
qSS-psr-1B.2	19	*BS00022030-BS00024037*	3.83	1.04	1	0.05	-2.31	0.5	-0.5
qSS-psr-3B	4	*wPt-4412-BS00071108*	129.19*	78.27	76.82	1.46	-20.29	2.79	-2.79
qSS-psr-5B	29	*BS00099534-BS00001525*	3.5	0.93	0.92	0.01	2.22	-0.24	0.24
qSS-psr-7A	142	*BS00084312-BS00025521*	3.12	0.85	0.82	0.03	-2.1	0.41	-0.41

PVE: phenotypic variation explained by the QTL; PVE (A): phenotypic variation explained by additive effect; PVE (AbyE): phenotypic variation explained by additive by environment effect; Add: additive effect; AbyE_05: additive effect of QTL in 2005; AbyE_06: additive effect of QTL in 2006.

Asterisk (*) means QTL by environment effect is significant.

Table S9 Yellow rust resistance QTL detected by single QTL analysis in the Avalon×Cadenza DH population

QTL locus	Position	Flanking markers	LOD	PVE (%)	Add
qYrRace 03-7 -psr-2B	183	*BS00070104-BS00004405*	4.92	5.91	-0.64
qYrRace 03-7 -psr-2D	0	*bArc124A-BS00128354*	5.35	5.41	0.61
qYrRace 03-7 -psr-6A	13	*BS00067017-gwm334*	4.08	4.59	0.57
Yr6 (7B)	58	*gwm577-BS00010560*	32.21	45.68	1.78
Yr7 (2B)	153	*BS00074789-wmc175A*	38.3	51.09	1.62
qYrRace 04-44 -psr-3B	106	*BS00088281-BS00084911*	5.65	5.04	-0.51
qYrRace 04-44 -psr-6A	56	*BS00023976-BS00023086*	6.95	6.24	0.57
qYrRace 04-44 -psr-7B	67	*BS00010181-BS00082001*	9.14	8.45	0.66

PVE: phenotypic variation explained by the QTL; Add: additive effect.

Table S10 Additive effects of GY, PH and EM MET QTL in 2005 to 2008

MET QTL	Add by single QTL analysis			
	2005	2006	2007	2008
qGY-psr-2D.1	-0.67	-0.35	-0.33	-0.46
qGY-psr-3A.2	-0.11	-0.07	-0.26	-0.33
qGY-psr-3B.2	0.31	0.14	0.20	0.15
qPH-psr-2A.1	2.61	2.83	2.39	1.80
qPH-psr-2D	-5.10	-5.00	-5.8	-4.86
qPH-psr-3A	-4.26	-3.85	-5.36	-4.51
qPH-psr-3B.1	2.87	1.97	2.66	2.67
qPH-psr-4D	-4.57	-5.00	-3.53	-4.64
qPH-psr-5A.1	-1.88	-2.46	-2.05	-1.36
qEM-psr-1B.2	-1.68	-2.05	-2.7	-1.38
qEM-psr-1D.1	2.44	4.53	5.30	0.00
qEM-psr-3A	-2.52	-4.42	-2.93	-2.11
qEM-psr-5A	1.08	4.01	3.59	1.22
qEM-psr-6A.1	-1.83	-2.87	0.04	0.06

MET: multi-environment QTL analysis; Add: additive effect

Table S11 Predicted performance of ideal simulated DH lines in four years for scenarios 1 (all QTL independent) and 2 (some QTL linkages present)

Simulated DH lines	Predicted phenotype based on MET QTL			Predicted PH (cm) phenotype based on single QTL analysis[a]				Predicted EM (%) phenotype based on single QTL analysis[a]				Predicted GY (t/ha) phenotype based on single QTL analysis[a]			
	PH (cm)	EM (%)	GY (t/ha)	2005	2006	2007	2008	2005	2006	2007	2008	2005	2006	2007	2008
SDH1	75.08	98.30	9.18	71.65	78.49	78.53	71.31	98.69	95.28	101.44	97.99	9.45	7.90	9.51	10.24
SDH2	75.08	98.65	9.18	71.65	78.49	78.53	71.31	100.37	100.02	101.90	99.46	9.45	7.90	9.51	10.24
SDH3	75.08	99.07	9.18	71.65	78.49	78.53	71.31	95.98	94.23	98.02	100.42	9.45	7.90	9.51	10.24
SDH4	75.68	98.30	9.18	73.10	79.24	79.21	72.19	98.69	95.28	101.44	97.99	9.45	7.90	9.51	10.24
SDH5	75.68	98.65	9.18	73.10	79.24	79.21	72.19	100.37	100.02	101.90	99.46	9.45	7.90	9.51	10.24
SDH6	75.68	99.07	9.18	73.10	79.24	79.21	72.19	95.98	94.23	98.02	100.42	9.45	7.90	9.51	10.24
SDH7	76.07	98.30	9.18	73.62	77.51	79.75	73.93	98.69	95.28	101.44	97.99	9.45	7.90	9.51	10.24
SDH8	76.07	98.65	9.18	73.62	77.51	79.75	73.93	100.37	100.02	101.90	99.46	9.45	7.90	9.51	10.24
SDH9	76.07	99.07	9.18	73.62	77.51	79.75	73.93	95.98	94.23	98.02	100.42	9.45	7.90	9.51	10.24

a: additive effect of GY, PH and EM QTL by single QTL analysis see Table S10

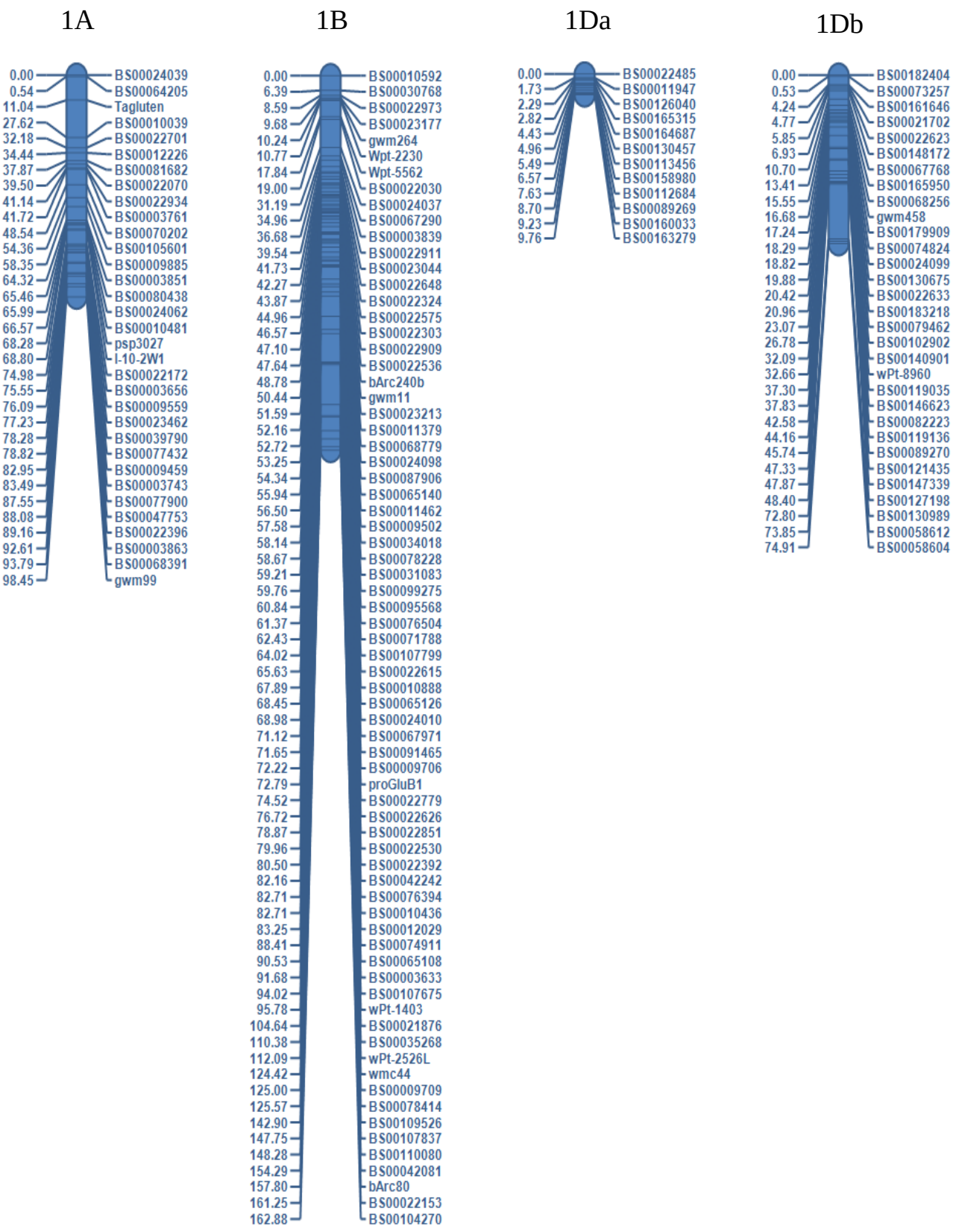


Fig.S1 Genetic map of Avalon×Cadenza population

Fig.S1 continued

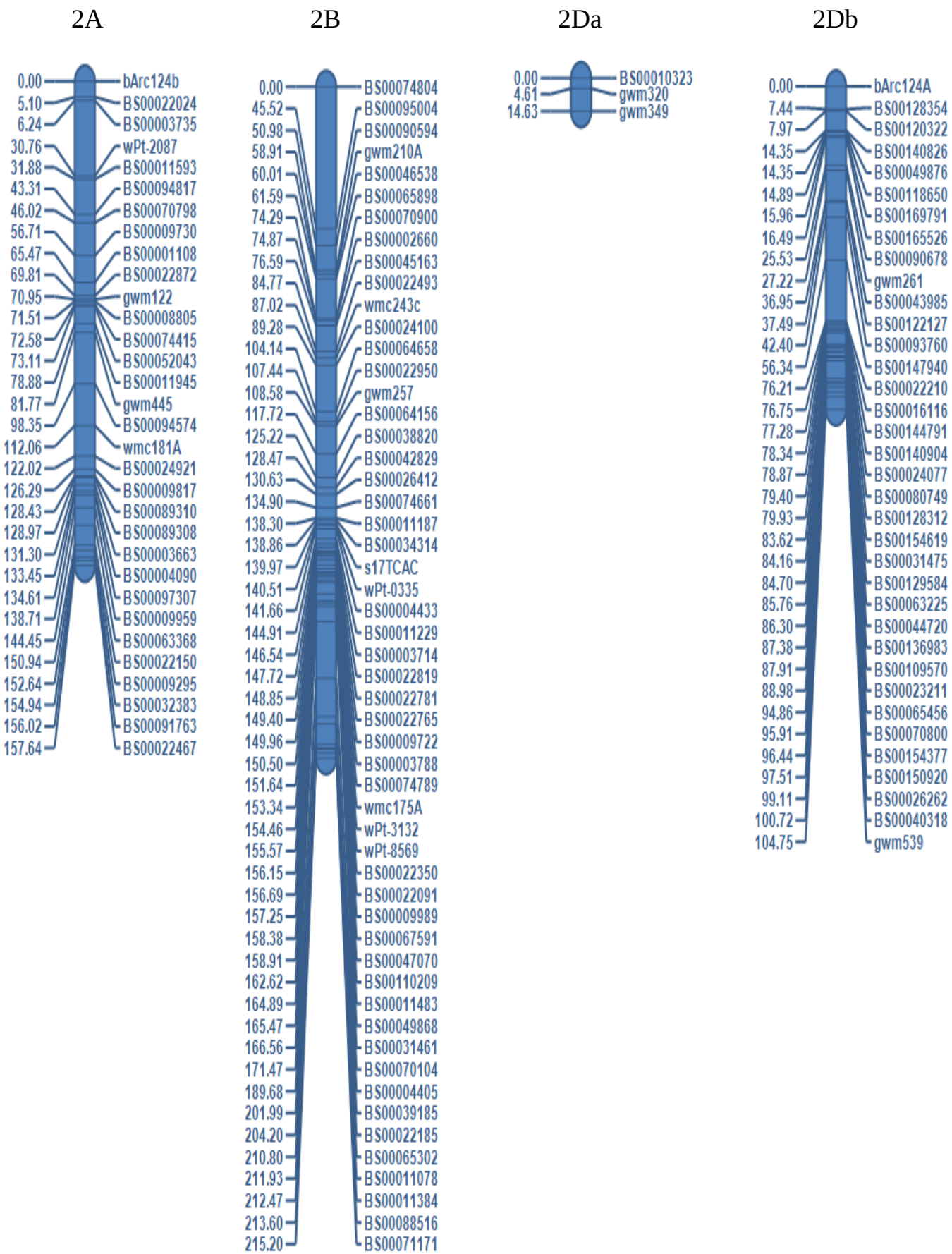


Fig.S1 Continued

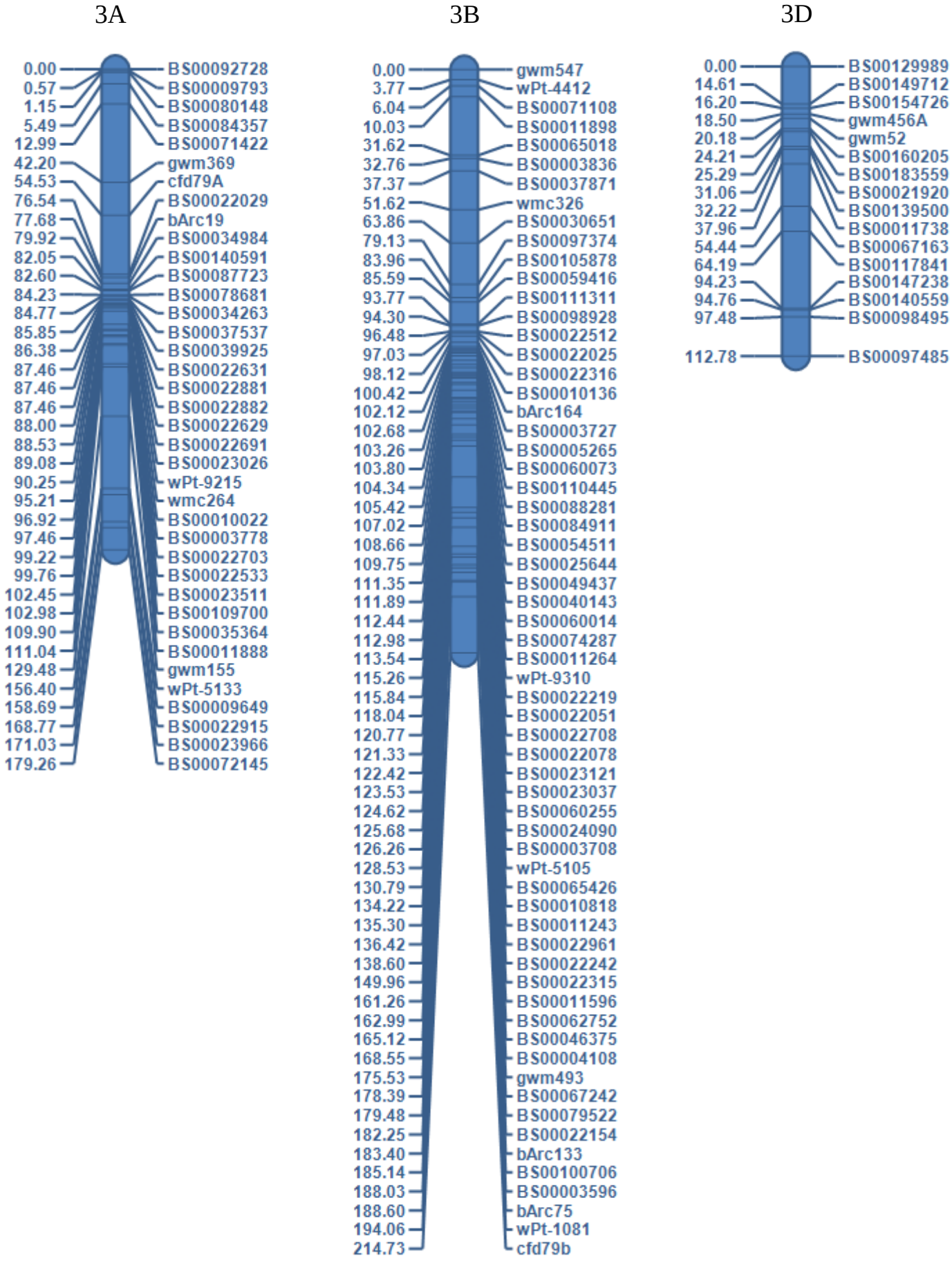


Fig.S1 Continued

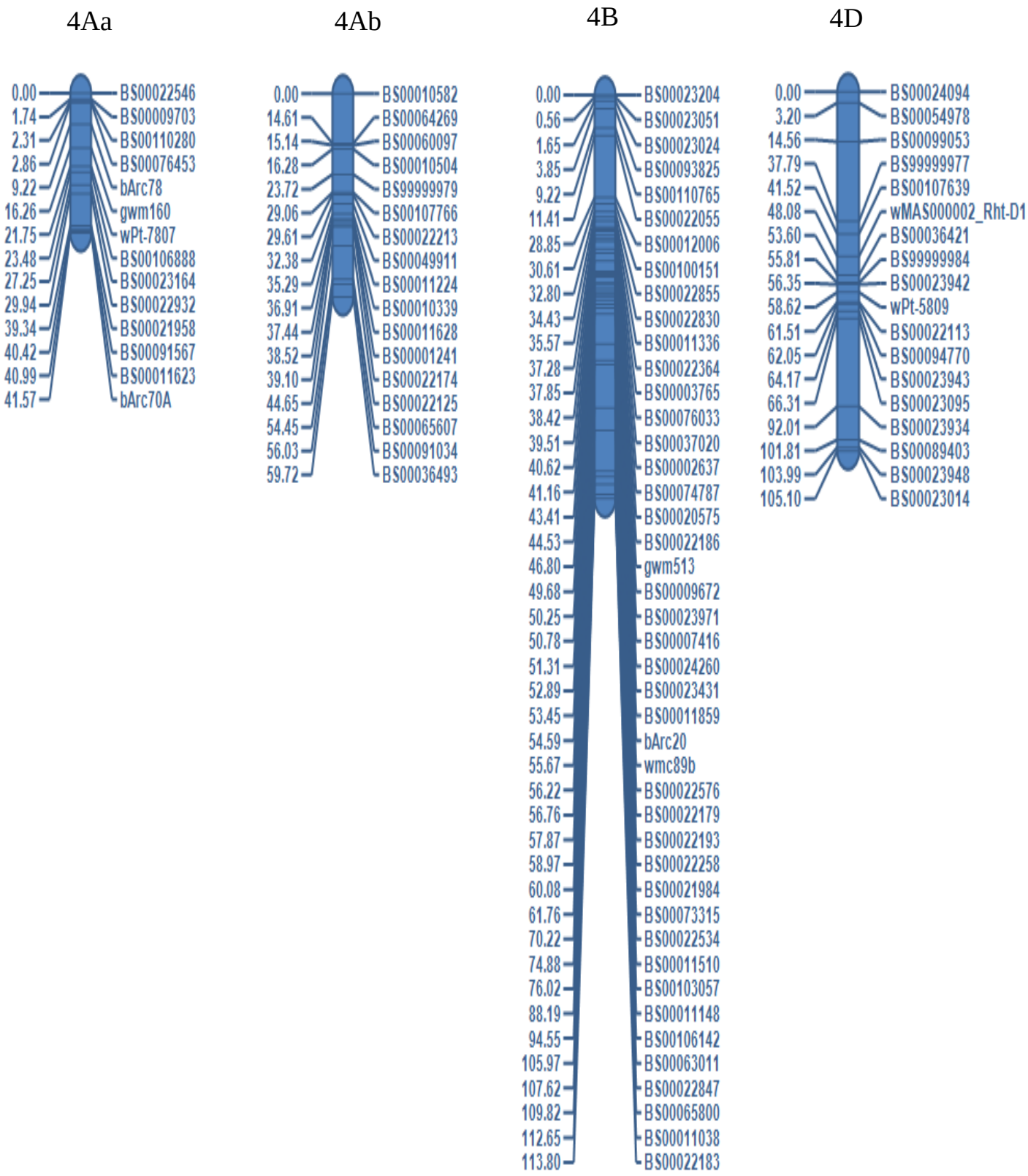


Fig.S1 Continued

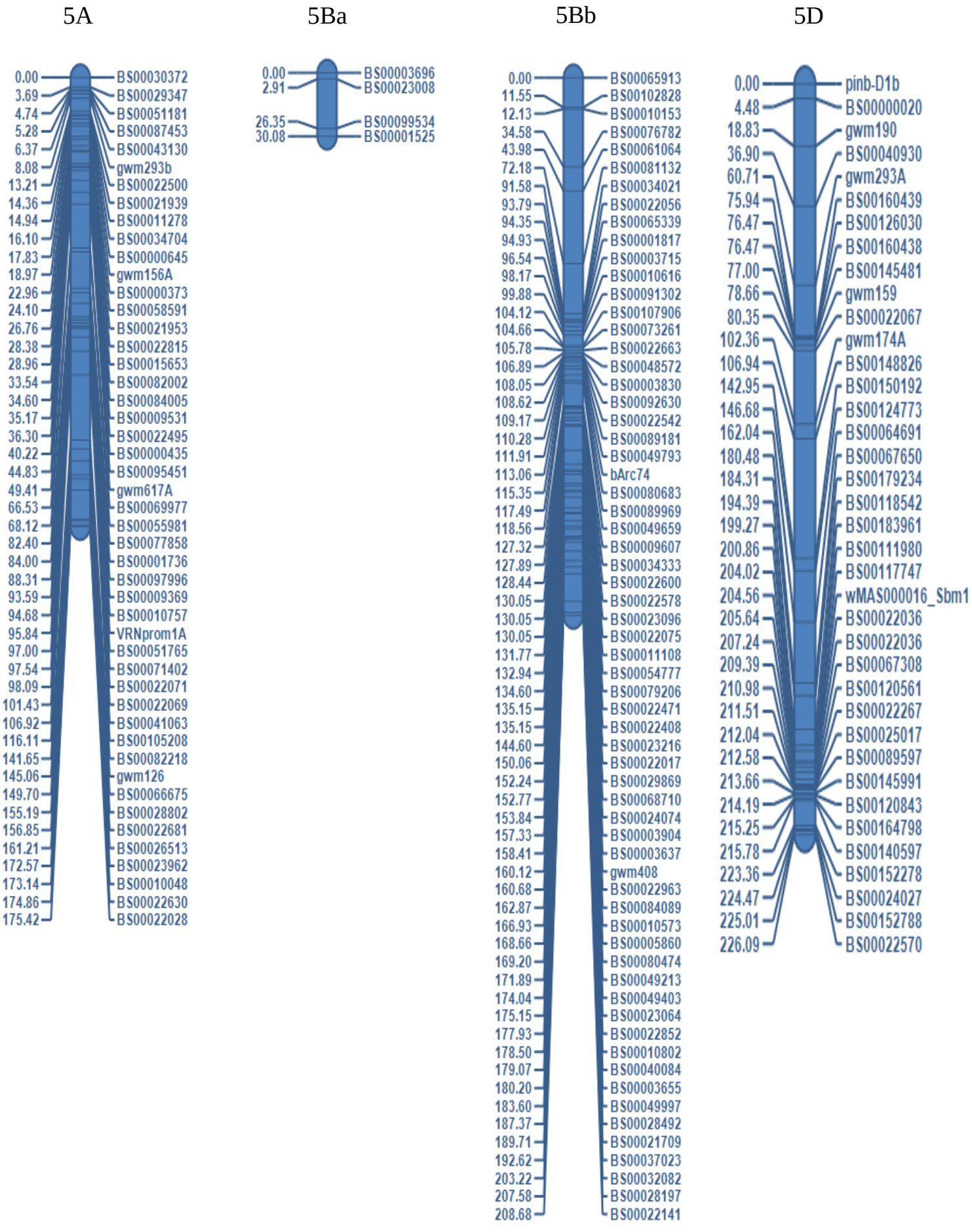
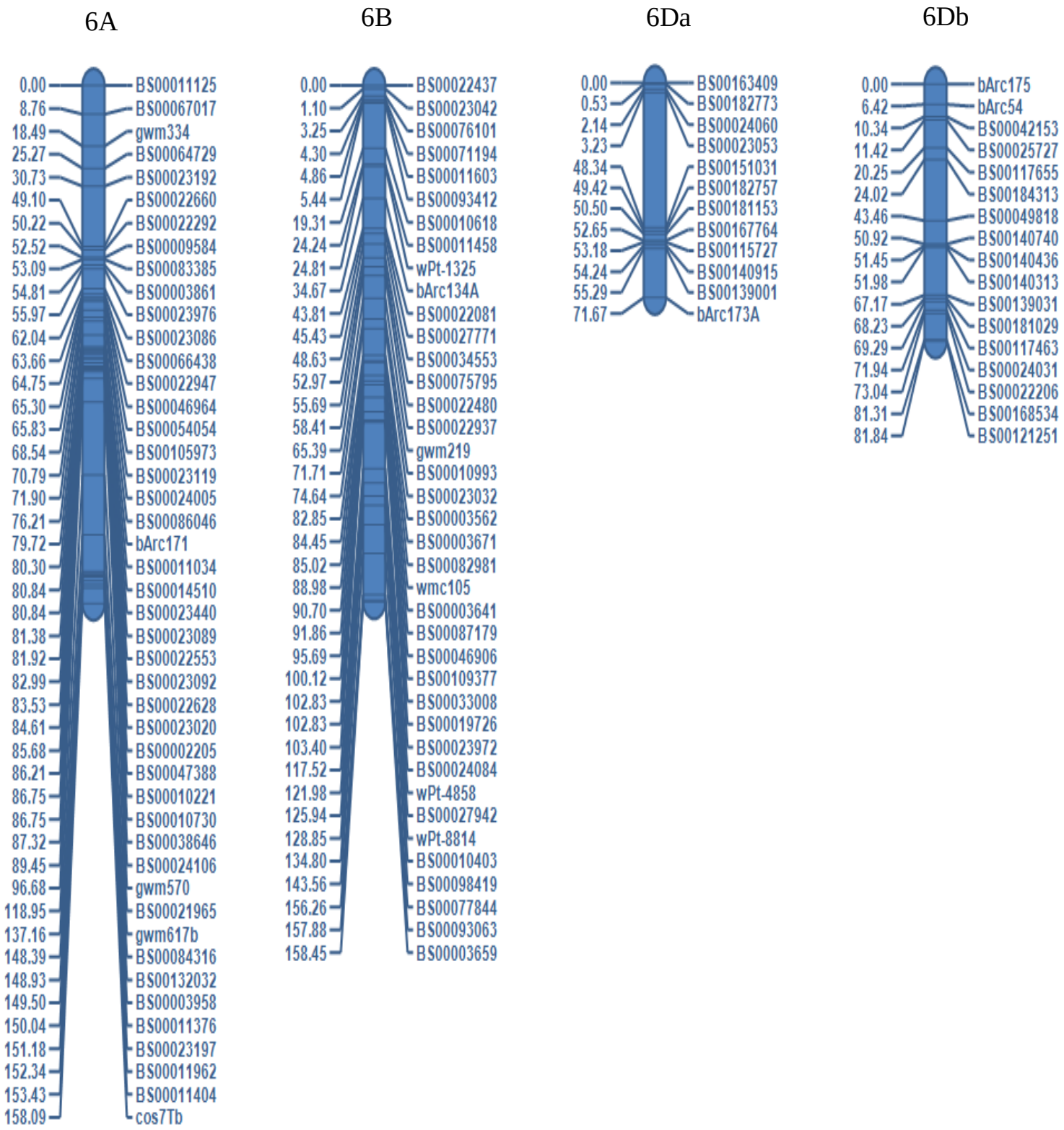


Fig.S1 Continued



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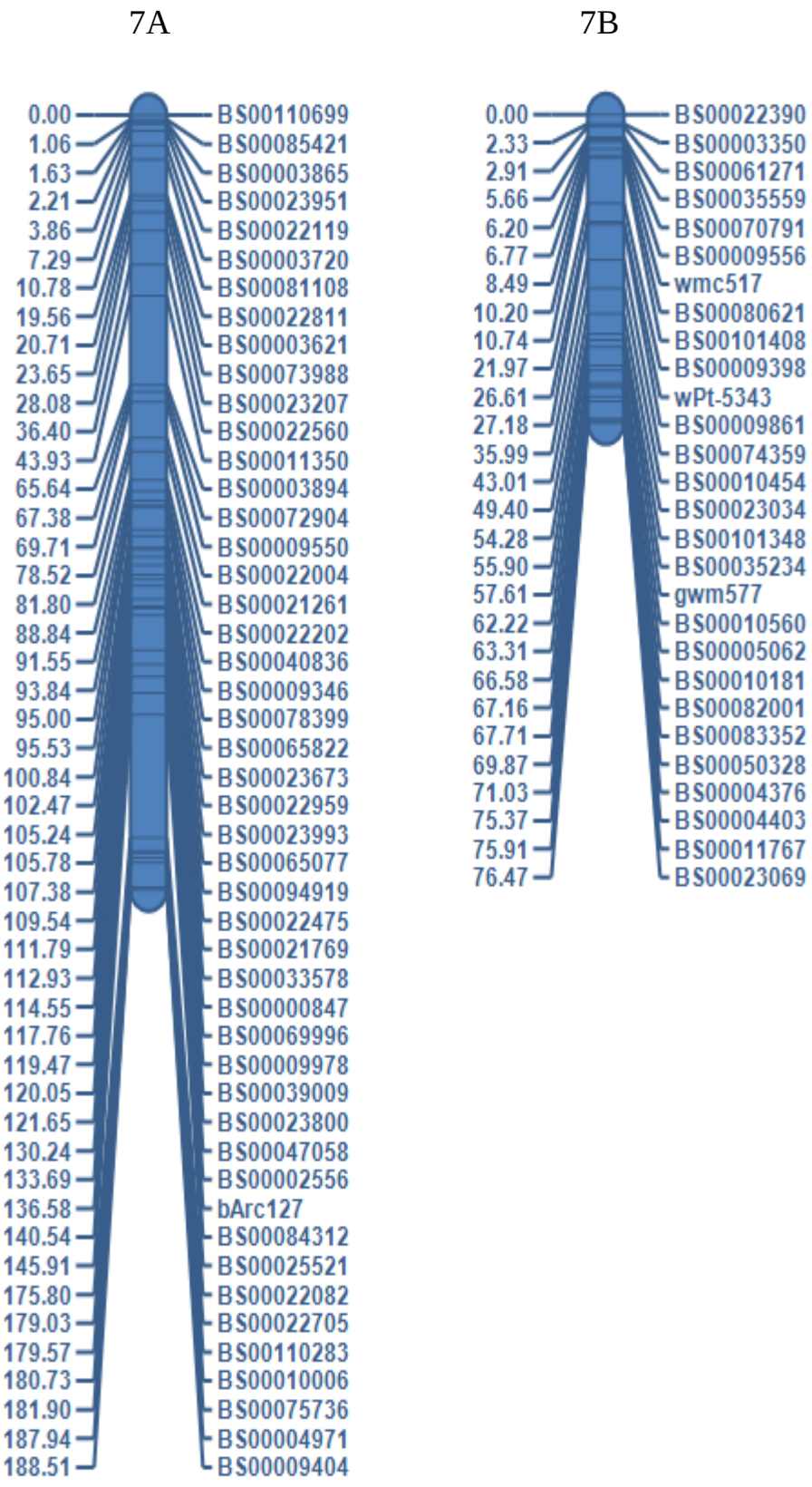
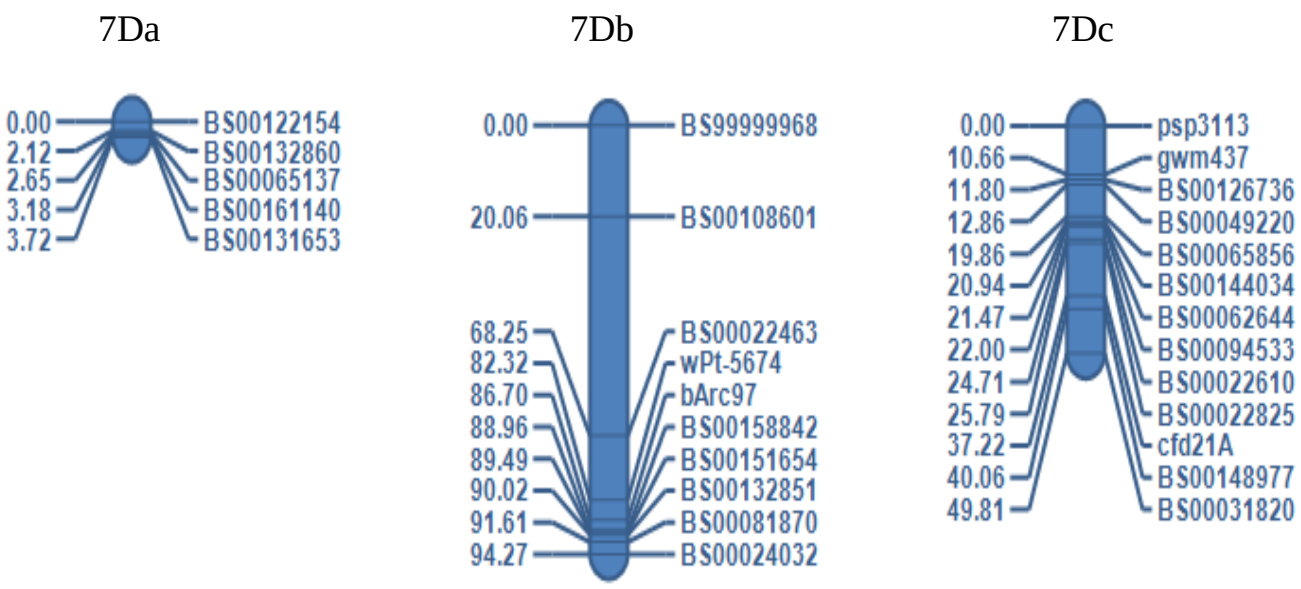


Fig.S1 Continued



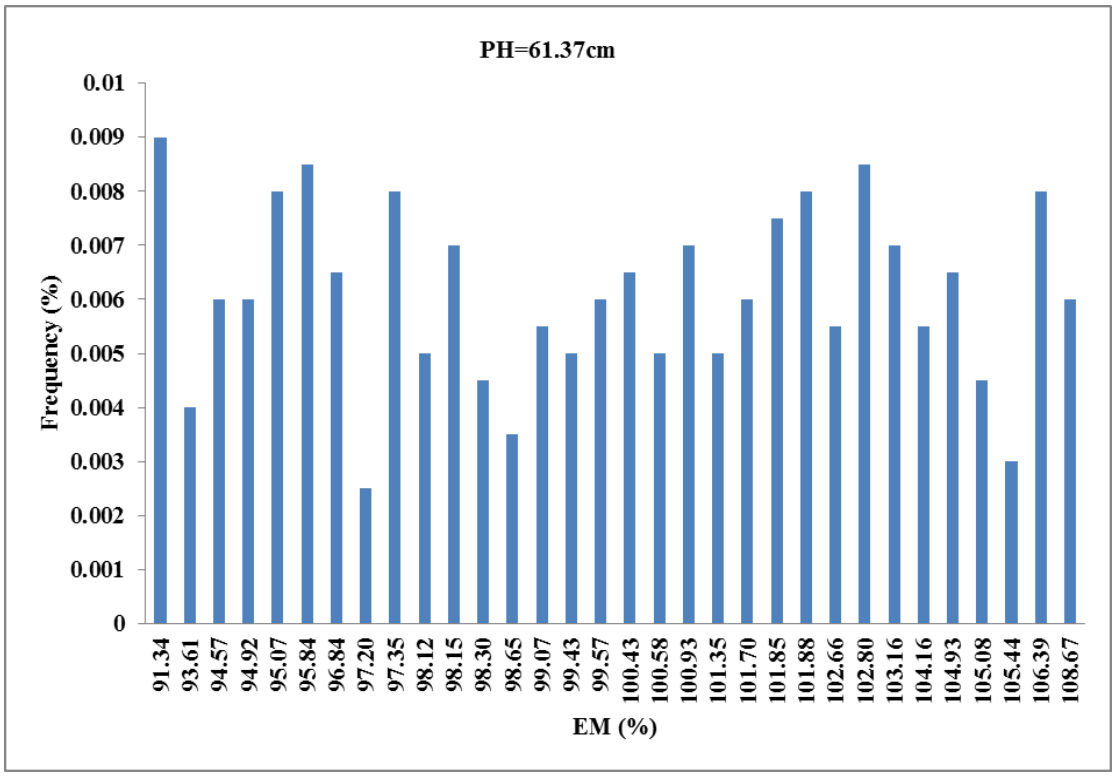


Fig.S2 Frequency of simulated high-yield DH lines with the PH of 61.37cm with different EM in scenario 1

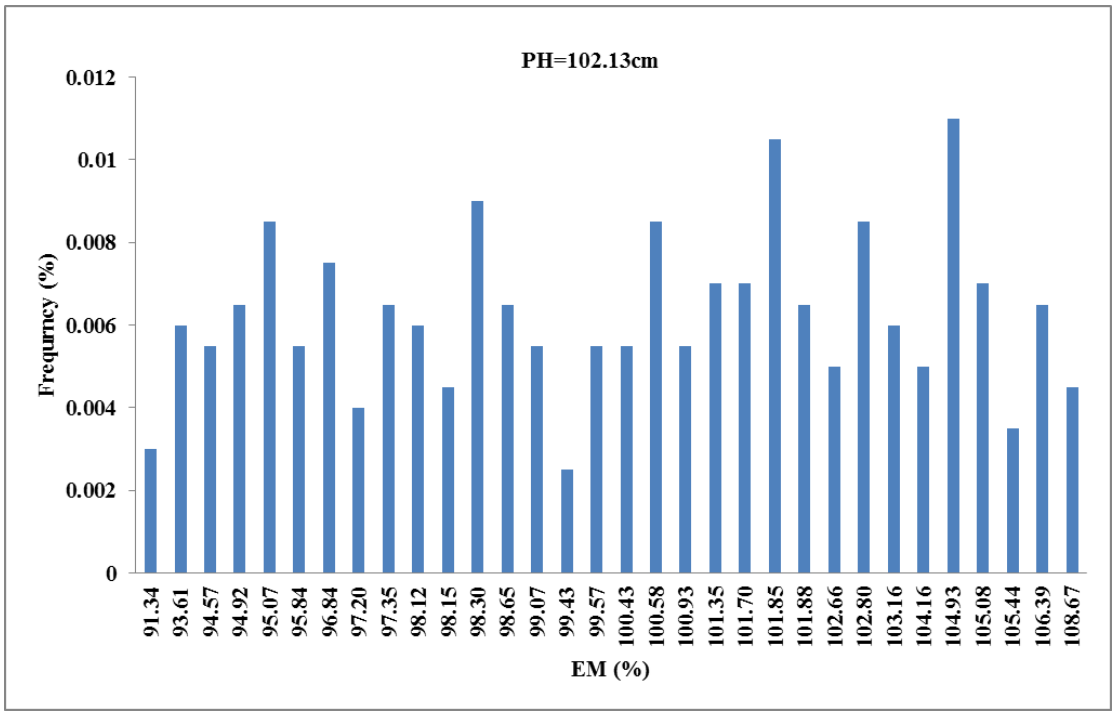


Fig.S3 Frequency of simulated high-yield DH lines with the PH of 102.13cm with different EM in scenario 1

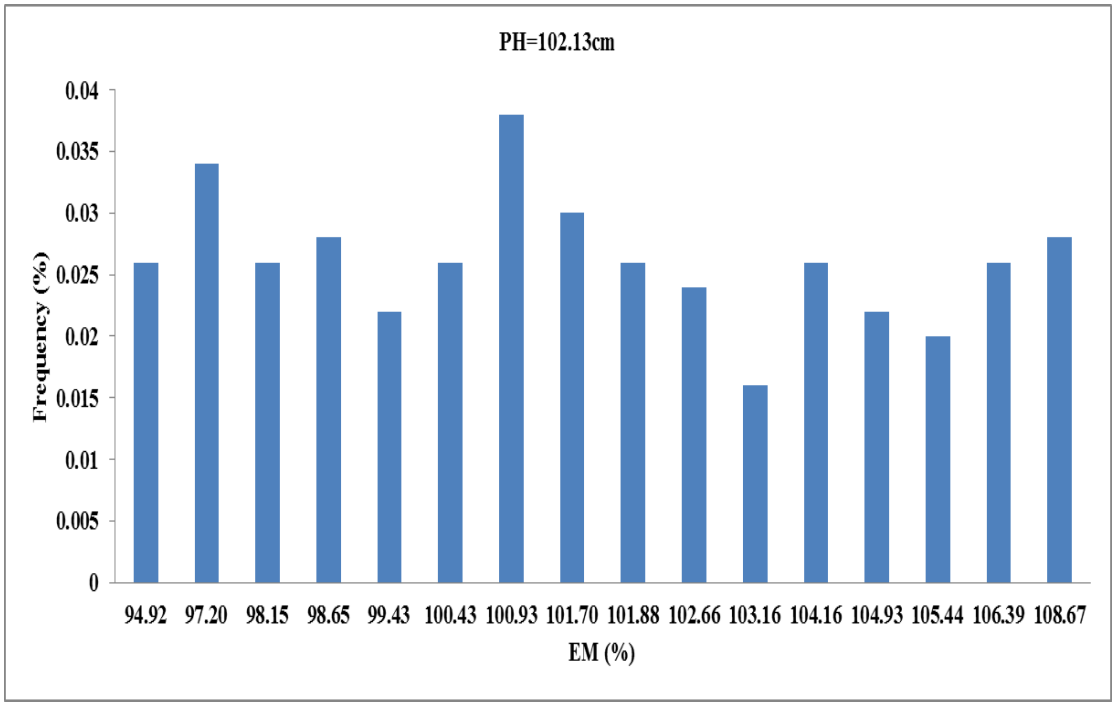


Fig.S4 Frequency of simulated high-yield DH lines with the PH of 102.13cm and different EM in scenario 2

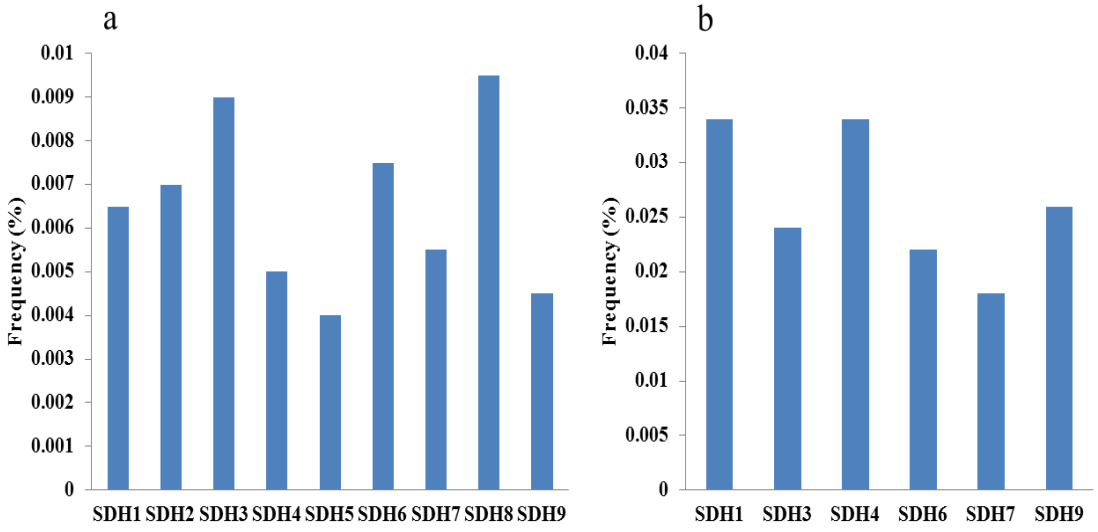


Fig.S5 Frequency of ideal simulated DH lines for scenario 1 (a) and scenario 2 (b)

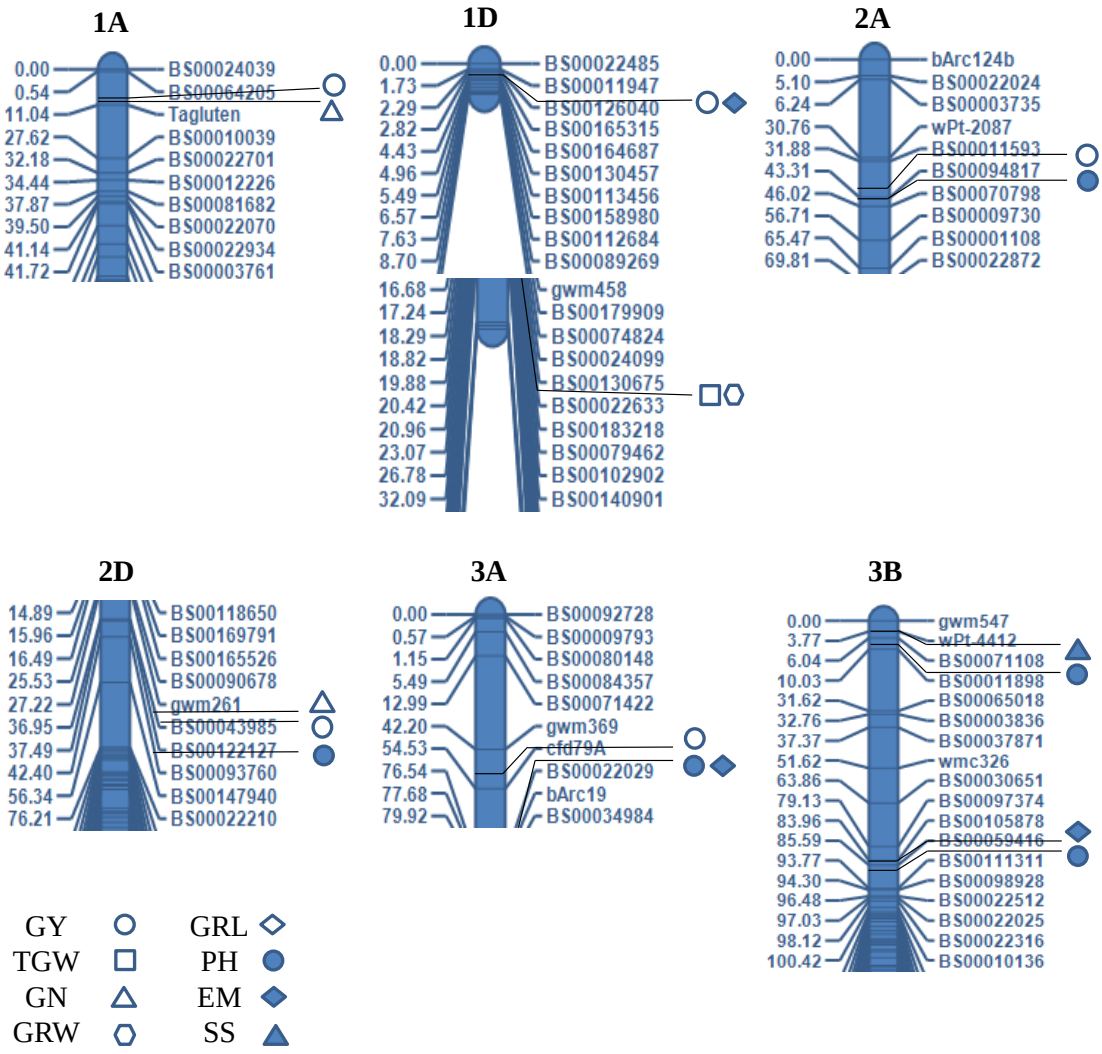


Fig.S6 Pictures of map locations of common QTL for GY (empty circle), yield components (TGW=square, GN= triangle, GRW=hexagon, GRL=diamond, all empty), PH (filled circle), EM (filled diamond) and SS (filled triangle).

Fig.S6 Continued