Genome Wide QTL Mapping for Resistance to Verticillium Wilt, Fiber Quality and Yield Traits in Cotton Chromosome Segment Substitution Lines

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	line	Year	BW(g)	LP(%)	FL(mm)	FS(cN/tex)	MIC
G.babadense	7124	2003	3.2	33.0	33.8	37.4	4.2
		2004	3.6	34.0	33.1	38.2	4.4
	Hai1	2003	2.6	32.8	33.5	38.2	4.4
		2004	3.9	33.9	32.9	42.4	4.6
	Jiza75	2003	2.8	30.6	36.2	35.8	3.7
		2004	3.6	30.0	37.5	38.8	4.1
G.hirsutum	CCRI45	2003	5.9	38.4	29.6	28.0	5.1
		2004	5.5	38.0	29.3	27.7	5.4
	CCRI36	2003	4.9	42.7	29.0	27.4	4.4
		2004	5.0	41.8	28.2	26.1	4.2
	CCRI37	2003	4.6	42.1	27.1	25.4	4.6
		2004	5.0	41.4	26.6	26.4	4.3
	CCRI394	2003	5.0	41.7	29.1	27.9	4.5
		2004	4.9	43.0	29.0	27.9	4.3

fiber quality for F1 between G.hirsutum and G.babadense

Combination	Fiber length(mm)		Fiber strength(cN/tex)		Micronaire	
	2003	2004	2003	2004	2003	2004
CCRI45×7124	37.1	36.3	33.7	37.0	3.7	3.9
CCRI45×海1	34.8	35.1	33.8	35.2	3.4	3.9
CCRI45×吉扎75	36.3	36.3	32.0	35.9	3.4	3.5
CCRI36×7124	35.3	35.2	34.5	37.2	3.3	3.4
CCRI36×海1	33.6	34.4	35.0	37.7	3.5	3.5
CCRI36×吉扎75	35.8	36.4	33.8	35.7	3.3	3.2
CCRI37×7124	35.6	35.3	34.8	36.2	3.6	3.9
CCRI37×海1	34.1	33.8	35.5	37.7	3.5	4.1
CCRI37×吉扎75	36.0	36.0	37.2	34.7	3.3	3.7
CCRI394×7124	35.3	36.2	33.6	35.9	3.3	3.4
CCRI394×海1	33.5	34.7	32.3	36.8	3.1	3.5
CCRI394×吉扎75	34.7	35.9	32.6	35.9	2.9	3.3
Hai1（G.babadense）	33.5	32.9	38.2	42.4	4.4	4.6
CCRI45（G.hirsutum）	29.6	29.3	28.0	27.7	5.1	5.4

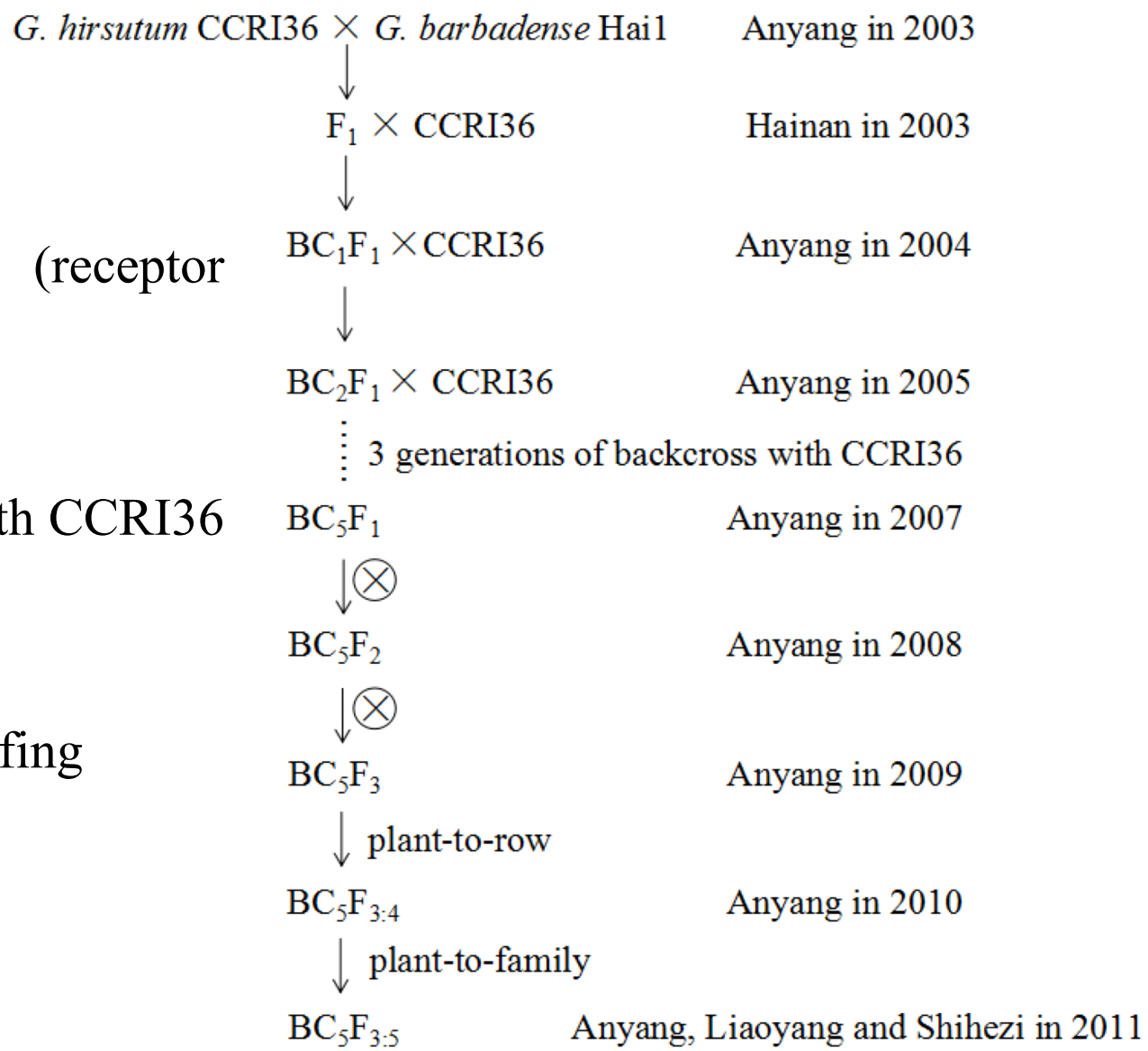
Chromosome Segment Substitution Lines (CSSLs) from *G. hirsutum* × *G. barbadense*

Flow chart of construction of CSSLs:

(1) Hybridization between **CCRI36** (receptor parent) and **Hai 1** (donor parent)

(2) Five generations of backcrossing with CCRI36 and as recurrent parent

(3) Three generations of consecutive selfing



Identification of QTLs for lint percentage

Materials: BC_1F_1 population

Results:

(1) **Twenty-six** QTLs for lint percentage were identified on **nine** chromosomes

(2) **Nine** stable or common QTLs could be used for marker-assisted selection

(3) **Fifty** percent of the QTLs were from *G. barbadense* and increased LP by 1.07% -2.41%

Shi et al., Journal of Integrative Plant Biology, 2015

Table 3. Lint percentage QTL detected in the populations using composite interval mapping

QTL	Population	Chromosome	Position (cM)	Nearest marker	Confidence interval (cM)	LOD	Additive	R^2 (%)
qLP-C5-1	BC_1F_1	5	145.3	SWU0916	142–147.7	3.88	1.95	7.50
qLP-C5-2	BC_2F_1-NY	5	151.1	CGR6733	149.8–153	3.23	1.26	6.84
qLP-C5-3	BC_2F1-NY	5	156.8	HAU0215	153.8–159.8	2.52	1.11	5.40
qLP-C9-1	BC_2F_1	9	189.5	HAU1617	188.1–192.1	2.55	0.97	4.73
qLP-C10-1	BC_1F_1	10	85.3	BNL1665	78.4–85.6	3.09	−1.74	5.92
qLP-C10-2	BC_1F_1	10	87.8	DC40188	86.2–92.5	3.28	−1.84	6.75
qLP-C12-1	BC_2F_1	12	105.7	DPL0400	102.7–107.5	4.41	−1.64	9.24
qLP-C12-2	BC_2F_1	12	131.9	DPL0443	129.8–132.9	2.65	−1.51	7.21
qLP-C14-1	BC_2F_1	14	133	CGR5581	117.3–133.9	2.99	1.06	6.09
qLP-C14-2	BC_2F_1	14	135.8	HAU1888	133.9–139.9	2.82	1.03	5.76
qLP-C15-1	BC_1F_1	15	49.4	HAU3050a	43.6–54.3	2.63	1.76	5.89
	BC_2F_1-NY	15	52.6	DC40217	49.3–53.6	3.67	1.34	8.03
qLP-C15-2	BC_2F_1-NY	15	55.2	NAU3714	53.6–59	3.31	1.27	7.09
qLP-C16-1	BC_2F_1-NY	16	137.1	PGML01330	134.7–140.1	3.55	−1.58	10.53
qLP-C16-2	BC_2F_1-NY	16	143.2	NAU6664	141.2–145.8	6.29	−1.83	14.74
qLP-C16-3	BC_2F_1-NY	16	148	Gh002	146.6–150	7.52	−1.99	17.21
qLP-C16-4	BC_2F_1-NY	16	152	PGML00820	150.4–154.1	6.41	−1.85	15.07
qLP-C16-5	BC_2F_1-NY	16	156.1	CGR5018	154.1–158.2	5.12	−1.78	13.42
qLP-C16-6	BC_1F_1	16	177.7	BNL3065	177.2–181.7	4.39	−2.26	10.11
	BC_2F_1	16	176.7	BNL3065	176.7–182.5	3.01	−1.07	6.29
qLP-C16-7	BC_1F_1	16	189.3	CGR6680	188.3–191.4	5.79	−2.41	11.60
	BC_1S_1	16	189.3	CGR6680	186–191.4	5.04	−2.11	11.35
	BC_2F_1	16	189.3	CGR6680	182.9–191.4	3.64	−1.18	7.52
qLP-C16-8	BC1S1	16	192.8	DPL0492a	192.4–202.3	4.10	−1.92	9.39
qLP-C17-1	BC_1F_1	17	91.3	NAU6542	90.2–92.3	10.81	3.77	27.51
	BC_2F_1	17	90.3	NAU6542	85.7–93.3	5.80	1.56	12.44
	BC_2F_1-NY	17	91.3	NAU6542	83.3–94.1	3.65	1.39	8.61
qLP-C17-2	BC_1F_1	17	94.9	JESPR195	93.8–96.5	11.70	3.70	26.40
	BC_2F_1	17	94.9	JESPR195	93.3–100.1	5.74	1.53	12.37
	BC_2F_1-NY	17	94.9	JESPR195	94.1–97	3.99	1.40	8.69
qLP-C17-3	BC_2F_1-NY	17	100	DPL0279	97–105.1	3.39	1.57	10.80
qLP-C17-4	BC_1S_1	17	114.6	PGML04142	110–115.5	6.51	2.50	15.78
qLP-C17-5	BC_1S_1	17	118.7	CGR6185	118.4–119.8	7.72	2.78	19.38
qLP-C21-1	BC_1S_1	21	60	DPL0582	48.7–62.6	2.86	−1.56	6.16

BC_2F_1-NY, BC_2F_1 population planted in disease nursery. Data with "–" indicates that the locus derived from Hai1 is positive to the additive value of trait. cM, centiMorgan; LOD, logarithm of odds; QTL, quantitative trait locus.

Identification of QTLs for *Verticillium* wilt resistance

Materials: BC_1F_1, BC_1S_1 and BC_2F_1 populations

Results:

(1) A total of **48** QTLs for VW resistance were identified, and **37** of these QTLs had positive additive effects, which indicated that the **G. barbadense** alleles increased resistance to VW anddecreased the disease index (DI) by about 2.2-10.7

(2) All the QTLs were located on **19** chromosomes, in which **33** in the A subgenome and 15 QTLs in the D subgenome. The **6** QTLs were found to be stable

(3) The **6** QTLs were consistent with those identified previously, and another **42** were new, unreported QTLs, of which **31** QTLs were from *G. barbadense*

(4) By meta-analysis, **17** QTL hotspot regions were identified and 10 of them were new, unreported hotspot regions**. 29** QTLs in this paper were in 12 hotspot regions and were all from G. barbadense.

Shi et al., BMC Genomics, 2016

Figure 1 The details of CSSLs development

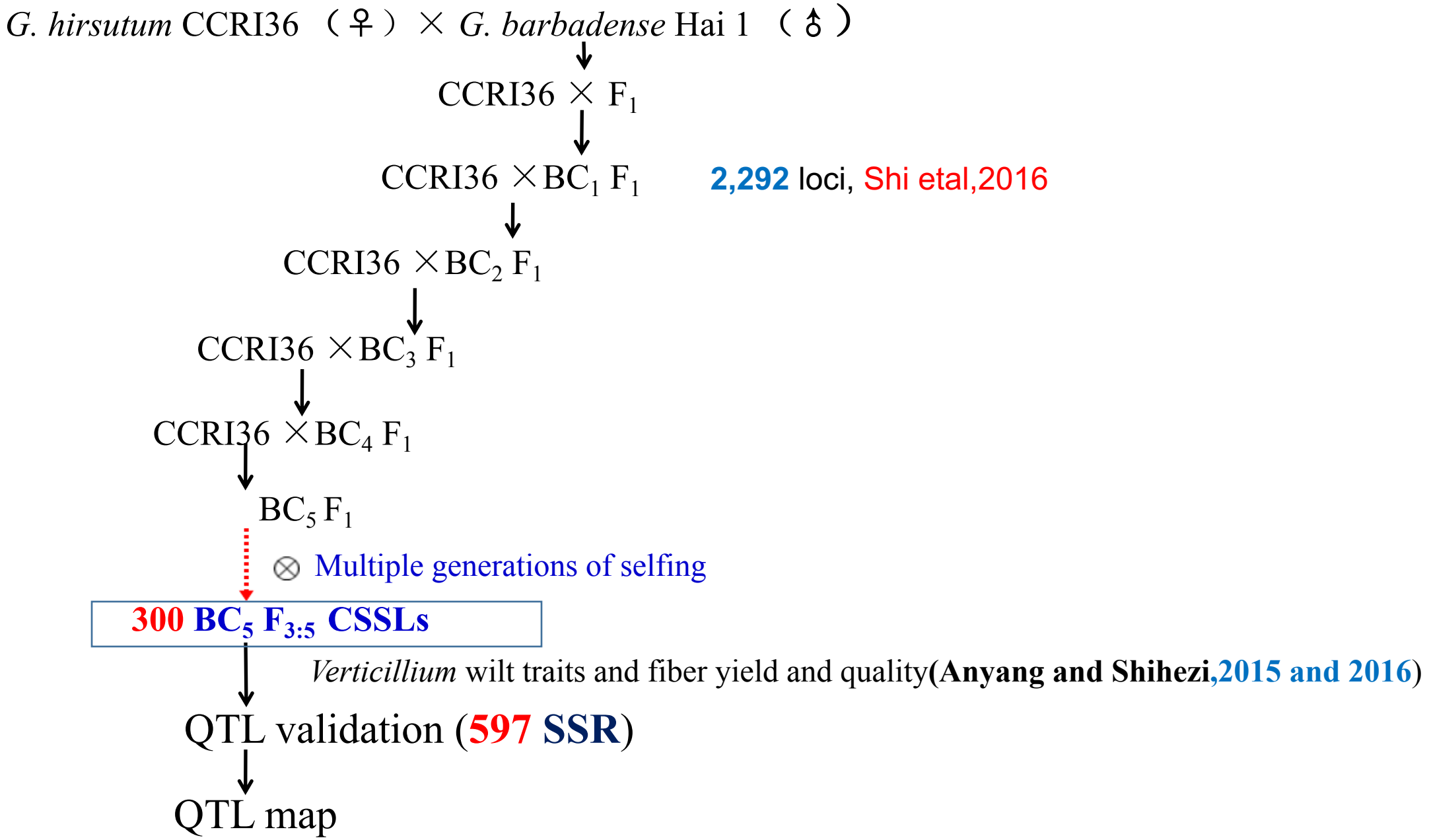


Table 2. 1: Details of 8 environments of fields used to evaluate CSSL population

Year	Environments	Abbreviation used	Replication	Layout
2015	Anyang July	AYJul15	2	5×0.8 m
	Anyang August	AYAug15	2	5×0.8 m
	Xinjiang July	XJJul15	2	3× (0.66+0.10) m
	Xinjiang August	XJAug15	2	3× (0.66+0.10) m
2016	Anyang July	AYJul16	2	5×0.8 m
	Anyang August	AYAug16	2	5×0.8 m
	Xinjiang July	XJJul16	2	3× (0.66+0.10) m
	Xinjiang August	XJAug16	2	3× (0.66+0.10) m

Table 2.2: Details of primers used in this study

SL. No.	Primer Name	No. of polym.	Discovered by/Source	Manufacturer
1	BNL	43	Brookhaven National Laboratory, NY	Invitrogen Co. Ltd. Shanghai
2	C2	1	Monsanto Company, USA	do
3	CER	5	Monsanto Company, USA	do
4	CGR	48	Monsanto Company, USA	do
5	CICR	13	ICR, CAAS, Anyang, China	do
6	CIR	9	CIRAD, France	do
7	CM	1	Texas A & M University, USA	do
8	COT	4	Texas A & M University, USA	do
9	DC	10	Monsanto Company, USA	do
10	DPL	77	Delta and Pine Land, USA	do
11	Gh	25	Texas A & M University, USA	do
12	HAU	100	Huazhong Agricultural University, CHN	do
13	JESPR	7	Texas A & M University, USA	do
14	MGHES	2	USDA-ARS, Texas	do
15	MUCS	7	University of California Davis, USA	do
16	MUSB	7	University of California Davis, USA	do
17	MUSS	13	University of California Davis, USA	do
18	NAU	173	Nanjing Agricultural University, CHN	do
19	PGML	15	Plant Genome Mapping Lab	do
20	SHIN	5	Monsanto Company, USA	do
21	STV	4	Stoneville, USA	do
22	TMB	23	USDA-ARS, Texas	do
23	SWU	5	South West University, CHN	Beijing Genomics Inst.
	total	597		

Table 3. 2: Descriptive statistics of resistance to VW with broad sense Heritability (H^2_B) measured in the Greenhouse and fields in $BC_5F_{3:5}$

			CSSL popul.							Parents			H^2 (%)
Test	Traits	Env	Mean	Max.	Mini.	SD	Skew	Kurt	Var	CCRI36	Hai1	Mid parent	
Green House	Disease Index (%)	25DAI	33.16	75.00	1.30	12.93	0.61	0.52	167.06	39.32	21.35	30.34	85.70
		32DAI	32.72	69.30	5.30	11.45	0.28	0.29	131.11	27.40	24.01	25.71	83.79
		39DAI	35.12	75.00	0.00	10.53	0.33	1.14	110.99	28.30	19.17	23.73	81.39
Field	Disease Index (%)	AYJul15	21.90	73.20	0.00	13.10	0.94	1.33	171.55	31.03	6.21	18.62	97.07
		AYAug15	43.33	73.50	14.30	9.54	-0.18	0.09	91.06	47.70	19.50	33.60	94.87
		XJJul15	6.52	18.50	0.30	3.44	0.56	0.00	11.81	6.76	4.14	5.45	72.03
		XJAug15	35.10	53.29	16.67	5.45	0.23	0.35	29.69	29.63	25.83	27.83	67.90
		AYJul16	25.02	59.72	0.00	11.32	0.06	-0.20	128.11	25.57	5.59	15.58	96.60
		AYAug16	28.96	63.24	0.00	12.41	0.16	-0.35	153.91	32.89	5.60	19.25	96.56
		XJJul16	26.21	56.61	2.81	10.75	0.29	-0.46	115.56	30.18	5.43	17.81	82.79
		XJAug16	39.94	72.64	3.37	13.87	0.03	-0.47	192.27	46.52	6.41	26.47	85.33

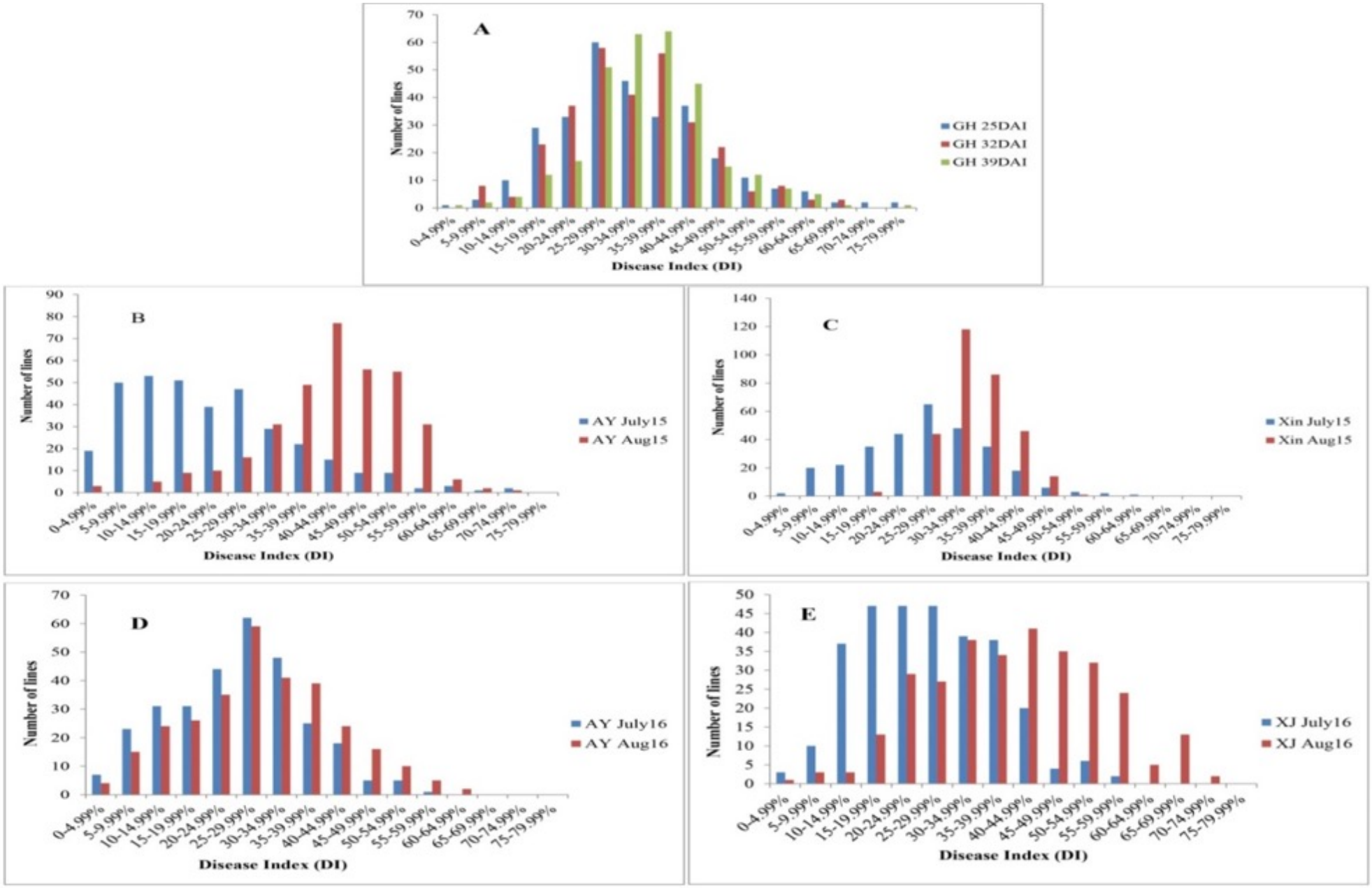


Figure 3. 2: Frequency distribution of disease index (DI) in the CSSL population

A=Greenhouse 2015, B=Anyang 2015, C=Xinjiang 2015, D= Anyang 2016, E=Xinjiang 2016

Table 3. 4: QTLs for *Verticillium* wilt resistance detected during different stages of growth at greenhouse and fields. Consistent QTL are in red colour

QTLs	Growth stage	Env	Chr	Position (cM)	Nearest marker	LOD	Add	PV (%)
qVW-Chr01-1	August	AYAug15	Chr01	31.1	TMB0119	2.63	7.73	3.80
qVW-Chr01-2	July	AYJul16	Chr01	70.3	MUCS084	2.97	-8.77	4.48
qVW-Chr01-3	July	XJJul16	Chr01	122.7	TMB152	3.15	-3.37	5.60
	August	XJAug16	Chr01	122.7	TMB152	4.27	-5.05	7.59
qVW-Chr02-1	Seedling	25DAI	Chr02	15.1	BNL1434	2.59	12.97	3.95
qVW-Chr02-2	July	XJJul15	Chr02	50.0	TMB1587	6.48	13.25	9.33
qVW-Chr02-3	August	AYAug16	Chr02	129.8	CICR800	2.59	9.95	3.89
qVW-Chr03-1	August	XJAug16	Chr03	98.0	CER0028	2.85	-6.02	4.26
qVW-Chr03-2	July	XJJul16	Chr03	114.4	HAU0195	3.95	-5.99	6.38
	August	XJAug16	Chr03	114.4	HAU0195	4.88	-8.50	7.71
qVW-Chr05-1	July	AYJul15	Chr05	32.3	CIR102	3.84	-5.44	5.89
	August	AYAug15	Chr05	32.3	CIR102	3.48	-4.07	5.31
	July	AYJul16	Chr05	32.3	CIR102	3.47	-4.43	5.42
	August	AYAug16	Chr05	32.3	CIR102	2.88	-4.46	4.56
	July	XJJul16	Chr05	32.3	CIR102	6.66	-5.65	9.77
	August	XJAug16	Chr05	32.3	CIR102	4.59	-6.16	6.97
qVW-Chr05-2	August	AYAug15	Chr05	34.4	DC20067	2.82	-3.90	4.33
	July	XJJul16	Chr05	34.4	DC20067	3.59	-4.48	5.43
qVW-Chr05-3	July	AYJul15	Chr05	36.0	BNL1042	3.32	-5.08	4.89
	August	AYAug15	Chr05	36.0	BNL1042	3.57	-4.23	5.46
	July	AYJul16	Chr05	36.0	BNL1042	5.07	-5.42	7.71
	August	AYAug16	Chr05	36.0	BNL1042	2.98	-4.57	4.56
	July	XJJul16	Chr05	36.0	BNL1042	6.96	-5.87	10.03
	August	XJAug16	Chr05	36.0	BNL1042	4.45	-6.15	6.61

QTLs	Growth stage	Env	Chr	Position (cM)	Nearest marker	LOD	Add	PV (%)
qVW-Chr05-4	July	AYJul15	Chr05	38.2	HAU0746	3.19	-5.69	4.76
	July	AYJul16	Chr05	38.2	HAU0746	2.99	-4.68	4.47
	July	XJJul16	Chr05	38.2	HAU0746	5.18	-5.80	7.62
	August	XJAug16	Chr05	38.2	HAU0746	3.26	-5.98	4.86
qVW-Chr05-5	July	XJJul16	Chr05	39.6	CGR6708a	2.83	-5.64	4.31
qVW-Chr05-6	July	AYJul15	Chr05	41.4	TMB1296	3.48	-5.39	5.23
	August	AYAug15	Chr05	41.4	TMB1296	2.83	-3.78	4.15
	July	AYJul16	Chr05	41.4	TMB1296	3.47	-4.56	5.18
	August	AYAug16	Chr05	41.4	TMB1296	2.82	-4.53	4.25
	July	XJJul16	Chr05	41.4	TMB1296	6.96	-6.06	10.17
	August	XJAug16	Chr05	41.4	TMB1296	4.34	-6.23	6.44
qVW-Chr05-7	July	XJJul16	Chr05	43.1	TMB1120	3.92	-4.74	5.84
	August	XJAug16	Chr05	43.1	TMB1120	6.30	-7.69	9.22
qVW-Chr05-8	July	XJJul16	Chr05	44.6	CGR5590	2.57	-5.63	4.32
qVW-Chr05-9	July	XJJul16	Chr05	46.2	CGR5025	4.19	-4.95	6.22
	August	XJAug16	Chr05	46.2	CGR5025	4.46	-6.65	6.75
qVW-Chr05-10	July	AYJul15	Chr05	64.3	MUCS530	4.87	12.73	7.18
qVW-Chr05-11	July	XJJul16	Chr05	89.9	MUSS317	3.23	-6.92	4.85
	August	XJAug16	Chr05	89.9	MUSS317	3.84	-9.71	5.74
qVW-Chr05-12	Seedling	39DAI	Chr05	135.6	DPL0174b	2.78	3.60	4.16
qVW-Chr05-13	Seedling	32DAI	Chr05	167.4	COT010	3.73	10.64	5.76
	Seedling	39DAI	Chr05	167.4	COT010	3.73	10.64	5.76
qVW-Chr05-14	August	XJAug15	Chr05	168.6	CGR5925a	3.35	2.81	5.00
qVW-Chr05-15	August	AYAug15	Chr05	197.4	HAU1050	3.11	-2.64	4.69
	July	XJJul16	Chr05	197.4	HAU1050	3.80	-2.96	5.62
	August	XJAug16	Chr05	197.4	HAU1050	4.03	-3.94	5.98
qVW-Chr06-1	August	XJAug15	Chr06	29.8	Gh082	3.94	9.40	5.59
qVW-Chr06-2	July	AYJul16	Chr06	66.1	NAU5433	3.55	-6.89	5.28
	July	XJJul16	Chr06	66.1	NAU5433	3.69	-6.68	5.50
	August	XJAug16	Chr06	66.1	NAU5433	4.53	-9.50	6.67

QTLs	Growth stage	Env	Chr	Position (cM)	Nearest marker	LOD	Add	PV (%)
qVW-Chr07-1	August	AYAug16	Chr07	92.2	NAU1085	2.62	-4.19	4.05
	July	XJJul16	Chr07	92.2	NAU1085	3.91	-4.41	5.97
	August	XJAug16	Chr07	92.2	NAU1085	3.37	-5.29	5.18
qVW-Chr09-1	July	XJJul16	Chr09	85.3	DPL0679	2.64	10.77	4.09
qVW-Chr09-2	August	XJAug16	Chr09	29.2	DPL0171	3.55	-5.09	5.28
qVW-Chr10-1	July	AYJul16	Chr10	150.7	NAU2869	3.37	-6.75	5.12
	August	AYAug16	Chr10	150.7	NAU2869	3.28	-7.31	5.00
	July	XJJul16	Chr10	150.7	NAU2869	2.69	-5.73	4.09
	August	XJAug16	Chr10	150.7	NAU2869	3.41	-8.31	5.17
qVW-Chr10-2	July	XJJul16	Chr10	199.7	HAU1701	2.90	6.64	4.36
	August	XJAug16	Chr10	199.7	HAU1701	2.61	7.80	3.94
qVW-Chr10-3	August	XJAug16	Chr10	203.5	Gh058	2.53	8.37	3.79
qVW-Chr11-1	July	XJJul15	Chr11	193.6	DPL0103	2.72	6.01	4.08
qVW-Chr11-2	July	AYJul16	Chr11	253.0	DPL0209	3.97	-7.00	6.06
	July	XJJul16	Chr11	253.0	DPL0209	5.40	-7.65	8.01
	August	XJAug16	Chr11	253.0	DPL0209	6.06	-10.48	9.04
qVW-Chr12-1	August	AYAug15	Chr12	101.5	HAU0734	2.80	8.38	4.19
qVW-Chr14-1	August	AYAug16	Chr14	184.6	NAU5465	2.50	-10.47	3.76
qVW-Chr14-2	July	AYJul16	Chr14	203.0	HAU0883	3.32	-5.89	5.42
	August	XJAug16	Chr14	203.0	HAU0883	4.27	-8.15	6.91
qVW-Chr15-1	July	XJJul16	Chr15	16.3	CICR815	2.64	6.63	3.96
	August	XJAug16	Chr15	16.3	CICR815	2.56	8.43	3.85
qVW-Chr15-2	August	XJAug16	Chr15	88.2	NAU2985	2.77	-5.79	4.15
qVW-Chr17-1	July	XJJul16	Chr17	23.3	HAU2014	4.58	-5.46	6.78
	August	XJAug16	Chr17	23.3	HAU2014	5.25	-7.49	7.66
qVW-Chr17-2	July	XJJul16	Chr17	122.8	HAU0195	2.55	-3.87	3.87
	August	XJAug16	Chr17	122.8	HAU0195	2.50	-4.94	3.79

QTLs	Growth stage	Env	Chr	Position (cM)	Nearest marker	LOD	Add	PV (%)
qVW-Chr19-1	July	AYJul16	Chr19	17.4	NAU3405	3.12	-5.01	4.66
	August	AYAug16	Chr19	17.4	NAU3405	4.05	-6.23	6.00
	August	XJAug16	Chr19	17.4	NAU3405	5.04	-7.75	7.43
	July	XJJul16	Chr19	17.4	NAU3405	5.42	-6.22	7.96
qVW-Chr19-2	July	AYJul15	Chr19	145.9	NAU5475	4.03	-6.38	5.98
	August	AYAug15	Chr19	145.9	NAU5475	2.54	-4.01	3.82
	July	AYJul16	Chr19	145.9	NAU5475	2.85	-4.57	4.27
	July	XJJul16	Chr19	145.9	NAU5475	6.45	-6.45	9.40
	August	XJAug16	Chr19	145.9	NAU5475	5.58	-7.76	8.18
qVW-Chr19-3	August	XJAug16	Chr19	185.6	HAU1385b	2.61	-5.77	3.91
qVW-Chr19-4	July	XJJul15	Chr19	197.0	NAU2274	2.72	6.01	4.08
qVW-Chr19-5	July	AYJul15	Chr19	221.3	NAU3652	3.83	19.47	6.80
qVW-Chr19-6	August	XJAug16	Chr19	257.1	HAU1785	3.47	-8.39	5.20
	August	AYAug15	Chr19	257.1	HAU1785	2.51	-5.42	3.79
	July	XJJul16	Chr19	257.1	HAU1785	3.01	-6.07	4.53
qVW-Chr19-7	August	XJAug16	Chr19	259.7	CGR5126	2.56	-7.22	3.84
qVW-Chr20-1	July	AYJul15	Chr20	175.5	NAU3665	3.64	-6.31	6.74
	August	AYAug15	Chr20	175.5	NAU3665	2.73	-4.07	4.53
	July	AYJul16	Chr20	175.5	NAU3665	2.80	-4.56	4.89
	August	AYAug16	Chr20	175.5	NAU3665	3.41	-5.61	6.15
	July	XJJul16	Chr20	175.5	NAU3665	6.52	-6.54	11.14
	August	XJAug16	Chr20	175.5	NAU3665	5.73	-7.87	9.69

QTLs	Growth stage	Env	Chr	Position (cM)	Nearest marker	LOD	Add	PV (%)
qVW-Chr21-1	July	XJJul15	Chr21	147.9	NAU5217	2.72	6.01	4.08
qVW-Chr21-2	August	AYAug15	Chr21	278.3	HAU1283	2.54	-10.28	3.81
qVW-Chr22-1	July	AYJul15	Chr22	21.8	NAU2026	2.89	-4.75	4.39
	August	XJAug16	Chr22	21.8	NAU2026	5.51	-6.28	7.06
	July	XJJul16	Chr22	21.8	NAU2026	4.84	-4.58	6.26
qVW-Chr22-2	July	XJJul16	Chr22	26.2	Gh200	2.90	12.75	3.74
	August	XJAug16	Chr22	26.2	Gh200	2.97	16.66	3.83
qVW-Chr22-3	August	AYAug15	Chr22	108.2	CIR224b	5.22	-3.81	7.67
	July	XJJul16	Chr22	108.2	CIR224b	6.87	-4.25	9.13
	August	XJAug16	Chr22	108.2	CIR224b	5.95	-5.09	7.88
qVW-Chr22-4	July	XJJul15	Chr22	149.7	CER0139b	2.52	3.91	3.78
qVW-Chr23-1	July	AYJul16	Chr23	86.9	Gh499	2.92	-8.40	4.42
qVW-Chr23-2	July	AYJul15	Chr23	208.1	NAU5189	3.32	-7.98	5.32
	July	XJJul16	Chr23	208.1	NAU5189	4.35	-7.26	6.77
	August	XJAug16	Chr23	208.1	NAU5189	4.98	-9.92	7.59
qVW-Chr24-1	August	AYAug15	Chr24	0.00	DPL0031	2.90	-13.23	4.31
qVW-Chr25-1	July	AYJul16	Chr25	94.6	CER0086b	5.11	-9.57	7.50
	August	AYAug16	Chr25	94.6	CER0086b	2.78	-7.83	4.17
	July	XJJul16	Chr25	94.6	CER0086b	2.67	-6.62	3.98
	August	XJAug16	Chr25	94.6	CER0086b	3.74	-10.06	5.52
qVW-Chr26-1	August	AYAug15	Chr26	8.2	NAU4925	4.03	7.97	6.08
	July	XJJul15	Chr26	8.2	NAU4925	3.09	2.27	4.61
qVW-Chr26-2	Seedling	25DAI	Chr26	172.9	CGR6759	2.60	12.97	3.89
	Seedling	32DAI	Chr26	172.9	CGR6759	2.74	11.18	4.11
	Seedling	39DAI	Chr26	172.9	CGR6759	2.74	11.18	4.11

QTLs identifications for *Verticillium* wilt in the CSSLs population

➢QTL mapping in the greenhouse

A total of **four** QTLs for *Verticillium* wilt were identified in greenhouse. Among four QTLs, **two** are stable (Figure 3.3, Table 3.4).

➢QTL mapping in the fields

- A total of **56** QTLs for *Verticillium* wilt were detected. Among them **30** QTLs are stable.

- Among them, **38** QTLs (68%) had negative additives effects, which indicate that the *G. barbadense* alleles increased *Verticillium* wilt resistance and decrease DI by about 2.64 to 13.23.

- The highest number of QTLs **(15)** was detected on Chromosome **05** (Figure 3.3, Table 3.4).

Table 3. 8: Descriptive statistics of fiber and yield traits with broad sense Heritability (H^2_B) measured in the fields experiments in $BC_5F_{3:5}$ population

	CSSL population							Parents			H^2 (%)
Traits	**Mean**	**Max.**	**Mini.**	**SD**	**Skewness**	**Kurtosis**	**Variance**	**CCRI36**	**Hai1**	**Mid parent**	
FL (mm)	27.93	30.91	25.78	0.80	0.56	1.02	0.64	28.44	33.80	31.12	87.52
FU (%)	83.78	86.48	81.71	0.82	0.04	0.24	0.67	84.62	83.00	83.81	76.28
FS (cN/Tex)	29.10	34.11	25.28	1.30	0.53	0.90	1.69	31.61	40.90	36.26	84.92
FM (Unit)	4.41	5.18	3.50	0.23	-0.18	1.60	0.05	4.63	4.70	4.67	86.25
FE (%)	6.78	6.98	6.61	0.07	0.16	-0.52	0.00	6.82	7.30	7.06	86.05
BW (g)	5.35	6.65	4.68	0.30	0.94	1.92	0.09	5.35	5.85	5.64	77.39
LP (%)	39.68	46.56	34.93	1.72	0.41	0.52	2.97	40.71	42.60	41.65	63.40
SI (g)	11.54	13.83	9.43	0.70	0.11	0.35	0.49	11.11	11.29	11.20	64.80
PH (cm)	73.81	96.35	51.18	7.41	0.12	-0.12	58.23	74.04	75.30	74.67	82.54

FL= Fiber Length; FU= Fiber Uniformity; FS= Fiber Strength; FM= Fiber Micronaire; FE= Fiber Elongation; BW= Boll Weight; LP= Lint percentage SI= Seed Index and PH= Plant Height

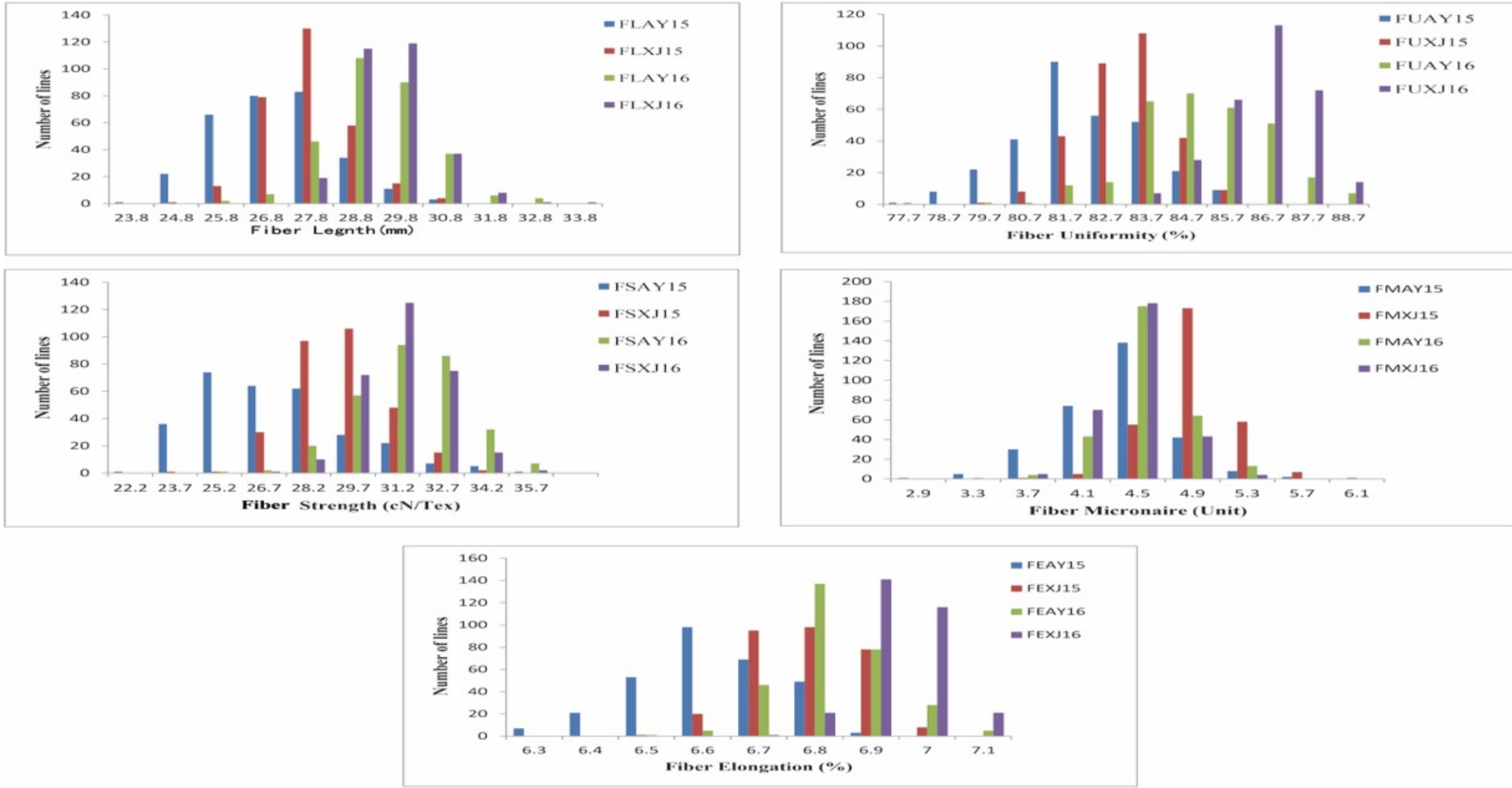


Figure 3. 5: Frequency distribution of fiber quality traits

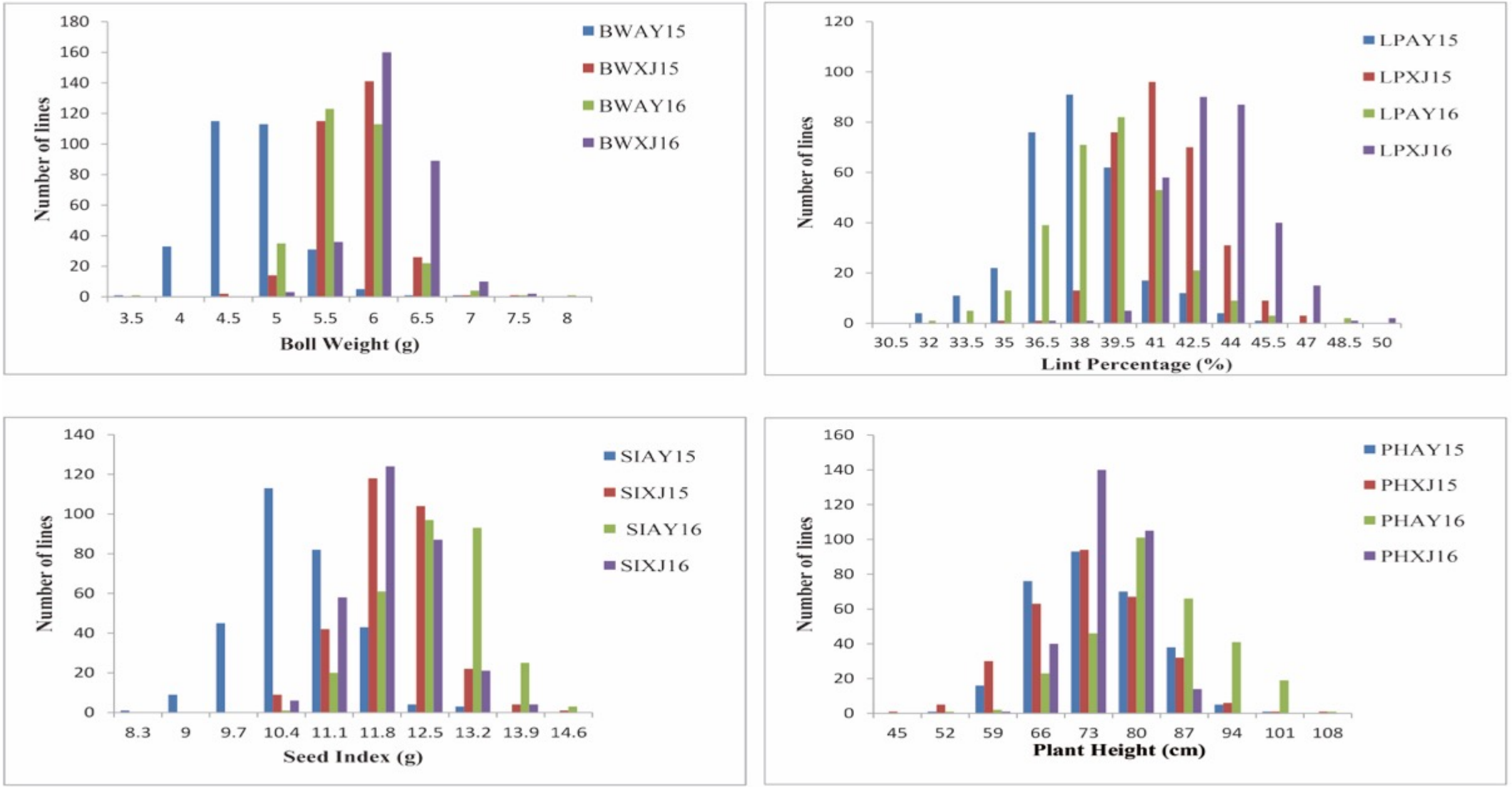


Figure 3. 6: Frequency distribution of yield related traits

Table 3. 9: Pearson correlation analysis among fiber quality and yield related traits based on mean of 4 environments

Traits	FL	FU	FS	FM	FE	BW	LP	SI
FU	0.347**							
FS	**0.829****	0.439**						
FM	**-0.222****	0.109*	**-0.246****					
FE	0.741**	0.299**	0.734**	-0.025				
BW	0.125*	0.167**	0.041	0.357**	0.080			
LP	-0.021	0.070	-0.110	**0.448****	-0.034	0.028		
SI	-0.019	0.076	0.049	-0.089	0.063	0.357**	**-0.539****	
PH	0.382**	0.114*	0.303**	0.223**	0.373**	0.233**	0.092	-0.076

*Indicates correlation is significant at the 0.05 level
**Indicates correlation is significant at the 0.01 level

QTL forVerticillium wilt resistance(DI), fiber quality and yield related traits

- A total of **251** QTLs have been detected. Among them **98** of the fiber quality traits and **93** of the yield
- related traits,**60** for forVerticillium wilt resistance(DI) . Of these, **86** QTLs are consistent

- Three chromosomes **Chr05, Chr19 and Chr20** contained more QTLs

Table 1 QTL details in the CSSL population

	DI	FL	FS	FU	FM	FE	BW	LP	SI	PH	Total QTLs
Total QTLs	60	32	21	8	24	13	38	18	10	27	251
Stable QTLs	32	12	8	0	5	2	10	6	5	6	86
Located on Chr No.	21	15	11	6	16	9	17	10	5	15	-
Max. on one Chr.	15	6	5	2	3	3	4	4	5	5	-
Chr. having Max. No.	5	20	20	19	15	05	19	18	20	05	-

Chr	Sl.	Cluster Name	QTLs	Env	Triats	Position	Nearest Marker	LOD	Add	PV (%)
Chr05	6	C05-cluster-4	qVW-Chr05-4	AYJul15	VW	38.2	HAU0746	3.19	-5.69	4.76
				AYJul16	VW	38.2	HAU0746	2.99	-4.68	4.47
				XJJul16	VW	38.2	HAU0746	5.18	-5.80	7.62
				XJAug16	VW	38.2	HAU0746	3.26	-5.98	4.86
			qFL-Chr05-3	AY16	FL	38.2	HAU0746	4.34	0.56	6.42
				XJ16	FL	38.2	HAU0746	4.42	0.44	6.08
			qFS-Chr05-1	AY15	FS	38.2	HAU0746	5.74	1.38	8.40
				AY16	FS	38.2	HAU0746	3.11	0.75	4.64
				XJ16	FS	38.2	HAU0746	2.82	0.61	4.23
	7	C05-cluster-5	qVW-Chr05-11	XJJul16	VW	89.9	MUSS317	3.23	-6.92	4.85
				XJAug16	VW	89.9	MUSS317	3.84	-9.71	5.74
			qSI-Chr05-1	SIAY16	SI	89.92	MUSS317	2.90	-0.45	4.32
			qLP-Chr05-1	XJ15	LP	89.92	MUSS317	4.09	1.28	5.90
				XJ16	LP	89.92	MUSS317	4.75	1.39	6.81
			qFL-Chr05-4	XJ16	FL	89.92	MUSS317	2.79	0.51	3.80
	8	C05-cluster-6	qVW-Chr05-15	AYAug15	VW	197.4	HAU1050	3.11	-2.64	4.69
				XJJul16	VW	197.4	HAU1050	3.80	-2.96	5.62
				XJAug16	VW	197.4	HAU1050	4.03	-3.94	5.98
			qPH-Chr05-5	PHAY16	PH	197.41	HAU1050	3.03	2.32	4.59
Chr06	9	C06-cluster-1	qVW-Chr06-1	XJAug15	VW	29.8	Gh082	3.94	9.40	5.59
			qFL-Chr06-1	XJ15	FL	29.8	Gh082	3.25	0.89	5.57
			qFS-Chr06-1	AY15	FS	29.8	Gh082	3.72	2.38	5.92
				XJ15	FS	29.8	Gh082	3.35	1.39	5.39
	10	C06-cluster-2	qVW-Chr06-2	AYJul16	VW	66.1	NAU5433	3.55	-6.89	5.28
				XJJul16	VW	66.1	NAU5433	3.69	-6.68	5.50
				XJAug16	VW	66.1	NAU5433	4.53	-9.50	6.67
			qBW-Chr06-1	AY15	BW	66.1	NAU5433	4.78	0.45	7.05
				XJ16	BW	66.1	NAU5433	4.57	0.24	6.72
			qFM-Chr06-1	AY15	FM	66.1	NAU5433	2.88	0.22	4.19
				XJ16	FM	66.1	NAU5433	3.11	0.14	4.65

Chr	Sl.	Cluster Name	QTLs	Env	Triats	Position	Nearest Marker	LOD	Add	PV (%)
Chr07	11	C07-cluster-1	qVW-Chr07-1	AYAug16	VW	92.2	NAU1085	2.62	-4.19	4.05
				XJJul16	VW	92.2	NAU1085	3.91	-4.41	5.97
				XJAug16	VW	92.2	NAU1085	3.37	-5.29	5.18
			qFL-Chr07-2	XJ16	FL	92.2	NAU1085	3.32	0.33	4.77
			qFS-Chr07-2	AY15	FS	92.2	NAU1085	3.53	0.92	5.06
Chr10	12	C10-cluster-1	qVW-Chr10-1	AYJul16	VW	150.7	NAU2869	3.37	-6.75	5.12
				AYAug16	VW	150.7	NAU2869	3.28	-7.31	5.00
				XJJul16	VW	150.7	NAU2869	2.69	-5.73	4.09
				XJAug16	VW	150.7	NAU2869	3.41	-8.31	5.17
			qBW-Chr10-2	AY15	BW	150.7	NAU2869	4.90	0.45	7.35
				XJ15	BW	150.7	NAU2869	4.06	0.24	6.18
				XJ16	BW	150.7	NAU2869	3.68	0.22	5.63
			qLP-Chr10-1	XJ15	LP	150.7	NAU2869	4.92	1.30	7.46
				AY16	LP	150.7	NAU2869	3.55	1.48	5.19
				XJ16	LP	150.7	NAU2869	4.87	1.30	7.38
			qFU-Chr10-1	AY16	FU	150.7	NAU2869	2.85	0.90	4.37
			qFM-Chr10-1	XJ15	FM	150.7	NAU2869	4.05	0.19	6.13
				AY15	FM	150.7	NAU2869	2.53	0.21	3.86
				XJ16	FM	150.7	NAU2869	4.18	0.17	6.32
Chr11	13	C11-cluster-1	qVW-Chr11-2	AYJul16	VW	253.0	DPL0209	3.97	-7.00	6.06
				XJJul16	VW	253.0	DPL0209	5.40	-7.65	8.01
				XJAug16	VW	253.0	DPL0209	6.06	-10.48	9.04
			qBW-Chr11-2	AY15	BW	253.0	DPL0209	3.85	0.38	5.72
				XJ16	BW	253.0	DPL0209	6.04	0.27	9.14
			qFM-Chr11-1	XJ16	FM	253.0	DPL0209	6.33	0.20	9.55

Chr	Sl.	Cluster Name	QTLs	Env	Triats	Position	Nearest Marker	LOD	Add	PV (%)
Chr19	20	C19-cluster-3	qVW-Chr19-3	XJAug16	VW	185.6	HAU1385b	2.61	-5.77	3.91
			qLP-Chr19-1	AY16	LP	185.6	HAU1385b	2.89	1.08	4.32
	21	C19-cluster-4	qVW-Chr19-5	AYJuly15	VW	221.3	NAU3652	3.83	19.47	6.80
			qFL-Chr19-3	XJ15	FL	221.3	NAU3652	3.94	-0.30	5.68
				AY16	FL	221.3	NAU3652	4.25	-0.37	6.19
			qFU-Chr19-2	AY16	FU	221.3	NAU3652	2.53	0.43	3.81
			qPH-Chr19-1	PHAY16	PH	221.3	NAU3652	3.21	-2.74	4.82
	22	C19-cluster-5	qVW-Chr19-6	XJAug16	VW	257.1	HAU1785	3.47	-8.39	5.20
				AYAug15	VW	257.1	HAU1785	2.51	-5.42	3.79
				XJJul16	VW	257.1	HAU1785	3.01	-6.07	4.53
			qBW-Chr19-3	XJ16	BW	257.1	HAU1785	3.50	0.21	5.21
	23	C19-cluster-6	qVW-Chr19-7	XJAug16	VW	259.7	CGR5126	2.56	-7.22	3.84
			qBW-Chr19-4	AY16	BW	259.7	CGR5126	2.66	0.35	3.99
				XJ16	BW	259.7	CGR5126	4.07	0.23	6.04
Chr20	24	C20-cluster-1	qVW-Chr20-1	AYJuly15	VW	175.5	NAU3665	3.64	-6.31	6.74
				AYAug15	VW	175.5	NAU3665	2.73	-4.07	4.53
				AYJul16	VW	175.5	NAU3665	2.80	-4.56	4.89
				AYAug16	VW	175.5	NAU3665	3.41	-5.61	6.15
				XJJul16	VW	175.5	NAU3665	6.52	-6.54	11.14
				XJAug16	VW	175.5	NAU3665	5.73	-7.87	9.69
			qBW-Chr20-1	AY15	BW	175.5	NAU3665	3.07	0.26	5.26
				XJ15	BW	175.5	NAU3665	2.56	0.14	4.72
				XJ16	BW	175.5	NAU3665	3.22	0.15	5.42
			qLP-Chr20-1	XJ15	LP	175.5	NAU3665	5.76	1.01	9.46
				AY16	LP	175.5	NAU3665	2.87	1.01	4.99
				XJ16	LP	175.5	NAU3665	6.24	1.05	10.06
			qFL-Chr20-5	AY15	FL	175.5	NAU3665	4.89	0.66	8.21
				XJ16	FL	175.5	NAU3665	4.19	0.44	7.26
				XJ15	FL	175.5	NAU3665	2.64	0.37	4.67
			qFS-Chr20-5	AY15	FS	175.5	NAU3665	5.34	1.35	9.20
			qFM-Chr20-1	XJ16	FM	175.5	NAU3665	3.56	0.12	6.46
				AY15	FM	175.5	NAU3665	3.60	0.13	5.48
			qPH-Chr20-3	PHAY15	PH	175.5	NAU3665	2.92	3.18	4.77
				PHAY16	PH	175.5	NAU3665	3.39	4.07	5.70
				PHXJ16	PH	175.5	NAU3665	3.09	2.10	5.44
				PHAY16	PH	175.5	NAU3665	3.30	3.03	5.06

Chr	Sl.	Cluster Name	QTLs	Env	Triats	Position	Nearest Marker	LOD	Add	PV (%)
Chr23	27	C23-cluster-1	qVW-Chr23-1	AYJul16	VW	86.9	Gh499	2.92	-8.40	4.42
			qFM-Chr23-1	XJ16	FM	86.9	Gh499	4.01	0.21	5.75
	28	C23-cluster-2	qVW-Chr23-2	AYJuly15	VW	208.1	NAU5189	3.32	-7.98	5.32
				XJJul16	VW	208.1	NAU5189	4.35	-7.26	6.77
				XJAug16	VW	208.1	NAU5189	4.98	-9.92	7.59
			qBW-Chr23-2	AY15	BW	208.1	NAU5189	6.39	0.52	9.99
				XJ15	BW	208.1	NAU5189	3.10	0.21	4.83
				XJ16	BW	208.1	NAU5189	4.04	0.23	6.32
			qFM-Chr23-2	XJ16	FM	208.1	NAU5189	5.81	0.20	8.93
				XJ15	FM	208.1	NAU5189	2.56	0.15	4.06
Chr25	29	C25-cluster-1	qVW-Chr25-1	AYJul16	VW	94.6	CER0086b	5.11	-9.57	7.50
				AYAug16	VW	94.6	CER0086b	2.78	-7.83	4.17
				XJJul16	VW	94.6	CER0086b	2.67	-6.62	3.98
				XJAug16	VW	94.6	CER0086b	3.74	-10.06	5.52
			qBW-Chr25-1	AY15	BW	94.6	CER0086b	5.94	0.56	8.32
				XJ16	BW	94.6	CER0086b	4.93	0.29	7.14
			qLP-Chr25-1	XJ15	LP	94.6	CER0086b	2.97	1.17	4.41
				XJ16	LP	94.6	CER0086b	3.14	1.21	4.66
			qFM-Chr25-2	XJ16	FM	94.6	CER0086b	4.95	0.21	7.29
				AY15	FM	94.6	CER0086b	2.67	0.24	3.91
Chr26	30	C26-cluster-1	qVW-Chr26-1	AYAug15	VW	8.2	NAU4925	4.03	7.97	6.08
				XJJul15	VW	8.2	NAU4925	3.09	2.27	4.61
			qLP-Chr26-2	AY15	LP	8.2	NAU4925	8.16	1.68	4.04

clusters for VW diseae index and fiber related traits

- A total of **30** on **16** chromosomes. Chromosome **19** (**6** clusters)
- Most of the QTLs for **fiber traits** were clustered with the **disease index**.
- **Six** clusters, **C01-cluster-1, C05-cluster-4, C07-cluster-1, C19-cluster-2, C22-cluster-1 and C22-cluster-2**, which had **positive** correlation between VW resistance and fiber quality traits.
- **Two** clusters, **C10-cluster-1 and C25-cluster-1** had also **positive** correlation between VW resistance and yield related traits, **boll weight** and **lint percentage**.
- **One** cluster, **C20-cluster-1** is important for both VW resistance and fiber related traits.

QTLs	Env	Triats	LOD	Add	PV (%)
qVW-Chr20-1	AYJuly15	VW	3.64	-6.31	6.74
	AYAug15	VW	2.73	-4.07	4.53
	AYJul16	VW	2.80	-4.56	4.89
	AYAug16	VW	3.41	-5.61	6.15
	XJJul16	VW	6.52	-6.54	11.14
	XJAug16	VW	5.73	-7.87	9.69
qBW-Chr20-1	AY15	BW	3.07	**0.26**	5.26
	XJ15	BW	2.56	**0.14**	4.72
	XJ16	BW	3.22	**0.15**	5.42
qLP-Chr20-1	XJ15	LP	5.76	**1.01**	9.46
	AY16	LP	2.87	**1.01**	4.99
	XJ16	LP	6.24	**1.05**	10.06
qFL-Chr20-5	AY15	FL	4.89	**0.66**	8.21
	XJ16	FL	4.19	**0.44**	7.26
	XJ15	FL	2.64	**0.37**	4.67
qFS-Chr20-5	AY15	FS	5.34	**1.35**	9.20
qFM-Chr20-1	XJ16	FM	3.56	**0.12**	6.46
	AY15	FM	3.60	**0.13**	5.48
qPH-Chr20-3	PHAY15	PH	2.92	**3.18**	4.77
	PHAY16	PH	3.39	**4.07**	5.70
	PHXJ16	PH	3.09	**2.10**	5.44
	PHAY16	PH	3.30	**3.03**	5.06

Thank You