The Response of QTL in Generation during Selection

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선발과정에서의 세대별 QTL 좌위 고정에 관한 연구

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SUMMARY

The objective of this study was to determine the response of QTL in each generation during selection to develop inbred lines.

The simulation program was written in Fortran. Magnitude of QTL effects, base population size, number of QTL assigned to population, and the allelic frequency for the positive allele at each major QTL were highly associated with number of generations to fixation of QTLs during selection. Populations with larger QTL effects and larger base population size had more individuals with fixed QTL. However, a smaller number of QTL assigned to population had a higher fraction of individuals with fixed QTL at each generation compared with more populations with QTL. This simulation study will help to design biological experiments for detection of QTL-marker association using inbred population and to determine optimum number of lines with fixed QTL during inbred line development. To complement this study, additional simulation should be need with abundant replicates, more various population sizes, magnitude of QTL effects, and recombination between markers and QTLs.

(Key words : QTL, selection response and inbred population)

INTRODUCTION

Genetic markers associated with QTL are of great value in breeding programs. An important aim in animal breeding and genetics is to identify and characterize QTLs that contribute to variation in quantitative traits both between and within populations.

Genetic markers associated with QTL may be a powerful way to improve traits expressed late in life or measurable only after slaughter. Selection of breedersbased on phenotypic values of the individual or its relatives is not always a good indicator of genotype, especially for quantitative traits with low heritability (Smith and Simpson, 1986). Several studies have shown selection response in a breeding program may be improved by using genetic markers (Dentine, 1992; Kashi et al., 1990; Meuwissen and Van Adrendonk, 1992; Smith and Simpson, 1986; Soller, 1978; Soller and Beckmann, 1983).

One application of using a linkage map with se-

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veral hundred polymorphisms positioned over the genome has been to identify regions of deoxyribonucleic acid (DNA) which affect production traits (Georges et al., 1995). The polymorphisms known as genetic markers may be linked to quantitative trait loci that affect an animal's performance. Once marker-QTL associations have been identified and mapped, marker assisted selection for specific quantitative trait loci can be more effective than mass selection (Kashi et al., 1986; Smith and Simpson, 1986; Soller and Beckmann, 1982; Soller and Beckmann, 1983; Soller and Genizi, 1978). The empirical confidence interval for an estimate of a QTL location is strongly influenced by population size and gene effect with an infinite number of markers (Darvasi, 1993).

The objective of this study was to determine the response of QTL in each generation during selection to develop inbred lines.

MATERIALS AND METHODS

The simulation program was written in Fortran. The program was set up to simulate five generations of animals or plants and to generate 30 different populations in each group.

To obtain the initial population for development of inbred lines, the base generation was created by randomly assigning both major QTLs with values dependent on assignment by to position and for other loci values of 0 or 1 at each 60 loci (i.e., total 120 loci for one complete genome) for two chromosomes (A and B) for each individual in the base population. In the simulation program, size of base population (3,000, 1,500, and 750), number of QTL in a population (1, 2, 5, and 10), position of QTL effects on loci dependent on number of QTL in a population, magnitude of QTL value (5 to 50 as small effects, 30 to 75 as medium effects, and 50 to 95 as large effects in Group 1 and 5 to 23 as small effects, 30 to 48 as medium effects, and 50 to 68

as large effects in Group 2), and the allelic frequencies for the positive allele at each major QTL (.05 and .2) were initially assigned by external reading parameters to generate genotypes including QTL for base population. For example, to assign a magnitude of QTL value in a population, the values of QTLs were ranged from 5 to 50 by 5 in Group 1 and from 5 to 23 by 2 as magnitude of increasing dependent on assignment of number of QTL, i.e., if 5 QTL were assigned as numbers of QTL then 5, 10, 15, 20, and 25 were used in Group 1 and 5, 7, 9, 11, and 13 were used in Group 2 as magnitude of QTL value with randomly assigned position of QTL.

Then numbers of individuals used as selected parent individuals during selection were assigned. The remaining generations were generated from inbreeding selected parent individuals of the previous generation. The parents were selected by choosing the superior individuals based on their own phenotypes.

To identify markers in selected population, if a value of greater than 1 on loci indicated a major favorable allele(major QTL) with markers denoted 2 which will be used as covariates in the analysis later. And if a value of equal to 1 or 0 on loci indicated a unfavorable allele with markers denoted 1.

Five generations were considered for selection. To investigate the effect of population structure, three different base population sizes of 3,000, 1,500, and 750 for the base generation were used. For each different base population size, the upper 10% of individuals from each base population (for example, if size of base population of 3,000, then 10% of 3,000 = 300) were selected and then matted with testers to creat the next generation. 80% of individuals from the second generation were selected (for example, if size of base population of 3,000, then 80% of 300 = 240) and then matted with testers to creat the next generation. 75% of individuals from the third generation were selected (for example, if

size of base population of 3,000, then 75% of 240 = 180) and then matted with testers to creat the next generation. And finally 11% of individuals from the fourth generation were selected (for example, if size of base population of 3,000, then 11% of 180 = 20) and then only the best one individual in the last generation was used to mate to produce F_1 progeny.

RESULTS

1. Fixed QTL at Each Generation

Number of individuals that had fixed QTL at each generation were calculated for combinations of parameters with the various population sizes, numbers of QTLs, and initial QTL frequencies in each generation during selection.

When the initial populations started with the higher initial QTL frequency of .2, the population had more individuals with QTLs fixed at initial population than with an initial QTL frequency of .05 with larger base population size and fewer QTL in whole generations because populations with the higher initial QTL frequency had more QTLs held at each initial population than in lower initial QTL frequency.

Although all QTLs were fixed by the last generation at various QTL effects and number of QTL, number of fixed QTL at each generation during selection was associated with the following factors; magnitude of QTL effects, base population size, and number of QTL assigned to the population. Populations with larger effects of QTL and larger base population size had more individuals with fixed QTL. However when fewer QTL were assigned to the initial population, the population had more of the initial QTL fixed at each generation compared with when more QTL were assigned to the initial population because some QTL were lost during selection when the population contained 10 QTLs (Table 1).

The same trend was observed for an initial QTL frequency of .2. QTLs began to be fixed from the third generation with 1, 2, and 5 QTLs and large QTL effects with base population of 3,000 for an initial QTL frequency of .2 (Table 2).

2. Development of Inbred Line

The phenotypic and genetic responses to selection and inbreeding are shown separately for each generation. The results are presented for genetic variances of each line, fraction of homozygous loci (%), fraction of heterozygous loci (%), and number of loci with fixed major QTLs and unfavorable alleles (1 or 0) for initial QTL frequency of .05 (Tables 3~6), and for initial QTL frequency of .2 (Tables 7~10).

3. With an Initial QTL Frequency of .05

1) The First Generation

Estimates of genetic variances ranged from 1.33 to 12.45 for different numbers of QTL (1, 2, 5, and 10) with large QTL effects, from 1.38 to 12.46 for different numbers of QTL with medium QTL effects, and from 1.33 to 12.36 for different numbers of QTL with small QTL effects. Fraction of homozygous loci ranged from 50.18% to 52.19% for different numbers of QTL with large QTL effects, from 50.21% to 52.27% for different numbers of QTL with medium QTL effects, and from 50.19% to 52.15% out of total numbers of loci in each population for different numbers of QTL with small QTL effects (Tables 3~6).

More genetic variances with larger number of QTL were observed compared with fewer number of QTL at the first generation. Populations had about 51% of homozygous loci with various number of QTL, base population size, and magnitude of QTL effects. Percentage of fixed loci with unfavorable alleles with effects of 1 was the same as fixed loci with unfavorable alleles with effects of 0.

Table 1. The number of individuals with fixed QTL with various numbers of QTL, effects of QTL, and initial base population sizes at initial QTL frequency of .05 in each generation

Q	G	GEN	L			M			S		
			P3000	P1500	P750	P3000	P1500	P750	P3000	P1500	P750
1	1	2	297.74	145.33	69.98	297.05	144.89	68.95	269.67	132.76	59.82
		3	239.97	119.92	59.44	239.94	119.85	59.20	234.32	116.10	53.56
		4	179.99	90.00	44.98	180.00	89.99	44.86	178.56	88.77	41.24
		5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	2	2	294.73	147.47	69.67	292.84	146.32	68.11	247.86	120.00	57.23
		3	240.00	119.92	59.40	239.88	119.77	59.07	216.59	105.48	49.03
		4	180.00	89.99	44.93	179.98	90.00	44.87	168.63	81.50	38.28
		5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	1.00
2	1	2	295.60	146.67	68.59	292.10	143.03	67.11	257.47	128.37	58.70
		3	239.97	119.79	59.19	239.88	119.72	58.57	225.20	111.51	51.36
		4	180.00	90.00	44.91	180.00	89.99	44.73	172.73	85.89	39.80
		5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	2	2	293.81	145.88	69.99	287.76	145.23	66.90	258.05	123.30	58.37
		3	239.97	119.89	59.34	239.74	119.74	58.82	224.00	107.97	49.68
		4	180.00	89.99	44.91	179.98	89.99	44.82	172.60	83.70	38.94
		5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
5	1	2	285.15	140.32	67.15	284.82	140.45	66.27	268.60	131.03	61.38
		3	239.69	119.14	58.26	239.42	118.89	57.86	230.43	114.06	53.78
		4	179.99	89.70	44.45	179.95	89.67	44.26	175.58	87.10	41.44
		5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	2	2	286.67	142.19	66.60	281.16	139.06	66.55	257.64	128.03	60.83
		3	239.74	119.66	57.90	239.04	118.86	58.02	225.68	111.91	52.77
		4	179.96	89.97	44.18	179.80	89.75	44.33	173.44	86.03	40.69
		5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
10	1	2	269.42	133.23	64.80	267.27	133.88	63.23	263.95	128.88	61.43
		3	235.28	116.77	56.27	234.18	116.70	55.33	229.84	112.59	53.38
		4	178.53	88.72	43.15	178.11	88.70	42.58	175.07	85.92	41.09
		5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	2	2	269.83	132.01	63.76	269.24	132.69	63.75	260.43	126.76	61.26
		3	235.67	115.74	55.69	235.07	115.97	55.61	226.98	110.87	52.93
		4	178.68	88.30	42.73	178.36	88.35	42.79	173.54	84.96	40.70
		5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

* L= large QTL effects, M= medium QTL effects, S= small QTL effects, Q= number of QTL, G= group, GEN= generation, P3000=base population size of 3,000, P1500= base population size of 1,500, and P750= base population size of 750.

Table 2. The number of individuals with fixed QTL with various numbers of QTL, effects of QTL, and initial base population sizes at initial QTL frequency of .2 in each generation

Q	G	GEN	L			M			S		
			P3000	P1500	P750	P3000	P1500	P750	P3000	P1500	P750
1	1	2	299.85	149.51	74.11	299.54	149.47	74.06	293.86	146.45	72.63
		3	240.00	119.98	59.94	240.00	119.96	59.90	238.99	119.29	59.04
		4	180.00	90.00	44.99	180.00	90.00	44.99	179.83	89.81	44.59
		5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	2	2	299.93	149.63	73.82	299.46	149.30	73.81	292.39	146.10	71.71
		3	240.00	119.97	59.90	240.00	119.96	59.88	237.04	118.15	58.18
		4	180.00	90.00	45.00	180.00	90.00	44.99	178.44	89.08	43.86
		5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2	1	2	299.93	149.56	74.25	299.54	149.02	73.90	292.67	145.22	71.27
		3	240.00	120.00	59.94	239.98	119.96	59.90	238.29	118.56	58.16
		4	180.00	90.00	45.00	180.00	90.00	44.99	179.12	89.24	44.05
		5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	2	2	299.86	149.73	73.88	299.24	149.05	73.82	290.50	144.45	71.88
		3	240.00	120.00	59.90	239.93	119.99	59.86	237.00	117.68	58.37
		4	180.00	90.00	45.00	180.00	90.00	44.99	178.55	88.97	44.09
		5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
5	1	2	299.56	149.61	74.11	299.75	149.49	73.80	295.85	147.19	72.45
		3	239.99	119.99	59.94	240.00	119.98	59.91	238.98	119.16	59.11
		4	180.00	90.00	45.00	180.00	90.00	44.99	179.57	89.69	44.63
		5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	2	2	299.42	149.57	73.61	299.32	149.07	73.71	294.09	144.89	72.47
		3	240.00	120.00	59.85	239.99	119.94	59.84	238.53	118.41	58.92
		4	180.00	90.00	44.99	180.00	90.00	44.98	179.35	89.25	44.40
		5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
10	1	2	299.24	149.50	73.89	299.33	149.36	73.70	296.81	148.00	73.15
		3	239.99	119.99	59.90	239.98	119.96	59.83	239.35	119.58	59.48
		4	180.00	90.00	44.99	180.00	90.00	44.98	179.79	89.82	44.79
		5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	2	2	299.58	149.34	73.77	299.20	148.95	73.61	297.47	147.50	72.81
		3	240.00	119.98	59.87	239.99	119.96	59.82	239.37	119.40	59.19
		4	180.00	90.00	44.99	180.00	90.00	44.98	179.74	89.75	44.58
		5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

* L= large QTL effects, M= medium QTL effects, S= small QTL effects, Q= number of QTL, G= group, GEN= generation, P3000=base population size of 3,000, P1500= base population size of 1,500, and P750= base population size of 750.

Table 3. Summary of information from selection procedure with 1 QTL in each initial population with initial frequency of QTL of .05

M	G	PM	L			M			S		
			P3000	P1500	P750	P3000	P1500	P750	P3000	P1500	P750
1	1	GV	1.35	1.37	1.40	1.39	1.39	1.38	1.38	1.36	1.33
		%HT	49.82	49.79	49.76	49.78	49.78	49.79	49.79	49.80	49.81
		%HM	50.18	50.21	50.24	50.22	50.22	50.21	50.21	50.20	50.19
		FF	0.88	0.91	0.94	0.93	0.93	0.93	0.91	0.90	0.87
		F1	24.65	24.65	24.66	24.65	24.65	24.64	24.65	24.66	24.67
		F0	24.65	24.64	24.64	24.65	24.64	24.64	24.65	24.65	24.65
	2	GV	2.83	2.81	2.72	2.81	2.79	2.66	2.43	2.39	2.25
		%HT	24.59	24.63	24.69	24.58	24.64	24.68	24.70	24.72	24.87
		%HM	75.41	75.37	75.31	75.42	75.36	75.32	75.30	75.28	75.13
		FF	1.56	1.55	1.47	1.55	1.53	1.43	1.28	1.25	1.15
		F1	39.69	39.47	38.72	39.91	39.54	38.91	40.61	40.20	39.19
		F0	34.16	34.36	35.12	33.96	34.28	34.99	33.41	33.83	34.79
	3	GV	3.44	3.44	3.40	3.44	3.43	3.37	3.16	3.10	2.86
		%HT	12.11	12.18	12.32	12.11	12.17	12.26	12.13	12.23	12.38
		%HM	87.89	87.82	87.68	87.89	87.83	87.74	87.87	87.77	87.62
		FF	1.67	1.66	1.64	1.66	1.66	1.62	1.50	1.47	1.33
		F1	50.84	49.60	46.72	50.97	49.67	47.02	51.56	50.32	47.47
		F0	35.39	36.55	39.32	35.26	36.50	39.11	34.80	35.99	38.82
	4	GV	3.69	3.69	3.68	3.69	3.69	3.68	3.56	3.49	3.26
		%HT	5.92	6.02	6.11	5.91	6.00	6.08	5.94	6.03	6.16
		%HM	94.08	93.98	93.89	94.09	94.00	93.92	94.06	93.97	93.84
		FF	1.67	1.67	1.66	1.67	1.67	1.66	1.60	1.56	1.45
		F1	58.87	56.85	52.12	59.02	56.95	52.47	59.32	57.37	52.84
		F0	33.54	35.46	40.11	33.41	35.39	39.78	33.14	35.03	39.55
	5	P	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
		Q1	0.68	0.65	0.60	0.68	0.65	0.59	0.68	0.66	0.60
		Q0	0.31	0.33	0.39	0.31	0.33	0.39	0.30	0.33	0.39
		GV	3.81	3.81	3.81	3.81	3.81	3.80	3.77	3.68	3.58
		TNL	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00
		NHT	1.52	1.65	1.87	1.66	1.63	1.89	1.67	1.81	1.88
		%HT	2.53	2.74	3.12	2.77	2.72	3.16	2.78	3.02	3.13
		NHM	58.48	58.35	58.13	58.34	58.37	58.11	58.33	58.19	58.12
		%HM	97.47	97.26	96.88	97.23	97.28	96.84	97.22	96.98	96.87
		FF	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.96	0.94
		%FH	1.71	1.71	1.72	1.71	1.71	1.72	1.70	1.65	1.61
		%FT	1.67	1.67	1.67	1.67	1.67	1.66	1.65	1.60	1.56
		F1	39.93	38.18	34.77	39.70	38.30	34.59	40.26	38.41	34.87
		%F1	66.54	63.64	57.94	66.17	63.83	57.66	67.09	64.02	58.12
		F0	17.55	19.17	22.36	17.64	19.07	22.52	17.09	18.82	22.32
		%F0	29.26	31.95	37.27	29.39	31.78	37.53	28.48	31.37	37.19

Table 4. Summary of information from selection procedure with 2 QTL in each initial population with initial frequency of QTL of .05

M	G	PM	L			M			S		
			P3000	P1500	P750	P3000	P1500	P750	P3000	P1500	P750
2	1	GV	2.75	2.76	2.74	2.70	2.70	2.63	2.74	2.73	2.70
		%HT	49.57	49.56	49.54	49.56	49.57	49.63	49.57	49.59	49.56
		%HM	50.43	50.44	50.46	50.44	50.43	50.37	50.43	50.41	50.44
		FF	1.85	1.87	1.86	1.83	1.82	1.75	1.85	1.83	1.83
		F1	24.29	24.29	24.31	24.31	24.31	24.31	24.30	24.29	24.32
		F0	24.29	24.29	24.29	24.30	24.30	24.32	24.29	24.29	24.29
	2	GV	5.49	5.45	5.27	5.33	5.33	5.06	4.77	4.68	4.45
		%HT	24.31	24.33	24.45	24.38	24.38	24.52	24.52	24.56	24.62
		%HM	75.69	75.67	75.55	75.62	75.62	75.48	75.48	75.44	75.38
		FF	3.08	3.04	2.89	2.95	2.94	2.73	2.54	2.48	2.33
		F1	38.37	38.17	37.75	38.62	38.34	37.93	39.93	39.49	38.69
		F0	34.25	34.46	34.91	34.04	34.33	34.83	33.01	33.46	34.35
	3	GV	6.75	6.74	6.64	6.74	6.72	6.54	6.18	6.05	5.59
		%HT	11.96	12.03	12.12	11.97	12.03	12.15	12.04	12.13	12.23
		%HM	88.04	87.97	87.88	88.03	87.97	87.85	87.96	87.87	87.77
		FF	3.32	3.32	3.24	3.31	3.30	3.17	2.97	2.90	2.64
		F1	49.13	47.88	45.44	49.03	47.89	45.47	50.51	49.29	46.79
		F0	35.59	36.78	39.20	35.69	36.77	39.21	34.48	35.68	38.34
	4	GV	7.25	7.25	7.24	7.25	7.25	7.21	6.96	6.84	6.37
		%HT	5.87	5.92	6.02	5.87	5.91	6.00	5.85	5.93	6.07
		%HM	94.13	94.08	93.98	94.13	94.09	94.00	94.15	94.07	93.93
		FF	3.33	3.33	3.32	3.33	3.33	3.31	3.18	3.12	2.87
		F1	57.12	55.12	50.72	57.04	55.23	50.69	58.03	56.13	51.90
		F0	33.67	35.63	39.94	33.75	35.52	40.00	32.94	34.83	39.16
	5	P	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
		Q1	0.66	0.63	0.58	0.66	0.63	0.58	0.67	0.64	0.58
		Q0	0.31	0.34	0.39	0.31	0.33	0.38	0.30	0.33	0.39
		GV	7.49	7.49	7.49	7.49	7.49	7.49	7.32	7.28	7.13
		TNL	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00
		NHT	1.74	1.64	1.72	1.80	1.73	1.71	1.74	1.75	1.97
		%HT	2.89	2.73	2.86	2.99	2.89	2.84	2.90	2.92	3.29
		NHM	58.26	58.36	58.28	58.20	58.27	58.29	58.26	58.25	58.03
		%HM	97.11	97.27	97.14	97.01	97.11	97.16	97.10	97.08	96.71
		FF	2.00	2.00	2.00	2.00	2.00	2.00	1.94	1.94	1.89
		%FH	3.43	3.43	3.43	3.44	3.43	3.43	3.34	3.33	3.26
		%FT	3.33	3.33	3.33	3.33	3.33	3.33	3.24	3.23	3.16
		F1	38.47	36.88	33.94	38.54	37.20	34.21	39.22	37.53	33.78
		%F1	64.12	61.47	56.56	64.24	62.00	57.02	65.37	62.56	56.30
		F0	17.79	19.48	22.35	17.66	19.07	22.08	17.10	18.77	22.35
		%F0	29.65	32.47	37.24	29.43	31.78	36.80	28.49	31.29	37.26

Table 5. Summary of information from selection procedure with 5 QTL in each initial population with initial frequency of QTL of .05

M	G	PM	L P3000	L P1500	L P750	M P3000	M P1500	M P750	S P3000	S P1500	S P750
5	1	GV	6.57	6.55	6.55	6.49	6.56	6.58	6.46	6.54	6.55
		%HT	48.91	48.98	48.97	48.98	48.92	48.97	49.00	48.99	48.92
		%HM	51.09	51.02	51.03	51.02	51.08	51.03	51.00	51.01	51.08
		FF	4.59	4.56	4.56	4.50	4.58	4.57	4.47	4.55	4.58
		F1	23.25	23.22	23.23	23.27	23.25	23.23	23.26	23.22	23.25
		F0	23.25	23.24	23.24	23.25	23.24	23.23	23.26	23.25	23.25
	2	GV	12.29	12.24	11.99	12.16	12.16	11.93	11.49	11.48	11.13
		%HT	23.67	23.69	23.83	23.73	23.71	23.85	23.92	23.98	24.05
		%HM	76.33	76.31	76.17	76.27	76.29	76.15	76.08	76.02	75.95
		FF	7.03	6.98	6.76	6.92	6.93	6.71	6.42	6.39	6.13
		F1	35.42	35.37	35.33	35.71	35.70	35.64	37.18	36.96	36.61
		F0	33.89	33.96	34.08	33.64	33.66	33.80	32.48	32.66	33.21
	3	GV	15.85	15.74	15.25	15.76	15.64	15.21	14.90	14.77	14.02
		%HT	11.49	11.57	11.75	11.55	11.58	11.73	11.66	11.75	11.84
		%HM	88.51	88.43	88.25	88.45	88.42	88.27	88.34	88.25	88.16
		FF	8.18	8.11	7.76	8.12	8.03	7.73	7.55	7.46	7.00
		F1	43.84	43.00	41.76	43.97	43.45	42.16	46.25	45.38	43.85
		F0	36.49	37.33	38.73	36.36	36.93	38.39	34.54	35.41	37.31
	4	GV	17.19	17.16	16.94	17.18	17.14	16.94	16.71	16.59	15.80
		%HT	5.62	5.74	5.82	5.65	5.68	5.79	5.64	5.73	5.87
		%HM	94.38	94.26	94.18	94.35	94.32	94.21	94.36	94.27	94.13
		FF	8.33	8.31	8.18	8.33	8.30	8.17	8.04	7.97	7.52
		F1	51.68	49.80	46.22	51.56	50.00	46.58	53.09	51.51	48.24
		F0	34.37	36.14	39.79	34.47	36.03	39.46	33.23	34.79	38.37
	5	P	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
		Q1	0.60	0.58	0.53	0.61	0.58	0.53	0.61	0.59	0.54
		Q0	0.31	0.34	0.39	0.31	0.34	0.38	0.30	0.33	0.38
		GV	17.76	17.76	17.74	17.76	17.75	17.73	17.57	17.58	17.22
		TNL	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00
		NHT	1.60	1.65	1.74	1.66	1.69	1.77	1.60	1.64	1.71
		%HT	2.67	2.74	2.91	2.76	2.82	2.94	2.66	2.73	2.86
		NHM	58.40	58.35	58.26	58.34	58.31	58.23	58.40	58.36	58.29
		%HM	97.33	97.26	97.09	97.24	97.18	97.06	97.34	97.27	97.14
		FF	5.00	5.00	4.99	5.00	5.00	4.99	4.93	4.94	4.82
		%FH	8.57	8.57	8.57	8.57	8.57	8.57	8.44	8.46	8.26
		%FT	8.33	8.33	8.32	8.33	8.33	8.32	8.22	8.23	8.03
		F1	35.40	33.91	30.80	35.52	33.93	31.21	36.07	34.46	31.76
		%F1	58.99	56.52	51.33	59.19	56.56	52.02	60.12	57.43	52.94
		F0	18.00	19.44	22.47	17.83	19.38	22.03	17.40	18.97	21.71
		%F0	30.00	32.41	37.45	29.71	32.30	36.72	29.00	31.61	36.18

Table 6. Summary of information from selection procedure with 10 QTL in each initial population with initial frequency of QTL of .05

M	G	PM	L			M			S		
			P3000	P1500	P750	P3000	P1500	P750	P3000	P1500	P750
10	1	GV	12.35	12.28	12.45	12.32	12.46	12.33	12.36	12.22	12.26
		%HT	47.86	47.93	47.81	47.89	47.73	47.86	47.85	47.96	47.91
		%HM	52.14	52.07	52.19	52.11	52.27	52.14	52.15	52.04	52.09
		FF	9.19	9.11	9.33	9.17	9.37	9.18	9.21	9.04	9.11
		F1	21.47	21.48	21.46	21.46	21.45	21.48	21.47	21.50	21.50
		F0	21.48	21.48	21.41	21.48	21.45	21.48	21.47	21.50	21.48
	2	GV	21.57	21.44	21.41	21.49	21.59	21.18	21.21	20.92	20.66
		%HT	22.83	22.88	22.95	22.84	22.81	23.04	22.93	23.05	23.18
		%HM	77.17	77.12	77.05	77.16	77.19	76.96	77.07	76.95	76.82
		FF	13.07	12.94	12.89	13.01	13.09	12.68	12.76	12.50	12.23
		F1	32.41	32.39	32.39	32.61	32.57	32.64	33.29	33.28	33.21
		F0	31.69	31.79	31.76	31.54	31.53	31.65	31.02	31.17	31.38
	3	GV	27.80	27.49	26.85	27.68	27.55	26.59	27.13	26.64	25.78
		%HT	10.99	11.05	11.22	10.98	11.05	11.27	11.04	11.16	11.35
		%HM	89.01	88.95	88.78	89.02	88.95	88.73	88.96	88.84	88.65
		FF	15.45	15.21	14.71	15.37	15.26	14.50	14.96	14.59	13.93
		F1	37.96	37.74	37.63	38.30	38.11	38.01	39.99	39.60	39.11
		F0	35.60	36.00	36.44	35.35	35.58	36.21	34.01	34.66	35.60
	4	GV	31.05	30.83	30.08	31.00	30.83	29.93	30.45	29.95	28.89
		%HT	5.27	5.31	5.52	5.28	5.34	5.50	5.32	5.40	5.58
		%HM	94.73	94.69	94.48	94.72	94.66	94.50	94.68	94.60	94.42
		FF	16.50	16.33	15.78	16.46	16.33	15.67	16.06	15.72	14.98
		F1	43.28	42.05	40.62	43.29	42.51	40.93	45.26	44.18	42.64
		F0	34.95	36.32	38.08	34.97	35.81	37.91	33.35	34.70	36.80
	5	P	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.16	0.16
		Q1	0.53	0.49	0.46	0.52	0.50	0.46	0.53	0.51	0.48
		Q0	0.31	0.34	0.38	0.31	0.34	0.38	0.31	0.32	0.36
		GV	32.29	32.28	32.13	32.29	32.27	32.08	32.04	31.88	31.28
		TNL	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00
		NHT	1.39	1.36	1.61	1.48	1.53	1.48	1.40	1.56	1.67
		%HT	2.32	2.27	2.68	2.47	2.56	2.46	2.33	2.60	2.79
		NHM	58.61	58.64	58.39	58.52	58.47	58.52	58.60	58.44	58.33
		%HM	97.68	97.73	97.32	97.53	97.44	97.54	97.67	97.40	97.21
		FF	10.00	9.99	9.92	10.00	9.99	9.91	9.90	9.83	9.59
		%FH	17.07	17.05	17.00	17.10	17.09	16.94	16.90	16.83	16.45
		%FT	16.67	16.66	16.53	16.67	16.65	16.52	16.50	16.38	15.99
		F1	30.84	28.89	26.61	30.54	29.09	26.72	30.95	29.91	27.79
		%F1	51.41	48.14	44.36	50.90	48.48	44.54	51.58	49.85	46.31
		F0	17.77	19.76	21.86	17.98	19.39	21.89	17.75	18.70	20.95
		%F0	29.61	32.93	36.43	29.96	32.31	36.48	29.59	31.17	34.91

Table 7. Summary of information from selection procedure with 1 QTL in each initial population with initial frequency of QTL of .2

M	G	PM	L P3000	L P1500	L P750	M P3000	M P1500	M P750	S P3000	S P1500	S P750
1	1	GV	1.35	1.37	1.40	1.39	1.39	1.38	1.38	1.36	1.33
		%HT	49.82	49.79	49.76	49.78	49.78	49.79	49.79	49.80	49.81
		%HM	50.18	50.21	50.24	50.22	50.22	50.21	50.21	50.20	50.19
		FF	0.88	0.91	0.94	0.93	0.93	0.93	0.91	0.90	0.87
		F1	24.65	24.65	24.66	24.65	24.65	24.64	24.65	24.66	24.67
		F0	24.65	24.64	24.64	24.65	24.64	24.64	24.65	24.65	24.65
	2	GV	2.83	2.81	2.72	2.81	2.79	2.66	2.43	2.39	2.25
		%HT	24.59	24.63	24.69	24.58	24.64	24.68	24.70	24.72	24.87
		%HM	75.41	75.37	75.31	75.42	75.36	75.32	75.30	75.28	75.13
		FF	1.56	1.55	1.47	1.55	1.53	1.43	1.28	1.25	1.15
		F1	39.69	39.47	38.72	39.91	39.54	38.91	40.61	40.20	39.19
		F0	34.16	34.36	35.12	33.96	34.28	34.99	33.41	33.83	34.79
	3	GV	3.44	3.44	3.40	3.44	3.43	3.37	3.16	3.10	2.86
		%HT	12.11	12.18	12.32	12.11	12.17	12.26	12.13	12.23	12.38
		%HM	87.89	87.82	87.68	87.89	87.83	87.74	87.87	87.77	87.62
		FF	1.67	1.66	1.64	1.66	1.66	1.62	1.50	1.47	1.33
		F1	50.84	49.60	46.72	50.97	49.67	47.02	51.56	50.32	47.47
		F0	35.39	36.55	39.32	35.26	36.50	39.11	34.80	35.99	38.82
	4	GV	3.69	3.69	3.68	3.69	3.69	3.68	3.56	3.49	3.26
		%HT	5.92	6.02	6.11	5.91	6.00	6.08	5.94	6.03	6.16
		%HM	94.08	93.98	93.89	94.09	94.00	93.92	94.06	93.97	93.84
		FF	1.67	1.67	1.66	1.67	1.67	1.66	1.60	1.56	1.45
		F1	58.87	56.85	52.12	59.02	56.95	52.47	59.32	57.37	52.84
		F0	33.54	35.46	40.11	33.41	35.39	39.78	33.14	35.03	39.55
	5	P	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
		Q1	0.68	0.65	0.60	0.68	0.65	0.59	0.68	0.66	0.60
		Q0	0.31	0.33	0.39	0.31	0.33	0.39	0.30	0.33	0.39
		GV	3.81	3.81	3.81	3.81	3.81	3.80	3.77	3.68	3.58
		TNL	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00
		NHT	1.52	1.65	1.87	1.66	1.63	1.89	1.67	1.81	1.88
		%HT	2.53	2.74	3.12	2.77	2.72	3.16	2.78	3.02	3.13
		NHM	58.48	58.35	58.13	58.34	58.37	58.11	58.33	58.19	58.12
		%HM	97.47	97.26	96.88	97.23	97.28	96.84	97.22	96.98	96.87
		FF	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.96	0.94
		%FH	1.71	1.71	1.72	1.71	1.71	1.72	1.70	1.65	1.61
		%FT	1.67	1.67	1.67	1.67	1.67	1.66	1.65	1.60	1.56
		F1	39.93	38.18	34.77	39.70	38.30	34.59	40.26	38.41	34.87
		%F1	66.54	63.64	57.94	66.17	63.83	57.66	67.09	64.02	58.12
		F0	17.55	19.17	22.36	17.64	19.07	22.52	17.09	18.82	22.32
		%F0	29.26	31.95	37.27	29.39	31.78	37.53	28.48	31.37	37.19

Table 8. Summary of information from selection procedure with 2 QTL in each initial population with initial frequency of QTL of .2

M	G	PM	L P3000	L P1500	L P750	M P3000	M P1500	M P750	S P3000	S P1500	S P750
2	1	GV	3.60	3.55	3.64	3.61	3.59	3.64	3.62	3.61	3.61
		%HT	48.68	48.70	48.60	48.63	48.63	48.62	48.64	48.63	48.63
		%HM	51.32	51.30	51.40	51.37	51.37	51.38	51.36	51.37	51.37
		FF	2.95	2.90	3.01	2.98	2.96	3.02	2.99	2.98	2.97
		F1	24.20	24.20	24.21	24.19	24.22	24.17	24.19	24.18	24.20
		F0	24.17	24.21	24.18	24.19	24.19	24.18	24.18	24.21	24.19
	2	GV	5.78	5.75	5.72	5.75	5.73	5.70	5.59	5.56	5.52
		%HT	24.11	24.16	24.20	24.11	24.17	24.19	24.17	24.21	24.28
		%HM	75.89	75.84	75.80	75.89	75.84	75.81	75.83	75.79	75.72
		FF	3.31	3.29	3.26	3.29	3.27	3.24	3.17	3.15	3.11
		F1	39.63	39.06	38.35	39.68	39.22	38.34	40.03	39.49	38.52
		F0	32.95	33.49	34.19	32.91	33.35	34.23	32.63	33.16	34.09
	3	GV	6.77	6.77	6.76	6.77	6.76	6.75	6.66	6.63	6.55
		%HT	11.89	11.97	12.00	11.87	11.96	12.02	11.92	11.93	12.10
		%HM	88.11	88.03	88.00	88.13	88.04	87.98	88.08	88.07	87.90
		FF	3.33	3.33	3.33	3.33	3.33	3.32	3.27	3.25	3.20
		F1	50.71	49.17	46.52	50.70	49.28	46.49	50.99	49.59	46.62
		F0	34.06	35.52	38.15	34.10	35.42	38.17	33.83	35.23	38.08
	4	GV	7.25	7.25	7.25	7.25	7.25	7.25	7.20	7.18	7.10
		%HT	5.83	5.92	5.99	5.79	5.85	5.93	5.84	5.88	6.00
		%HM	94.17	94.08	94.01	94.21	94.15	94.07	94.16	94.12	94.00
		FF	3.33	3.33	3.33	3.33	3.33	3.33	3.31	3.29	3.25
		F1	58.55	56.21	51.91	58.52	56.45	51.91	58.67	56.63	51.99
		F0	32.29	34.53	38.77	32.36	34.36	38.83	32.18	34.19	38.76
	5	P	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
		Q1	0.67	0.64	0.59	0.67	0.64	0.59	0.67	0.65	0.59
		Q0	0.30	0.32	0.38	0.30	0.32	0.38	0.29	0.32	0.38
		GV	7.49	7.49	7.49	7.49	7.49	7.49	7.47	7.47	7.44
		TNL	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00
		NHT	1.77	1.81	1.88	1.61	1.60	1.84	1.63	1.66	1.79
		%HT	2.94	3.02	3.13	2.69	2.66	3.06	2.71	2.77	2.99
		NHM	58.23	58.19	58.12	58.39	58.40	58.16	58.37	58.34	58.21
		%HM	97.06	96.98	96.87	97.31	97.34	96.94	97.29	97.23	97.01
		FF	2.00	2.00	2.00	2.00	2.00	2.00	1.99	1.99	1.98
		%FH	3.44	3.44	3.44	3.43	3.43	3.44	3.42	3.42	3.41
		%FT	3.33	3.33	3.33	3.33	3.33	3.33	3.32	3.32	3.31
		F1	39.38	37.61	34.42	39.33	37.77	34.48	39.57	38.04	34.33
		%F1	65.64	62.68	57.37	65.54	62.94	57.46	65.95	63.40	57.22
		F0	16.85	18.58	21.70	17.06	18.64	21.69	16.81	18.30	21.89
		%F0	28.08	30.96	36.16	28.43	31.06	36.14	28.02	30.51	36.48

Table 9. Summary of information from selection procedure with 5 QTL in each initial population with initial frequency of QTL of .2

M	G	PM	L			M			S		
			P3000	P1500	P750	P3000	P1500	P750	P3000	P1500	P750
5	1	GV	8.56	8.61	8.59	8.66	8.59	8.61	8.66	8.59	8.61
		%HT	46.62	46.56	46.61	46.49	46.60	46.55	46.49	46.58	46.57
		%HM	53.38	53.44	53.39	53.51	53.40	53.45	53.51	53.42	53.43
		FF	7.41	7.48	7.45	7.55	7.44	7.47	7.56	7.45	7.47
		F1	22.99	22.98	22.96	22.97	22.98	22.99	22.98	22.99	22.97
		F0	22.99	22.98	22.98	22.99	22.98	22.99	22.98	22.98	22.99
	2	GV	13.62	13.62	13.52	13.63	13.59	13.49	13.43	13.32	13.27
		%HT	22.92	22.95	23.06	22.93	22.98	23.09	23.01	23.07	23.15
		%HM	77.08	77.05	76.94	77.07	77.02	76.91	76.99	76.93	76.85
		FF	8.21	8.20	8.11	8.22	8.18	8.08	8.04	7.95	7.90
		F1	37.02	36.73	36.07	37.23	36.79	36.13	37.72	37.32	36.39
		F0	31.85	32.12	32.76	31.62	32.06	32.70	31.23	31.66	32.56
	3	GV	16.04	16.04	16.00	16.04	16.03	15.99	15.92	15.84	15.74
		%HT	11.27	11.37	11.47	11.28	11.35	11.47	11.32	11.35	11.51
		%HM	88.73	88.63	88.53	88.72	88.65	88.54	88.68	88.65	88.49
		FF	8.33	8.33	8.30	8.33	8.33	8.29	8.25	8.19	8.12
		F1	47.46	46.23	43.67	47.70	46.30	43.66	48.02	46.72	43.98
		F0	32.93	34.06	36.56	32.69	34.03	36.59	32.42	33.73	36.39
	4	GV	17.19	17.19	17.18	17.19	17.19	17.18	17.14	17.09	17.02
		%HT	5.50	5.63	5.72	5.48	5.57	5.71	5.50	5.58	5.68
		%HM	94.50	94.37	94.28	94.52	94.43	94.29	94.50	94.42	94.32
		FF	8.33	8.33	8.33	8.33	8.33	8.33	8.30	8.27	8.23
		F1	55.04	53.14	48.85	55.27	53.20	48.75	55.49	53.39	49.06
		F0	31.13	32.90	37.10	30.91	32.89	37.21	30.70	32.75	37.03
	5	P	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
		Q1	0.63	0.61	0.55	0.64	0.61	0.55	0.64	0.61	0.56
		Q0	0.28	0.30	0.36	0.28	0.31	0.36	0.28	0.31	0.36
		GV	17.76	17.76	17.76	17.76	17.76	17.76	17.76	17.75	17.69
		TNL	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00
		NHT	1.61	1.63	1.69	1.50	1.66	1.74	1.69	1.61	1.76
		%HT	2.68	2.71	2.82	2.50	2.77	2.89	2.82	2.68	2.93
		NHM	58.39	58.37	58.31	58.50	58.34	58.26	58.31	58.39	58.24
		%HM	97.32	97.29	97.18	97.50	97.23	97.11	97.18	97.32	97.07
		FF	5.00	5.00	5.00	5.00	5.00	5.00	5.00	4.99	4.98
		%FH	8.57	8.57	8.58	8.55	8.57	8.59	8.58	8.55	8.55
		%FT	8.33	8.33	8.33	8.33	8.33	8.33	8.33	8.32	8.29
		F1	37.21	35.90	32.40	37.38	35.78	32.39	37.32	35.73	32.45
		%F1	62.01	59.84	54.00	62.29	59.63	53.98	62.20	59.56	54.09
		F0	16.19	17.47	20.91	16.12	17.56	20.87	15.99	17.67	20.81
		%F0	26.98	29.12	34.85	26.87	29.27	34.79	26.64	29.44	34.68

Table 10. Summary of information from selection procedure with 10 QTL in each initial population with initial frequency of QTL of .2

M	G	PM	L			M			S		
			P3000	P1500	P750	P3000	P1500	P750	P3000	P1500	P750
10	1	GV	15.74	15.75	15.74	15.80	15.83	15.72	15.79	15.80	15.80
		%HT	43.17	43.16	43.18	43.08	43.01	43.16	43.10	43.11	43.11
		%HM	56.83	56.84	56.82	56.92	56.99	56.84	56.90	56.89	56.89
		FF	14.91	14.92	14.90	15.01	15.08	14.90	14.99	14.99	15.00
		F1	20.96	20.95	20.97	20.95	20.95	20.96	20.95	20.94	20.95
		F0	20.96	20.97	20.95	20.95	20.96	20.98	20.95	20.95	20.94
	2	GV	24.73	24.74	24.59	24.75	24.70	24.53	24.61	24.51	24.36
		%HT	21.02	21.01	21.18	21.00	21.02	21.19	21.07	21.14	21.25
		%HM	78.98	78.99	78.82	79.00	78.98	78.81	78.93	78.86	78.75
		FF	16.34	16.35	16.17	16.36	16.31	16.10	16.21	16.11	15.94
		F1	32.95	32.69	32.45	33.16	33.03	32.58	33.53	33.49	33.04
		F0	29.68	29.96	30.20	29.48	29.64	30.13	29.18	29.26	29.76
	3	GV	29.16	29.16	29.10	29.16	29.15	29.06	29.07	29.01	28.82
		%HT	10.32	10.36	10.48	10.31	10.32	10.45	10.33	10.37	10.56
		%HM	89.68	89.64	89.52	89.69	89.68	89.55	89.67	89.63	89.44
		FF	16.66	16.66	16.59	16.66	16.65	16.56	16.58	16.52	16.36
		F1	42.36	41.22	39.01	42.48	41.50	39.20	42.78	41.92	39.82
		F0	30.66	31.77	33.92	30.55	31.54	33.79	30.31	31.19	33.27
	4	GV	31.25	31.25	31.24	31.25	31.25	31.24	31.22	31.19	31.07
		%HT	5.06	5.13	5.22	5.05	5.05	5.15	5.06	5.08	5.25
		%HM	94.94	94.87	94.78	94.95	94.95	94.85	94.94	94.92	94.75
		FF	16.67	16.67	16.66	16.67	16.67	16.65	16.64	16.62	16.53
		F1	49.48	47.66	43.71	49.56	47.90	43.83	49.80	48.19	44.34
		F0	28.79	30.55	34.41	28.72	30.39	34.36	28.50	30.11	33.88
	5	P	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17
		Q1	0.57	0.55	0.50	0.57	0.55	0.50	0.58	0.55	0.51
		Q0	0.26	0.28	0.33	0.26	0.28	0.33	0.26	0.28	0.33
		GV	32.29	32.29	32.29	32.29	32.29	32.29	32.28	32.29	32.23
		TNL	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00
		NHT	1.44	1.56	1.67	1.47	1.47	1.44	1.47	1.48	1.46
		%HT	2.40	2.61	2.78	2.45	2.45	2.41	2.44	2.47	2.44
		NHM	58.56	58.44	58.33	58.53	58.53	58.56	58.53	58.52	58.54
		%HM	97.60	97.39	97.22	97.55	97.55	97.59	97.56	97.53	97.56
		FF	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	9.98
		%FH	17.08	17.12	17.15	17.09	17.09	17.09	17.09	17.10	17.05
		%FT	16.67	16.67	16.67	16.67	16.67	16.67	16.66	16.67	16.63
		F1	33.55	32.17	29.41	33.57	32.30	29.20	33.94	32.46	29.73
		%F1	55.92	53.62	49.01	55.94	53.83	48.67	56.57	54.10	49.54
		F0	15.01	16.26	18.93	14.96	16.23	19.35	14.60	16.06	18.83
		%F0	25.01	27.11	31.54	24.94	27.05	32.26	24.33	26.76	31.39

2) The Second Generation

Estimates of genetic variances ranged from 2.72 to 21.57 for different numbers of QTL with large QTL effects, from 2.66 to 21.59 for different numbers of QTL with medium QTL effects, and from 2.25 to 21.21 for different numbers of QTL with small QTL effects. Fraction of homozygous loci ranged from 75.31% to 77.17% for different numbers of QTL with large QTL effects, from 75.32% to 77.19% for different numbers of QTL with medium QTL effects, and from 75.13% to 77.07% out of total numbers of loci in each population for different numbers of QTL with small QTL effects (Tables 3~6).

More genetic variances with larger number of QTL were also observed compared with fewer number of QTL at the second generation. Populations had about 76% of homozygous loci with various number of QTL, base population size, and magnitude of QTL effects. Percentage of fixed loci with unfavorable alleles with effects of 1 was slightly greater than of fixed loci with unfavorable alleles with effects of 0.

3) The Third Generation

Estimates of genetic variances ranged from 3.40 to 27.80 for different numbers of QTL with large

QTL effects, from 3.37 to 27.68 for different numbers of QTL with medium QTL effects, and from 2.86 to 27.13 for different numbers of QTL with small QTL effects. Fraction of homozygous loci ranged from 87.68% to 89.01% for different numbers of QTL with large QTL effects, from 87.74% to 89.02% for different numbers of QTL with medium QTL effects, and from 87.62% to 88.96% out of total numbers of loci in each population for different numbers of QTL with small QTL effects (Tables 3~6).

More genetic variances with larger number of QTL were also observed compared with fewer number of QTL at the third generation. Populations had about 88% of homozygous loci with various number of QTL, base population size, and magnitude of QTL effects. Percentage of fixed loci with unfavorable alleles with effects of 1 was much greater than of fixed loci with unfavorable alleles with effects of 0 at fewer number of QTL.

4) The Forth Generation

Estimates of genetic variances ranged from 3.68 to 31.05 for different numbers of QTL with large QTL effects, from 3.68 to 31.00 for different numbers of QTL with medium QTL effects, and from 3.26 to 30.45 for different numbers of QTL with

small QTL effects. Fraction of homozygous loci ranged from 93.89% to 94.73% for different numbers of QTL with large QTL effects, from 93.92% to 94.72% for different numbers of QTL with medium QTL effects, and from 93.84% to 94.68% out of total numbers of loci in each population for different numbers of QTL with small QTL effects (Tables 3~6).

More genetic variances with larger number of QTL were also observed compared with fewer number of QTL at the fourth generation. Populations had about 94% of homozygous loci with various number of QTL, base population size, and magnitude of QTL effects. Percentage of fixed loci with unfavorable alleles with effects of 1 was also much greater than of fixed loci with unfavorable alleles with effects of 0 at fewer number of QTL.

5) The Fifth Generation

Fraction of homozygous loci ranged from 96.88% to 97.73% for different numbers of QTL with large QTL effects, from 96.84% to 97.53% for different numbers of QTL with medium QTL effects, and from 96.87% to 97.67% out of total numbers of loci in each population for different numbers of QTL with small QTL effects (Tables 3~6).

Populations had about 97% of homozygous loci with various number of QTL, base population size, and magnitude of QTL effects. Percentage of fixed loci with unfavorable alleles with effects of 1 was also much greater than of fixed loci with unfavorable alleles with effects of 0 at fewer number of QTL.

6) With an Initial QTL Frequency of .2

The similar results at each generation were found in with initial frequency of QTL of .2 compared with an initial frequency of QTL of .05 (Tables 7~10).

DISCUSSION

Magnitude of QTL effects, base population size, number of QTL assigned to population, and the allelic frequency for the positive allele at each major QTL were highly associated with number of generations to fixation of QTLs during selection. Populations with larger QTL effects and larger base population size had more individuals with fixed QTL. However, a smaller number of QTL assigned to population had a higher fraction of individuals with fixed QTL at each generation compared with more populations with QTL.

This simulation study will help to design biological experiments for detection of QTL-marker association using inbred population and to determine optimum number of lines with fixed QTL during inbred line development.

To complement this study, additional simulation should be need with abundant replicates, more various population sizes, magnitude of QTL effects, and recombination between markers and QTLs.

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