CHAPTER 4
RESULTS AND DISCUSSIONS

4.1 Number of genes

The minimum number of effective factors (k) or the number of segregating genes involved in the seed yield per plant and yield components were estimated for six crosses which were grown on three highland locations for two years. Each trait which the joint-scaling test had shown that additive and dominance effects could explain the gene action for some crosses (Tables 1-3). As well, the first three assumptions underlying Wright's equation were met (Snijders, 1990).

For plant height, the estimates of minimum number of genes (effective factors; k) controlling this trait were in the range of 3.06-18.40 at all locations. At Inthanon station ranged from 3.06 to 18.40, Khunpae was 5.51-8.55 and Pangda was 7.99-14.69.

For number of nodes per plant, the estimates were in the range of 4.90-20.55 at all locations. At Inthanon station ranged from 4.90 to 18.35, Khunpae was 7.06-20.55 and Pangda was 7.56-18.33.

For the number of branches per plant, the estimates were in the range of 2.35-18.90 at all locations. At Inthanon station ranged from 2.35 to 16.01, Khunpae was 3.50-18.90 and Pangda was 12.37-18.33.

For the number of pods per plant, the estimates were in the range of 1.84-12.75 at all locations. At Inthanon station ranged from 1.84 to 10.41, Khunpae was 2.53-9.23 and Pangda was 3.22-12.75.

For the number of seeds per pod, the estimates were in the range of 6.46-22.72 at all locations. At Inthanon station ranged from 6.46 to 18.62, Khunpae was 12.14-20.26 and Pangda was 22.72.

For 100-seed weight, the estimates were in the range of 20.45-28.68 at all locations. At Inthanon station ranged from 20.45 to 28.67 and Pangda was 24.69-28.68.

For seed yield per plant, the estimates were in the range of 0.69-11.56 at all locations. At Inthanon station ranged from 0.69 to 11.56, Khunpae was 3.17-8.38 and Pangda was 2.24.

The estimates of minimum number of gene controlling yield and yield components in azuki bean grown on three highland locations and in two years revealed that these estimates were varied between small number of genes, seed yield per plant (0.69-11.56), to many of genes control, 100-seed weight (20.45-28.68). This result of the small number of gene control for seed yield per plant may not be true and it was probably that all additive gene effects are of equal importance in this trait. Seed yield was controlled by non-additive gene action which was more important than additive gene action. But 100-seed weight was controlled by many genes, this trait was controlled by additive gene which is more important than non-additive gene action (Kunkaew *et al.*, 2006; 2007a; 2007b). Falconer (1989) pointed out the estimate from a comparison of the total range with the amount of additive genetic variance in the original population. In principle, it is clear that with a given amount of initial variation, a small number of genes will produce less total response than a larger number; and that if a given amount of variation is produced by few genes, the magnitude of this effects must be greater than if it is produced by many. Snijders (1990) suggested that the results of the method used to calculate the number of genes should be viewed with caution. Besides, the fact that Wright's equation is not a very accurate estimator, possibly also not all assumptions were met.

The results revealed that many number of effective factors controlled 100-seed weight which resulted in different high levels of the means of parents in the crosses. In addition, the result showed that number of effective factors were different among the crosses over three highland locations and two years in each trait, indicating that the expression of gene effects was influenced by environmental factors and varied from location to location and year to year.

Table 1 Number of effective factors (k) controlling the plant height, number of nodes per plant and number of branches per plant in azuki bean crosses, grown at three highland locations in two growing seasons, 2005 and 2006.

Locations	Crosses	Plant height		No. of nodes per plant		No. of branch per plant	
		2005	2006	2005	2006	2005	2006
Inthanon	K x H	8.37	11.30	-	8.84	-	2.87
	K x A	-	18.40	-	10.75	-	-
	K x E	-	-	13.03	4.90	-	-
	H x A	-	4.43	-	7.42	-	16.01
	H x E	-	-	16.17	-	-	2.35
	A x E	3.06	7.42	18.35	12.23	6.52	-
Khunpae	K x H	7.89	-	11.58	7.06	-	18.90
	K x A	-	-	-	-	-	-
	K x E	-	6.88	-	13.17	-	9.42
	H x A	-	-	20.55	-	10.09	-
	H x E	-	8.55	-	7.84	-	7.90
	A x E	5.51	8.50	-	9.32	-	3.50
Pangda	K x H	-	-	-	10.59	18.33	12.37
	K x A	13.15	-	-	-	12.51	-
	K x E	-	-	-	-	-	-
	H x A	13.16	-	-	-	12.79	-
	H x E	-	-	-	-	-	-
	A x E	14.69	7.99	-	7.56	-	13.64

Missing values, imply the estimates did not meet Wright's assumptions.

Table 2 Number of effective factors (k) controlling the number of pods per plant and number of seeds per pod in azuki bean crosses, grown at three highland locations in two growing seasons, 2005 and 2006.

Locations	Crosses	No. of pods per plant		No. of seeds per pod	
		2005	2006	2005	2006
Inthanon	K x H	-	6.73	-	15.23
	K x A	-	-	18.62	-
	K x E	-	-	-	-
	H x A	-	1.84	-	-
	H x E	-	3.30	-	6.46
	A x E	-	10.40	-	-
Khunpae	K x H	-	-	-	-
	K x A	-	-	20.26	12.14
	K x E	-	-	-	-
	H x A	2.66	9.23	-	-
	H x E	-	2.53	-	12.48
	A x E	-	5.56	-	-
Pangda	K x H	-	5.20	-	-
	K x A	-	-	22.72	-
	K x E	-	-	-	-
	H x A	12.75	-	-	-
	H x E	-	-	-	-
	A x E	-	3.22	-	-

Missing values, imply the estimates did not meet Wright's assumptions.

Table 3 Number of effective factors (k) controlling the 100-seed weight and seed yield per plant in azuki bean crosses, grown at three highland locations in two growing seasons, 2005 and 2006.

Locations	Crosses	100-seed weight		Seed yield per plant	
		2005	2006	2005	2006
Inthanon	K x H	-	-	2.30	-
	K x A	28.67	-	-	-
	K x E	-	-	-	-
	H x A	-	-	3.32	11.56
	H x E	-	20.45	-	0.69
	A x E	-	-	-	-
Khunpae	K x H	-	-	5.74	-
	K x A	-	-	-	-
	K x E	-	-	-	-
	H x A	-	-	8.38	3.17
	H x E	-	-	-	4.94
	A x E	-	-	-	-
Pangda	K x H	-	-	-	-
	K x A	-	28.68	-	-
	K x E	-	-	-	-
	H x A	-	-	-	-
	H x E	-	24.69	-	-
	A x E	-	-	-	2.24

Missing values, imply the estimates did not meet Wright's assumptions.

4.2 Combining ability

Analysis of variance for diallel cross of azuki bean parents over the three test sites and two years are presented in Tables 4 and 5. Results showed that significant differences were found among the locations (L) and among the entries (parents and offsprings) for all characters in each year. These results indicated that environmental conditions, especially temperature and moisture factors which varied from environment to environment, influenced the expression of yield and yield components of azuki bean parents and their progenies.

Interaction of entries with location (Entries x L) was found to be significant for all traits and each year, except the number of nodes per plant and seed yield per plant in the first year (2005), indicating that parents and their progenies were responsive to environmental conditions as far as these all components were concerned (except these both traits in the first year). These results agree with those of Yoopum and Julsrigival (2001), Julsrigival *et al*. (2004) and Kunkaew *et al*. (2004) who reported that some agronomic characters of azuki bean genotypes such as plant height, number of branches per plant and so on were rather stable while seed yield per plant and seed size were unstable when planted under different highland conditions.

Analysis of variance of combining ability indicated that effects of general combining ability (g.c.a.) were found to be significant for all traits in each year. The interaction of g.c.a. effects and locations (g.c.a. x L) was statistically evident for number of seeds per pod and 100-seed weight in the first year (2005), and for number of nodes per plant and 100-seed weight in the second year (2006). The significant g.c.a. effects and g.c.a. x L were found among these traits which revealed that additive genetic effects were important in the inheritance of these traits and the action of additive gene was influenced by the environmental variation. These results were supported by the works of Han *et al.* (1984) and Kunkaew *et al.* (2006; 2007a) who reported that seed yield and some of yield components of azuki bean were polygenetically controlled by additive gene effects. In addition, variations of these economic traits were influenced greatly by environments. Hence, interaction of g.c.a. effects with location of these evaluated traits was statistically evident.

For specific combining ability (s.c.a.) analysis, significant effects were found for most traits except 100-seed weight in the first year, indicating that the significant role of

Table 4 Combined analysis of variance for seed yield per plant and yield components in a diallel cross of azuki bean, grown at three highland locations in 2005 growing season.

Source of Variance	df	Mean square						
		Plant height	No. of nodes per plant	No. of branches per plant	No. of pods per plant	No. of seeds per pod	100-seed weight	Seed yield per plant
Locations (L)	2	90.68**	15.83**	12.80**	240.79**	11.13**	122.21**	432.79**
Block/L	9	3.91	0.59*	1.09**	40.59**	0.10	0.81**	12.93
Entries	9	40.89**	7.02**	10.75**	285.53**	4.59**	57.97**	202.17**
Entries x L	18	6.92**	0.42	1.01**	16.23*	0.41**	1.52**	15.83
g.c.a.	3	35.62**	7.50**	7.13**	166.33**	12.69**	172.92**	33.15*
s.c.a.	6	43.53**	6.79**	12.56**	345.13**	0.54**	0.50	286.68**
g.c.a.x L	6	3.75	0.34	0.27	6.23	0.80**	3.28**	19.39
s.c.a.x L	12	8.50**	0.46	1.37**	21.22*	0.21**	0.63**	14.04
Error	81	2.72	0.28	0.34	9.30	0.06	0.25	9.43
CV (%)		8.94	6.13	7.53	13.12	5.61	3.18	19.00

*, ** Significant difference at the p<0.05 and p<0.01 level, respectively.

Table 5 Combined analysis of variance for seed yield per plant and yield components in a diallel cross of azuki bean, grown at three highland locations in 2006 growing season.

Source of Variance	df	Mean square						
		Plant height	No. of nodes per plant	No. of branches per plant	No. of pods per plant	No. of seeds per pod	100-seed weight	Seed yield per plant
Locations (L)	2	557.78**	150.29**	161.98**	2078.42**	4.14**	313.88**	569.72**
Block/L	9	7.86**	0.70	0.80	27.59**	0.24**	1.37**	13.68**
Entries	9	22.85**	4.71**	10.03**	218.69**	4.74**	57.57**	110.43**
Entries x L	18	5.52*	1.36**	1.95**	31.33**	0.19**	1.62**	19.40**
g.c.a.	3	38.47**	5.70**	5.71**	156.56**	13.15**	167.22**	46.28**
s.c.a.	6	15.03**	4.21**	12.18**	249.75**	0.54**	2.75**	142.50**
g.c.a.x L	6	4.80	1.16**	0.56	6.02	0.12	2.02**	8.09
s.c.a.x L	12	5.88*	1.46**	2.65**	43.98**	0.22**	1.42**	25.05**
Error	81	2.56	0.36	0.83	6.21	0.08	0.46	3.71
CV (%)		10.42	8.47	13.72	12.38	6.67	4.76	16.21

*, ** Significant difference at the p<0.05 and p<0.01 level, respectively.

non-additive effects was involved in the inheritance of these traits. The interaction of s.c.a. effects with location (s.c.a. x L) was significant for most traits in both years, except the number of node per plant and seed yield per plant in 2005. The significance of s.c.a. effects and s.c.a. x L were found among these traits, indicating that non-additive genetic effects were important in the inheritance of these traits and the non-additive genetic effects were also influenced by the environmental variations.

Estimation of combining ability effects among the azuki bean parents are presented in Table 6. Results showed that g.c.a. effects in Kamuidainagon (g1) parent were significantly positive for 100-seed weight in both years, Hondawase (g2) parent gave significant number of branches per plant and number of pods per plant in the first year, Akatsukidainagon (g3) parent gave significantly positive plant height, number of nodes per plant, number of branches per plant and number of pods per plant in both years, and for 100-seed weight in the first year. As well, Erimo parent (g4) showed significant positive across-site effects for plant height, number of nodes per plant, number of seeds per pod and seed yield per plant for two years, and gave significant positive effects only for number of pods per plant in the second year. The significant positive across-site effects of g.c.a. of this Erimo parent especially for seed yield and some important yield components, i.e., plant height, number of nodes per plant and so on indicated that this promising parent performed as better combiner and more consistent than other parents.

The estimation of specific combining ability effects revealed that there were the cross of Kamuidainagon x Hondawase (s12) which gave significant positive s.c.a. effects for number of pods per plant, number of seeds per pod and seed yield per plant in the first year. Kamuidainagon x Akatsukidainagon (s13) gave significant positive s.c.a. effects for number of seeds per pod in the first year. Kamuidainagon x Erimo (s14) gave significant positive s.c.a. effects for plant height, number of nodes per plant, number of branches per plant and number of pods per plant for two years, and gave seed yield per plant in the second year. Hondawase x Akatsukidainagon (s23) cross gave significant positive s.c.a. effects for number of nodes per plant, number of pods per plant, number of seeds per pod and seed yield per plant in the second year. Hondawase x Erimo (s24) cross gave significant positive s.c.a. effects for plant height and number of branches per plant for two years, in the first year this cross showed significant positive effect for number of nodes per plant, and for number of pods per plant and 100-seed weight in the second year. Akatsukidainagon x Erimo (s34) gave significant positive s.c.a. effects for plant height, number of branches per plant, number of pods per plant and seed yield per plant in the first year.

From the results of both g.c.a. and s.c.a. effects, it should be noted that parents which showed as a good combiner for anyone of traits will provide good s.c.a. in cross combination as well. For example, Erimo parent (g1) which performed as a good combiner for seed yield per plant, plant height, number of nodes per plant and so on in both years also gave good s.c.a. for seed yield per plant in cross s34 in the first year and cross s14 in the second year. As well, this Erimo parent gave good s.c.a. effect in s14 in both years for plant height, number of nodes per plant and number of branches per plant. In contrast, other three parents which showed negative g.c.a. effects also showed negative s.c.a. effects to most cross combinations. However, there are parents such as g1 and g2 which showed poor g.c.a. effect for seed yield per plant but these two parents showed good s.c.a. combination in the first year.

Table 6 Estimate of general (g_i) and specific (s_{ij}) combining ability effects for seed yield per plant and yield components in a diallel cross of azuki bean, grown at three highland locations in two growing seasons, 2005 and 2006.

Parents and Crosses	Plant height	No. of nodes per plant	No. of branches per plant	No. of pods per plant	No. of seeds per pod	100-seed weight	Seed yield per plant
				2005 growing season			
General combining ability (g_i±SE)							
g1	-0.76±0.17**	-0.44±0.05**	-0.47±0.06**	-2.21±0.31**	-0.02±0.03	1.96±0.05**	0.12±0.31
g2	-0.41±0.17*	-0.04±0.05	0.16±0.06*	0.65±0.31*	-0.30±0.03**	-0.59±0.05**	-0.79±0.31*
g3	0.44±0.17*	0.20±0.05**	0.20±0.06**	1.24±0.31**	-0.28±0.03**	0.34±0.05**	-0.17±0.31
g4	0.73±0.17**	0.28±0.05**	0.12±0.06	0.32±0.31	0.60±0.03**	-1.71±0.05**	0.84±0.31**
Specific combining ability (s_{ij}±SE)							
s12	-0.54±0.41	-0.13±0.13	0.23±0.14	3.77±0.75**	0.20±0.06**	0.18±0.12	3.54±0.76**
s13	-0.58±0.41	0.06±0.13	-0.11±0.14	-1.06±0.75	0.20±0.06**	0.04±0.12	0.43±0.76
s14	2.02±0.37**	0.55±0.12**	0.59±0.13**	1.97±0.68**	-0.13±0.05*	-0.20±0.11	0.85±0.69
s23	-0.33±0.41	0.18±0.13	0.09±0.14	1.34±0.75	-0.02±0.06	-0.18±0.12	-0.33±0.76
s24	1.26±0.37**	0.33±0.12**	0.35±0.13**	-1.97±0.68**	-0.02±0.05	0.17±0.11	0.17±0.69
s34	0.96±0.37*	0.09±0.12	0.29±0.13*	2.49±0.68**	-0.04±0.05	0.04±0.11	1.52±0.69*
				2006 growing season			
General combining ability (g_i±SE)							
g1	-0.68±0.16**	-0.38±0.06**	-0.37±0.09**	-2.06±0.25**	-0.02±0.03	2.13±0.07**	0.30±0.20
g2	-0.58±0.16**	-0.03±0.06	-0.03±0.09	0.09±0.25	-0.32±0.03**	-0.72±0.07**	-1.09±0.20**
g3	0.55±0.16**	0.28±0.06**	0.29±0.09**	1.40±0.25**	-0.27±0.03**	-0.02±0.07	-0.01±0.20
g4	0.71±0.16**	0.13±0.06*	0.12±0.09	0.57±0.25*	0.61±0.03**	-1.39±0.07**	0.81±0.20**
Specific combining ability (s_{ij}±SE)							
s12	-1.22±0.40**	-0.14±0.15	-0.41±0.22	-1.17±0.62	0.09±0.07	0.15±0.17	-0.26±0.48
s13	-0.17±0.40	0.00±0.15	0.24±0.22	-0.33±0.62	0.12±0.07	0.26±0.17	0.16±0.48
s14	1.34±0.36**	0.35±0.13*	0.78±0.20**	3.69±0.56**	-0.04±0.06	-0.33±0.15*	2.38±0.43**
s23	-0.45±0.40	0.51±0.15**	0.25±0.22	2.25±0.62**	0.21±0.07**	-0.49±0.17**	1.82±0.48**
s24	1.40±0.36**	0.07±0.13	0.54±0.20*	1.12±0.56*	-0.06±0.06	0.46±0.15**	0.54±0.43
s34	0.64±0.36	-0.03±0.13	0.02±0.20	0.89±0.56	-0.17±0.06*	-0.21±0.15	0.01±0.43

*, ** Significantly different from zero at the $p<0.05$ and $p<0.01$ level, respectively.
SE is the standard error value.

4.3 Generation mean analysis

Results of generation mean and standard error analysis for seed yield and yield components in the four inter-varietal crosses of azuki bean revealed significant differences among all six generation means, involving means of P1, P2, F1, F2, BC1 and BC2 generations. These significant differences of generation means indicate the presence of genetic variabilities of these traits in the material studied.

The joint-scaling test was used to estimate genetic parameters of seed yield per plant and yield components of populations at all locations in two years. By using this joint-scaling test, it is assumed that the presence of epistatic interaction accounted for the genetic variation in the generation means in the four inter-varietal crosses of azuki bean. The value of A, B and C-scale should be equal to zero with limit of their standard errors. The significance of any one of these scales will indicate the presence of non-allelic interaction of genes, as well, the estimation of genetic parameters of the trait under studying does not fit to the additive-dominance model (Mather and Jinks, 1982).

4.3.1 Plant height

Results of joint-scaling test of plant height are presented in Tables 7 and 9. Results showed that A x E cross gave A, B and C-scale not significant *t*-value in all three locations and both years, indicating that the plant height of this cross was fitted to the additive-dominance model in all environments. As well, K x H cross gave *t*-value fitting to the model at Khunpae in 2005 and both two years at Inthanon. K x A and H x A cross were fitted to model at Pangda in 2005 and at Khunpae in 2006. In addition, K x E and H x E crosses also were fitted to the model at Khunpae in 2006. The crosses which showed significant *t*-value at any location or year indicated that the expression of genetic interaction or epistatic effects were involved in this trait.

The analysis of gene effects on plant height among the four inter-varietal crosses of azuki bean is presented in Tables 8 and 10. Result showed that at Inthanon station, mean values (m) of plant height ranged 13.13-19.31 cm and 10.39-12.69 cm in 2005 and 2006, respectively. At Khunpae station were 16.32-20.18 cm and 15.88-17.80 cm and at Pangda station were 17.38-21.05 cm and 16.68-18.64 cm in 2005 and 2006, respectively.

The additive gene effect (d) was observed significantly in all crosses, except K x E, at Inthanon in the first year. At this location, d effect was significant for K x A, H x E and A x E crosses in 2006 as well. At Khunpae station, d effect showed significantly in K x A, H x E and A x E crosses in 2005 and for all crosses (except K x E and H x A) in 2006. At Pangda station, only K x A cross was significant for d effect in 2005.

The dominance gene effect (h) was observed for some crosses in both locations and years. Inthanon station, h showed significant effect for K x E, H x E and A x E crosses in the first year. Khunpae station, it was found that only K x E cross showed significance in both years, while h effect was significant for H x E cross in 2005 and significant effect for H x A and A x E in 2006. At Pangda station, h effect was significant for K x A and A x E crosses for two years, whereas K x H and H x E crosses gave significant h effect in 2006.

The epistatic interaction (i, j and l) analysis revealed that the additive x additive (i) was observed significantly for H x E cross in both years at Inthanon. At Khunpae, only K x E cross showed significant i effect in 2005. At Pangda, K x H, K x A and H x E showed significant i effect in 2006. The additive x dominance effect (j) was found significantly in H x E cross for both years at Inthanon. At Khunpae, K x A cross showed j effect significantly in both years. H x E and K x H cross gave j effect significantly in 2005 and 2006, respectively. At Pangda, j effect was found significantly for H x A cross in the first year. For dominance x dominance effect (l), it was significantly observed in H x E cross at Inthanon and Khunpae in 2005. Pangda station, this l effect was found significantly for K x H, K x A and H x E crosses in the second year.

The results showed that both additive and non-additive gene actions were involved in the inheritance of plant height in azuki bean, this similar results were reported by Kunkaew *et al*. (2006). The additive gene effects gave both positive and negative value, positive value of this gene effects resulted in increasing mean of plant height from the mid-parent, but negative value gave opposite results. This additive gene effects is considered as the fixable genes which is able to inherit to the progenies. The non-additive gene effects, which are unfixable genes, included dominance and epistatic interaction (i, j and l) effects. Thus, epistatic interaction revealed negligible effect but most crosses showed that both h and l had opposite signs, the interaction occurred, therefore, epistatic interaction to be found was predominantly of a duplicate type.

Table 7 Generation means and joint-scaling test for plant height in azuki bean crosses, grown at three highland locations in 2005 growing season.

Generations	K x H	K x A	K x E	H x A	H x E	A x E
			Inthanon station			
P1 ± SE	11.77 ± 0.31 (47)a[1]	14.27 ± 0.45 (51)c	13.26 ± 0.38 (63)c	16.10 ± 0.34 (69)b	16.77 ± 0.48 (57)cd	17.58 ± 0.44 (73)a
P2 ± SE	14.52 ± 0.31 (62)a	18.39 ± 0.37 (60)a	14.19 ± 0.47 (70)c	19.21 ± 0.34 (72)a	15.33 ± 0.47 (63)d	13.88 ± 0.39 (66)b
F1 ± SE	14.42 ± 1.14 (6)a	18.62 ± 0.94 (10)a	19.41 ± 0.98 (21)a	16.76 ± 0.58 (29)ab	20.50 ± 0.83 (22)b	19.91 ± 1.06 (18)a
F2 ± SE	13.64 ± 0.39 (83)a	14.93±0.38(100)bc	14.99 ± 0.55 (96)bc	17.89±0.46(100)ab	19.31 ± 0.50 (91)bc	18.76±0.64(101)a
BC1±SE	12.56 ± 0.83 (8)a	14.69 ± 0.70 (23)bc	17.33 ± 1.06 (20)b	17.41 ± 0.73 (22)ab	24.03 ± 1.03 (18)a	18.35 ± 1.59 (12)a
BC2±SE	13.56 ± 1.38 (9)a	17.10 ± 0.90 (15)ab	15.25 ± 1.00 (24)bc	20.42 ± 1.17 (15)a	19.81 ± 1.17 (14)b	17.41 ± 1.35 (19)a
Joint-scaling test						
A ± SE	-1.06 ± 2.04	-3.51 ± 1.75*	1.97 ± 2.37	1.98 ± 1.60	10.78 ± 2.27**	-0.79 ± 3.38
B ± SE	-1.83 ± 2.99	-2.81 ± 2.07	-3.10 ± 2.28	4.88 ± 2.43*	3.79 ± 2.52	1.03 ± 2.93
C ± SE	-0.55 ± 2.79	-10.17 ± 2.48**	-6.32 ± 3.02*	2.74 ± 2.24	4.14 ± 2.70	3.77 ± 3.38
			Khunpae station			
P1 ± SE	16.04 ± 0.43 (54)a	15.25 ± 0.31 (52)c	15.44 ± 0.39 (54)c	16.20 ± 0.34 (69)a	16.28 ± 0.36 (67)d	20.09 ± 0.46 (59)a
P2 ± SE	16.52 ± 0.40 (64)a	17.64 ± 0.32 (59)b	16.60 ± 0.41 (62)c	18.33 ± 0.36 (71)a	16.78 ± 0.38 (61)cd	16.58 ± 0.44 (63)b
F1 ± SE	16.57 ± 0.87 (14)a	17.42 ± 0.67 (12)b	22.81 ± 0.75 (16)a	18.33 ± 0.67 (19)a	19.00 ± 0.69 (11)bc	19.78 ± 0.86 (17)a
F2 ± SE	16.76 ± 0.42 (94)a	16.65 ± 0.36 (72)bc	16.30 ± 0.53 (89)c	17.78±0.41(100)a	19.40 ± 0.44 (80)b	18.96 ± 0.57 (95)ab
BC1±SE	16.53 ± 0.88 (16)a	19.58 ± 0.75 (12)a	19.96 ± 1.31 (13)b	17.50 ± 0.81 (20)a	22.46 ± 0.91 (13)a	19.69 ± 1.26 (13)a
BC2±SE	16.70 ± 0.87 (21)a	15.32 ± 0.78 (14)c	19.11 ± 0.92 (28)b	16.15 ± 0.90 (18)a	18.68 ± 0.99 (14)bc	18.11 ± 1.19 (17)ab
Joint-scaling test						
A ± SE	0.44 ± 2.00	6.50 ± 1.67**	1.67 ± 2.74	0.47 ± 1.79	9.64 ± 1.98**	-0.48 ± 2.70
B ± SE	0.31 ± 1.98	-4.41 ± 1.73*	-1.20 ± 2.02	-4.36 ± 1.95*	1.58 ± 2.13	-0.15 ± 2.58
C ± SE	1.34 ± 2.49	-1.11 ± 2.02	-12.47 ± 2.66**	-0.05 ± 2.16	6.53 ± 2.30**	-0.37 ± 2.92
			Pangda station			
P1 ± SE	20.01 ± 0.29 (63)a	19.28 ± 0.30 (76)a	19.22 ± 0.37 (71)a	19.44 ± 0.32 (76)a	20.46 ± 0.35 (67)a	21.53 ± 0.34 (75)a
P2 ± SE	18.68 ± 0.29 (71)ab	20.50 ± 0.34 (71)a	20.00 ± 0.50 (56)a	20.53 ± 0.39 (68)a	20.53 ± 0.54 (55)a	20.68 ± 0.41 (55)a
F1 ± SE	18.25 ± 0.62 (15)ab	17.30 ± 0.64 (22)a	21.50 ± 0.76 (26)a	19.27 ± 0.41 (28)a	21.57 ± 0.75 (28)a	23.13 ± 0.64 (23)a
F2 ± SE	17.38 ± 0.26 (113)b	18.57±0.39(108)a	19.34±0.40(109)a	20.39±0.39(113)a	19.55±0.43(111)a	21.85±0.37(111)a
BC1±SE	18.11 ± 0.86 (9)b	18.75 ± 0.70 (25)a	19.80 ± 0.74 (23)a	20.71 ± 0.67 (24)a	20.77 ± 0.79 (27)a	22.15 ± 0.79 (17)a
BC2±SE	18.33 ± 0.65 (16)b	17.91 ± 1.05 (12)a	19.37 ± 0.85 (26)a	18.60 ± 0.83 (21)a	20.08 ± 1.01 (17)a	21.33 ± 0.89 (18)a
Joint-scaling test						
A ± SE	-2.05 ± 1.85	0.92 ± 1.57	-1.12 ± 1.70	2.70 ± 1.44	-0.49 ± 1.79	-0.37 ± 1.74
B ± SE	-0.27 ± 1.48	-1.98 ± 2.21	-2.75 ± 1.92	-2.59 ± 1.76	-1.95 ± 2.22	-1.15 ± 1.94
C ± SE	-5.66 ± 1.67**	-0.08 ± 2.07	-4.85 ± 2.30*	3.07 ± 1.81	-5.94 ± 2.38*	-1.09 ± 2.03

K = Kamuidainagon, H = Hondawase, A = Akatsukidainagon and E = Erimo variety.
In parenthesis, is the number of plant.
[1] Means within columns followed by the same letter are not significantly different based on Duncan's Multiple Range Test (p=0.05).
SE is the standard error value.
*, ** Significantly different from zero at the P<0.05 and P<0.01 level, respectively.

Table 8 Estimation of genetic effects for plant height in azuki bean crosses, grown at three highland locations in 2005 growing season.

parameters	K x H	K x A	K x E	H x A	H x E	A x E
			Inthanon station			
m ± SE	13.13 ± 0.21**	16.47 ± 0.31**	16.19 ± 0.37**	17.96 ± 0.27**	19.31 ± 0.50**	15.78 ± 0.29**
d ± SE	-1.38 ± 0.22**	-2.13 ± 0.33**	-	-1.85 ± 0.34**	4.21 ± 1.55*	1.84 ± 0.29**
h ± SE	0.93 ± 0.70	1.62 ± 0.86	5.44 ± 0.91**	-	14.89 ± 3.81**	4.80 ± 0.87**
i ± SE	-	-	-	-	10.43 ± 3.70**	-
j ± SE	-	-	-	-	3.50 ± 1.59*	-
l ± SE	-	-	-	-	-25.00 ± 6.77**	-
X^2 (df)	0.5701 (3)	0.3520 (3)	0.2779 (4)	0.2326 (4)	-	1.4869 (3)
Probability	0.9032	0.9499	0.9912	0.9937	-	0.6853
			Khunpae station			
m ± SE	16.32 ± 0.28**	16.98 ± 0.23**	17.29 ± 0.61**	17.78 ± 0.41**	20.18 ± 0.47**	18.32 ± 0.31**
d ± SE	-0.23 ± 0.28	4.26 ± 1.08**	-	1.35 ± 1.21	3.78 ± 1.34**	1.75 ± 0.31**
h ± SE	0.58 ± 0.71	-	12.03 ± 1.90**	-2.78 ± 3.01	2.47 ± 0.74**	1.36 ± 0.78
i ± SE	-	-	4.99 ± 1.41**	-3.84 ± 2.92	-	-
j ± SE	-	5.46 ± 1.10**	-	2.42 ± 1.24	4.03 ± 1.37**	-
l ± SE	-	-	-	7.72 ± 5.31	-9.66 ± 2.40**	-
X^2 (df)	0.2899 (3)	0.0784 (3)	0.2430 (3)	-	0.0454 (1)	0.0406 (3)
Probability	0.9619	0.9943	0.9703	-	0.8312	0.9978
			Pangda station			
m ± SE	17.38 ± 0.26**	19.88 ± 0.22**	19.34 ± 0.40**	19.82 ± 0.22**	19.55 ± 0.43**	21.05 ± 0.25**
d ± SE	-0.22 ± 1.08	-0.56 ± 0.22*	0.43 ± 1.12	-	0.69 ± 1.28	0.45 ± 0.26
h ± SE	2.25 ± 2.48	-2.60 ± 0.56**	2.86 ± 2.89	-	4.58 ± 3.20	1.80 ± 0.59**
i ± SE	3.34 ± 2.39	-	0.98 ± 2.77	-	3.50 ± 3.09	-
j ± SE	-0.89 ± 1.10	-	0.82 ± 1.17	0.54 ± 0.25*	0.73 ± 1.32	-
l ± SE	-1.03 ± 4.62	-	2.90 ± 5.05	-	-1.06 ± 5.66	-
X^2 (df)	-	1.2894 (3)	-	0.1496 (4)	-	0.5139 (3)
Probability	-	0.7316	-	0.9973	-	0.9158

K = Kamuidainagon, H = Hondawase, A = Akatsukidainagon and E = Erimo variety.
SE is the standard error value.
*, ** Significantly different from zero at the P<0.05 and P<0.01 level, respectively.

Table 9 Generation means and joint-scaling test for plant height in azuki bean crosses, grown at three highland locations in 2006 growing season.

Generations	K x H	K x A	K x E	H x A	H x E	A x E
			Inthanon station			
P1 ± SE	9.42±0.41(51)ab[1]	10.05±0.36(25)ab	10.13±0.38(41)a	12.02±0.33(57)a	11.01±0.38(54)bc	13.68±0.39(45)a
P2 ± SE	10.75±0.41(55)ab	10.89±0.30(32)a	10.79±0.40(48)a	11.38±0.42(50)a	10.73±0.34(58)c	11.56±0.36(53)a
F1 ± SE	9.91±0.74(14)ab	10.06±0.47(16)ab	11.88±0.65(11)a	10.95±0.62(19)a	12.74±0.59(25)ab	12.55±0.85(13)a
F2 ± SE	11.08±0.42(75)a	10.34±0.35(54)ab	9.75±0.38(74)a	11.15±0.43(100)a	13.09±0.51(61)a	13.24±0.39(69)a
BC1±SE	10.27±0.70(22)ab	9.00±0.50(14)b	11.16±0.76(12)a	12.12±0.74(21)a	12.75±0.70(21)a	13.82±0.94(9)a
BC2±SE	8.86±0.84(16)b	9.82±0.76(11)ab	10.65±0.85(15)a	11.28±1.58(6)a	10.04±0.85(21)c	12.20±0.90(13)a
Joint-scaling test						
A ± SE	1.21 ± 1.64	-2.10 ± 1.16	0.31 ± 1.69	1.28 ± 1.65	1.75 ± 1.57	1.41 ± 2.10
B ± SE	-2.93 ± 1.88	-1.31 ± 1.62	-1.36 ± 1.86	0.24 ± 3.25	-3.39 ± 1.82	0.28 ± 2.01
C ± SE	4.32 ± 2.31	0.32 ± 1.73	-5.67 ± 2.08**	-0.69 ± 2.19	5.14 ± 2.40*	2.61 ± 2.37
			Khunpae station			
P1 ± SE	16.34±0.40(62)bc	16.03±0.51(59)c	16.24±0.47(66)c	15.72±0.46(60)b	16.35±0.45(73)b	16.84±0.41(72)ab
P2 ± SE	16.49±0.39(59)b	19.19±0.46(68)a	16.59±0.54(55)bc	20.28±0.50(74)a	19.57±0.48(67)a	15.71±0.40(66)b
F1 ± SE	14.54±0.84(15)cd	17.67±0.81(20)abc	19.13±0.84(24)ab	14.75±1.03(22)b	17.95±0.63(28)ab	18.93±0.82(18)ab
F2 ± SE	16.40±0.40(92)bc	16.41±0.45(94)bc	18.19±0.58(88)abc	18.56±0.55(103)ab	17.31±0.48(105)ab	17.39±0.45(102)ab
BC1±SE	13.31±0.78(19)d	18.95±0.83(23)ab	19.31±1.14(19)a	16.11±0.97(25)ab	15.11±0.96(18)b	19.29±1.06(13)a
BC2±SE	18.19±0.90(19)a	15.71±1.05(16)c	18.33±0.96(27)abc	16.43±2.73(4)ab	18.37±0.97(24)ab	16.78±0.95(21)ab
Joint-scaling test						
A ± SE	-4.25 ± 1.83*	4.20 ± 1.93*	3.26 ± 2.47	1.76 ± 2.25	-4.09 ± 2.08	2.81 ± 2.31
B ± SE	5.36 ± 2.02**	-5.43 ± 2.29*	0.94 ± 2.16	-2.17 ± 5.58	-0.78 ± 2.10	-1.08 ± 2.11
C ± SE	3.67 ± 2.40	-4.91 ± 2.52	1.67 ± 2.96	8.75 ± 3.08**	-2.60 ± 2.38	-0.86 ± 2.51
			Pangda station			
P1 ± SE	16.01±0.35(61)ab	14.75±0.39(70)c	17.95±0.48(71)abc	16.31±0.44(64)c	15.30±0.41(74)b	18.75±0.52(65)a
P2 ± SE	15.84±0.32(67)ab	18.01±0.40(66)b	16.96±0.41(78)bc	19.15±0.43(65)ab	16.75±0.44(73)ab	18.65±0.53(71)a
F1 ± SE	14.56±0.62(16)ab	17.76±0.66(26)b	19.60±0.88(22)a	19.73±0.71(24)a	19.30±0.73(31)a	21.31±1.06(18)a
F2 ± SE	16.68±0.37(107)a	16.99±0.39(110)b	17.98±0.58(113)abc	17.52±0.46(106)bc	17.39±0.52(108)ab	19.89±0.49(113)a
BC1±SE	13.83±0.73(19)b	18.41±0.75(24)b	16.34±0.95(24)c	15.71±0.83(21)c	20.15±1.00(24)a	19.30±1.31(13)a
BC2±SE	15.14±0.73(22)ab	20.88±1.01(14)a	19.07±1.05(30)ab	19.14±1.22(14)ab	19.62±1.00(26)a	18.55±0.97(26)a
Joint-scaling test						
A ± SE	-2.91 ± 1.63	4.31 ± 1.69*	-4.88 ± 2.14*	-4.62 ± 1.85*	5.71± 2.17**	-1.45 ± 2.88
B ± SE	-0.12 ± 1.61	5.98 ± 2.17**	1.57 ± 2.32	-0.61 ± 2.57	3.18 ± 22.17	-2.84 ± 2.27
C ± SE	5.75 ± 2.00**	-0.34 ± 2.12	-2.19 ± 2.98	-4.84 ± 2.40*	-1.08 ± 2.61	-0.44 ± 2.98

K = Kamuidainagon, H = Hondawase, A = Akatsukidainagon and E = Erimo variety.
In parenthesis, is the number of plant.
[1] Means within columns followed by the same letter are not significantly different based on Duncan's Multiple Range Test (*p*=0.05).
SE is the standard error value.
*, ** Significantly different from zero at the P<0.05 and P<0.01 level, respectively.

Table 10 Estimation of genetic effects for plant height in azuki bean crosses, grown at three highland locations in 2006 growing season.

parameters	K x H	K x A	K x E	H x A	H x E	A x E
			Inthanon station			
m ± SE	10.50 ± 0.45**	10.39 ± 0.22**	10.83 ± 0.27**	11.70 ± 0.26**	12.45 ± 0.36**	12.69 ± 0.26**
d ± SE	-	-0.50 ± 0.22*	-	0.36 ± 0.26	2.71 ± 1.11*	1.08 ± 0.26**
h ± SE	-1.75 ± 1.78	-0.59 ± 0.48	1.20 ± 0.64	-0.72 ± 0.60	-	0.54 ± 0.67
i ± SE	-1.44 ± 1.23	-	-	-	-1.73 ± 0.44**	-
j ± SE	-	-	-	-	2.57 ± 1.13*	-
l ± SE	-	-	-	-	-	-
X^2 (df)	0.2960 (3)	4.3717 (3)	0.1693 (4)	0.8793 (3)	0.1093 (2)	1.3962 (3)
Probability	0.9607	0.2240	0.9966	0.8304	0.9468	0.7064
			Khunpae station			
m ± SE	15.88 ± 0.27**	17.33 ± 0.29**	16.50 ± 0.34**	16.72 ± 0.58**	17.80 ± 0.31**	16.27 ± 0.28**
d ± SE	-4.88 ± 1.19**	3.24 ± 1.34*	-0.13 ± 0.34	-	-1.69 ± 0.32**	0.64 ± 0.28*
h ± SE	-	-	3.15 ± 0.79**	-3.02 ± 1.00**	-0.44 ± 0.65	2.60 ± 0.70**
i ± SE	-	-	-	-	-	-
j ± SE	-4.81 ± 1.22**	4.81 ± 1.38**	-	-	-	-
l ± SE	-	-	-	-	-	-
X^2 (df)	0.1678 (3)	0.0643 (3)	1.8502 (3)	0.8199 (4)	4.3865 (3)	2.2308 (3)
Probability	0.9826	0.9957	0.6040	0.9357	0.2226	0.5259
			Pangda station			
m ± SE	16.68 ± 0.37**	16.99 ± 0.39**	17.99 ± 0.31**	17.99 ± 0.31**	17.39 ± 0.52**	18.64 ± 0.35**
d ± SE	-	-	-	-0.15 ± 0.38	-	0.11 ± 0.36
h ± SE	-10.15 ± 2.56**	12.01 ± 2.98**	-	-	13.24 ± 3.52**	2.20 ± 0.87*
i ± SE	-8.79 ± 2.55**	10.63 ± 2.97**	-	-	9.97 ± 3.50**	-
j ± SE	-	-	-0.50 ± 0.32	-	-	-
l ± SE	11.83 ± 4.59*	-20.92 ± 5.48**	-	-	-18.86 ± 6.22**	-
X^2 (df)	0.0600 (2)	0.4801 (2)	0.3930 (4)	0.4169 (4)	0.0733 (2)	1.8343 (3)
Probability	0.9704	0.7865	0.9830	0.9810	0.9640	0.6075

K = Kamuidainagon, H = Hondawase, A = Akatsukidainagon and E = Erimo variety.
SE is the standard error value.
*, ** Significantly different from zero at the P<0.05 and P<0.01 level, respectively.

4.3.2 Number of nodes per plant

Results of joint-scaling test for this trait are presented in Tables 11 and 13. Results showed that K x E, H x E and A x E crosses fitted to the additive-dominance model in 2005 at Inthanon. At this location, it was found that all crosses (except H x E) fitted in 2006. At Khunpae, K x H and H x A crosses fitted in 2005, and for all crosses, except K x A and H x A crosses fitted in 2006. At Pangda, two crosses of K x H and A x E, fitted in 2006.

The analysis of genetic effects of this trait is presented in Tables 12 and 14. Results of gene effects of this trait at Inthanon indicated that m values ranged 6.91-7.89 and 4.63-5.45 for nodes per plant in 2005 and 2006, respectively. The effect of d showed significantly for A x E cross in both years. K x A and K x E crosses gave d effect significantly in the first year but K x H, H x A and H x E crosses were significant in the second year. For h effect, all crosses (except K x H) showed significantly in 2005, and two crosses, H x A and A x E, showed in 2006. The i effect was found in two crosses, K x A and H x A, in 2005. The j effect was significant for K x H and K x E crosses in both years. For l effect, it was significantly observed in H x A cross in the first year.

At Khunpae station, m values ranged 8.18-10.04 and 6.51-8.06 for nodes per plant in 2005 and 2006, respectively. The d effect showed significantly in K x H and K x E crosses in 2005, and in H x E and A x E crosses in 2006. The h effect was found significantly for all crosses, except K x H, in the first year, and in K x E, H x E and A x E crosses in the second year. The i effect was significantly found in two crosses, K x E and A x E, in 2005. The j effect gave significantly in cross K x A for both years, and A x E cross in the first year. For l effect, it showed significantly for A x E cross in the first year.

At Pangda station, m value ranged from 7.56-9.12 and 7.29-9.15 for nodes per plant in 2005 and 2006, respectively. The d effect showed significantly for A x E cross in both years. The h effect gave significantly for all crosses, except H x A cross in 2005. The i effect showed significantly for all crosses, except H x A and H x E crosses in the first year and K x A and H x E were significant in the second year. The j effect was found significantly in A x E cross in the first year. For l effect, it was found that all crosses except H x A and H x E crosses were significant in 2005 and K x A and H x E crosses were significant in 2006.

Table 11 Generation means and joint-scaling test for number of nodes per plant in azuki bean crosses, grown at three highland locations in 2005 growing season.

Generations	K x H	K x A	K x E	H x A	H x E	A x E
			Inthanon station			
P1 ± SE	6.52 ± 0.11(54)b[1]	6.56 ± 0.14(52)b	6.51 ± 0.11(67)c	7.37 ± 0.12(65)c	7.73 ± 0.19(51)b	7.99 ± 0.14(73)c
P2 ± SE	7.73 ± 0.11(62)a	8.22 ± 0.13(54)a	7.38 ± 0.16(69)bc	8.22 ± 0.13(59)ab	7.46 ± 0.17(56)b	7.12 ± 0.15(66)d
F1 ± SE	7.57 ± 0.30(7)a	8.33 ± 0.28(12)a	8.79 ± 0.28(19)a	8.00 ± 0.19(17)bc	9.25 ± 0.32(16)a	9.11 ± 0.32(19)a
F2 ± SE	7.33 ± 0.12(78)a	7.12±0.13(101)b	7.44±0.18(105)b	7.89 ± 0.13(94)bc	8.78 ± 0.16(89)a	8.14±0.18(101)bc
BC1±SE	7.80 ± 0.29(10)a	7.25 ± 0.23(24)b	8.00 ± 0.34(21)ab	8.35 ± 0.26(17)ab	9.08 ± 0.38(13)a	8.64 ± 0.47(11)ab
BC2±SE	7.20 ± 0.33(10)ab	8.58 ± 0.36(12)a	7.96 ± 0.34(24)ab	8.87 ± 0.31(15)a	8.67 ± 0.39(15)a	8.76±0.39(17)abc
Joint-scaling test						
A ± SE	1.51 ± 0.66*	-0.39 ± 0.55	0.70 ± 0.74	1.34 ± 0.56*	1.18 ± 0.85	0.18 ± 1.01
B ± SE	-0.90 ± 0.73	0.61 ± 0.78	-0.25 ± 0.75	1.51 ± 0.66*	0.62 ± 0.85	1.30 ± 0.86
C ± SE	-0.05 ± 0.79	-2.97 ± 0.79**	-1.71 ± 0.95	-0.02 ± 0.66	1.41 ± 0.95	-0.76 ± 0.98
			Khunpae station			
P1 ± SE	7.91 ± 0.16(56)a	7.77 ± 0.17(47)b	7.80 ± 0.17(54)b	8.93 ± 0.13(72)a	9.11 ± 0.13(72)bc	9.97 ± 0.16(58)b
P2 ± SE	8.52 ± 0.18(66)a	9.06 ± 0.16(52)a	8.48 ± 0.15(61)b	9.21 ± 0.14(72)a	8.84 ± 0.16(64)c	8.90 ± 0.14(62)c
F1 ± SE	8.20 ± 0.34(15)a	9.43 ± 0.29(14)a	10.06±0.32(18)a	9.86 ± 0.25(21)a	10.53±0.36(15)a	10.00±0.31(17)b
F2 ± SE	7.97 ± 0.17(96)a	8.25 ± 0.16(80)b	8.30 ± 0.20(89)b	9.28±0.14(100)a	9.99 ± 0.18(93)ab	9.81 ± 0.16(86)b
BC1±SE	7.93 ± 0.40(15)a	9.07 ± 0.34(15)a	8.59 ± 0.36(17)b	9.25 ± 0.29(20)a	10.88±0.35(17)a	10.15±0.37(13)ab
BC2±SE	8.20 ± 0.35(20)a	8.40 ± 0.43(10)b	9.73 ± 0.34(26)a	9.28 ± 0.31(18)a	10.00±0.44(13)ab	10.94±0.36(16)a
Joint-scaling test						
A ± SE	-0.24 ± 0.88	0.94 ± 0.77	-0.68 ± 0.81	-0.29 ± 0.64	2.12 ± 0.80**	0.34 ± 0.82
B ± SE	-0.32 ± 0.80	-1.69 ± 0.92	0.93 ± 0.76	-0.51 ± 0.68	0.62 ± 0.96	2.97 ± 0.80**
C ± SE	-0.95 ± 1.01	-2.68 ± 0.89**	-3.17 ± 1.03**	-0.73 ± 0.78	0.94 ± 1.04	0.39 ± 0.91
			Pangda station			
P1 ± SE	7.52 ± 0.13(58)b	7.53 ± 0.14(79)c	8.00 ± 0.15(68)b	8.50 ± 0.14(70)a	8.63 ± 0.18(64)ab	8.50 ± 0.16(72)c
P2 ± SE	7.45 ± 0.14(58)b	8.80 ± 0.15(69)a	8.47 ± 0.18(55)b	8.88 ± 0.18(66)a	8.64 ± 0.17(58)b	8.73 ± 0.18(59)c
F1 ± SE	8.33 ± 0.17 (9)ab	8.00 ± 0.31(19)bc	10.00±0.30(31)a	8.91 ± 0.23(32)a	9.60 ± 0.26(25)ab	10.08±0.28(25)ab
F2 ± SE	7.56±0.11(104)b	7.86±0.14(105)bc	8.52±0.18(114)b	8.93±0.16(113)a	8.56±0.17(112)ab	9.12±0.16(114)c
BC1±SE	8.80 ± 0.37 (5)a	8.81 ± 0.24(27)a	9.86 ± 0.37(21)a	9.35 ± 0.29(26)a	8.96 ± 0.28(27)ab	10.72±0.36(18)a
BC2±SE	8.00 ± 0.29(19)ab	8.75 ± 0.43(12)ab	9.23 ± 0.34(26)a	8.96 ± 0.32(23)a	9.65 ± 0.41(17)a	9.26 ± 0.37(19)bc
Joint-scaling test						
A ± SE	1.75 ± 0.78**	2.10 ± 0.59**	1.71 ± 0.81*	1.29 ± 0.65*	-0.30 ± 0.65	2.86 ± 0.79**
B ± SE	0.22 ± 0.61	0.70 ± 0.92	-0.01 ± 0.77	0.13 ± 0.71	1.06 ± 0.88	-0.28 ± 0.80
C ± SE	-1.40 ± 0.60*	-0.90 ± 0.87	-2.40 ± 0.97*	0.53 ± 0.82	-2.21 ± 0.89*	-0.90 ± 0.88

K = Kamuidainagon, H = Hondawase, A = Akatsukidainagon and E = Erimo variety.
In parenthesis, is the number of plant.
[1] Means within columns followed by the same letter are not significantly different based on Duncan's Multiple Range Test (p=0.05).
SE is the standard error value.
*, ** Significantly different from zero at the $P<0.05$ and $P<0.01$ level, respectively.

Table 12 Estimation of genetic effects for number of nodes per plant in azuki bean crosses, grown at three highland locations in 2005 growing season.

parameters	K x H	K x A	K x E	H x A	H x E	A x E
			Inthanon station			
m ± SE	7.36 ± 0.09**	7.37 ± 0.16**	6.91 ± 0.09**	7.89 ± 0.13**	7.66 ± 0.12**	7.55 ± 0.10**
d ± SE	-	-0.93 ± 0.12**	-0.41 ± 0.09**	-	0.15 ± 0.12	0.41 ± 0.10**
h ± SE	-	2.18 ± 0.66**	1.67 ± 0.24**	3.07 ± 0.95**	1.99 ± 0.29**	1.52 ± 0.27**
i ± SE	-	1.17 ± 0.44**	-	2.86 ± 0.95**	-	-
j ± SE	0.60 ± 0.08**	-	-	-	-	-
l ± SE	-	-	-	-5.71 ± 1.73**	-	-
X^2 (df)	0.0514 (4)	0.0395 (2)	5.3359 (3)	0.0617 (2)	3.2210 (3)	3.9659 (3)
Probability	0.9996	0.9804	0.1487	0.9696	0.3587	0.2651
			Khunpae station			
m ± SE	8.18 ± 0.12**	8.74 ± 0.12**	8.58 ± 0.21**	9.04 ± 0.09**	10.04 ± 0.14**	9.81 ± 0.16**
d ± SE	-0.30 ± 0.12*	-	-0.50 ± 0.14**	-0.13 ± 0.09	-	-
h ± SE	-0.21 ± 0.29	0.89 ± 0.28**	3.23 ± 0.77**	0.63 ± 0.22**	1.74 ± 0.33**	3.49 ± 1.26**
i ± SE	-	-	1.24 ± 0.54*	-	-	2.93 ± 1.22*
j ± SE	-	0.65 ± 0.12**	-	-	-	-0.53 ± 0.11**
l ± SE	-	-	-	-	-	-6.24 ± 2.26**
X^2 (df)	0.9016 (3)	0.0630 (3)	0.0564 (2)	1.1631 (3)	0.0961 (4)	0.0291 (1)
Probability	0.8250	0.9958	0.9721	0.7618	0.9988	0.8645
			Pangda station			
m ± SE	7.56 ± 0.11**	7.86 ± 0.14**	8.52 ± 0.18**	8.93 ± 0.16**	8.84 ± 0.19**	9.12 ± 0.16**
d ± SE	-	-	-	0.39 ± 0.44	-	1.46 ± 0.51**
h ± SE	4.22 ± 1.05**	3.54 ± 1.15**	5.87 ± 1.24**	1.11 ± 1.11	1.80 ± 0.65**	4.95 ± 1.25**
i ± SE	3.37 ± 1.05**	3.70 ± 1.14**	4.11 ± 1.24**	0.89 ± 1.08	0.76 ± 0.48	3.48 ± 1.21**
j ± SE	-	-	-	0.58 ± 0.45	-	1.57 ± 0.53**
l ± SE	-5.34 ± 1.98**	-6.50 ± 2.16**	-5.81 ± 2.23*	-2.30 ± 1.93	-	-6.06 ± 2.23**
X^2 (df)	0.0384 (2)	0.0983 (2)	0.0341 (2)	-	0.0540 (3)	-
Probability	0.9809	0.9520	0.9830	-	0.9967	-

K = Kamuidainagon, H = Hondawase, A = Akatsukidainagon and E = Erimo variety.
SE is the standard error value.
*, ** Significantly different from zero at the P<0.05 and P<0.01 level, respectively.

Table 13 Generation means and joint-scaling test for number of nodes per plant in azuki bean crosses, grown at three highland locations in 2006 growing season.

Generations	K x H	K x A	K x E	H x A	H x E	A x E
			Inthanon station			
P1 ± SE	4.53±0.14(51)a[1]	4.48±0.15(44)a	4.50±0.16(42)a	5.31±0.19(59)ab	5.24±0.17(49)bc	5.42±0.20(55)b
P2 ± SE	5.19±0.18(52)a	4.79±0.16(48)a	4.80±0.17(51)a	4.81±0.19(59)b	5.11±0.19(56)c	4.90±0.17(59)b
F1 ± SE	5.08±0.29(13)a	4.57±0.29(21)a	5.07±0.33(15)a	5.75±0.29(20)ab	5.57±0.27(28)abc	5.23±0.54(13)b
F2 ± SE	5.08±0.17(83)a	4.32±0.20(66)a	4.88±0.18(77)a	5.14±0.17(98)ab	5.97±0.21(76)ab	5.76±0.22(84)ab
BC1±SE	4.62±0.29(21)a	5.29±0.37(14)a	4.79±0.39(14)a	5.61±0.31(23)a	6.00±0.37(19)a	6.56±0.58(9)a
BC2±SE	4.75±0.41(12)a	4.56±0.36(16)a	5.19±0.33(21)a	5.43±0.61(7)ab	4.82±0.35(22)c	6.00±0.52(14)ab
Joint-scaling test						
A ± SE	-0.37 ± 0.66	1.52 ± 0.81	0.00 ± 0.87	0.16 ± 0.71	1.18 ± 0.81	2.46 ± 1.30
B ± SE	-0.77 ± 0.89	-0.24 ± 0.80	0.51 ± 0.75	0.29 ± 1.27	-1.04 ± 0.78	1.87 ± 1.19
C ± SE	0.46 ± 0.91	-1.14 ± 1.02	0.10 ± 1.01	-1.05 ± 0.94	2.40 ± 1.04*	2.27 ± 1.43
			Khunpae station			
P1 ± SE	6.30±0.16(71)ab	6.23±0.18(61)b	6.78±0.21(65)a	6.73±0.19(66)a	6.75±0.19(63)b	7.48±0.19(60)ab
P2 ± SE	6.64±0.20(61)ab	7.57±0.16(65)a	6.70±0.21(54)a	8.19±0.21(70)a	7.44±0.20(68)ab	5.83±0.16(70)c
F1 ± SE	6.16±0.37(19)ab	7.29±0.32(17)a	7.72±0.32(25)a	7.55±0.36(22)a	7.86±0.28(29)ab	7.73±0.37(15)ab
F2 ± SE	6.60±0.17(100)ab	6.57±0.18(103)b	6.95±0.19(102)a	8.06±0.18(103)a	7.39±0.18(108)ab	7.32±0.18(103)ab
BC1±SE	5.95±0.37(19)b	7.21±0.34(19)a	7.50±0.38(20)a	7.67±0.38(21)a	7.21±0.46(14)b	8.20±0.40(15)a
BC2±SE	7.25±0.41(16)a	6.50±0.41(18)b	7.61±0.35(28)a	8.25±1.18(4)a	7.87±0.37(23)a	6.88±0.43(16)b
Joint-scaling test						
A ± SE	-0.56 ± 0.84	0.90 ± 0.77	0.50 ± 0.85	1.06 ± 0.86	-0.18 ± 0.98	1.18 ± 0.91
B ± SE	1.70 ± 0.93	-1.86 ± 0.90*	0.79 ± 0.79	0.77 ± 2.40	0.44 ± 0.82	0.19 ± 0.95
C ± SE	1.15 ± 1.04	-2.10 ± 1.00*	-1.12 ± 1.04	2.23 ± 1.08*	-0.36 ± 0.96	0.50 ± 1.06
			Pangda station			
P1 ± SE	7.20±0.17(66)a	7.21±0.20(73)c	7.63±0.21(70)d	8.16±0.24(57)b	7.57±0.22(68)d	8.82±0.20(67)b
P2 ± SE	7.34±0.20(53)a	8.60±0.22(68)ab	7.91±0.21(74)cd	8.53±0.20(60)b	8.01±0.20(68)cd	8.06±0.20(78)b
F1 ± SE	8.07±0.30(14)a	9.08±0.37(26)a	9.63±0.37(24)a	10.42±0.33(26)a	9.54±0.36(28)ab	10.58±0.43(19)a
F2 ± SE	7.70±0.18(110)a	7.77±0.21(108)bc	7.93±0.21(113)cd	8.57±0.20(114)b	8.71±0.22(100)bc	9.53±0.21(113)ab
BC1±SE	8.00±0.32(19)a	8.90±0.35(31)a	8.63±0.41(24)bc	8.47±0.45(17)b	10.33±0.49(18)a	9.63±0.75(8)ab
BC2±SE	8.00±0.41(19)a	9.60±0.67(10)a	9.20±0.38(30)ab	9.78±0.68(9)a	10.14±0.46(22)a	8.68±0.44(25)b
Joint-scaling test						
A ± SE	0.73 ± 0.74	1.52 ± 0.81	0.00 ± 0.93	-1.64 ± 1.00	3.56 ± 1.06**	-0.15 ± 1.58
B ± SE	0.59 ± 0.90	1.52 ± 1.41	0.87 ± 0.88	0.60 ± 1.42	2.72 ± 1.00**	-1.28 ± 1.00
C ± SE	0.12 ± 0.97	-2.89 ± 1.17*	-3.07 ± 1.17**	-3.26 ± 1.09**	0.18 ± 1.18	0.08 ± 1.25

K = Kamuidainagon, H = Hondawase, A = Akatsukidainagon and E = Erimo variety.
In parenthesis, is the number of plant.
[1] Means within columns followed by the same letter are not significantly different based on Duncan's Multiple Range Test (p=0.05).
SE is the standard error value.
*, ** Significantly different from zero at the P<0.05 and P<0.01 level, respectively.

Table 14 Estimation of genetic effects for number of nodes per plant in azuki bean crosses, grown at three highland locations in 2006 growing season.

parameters	K x H	K x A	K x E	H x A	H x E	A x E
			Inthanon station			
m ± SE	4.86 ± 0.11**	4.63 ± 0.10**	4.66 ± 0.11**	5.03 ± 0.13**	5.45 ± 0.11**	5.21 ± 0.13**
d ± SE	-0.33 ± 0.11**	-0.12 ± 0.11	-0.17 ± 0.11	0.25 ± 0.13*	1.18 ± 0.51*	0.27 ± 0.13*
h ± SE	0.21 ± 0.26	-0.10 ± 0.26	0.47 ± 0.28	0.57 ± 0.28*	-	0.90 ± 0.38*
i ± SE	-	-	-	-	-	-
j ± SE	-	-	-	-	1.11 ± 0.53*	-
l ± SE	-	-	-	-	-	-
X^2 (df)	1.7653 (3)	6.1408 (3)	0.4828 (3)	1.7664 (3)	0.0811 (3)	5.5094 (3)
Probability	0.6225	0.1049	0.9226	0.6222	0.9940	0.1380
			Khunpae station			
m ± SE	6.51 ± 0.12**	6.90 ± 0.12**	6.73 ± 0.14**	8.06 ± 0.18**	7.09 ± 0.13**	6.68 ± 0.12**
d ± SE	-0.23 ± 0.12	-	0.02 ± 0.14	-0.58 ± 1.24	-0.36 ± 0.13**	0.85 ± 0.12**
h ± SE	-0.05 ± 0.30	-	0.92 ± 0.31**	-0.31 ± 2.62	0.74 ± 0.28**	1.26 ± 0.30**
i ± SE	-	-	-	-0.40 ± 2.59	-	-
j ± SE	-	0.67 ± 0.12**	-	0.15 ± 1.25	-	-
l ± SE	-	-	-	-1.43 ± 5.08	-	-
X^2 (df)	5.1575 (3)	0.0752 (4)	3.8219 (3)	-	0.5724 (3)	1.6958 (3)
Probability	0.1606	0.9993	0.2813	-	0.9027	0.6378
			Pangda station			
m ± SE	7.29 ± 0.12**	7.77 ± 0.21**	8.28 ± 0.23**	9.15 ± 0.17**	8.71 ± 0.22**	8.43 ± 0.14**
d ± SE	-0.06 ± 0.12	-	-	-	-	0.41 ± 0.14**
h ± SE	0.91 ± 0.28**	7.11 ± 1.74**	3.04 ± 0.89**	1.92 ± 0.34**	7.84 ± 1.61**	2.04 ± 0.36**
i ± SE	-	5.93 ± 1.73**	1.09 ± 0.62	-	6.10 ± 1.60**	-
j ± SE	-	-	-	-	-	-
l ± SE	-	-8.98 ± 3.23**	-	-	-12.38 ± 2.92**	-
X^2 (df)	1.3529 (3)	0.1497 (2)	0.0742 (3)	0.1545 (4)	0.0143 (2)	1.9259 (3)
Probability	0.7166	0.9278	0.9947	0.9971	0.9928	0.5879

K = Kamuidainagon, H = Hondawase, A = Akatsukidainagon and E = Erimo variety.
SE is the standard error value.
*, ** Significantly different from zero at the P<0.05 and P<0.01 level, respectively.

The results of joint-scaling test and estimation of genetic effect of this trait clearly indicated that dominance effect (h) and epistatic interaction (i, j and l) played more importance role in controlling this trait than additive gene effects. The epistatic interaction indicated predominantly for a duplicate type of gene to control this trait. These results are similar to the works of Kunkaew *et al.* (2006).

4.3.3 Number of branches per plant

Results of joint-scaling test for number of branches per plant are presented in Tables 15 and 17. Results showed that there were three crosses (K x H, H x A and H x E) that fitted to additive-dominance model at Inthanon in the first year. Khunpae station, most crosses fitted to the model in 2005, except K x A, H x A crosses and H x A cross in 2006. At Pangda station, it was found that K x H and A x E fitted to the model in 2005, and H x A in 2006.

The results of genetic effect analysis of this trait are presented in Tables 16 and 18. At Inthanon station, it was found that m value ranged 5.85-7.18 and 3.59-5.36 branches per plant in 2005 and 2006, respectively. The d effect showed significantly in A x E cross in the first year, and K x H and H x E crosses in the second year. The h effect showed significantly in all crosses in 2005, and only two crosses, K x E and H x E in 2006. The i effect gave significantly for K x A, H x A and H x E crosses in the first year. The j effect was found significantly only in K x H cross in 2005. For l effect, it was found significantly in K x A, H x A and H x E crosses in the first year.

At Khunpae station, m values ranged 7.02-9.06 in 2005, and 5.96-7.24 branches per plant in 2006. The d effect showed significantly for H x E cross in 2005, and K x H, H x A and A x E crosses in 2006. The h effect was found significantly in all crosses (except K x H) in the first year, and in most crosses (K x H, K x E, H x E and A x E) in the second year. The i effect was observed in K x E cross in the first year. The j effect was found significantly in K x A and A x E crosses in 2005, and K x A cross in 2006. For l effect, it was found significantly for K x E cross in the first year.

At Pangda, it was found that m values ranged 7.01-8.10 and 6.41-8.70 branches per plant in 2005 and 2006, respectively. The d effect showed significantly in K x A and A x E crosses in 2005, and in K x H, K x E and A x E crosses in 2006. The h effect gave significantly for all crosses in both years, except the crosses K x H and K x A in 2005.

Table 15 Generation means and joint-scaling test for number of branches per plant in azuki bean crosses, grown at three highland locations in 2005 growing season.

Generations	K x H	K x A	K x E	H x A	H x E	A x E
			Inthanon station			
P1 ± SE	4.81 ± 0.17(54)d[1]	5.19 ± 0.19(53)d	5.31 ± 0.15(67)d	5.54 ± 0.14(63)b	6.41 ± 0.21(61)de	7.99 ± 0.22(70)a
P2 ± SE	6.46 ± 0.16(70)bc	7.22 ± 0.16(55)ab	5.72 ± 0.19(67)cd	7.21 ± 0.14(58)a	5.60 ± 0.21(63)e	5.95 ± 0.18(66)b
F1 ± SE	7.83 ± 0.31 (6)a	7.36 ± 0.32(14)ab	7.71 ± 0.27(17)a	7.22 ± 0.23(23)a	8.68 ± 0.30(19)ab	8.42 ± 0.37(19)a
F2 ± SE	5.83 ± 0.18(80)bc	5.85 ± 0.17(99)cd	6.02±0.22(105)bcd	7.08 ± 0.16(87)a	7.18±0.20(107)cd	7.77±0.20(101)a
BC1±SE	6.55 ± 0.41(11)b	6.48 ± 0.34(21)bc	6.96 ± 0.35(23)ab	7.33 ± 0.26(18)a	9.00 ± 0.42(18)a	7.50 ± 0.56(10)a
BC2±SE	5.91 ± 0.44(11)cd	7.47 ± 0.40(15)a	6.79±0.41(24)abc	7.93 ± 0.38(15)a	7.88 ± 0.49(16)bc	8.00 ± 0.50(14)a
Joint-scaling test						
A ± SE	0.44 ± 0.90	0.41 ± 0.77	0.89 ± 0.77	1.91 ± 0.58**	2.91 ± 0.92**	-1.41 ± 1.20
B ± SE	-2.47 ± 0.94*	0.36 ± 0.88	0.16 ± 0.89	1.44 ± 0.81	1.46 ± 1.05	1.62 ± 1.09
C ± SE	-3.64 ± 0.96**	-3.73 ± 0.98**	-2.37 ± 1.05*	1.14 ± 0.79	-0.67 ± 1.04	0.31 ± 1.11
			Khunpae station			
P1 ± SE	6.74 ± 0.18(54)b	6.30 ± 0.18(57)d	6.38 ± 0.18(53)c	7.75 ± 0.16(68)b	8.70 ± 0.17(53)c	8.98 ± 0.20(60)a
P2 ± SE	8.32 ± 0.18(41)a	8.33 ± 0.17(60)a	6.87 ± 0.19(63)c	7.94 ± 0.15(69)b	7.32 ± 0.17(57)d	7.44 ± 0.20(63)b
F1 ± SE	7.58 ± 0.36(12)ab	7.93 ± 0.33(15)ab	8.94 ± 0.34(16)a	8.94 ± 0.26(17)a	9.67 ± 0.31(12)ab	9.00 ± 0.41(16)a
F2 ± SE	6.91 ± 0.18(93)b	7.05 ± 0.18(76)cd	7.02 ± 0.18(89)c	8.19±0.17(102)b	8.95 ± 0.19(83)bc	8.34 ± 0.21(92)ab
BC1±SE	7.59 ± 0.33(17)ab	8.29 ± 0.34(17)a	8.15 ± 0.44(13)b	8.39 ± 0.34(18)b	10.06±0.30(17)a	8.56 ± 0.46(16)a
BC2±SE	7.57 ± 0.38(21)b	7.50 ± 0.40(14)bc	8.62 ± 0.35(21)ab	7.86 ± 0.42(14)b	8.75 ± 0.51(12)c	9.31 ± 0.47(16)a
Joint-scaling test						
A ± SE	0.85 ± 0.78	2.36 ± 0.78**	0.99 ± 0.95	0.09 ± 0.75	1.75 ± 0.70*	-0.86 ± 1.02
B ± SE	-0.76 ± 0.85	-1.27 ± 0.89	1.43 ± 0.80	-1.17 ± 0.89	0.52 ± 1.08	2.18 ± 1.05*
C ± SE	-2.57 ± 1.06*	-2.29 ± 1.01*	-3.04 ± 1.01**	-0.83 ± 0.90	0.46 ± 1.01	-1.08 ± 1.20
			Pangda station			
P1 ± SE	6.82 ± 0.17(62)b	6.82 ± 0.15(65)a	6.57 ± 0.18(68)d	7.86 ± 0.17(69)b	8.22 ± 0.23(49)ab	7.82 ± 0.20(61)bc
P2 ± SE	7.26 ± 0.17(66)ab	7.36 ± 0.17(66)a	6.63 ± 0.21(56)d	8.25 ± 0.20(53)ab	6.84 ± 0.24(45)b	6.79 ± 0.20(52)c
F1 ± SE	7.31 ± 0.30(16)ab	7.05 ± 0.33(21)a	9.43 ± 0.29(28)a	8.65 ± 0.23(31)ab	8.68 ± 0.30(25)a	8.96 ± 0.30(24)b
F2 ± SE	6.81±0.18(113)b	6.93±0.18(101)a	7.40±0.18(111)cd	8.61±0.16(101)ab	7.59±0.19(104)ab	7.94±0.17(107)bc
BC1±SE	8.13 ± 0.58 (8)a	7.38 ± 0.29(29)a	8.95 ± 0.39(20)ab	9.00 ± 0.45(11)a	8.50 ± 0.40(18)a	10.06±0.36(16)a
BC2±SE	7.20 ± 0.37(20)ab	7.46 ± 0.46(13)a	8.00 ± 0.36(24)bc	8.33 ± 0.33(24)ab	8.94 ± 0.44(18)a	8.64 ± 0.50(14)b
Joint-scaling test						
A ± SE	2.11 ± 1.21	0.90 ± 0.68	1.90 ± 0.85*	1.50 ± 0.94	0.10 ± 0.88	3.35 ± 0.80**
B ± SE	-0.17 ± 0.82	0.51 ± 1.00	-0.05 ± 0.81	-0.22 ± 0.74	2.36 ± 0.96*	1.54 ± 1.06
C ± SE	-1.45 ± 0.96	-0.55 ± 1.00	-2.47 ± 0.98*	1.06 ± 0.85	-2.08 ± 1.01*	-0.75 ± 0.96

K = Kamuidainagon, H = Hondawase, A = Akatsukidainagon and E = Erimo variety.
In parenthesis, is the number of plant.
[1] Means within columns followed by the same letter are not significantly different based on Duncan's Multiple Range Test (p=0.05).
SE is the standard error value.
*, ** Significantly different from zero at the P<0.05 and P<0.01 level, respectively.

Table 16 Estimation of genetic effects for number of branches per plant in azuki bean crosses, grown at three highland locations in 2005 growing season.

parameters	K x H	K x A	K x E	H x A	H x E	A x E
			Inthanon station			
m ± SE	6.40 ± 0.13**	5.85 ± 0.17**	6.35 ± 0.23**	7.08 ± 0.16**	7.18 ± 0.20**	6.97 ± 0.13**
d ± SE	-	-	-	-	-	0.97 ± 0.14**
h ± SE	1.97 ± 0.30**	5.65 ± 1.26**	3.04 ± 0.70**	3.06 ± 1.12**	7.72 ± 1.53**	1.54 ± 0.33**
i ± SE	-	4.49 ± 1.25**	0.77 ± 0.54	2.21 ± 1.11*	5.04 ± 1.52**	-
j ± SE	0.82 ± 0.12**	-	-	-	-	-
l ± SE	-	-5.26 ± 2.31*	-	-5.56 ± 2.01**	-9.41 ± 2.79**	-
X^2 (df)	0.1384 (3)	0.4023 (2)	0.0734 (3)	0.2416 (2)	0.1291 (2)	4.0475 (3)
Probability	0.9868	0.8177	0.9948	0.8862	0.9374	0.2563
			Khunpae station			
m ± SE	7.12 ± 0.20**	7.38 ± 0.21**	7.02 ± 0.18**	7.82 ± 0.10**	9.06 ± 0.13**	8.68 ± 0.16**
d ± SE	-	-	-	-0.07 ± 0.11	0.81 ± 0.15**	-
h ± SE	1.13 ± 0.84	1.43 ± 0.35**	7.77 ± 1.33**	0.95 ± 0.25**	1.81 ± 0.30**	0.83 ± 0.38*
i ± SE	1.03 ± 0.57	0.73 ± 0.55	5.46 ± 1.32**	-	-	-
j ± SE	-	1.02 ± 0.12**	-	-	-	-0.77 ± 0.14**
l ± SE	-	-	-7.88 ± 2.45**	-	-	-
X^2 (df)	0.1830 (3)	0.0907 (2)	0.0314 (2)	2.3540 (3)	0.0566 (3)	0.0630 (3)
Probability	0.9802	0.9556	0.9844	0.5022	0.9964	0.9958
			Pangda station			
m ± SE	7.01 ± 0.12**	7.09 ± 0.11**	7.40 ± 0.18**	8.10 ± 0.12**	7.59 ± 0.19**	7.94 ± 0.17**
d ± SE	-0.19 ± 0.12	-0.25 ± 0.11*	-	-0.16 ± 0.13	-	0.70 ± 0.17**
h ± SE	0.11 ± 0.28	0.00 ± 0.28	7.14 ± 1.30**	0.72 ± 0.25**	5.69 ± 1.41**	7.29 ± 1.45**
i ± SE	-	-	4.31 ± 1.29**	-	4.54 ± 1.40**	5.64 ± 1.41**
j ± SE	-	-	-	-	-	-
l ± SE	-	-	-6.16 ± 2.33**	-	-7.00 ± 2.58**	-10.52 ± 2.64**
X^2 (df)	6.4938 (3)	3.2503 (3)	0.0534 (2)	3.9752 (3)	0.1377 (2)	0.0370 (1)
Probability	0.0899	0.3546	0.9736	0.2641	0.9334	0.8474

K = Kamuidainagon, H = Hondawase, A = Akatsukidainagon and E = Erimo variety.
SE is the standard error value.
*, ** Significantly different from zero at the P<0.05 and P<0.01 level, respectively.

Table 17 Generation means and joint-scaling test for number of branches per plant in azuki bean crosses, grown at three highland locations in 2006 growing season.

Generations	K x H	K x A	K x E	H x A	H x E	A x E
			Inthanon station			
P1 ± SE	3.19±0.16(52)b[1]	3.55±0.19(42)ab	3.76±0.18(42)b	4.55±0.17(47)ab	4.30±0.22(53)bc	5.31±0.18(45)a
P2 ± SE	4.76±0.23(45)a	3.98±0.19(41)ab	3.32±0.16(53)b	4.50±0.16(42)b	3.71±0.19(56)c	3.73±0.16(60)b
F1 ± SE	3.64±0.39(14)b	4.00±0.30(18)ab	4.93±0.37(15)a	4.60±0.34(10)ab	5.21±0.30(29)a	5.13±0.34(15)a
F2 ± SE	3.83±0.18(83)b	3.24±0.18(67)b	3.51±0.17(75)b	4.57±0.15(68)ab	4.72±0.22(78)ab	5.36±0.20(67)a
BC1±SE	4.00±0.32(20)b	4.23±0.36(13)ab	4.00±0.39(12)b	5.18±0.27(17)a	5.14±0.38(21)ab	5.00±0.45(10)a
BC2±SE	3.77±0.46(13)b	4.09±0.44(11)a	4.04±0.29(24)b	4.86±0.46(7)ab	4.24±0.40(21)abc	4.36±0.45(11)a
Joint-scaling test						
A ± SE	1.16 ± 0.77	0.91 ± 0.81	-0.70 ± 0.88	1.20 ± 0.67	0.78 ± 0.85	-0.44 ± 0.97
B ± SE	-0.86 ± 1.02	0.21 ± 0.94	-0.17 ± 0.70	0.61 ± 0.99	-0.45 ± 0.87	-0.14 ± 0.98
C ± SE	0.09 ± 1.10	-2.57 ± 0.98**	-2.92 ± 1.03**	0.04 ± 0.94	0.44 ± 1.11	2.12 ± 1.07*
			Khunpae station			
P1 ± SE	5.78±0.19(67)b	5.59±0.20(66)b	6.16±0.21(55)bc	6.60±0.21(60)bc	6.71±0.21(68)c	7.24±0.21(58)a
P2 ± SE	7.25±0.19(51)a	7.45±0.25(66)a	5.83±0.22(48)c	8.00±0.21(61)ab	6.99±0.21(67)bc	5.01±0.20(68)b
F1 ± SE	5.68±0.33(19)b	7.40±0.35(20)a	7.50±0.41(22)a	6.18±0.41(17)c	7.87±0.25(30)a	7.30±0.38(20)a
F2 ± SE	5.75±0.18(93)b	6.38±0.22(99)b	6.28±0.22(99)bc	7.78±0.21(97)ab	7.17±0.24(106)abc	7.00±0.23(101)a
BC1±SE	5.94±0.35(17)b	7.35±0.42(20)a	6.84±0.45(19)abc	6.63±0.38(19)abc	7.92±0.68(12)ab	7.36±0.53(14)a
BC2±SE	7.29±0.46(14)a	6.41±0.49(17)b	7.00±0.40(26)ab	8.25±0.63(4)a	7.55±0.53(20)ab	6.13±0.43(23)ab
Joint-scaling test						
A ± SE	0.42 ± 0.79	1.71 ± 0.94	0.02 ± 1.01	0.49 ± 0.90	1.26 ± 1.40	0.17 ± 0.15
B ± SE	1.63 ± 1.00	-2.03 ± 1.08	0.67 ± 0.92	2.32 ± 1.34	0.25 ± 1.11	-0.05 ± 0.97
C ± SE	-1.39 ± 1.01	-2.31 ± 1.16*	-1.87 ± 1.24	4.18 ± 1.20**	-0.75 ± 1.13	1.14 ± 1.24
			Pangda station			
P1 ± SE	6.11±0.19(70)b	6.15±0.19(74)c	7.39±0.22(61)b	7.73±0.24(59)c	7.06±0.22(71)bc	8.33±0.24(64)b
P2 ± SE	6.77±0.19(74)b	8.07±0.23(58)ab	6.88±0.19(74)b	8.11±0.23(65)bc	6.66±0.22(68)c	7.01±0.21(75)b
F1 ± SE	8.16±0.37(19)a	8.93±0.31(27)a	9.80±0.45(15)a	10.32±0.35(28)a	9.89±0.36(27)a	10.44±0.47(18)a
F2 ± SE	6.87±0.19(117)b	7.33±0.19(102)b	7.62±0.22(112)b	7.89±0.20(114)bc	7.82±0.23(103)b	8.58±0.21(113)b
BC1±SE	6.78±0.42(18)b	8.82±0.38(22)a	7.54±0.36(24)b	8.07±0.50(15)bc	9.83±0.43(23)a	10.14±0.80(7)a
BC2±SE	8.25±0.43(20)a	9.00±0.50(14)a	8.73±0.42(30)a	9.00±0.55(14)ab	9.32±0.44(25)a	8.38±0.44(24)b
Joint-scaling test						
A ± SE	-0.72 ± 0.93	2.56 ± 0.85**	-2.11 ± 0.87*	-1.92 ± 1.09	2.71 ± 0.96**	1.51 ± 1.68
B ± SE	1.57 ± 0.95	1.01 ± 1.08	0.79 ± 0.97	-0.43 ± 1.18	2.09 ± 0.97*	-0.71 ± 1.02
C ± SE	-1.71 ± 1.08	-2.74 ± 1.02**	-3.41 ± 1.29**	-4.94 ± 1.12**	-2.23 ± 1.19	-1.93 ± 1.30

K = Kamuidainagon, H = Hondawase, A = Akatsukidainagon and E = Erimo variety.
In parenthesis, is the number of plant.
[1] Means within columns followed by the same letter are not significantly different based on Duncan's Multiple Range Test (p=0.05).
SE is the standard error value.
*, ** Significantly different from zero at the P<0.05 and P<0.01 level, respectively.

Table 18 Estimation of genetic effects for number of branches per plant in azuki bean crosses, grown at three highland locations in 2006 growing season.

parameters	K x H	K x A	K x E	H x A	H x E	A x E
			Inthanon station			
m ± SE	3.97 ± 0.13**	3.59 ± 0.22**	4.03 ± 0.13**	4.55 ± 0.11**	4.03 ± 0.14**	5.36 ± 0.20**
d ± SE	-0.72 ± 0.13**	-	-	0.06 ± 0.11	0.34 ± 0.14*	0.64 ± 0.64
h ± SE	-0.21 ± 0.32	1.17 ± 0.74	1.26 ± 0.34**	0.24 ± 0.27	1.25 ± 0.30**	-2.09 ± 1.54
i ± SE	-	0.84 ± 0.53	-	-	-	-2.71 ± 1.50
j ± SE	-	-	-	-	-	-0.15 ± 0.65
l ± SE	-	-	-	-	-	3.29 ± 2.76
X^2 (df)	3.6633 (3)	0.1400 (3)	0.1244 (4)	4.0779 (3)	1.3380 (3)	-
Probability	0.3001	0.9866	0.9981	0.2531	0.7201	-
			Khunpae station			
m ± SE	6.49 ± 0.13**	6.77 ± 0.14**	5.96 ± 0.14**	7.24 ± 0.15**	6.83 ± 0.14**	6.15 ± 0.14**
d ± SE	-0.75 ± 0.13**	-	0.14 ± 0.15	-0.88 ± 0.19**	-0.13 ± 0.15	1.12 ± 0.14**
h ± SE	-0.94 ± 0.30**	-	1.28 ± 0.35**	-	1.00 ± 0.28**	1.33 ± 0.34**
i ± SE	-	-	-	-	-	-
j ± SE	-	0.93 ± 0.16**	-	-	-	-
l ± SE	-	-	-	-	-	-
X^2 (df)	6.9624 (3)	0.1677 (4)	4.1451 (3)	0.2543 (4)	1.4847 (3)	0.9599 (3)
Probability	0.0731	0.9966	0.2462	0.9925	0.6858	0.8109
			Pangda station			
m ± SE	6.41 ± 0.13**	7.33 ± 0.19**	8.20 ± 0.15**	8.70 ± 0.16**	7.82 ± 0.23**	7.62 ± 0.15**
d ± SE	-0.38 ± 0.13**	-	-1.19 ± 0.56*	-	-	0.68 ± 0.15**
h ± SE	1.48 ± 0.31**	8.12 ± 1.48**	2.49 ± 0.41**	2.12 ± 0.36**	10.06 ± 1.53**	2.37 ± 0.38**
i ± SE	-	6.30 ± 1.47**	-	-	7.03 ± 1.53**	-
j ± SE	-	-	-1.45 ± 0.57*	-	-	-
l ± SE	-	-9.87 ± 2.72**	-	-	-11.83 ± 2.73**	-
X^2 (df)	7.6641 (3)	0.2612 (2)	0.0652 (2)	0.1946 (4)	0.0247 (2)	3.8431 (3)
Probability	0.0534	0.8775	0.9679	0.9955	0.9877	0.2789

K = Kamuidainagon, H = Hondawase, A = Akatsukidainagon and E = Erimo variety.
SE is the standard error value.
*, ** Significantly different from zero at the $P<0.05$ and $P<0.01$ level, respectively.

The i effect showed significantly in K x E, H x E and A x E crosses in 2005, and in K x A and H x E crosses in 2006. The j effect gave significantly for K x E cross in the first year. For the l effect, it showed that three crosses (K x E, H x E and A x E) and two crosses (K x A and H x E) gave significantly in 2005 and 2006, respectively.

Results of joint-scaling test and genetic effect analysis indicated that both additive and non-additive effects were predominantly observed for controlling this trait. In addition, this trait revealed that some crosses, grown on different locations and years, showed predominantly of a duplicate type. These results are similar to the works of Kunkaew *et al.* (2006; 2007a).

4.3.4 Number of pods per plant

Results of joint-scaling test for this trait are presented in Tables 19 and 21. Results showed that K x H, H x A, H x E and A x E crosses fitted to the additive-dominance model at Inthanon in 2006. At Khunpae station, it was found that H x A cross and H x A, H x E and A x E crosses fitted to the model in 2005 and 2006, respectively. At Pangda station, H x A cross in 2005 and K x H and A x E crosses in 2006 fitted to the additive-dominance model.

The estimation of genetic effects of this trait is shown in Tables 20 and 22. At Inthanon, m values ranged from 13.65-26.33 and 6.57-12.08 pods per plant in the first year and second year, respectively. The d effect for H x A and H x E crosses were significant in 2005, and for K x H, H x E and A x E crosses were significant in 2006. The h effect gave significantly for most crosses in both years (except H x A and A x E crosses in 2005, and K x H and H x A crosses in 2006). The i effect showed significantly for K x A cross in both years, but H x E cross gave significantly in the first year. The j effect was significant for H x E and A x E crosses in first year. For the l effect, it was significantly observed in K x A, H x A and H x E crosses in 2005.

At Khunpae station, m values ranged from 19.94-32.51 and 18.30-23.43 pods per plant in the first and second year, respectively. The d effect for K x A, K x E and A x E crosses were significant in 2005, and were significant for all crosses except K x E and H x E crosses in 2006. The h effect for K x E, H x A, H x E and A x E crosses were significant in both years (except H x A in second year). The i effect gave significantly for K x E cross in both years. The j effect showed significantly for K x A and A x E crosses

Table 19 Generation means and joint-scaling test for number of pods per plant in azuki bean crosses, grown at three highland locations in 2005 growing season.

Generations	K x H	K x A	K x E	H x A	H x E	A x E
			Inthanon station			
P1 ± SE	10.89±0.53(46)b[1]	10.81±0.64(57)b	12.64±0.61(67)c	16.63±0.90(72)c	18.70±0.69(53)cd	23.69±1.13(67)b
P2 ± SE	15.82±0.56(44)b	19.48±0.81(61)a	15.15±0.91(72)bc	23.99±1.13(69)b	16.68±0.68(47)d	14.89±0.71(66)c
F1 ± SE	28.00±2.14(5)a	18.44±1.41(9)a	28.26±1.99(19)a	23.91±1.69(22)b	24.71±1.60(14)b	30.75±2.23(12)a
F2 ± SE	15.85±0.68(60)b	13.65±0.74(104b)	18.18±1.05(87)bc	24.44±1.27(101)b	22.78±0.82(72)bc	24.84±1.22(96)b
BC1±SE	17.00±1.33(9)b	17.41±1.39 (22)a	21.30±1.82(23)b	23.18±2.26(22)b	32.77±1.71(13)a	17.22±2.85(9)b
BC2±SE	15.67±1.82(9)b	19.80±1.77(15)a	19.75±1.89(24)b	31.38±2.94(16)a	21.80±1.60(15)bc	23.81±2.84(16)b
Joint-scaling test						
A ± SE	-4.89 ± 3.46	5.57 ± 3.18	1.70 ± 4.19	5.83 ± 4.90	22.13 ± 3.84**	-19.99 ± 6.23**
B ± SE	-12.48 ± 4.26**	1.68 ± 3.89	-3.92 ± 4.37	14.86 ± 6.23*	2.20 ± 3.64	1.98 ± 6.14
C ± SE	-19.31 ± 5.13**	-12.56 ± 4.22**	-11.59 ± 5.88*	9.31 ± 6.28	6.30 ± 4.69	-0.71 ± 6.74
			Khunpae station			
P1 ± SE	17.74±0.91(58)c	16.89±0.71(55)c	17.63±0.72(52)d	24.36±0.90(69)a	26.35±1.21(63)ab	29.42±1.17(59)b
P2 ± SE	27.11±1.29(46)a	25.17±0.75(53)ab	20.98±0.73(53)c	24.55±0.89(75)a	22.11±0.86(64)b	21.16±0.90(68)c
F1 ± SE	24.08±1.99(12)ab	23.89±1.95(9)b	30.14±1.37(14)a	29.69±2.07(16)a	29.30±2.77(10)ab	33.14±2.34(14)ab
F2 ± SE	19.94±1.03(94)bc	19.69±0.77(77)c	19.28±0.89(87)cd	25.58±1.04(105)a	29.37±1.27(95)a	27.65±1.22(95)b
BC1±SE	22.41±1.98(17)bc	26.50±1.79(12)a	21.16±1.50(19)c	27.22±2.18(18)a	37.44±2.50(18)a	26.80±2.95(10)b
BC2±SE	21.32±2.07(22)bc	19.57±1.68(14)c	26.45±1.59(22)b	24.60±2.46(15)a	30.73±3.50(11)a	37.00±3.84(9)a
Joint-scaling test						
A ± SE	3.00 ± 4.52	12.22 ± 4.15**	-5.46 ± 3.37	0.39 ± 4.90	19.24 ± 5.84**	-8.97 ± 6.45
B ± SE	-8.56 ± 4.76	-9.92 ± 3.96*	1.79 ± 3.54	-5.03 ± 5.42	10.05 ± 7.57	19.70 ± 8.07*
C ± SE	-13.27 ± 5.93*	-11.09 ± 5.09*	-21.80 ± 4.63**	-5.96 ± 6.01	10.42 ± 7.64	-6.26 ± 6.91
			Pangda station			
P1 ± SE	13.34±0.48(68)c	13.62±0.50(82)c	13.34±0.54(71)d	20.13±0.79(75)b	21.60±0.69(53)ab	19.20±0.52(70)cd
P2 ± SE	20.98±0.59(44)ab	19.90±0.66(62)b	14.89±0.73(57)d	21.33±0.82(67)b	14.60±0.66(60)c	16.92±0.83(51)d
F1 ± SE	23.91±0.99(11)a	21.68±1.26(19)ab	26.10±1.35(20)a	24.04±1.30(26)ab	26.32±1.45(19)a	27.35±1.26(20)b
F2 ± SE	15.63±0.47(95)c	15.68±0.63(109)c	17.85±0.82(106)c	21.65±0.88(113)b	19.61±0.76(105)b	22.00±0.80(115)bcd
BC1±SE	16.17±1.64(6)c	23.88±1.16(24)a	22.91±1.49(22)b	25.63±1.87(19)a	23.96±1.37(24)ab	33.36±1.75(14)a
BC2±SE	21.00±1.32(11)b	20.82±1.86(11)b	22.04±1.55(23)b	24.68±2.04(19)ab	25.15±1.92(13)a	23.93±2.01(15)bc
Joint-scaling test						
A ± SE	-4.91 ± 3.46	12.44 ± 2.68**	6.38 ± 3.31	7.09 ± 4.03	0.00 ± 3.17	20.16 ± 3.75**
B ± SE	-2.89 ± 2.88	0.05 ± 3.99	3.09 ± 3.46	4.00 ± 4.36	9.39 ± 4.15*	3.60 ± 4.30
C ± SE	-19.61 ± 2.83**	-14.18 ± 3.67**	-9.04 ± 4.35*	-2.92 ± 4.52	-10.40 ± 4.31*	-2.82 ± 4.17

K = Kamuidainagon, H = Hondawase, A = Akatsukidainagon and E = Erimo variety.
In parenthesis, is the number of plant.
[1] Means within columns followed by the same letter are not significantly different based on Duncan's Multiple Range Test (p=0.05).
SE is the standard error value.
*, ** Significantly different from zero at the $P<0.05$ and $P<0.01$ level, respectively.

Table 20 Estimation of genetic effects for number of pods per plant in azuki bean crosses, grown at three highland locations in 2005 growing season.

parameters	K x H	K x A	K x E	H x A	H x E	A x E
			Inthanon station			
m ± SE	18.29±0.66**	13.65 ± 0.74**	20.37 ± 0.70**	26.33 ± 1.31**	22.78 ± 0.82**	21.96 ± 1.40**
d ± SE	-	-	-	-4.58 ± 0.94**	10.97 ± 2.34**	-
h ± SE	13.06 ± 1.84**	23.11 ± 5.42**	13.90 ± 1.79**	-	25.05 ± 5.96**	-
i ± SE	-	19.80 ± 5.39**	-	-	18.03 ± 5.72**	-
j ± SE	-	-	-	-	9.96 ± 2.39**	-4.40 ± 0.67**
l ± SE	-	-27.05 ± 9.94**	-	-19.30 ± 6.01**	-42.36 ± 10.47**	4.60 ± 6.59
X^2 (df)	2.6632 (4)	2.6349 (2)	0.5973 (4)	0.8750 (3)	-	5.3929 (3)
Probability	0.6156	0.2678	0.9633	0.8314	-	0.1451
			Khunpae station			
m ± SE	19.94 ± 1.03**	20.85 ± 0.96**	20.35 ± 0.93**	24.31 ± 0.62**	32.51 ± 1.49**	29.89 ± 1.05**
d ± SE	1.09 ± 2.86	6.93 ± 2.46**	-2.40 ± 0.63**	0.00 ± 0.62	-	-10.20 ± 4.87*
h ± SE	9.37 ± 7.36	7.24 ± 4.46	20.66 ± 3.39**	3.89 ± 1.66*	3.04 ± 1.04**	8.30 ± 2.19**
i ± SE	7.72 ± 7.04	4.09 ± 2.86	9.56 ± 2.41**	-	-	-
j ± SE	5.78 ± 2.97	11.07 ± 2.51**	-	-	-	-14.33 ± 4.89**
l ± SE	-2.16 ± 12.88	-	-	-	-26.38 ± 7.29**	-
X^2 (df)	-	0.2136 (1)	0.3944 (2)	1.6550 (3)	1.3504 (3)	0.4855 (2)
Probability	-	0.6439	0.8210	0.6469	0.7172	0.7844
			Pangda station			
m ± SE	15.93 ± 0.72**	15.68 ± 0.63**	17.85 ± 0.82**	20.77 ± 0.55**	19.61 ± 0.76**	22.00 ± 0.80**
d ± SE	-4.02 ± 0.54**	-	-	-0.52 ± 0.56	-	9.42 ± 2.67**
h ± SE	16.26 ± 2.35**	31.59 ± 5.24**	30.49 ± 5.42**	3.51 ± 1.25**	28.00 ± 5.60**	35.87 ± 6.36**
i ± SE	9.43 ± 1.66**	26.67 ± 5.07**	18.51 ± 5.41**	-	19.79 ± 5.60**	26.58 ± 6.21**
j ± SE	-	3.14 ± 0.41**	-	-	-	8.28 ± 2.71**
l ± SE	-	-39.16 ± 9.51**	-27.98 ± 9.63**	-	-29.18 ± 10.36**	-50.34 ± 11.45**
X^2 (df)	0.0363 (2)	0.2090 (1)	0.1025 (2)	5.1535 (3)	1.3840 (2)	-
Probability	0.9820	0.6475	0.9500	0.1609	0.5005	-

K = Kamuidainagon, H = Hondawase, A = Akatsukidainagon and E = Erimo variety.
SE is the standard error value.
*, ** Significantly different from zero at the P<0.05 and P<0.01 level, respectively.

Table 21 Generation means and joint-scaling test for number of pods per plant in azuki bean crosses, grown at three highland locations in 2006 growing season.

Generations	K x H	K x A	K x E	H x A	H x E	A x E
			Inthanon station			
P1 ± SE	7.26±0.49(50)b[1]	8.18±0.63(40)ab	7.83±0.55(40)c	11.53±0.60(49)a	10.55±0.69(44)bc	14.89±0.73(37)b
P2 ± SE	12.61±0.75(44)a	11.11±0.68(37)a	8.57±0.54(51)c	9.88±0.66 (42)a	8.88±0.57(60)c	9.63±0.57(63)b
F1 ± SE	8.21±0.97(14)b	10.65±1.14(17)a	13.83±1.19(12)a	11.47±1.15(15)a	17.30±1.11(23)a	19.27±1.63(11)a
F2 ± SE	9.81±0.60(83)ab	6.27±0.63(67)b	8.65±0.60(72)bc	10.49±0.62(97)a	13.71±0.85(79)ab	14.63±0.76(63)b
BC1±SE	8.50±0.98(22)b	8.92±1.34(13)ab	9.00±1.06(16)c	11.36±1.1 (22)a	15.50±1.55(20)a	13.64±1.61(11)b
BC2±SE	8.00±1.38(15)b	8.50±1.46(12)ab	11.80±1.13(20)ab	10.71±2.08(7)a	13.33±1.66(18)ab	11.13±1.44(15)b
Joint-scaling test						
A ± SE	1.53 ± 2.25	-0.98 ± 2.98	-3.66 ± 2.49	-0.27 ± 2.55	3.15 ± 3.36	-6.89 ± 3.69
B ± SE	-4.83 ± 3.03	-4.76 ± 3.21	1.20 ± 2.62	0.08 ± 4.36	0.48 ± 3.55	-6.64 ± 3.36
C ± SE	2.93 ± 3.22	-15.50 ± 3.51**	-9.45 ± 3.48**	-2.37 ± 3.51	0.80 ± 4.16	-4.53 ± 4.55
			Khunpae station			
P1 ± SE	15.97±0.60(70)b	17.47±0.78(53)c	17.71±0.78(56)c	20.56±0.94(50)c	19.97±0.84(67)a	23.36±1.00(56)abc
P2 ± SE	20.92±0.72(51)a	24.06±0.84(49)a	14.72±0.75(53)c	26.13±0.86(54)ab	21.54±0.93(67)a	13.46±0.70(70)d
F1 ± SE	22.54±1.87(13)a	18.69±1.28(16)bc	27.44±2.00(16)a	24.75±1.62(12)bc	25.17±1.46(29)a	27.08±1.80(13)ab
F2 ± SE	15.93±0.81(94)b	18.14±0.81(98)bc	17.11±0.85(102)c	24.59±0.84(80)bc	23.08±1.00(108)a	21.46±0.85(97)bc
BC1±SE	13.32±1.34(19)b	21.88±1.62(17)ab	20.16±1.81(19)bc	22.83±1.51(18)bc	22.24±2.17(17)a	26.80±2.53(10)a
BC2±SE	22.22±1.98(18)a	15.65±1.83(17)c	23.76±1.85(21)ab	29.50±3.69(4)a	24.91±2.04(22)a	19.04±1.68(23)c
Joint-scaling test						
A ± SE	-11.88 ± 3.32**	7.61 ± 3.57*	-4.84 ± 4.21	0.36 ± 3.56	-0.67 ± 4.65	3.17 ± 5.46
B ± SE	0.98 ± 4.43	-11.45 ± 3.97**	5.37 ± 4.28	8.12 ± 7.60	3.11 ± 4.43	-2.45 ± 3.87
C ± SE	-18.27 ± 5.03**	-6.34 ± 4.29	-18.87 ± 5.37**	2.16 ± 4.85	0.48 ± 5.10	-5.11± 5.10
			Pangda station			
P1 ± SE	15.59±0.66(70)b	15.58±0.72(77)d	19.15±0.89(66)bc	23.74±1.09(62)b	21.17±0.85(65)cd	25.25±1.02(60)ab
P2 ± SE	21.60±0.76(58)a	23.05±0.90(60)bc	17.92±0.80(78)c	25.11±1.08(66)b	18.41±0.74(58)d	19.64±0.87(76)b
F1 ± SE	20.67±1.44(15)a	27.71±1.28(28)ab	34.00±1.92(17)a	34.63±1.73(19)a	29.90±1.37(21)a	31.67±2.02(15)a
F2 ± SE	18.27±0.67(113)ab	20.62±0.85(112)cd	21.24±0.90(113)bc	24.26±0.92(105)b	23.41±0.86(104)bc	27.33±0.98(109)ab
BC1±SE	18.11±1.41(18)ab	23.06±1.36(31)bc	21.92±1.75(24)bc	21.90±1.95(20)b	31.32±1.68(19)a	29.64±2.77(11)ab
BC2±SE	21.28±1.70(18)a	31.09±2.57(11)a	24.10±1.58(30)b	31.25±3.26(8)a	25.88±2.01(16)b	25.52±1.88(25)ab
Joint-scaling test						
A ± SE	-0.03 ± 3.23	2.83 ± 3.09	-9.32 ± 4.09*	-14.57 ± 4.40**	11.56 ± 3.73**	2.36 ± 5.98
B ± SE	0.29 ± 3.76	11.42 ± 5.37*	-3.72 ± 3.79	2.76 ± 6.82	3.43 ± 4.30	-0.27 ± 4.35
C ± SE	-5.46 ± 4.07	-11.60 ± 4.40**	-20.12 ± 5.41**	-21.08 ± 5.28**	-5.74 ± 4.53	1.09 ± 5.79

K = Kamuidainagon, H = Hondawase, A = Akatsukidainagon and E = Erimo variety.
In parenthesis, is the number of plant.
[1] Means within columns followed by the same letter are not significantly different based on Duncan's Multiple Range Test (p=0.05).
SE is the standard error value.
*, ** Significantly different from zero at the P<0.05 and P<0.01 level, respectively.

Table 22 Estimation of genetic effects for number of pods per plant in azuki bean crosses, grown at three highland locations in 2006 growing season.

parameters	K x H	K x A	K x E	H x A	H x E	A x E
			Inthanon station			
m ± SE	9.94 ± 0.42**	6.57 ± 0.76**	10.38 ± 0.42**	10.64 ± 0.43**	9.78 ± 0.43**	12.08 ± 0.45**
d ± SE	-2.52 ± 0.43**	-	-	0.83 ± 0.44	0.89 ± 0.44*	2.60 ± 0.45**
h ± SE	-1.37 ± 0.93	8.46 ± 2.74**	5.21 ± 1.10**	0.38 ± 1.02	7.87 ± 1.05**	4.92 ± 1.23**
i ± SE	-	7.38 ± 1.93**	-	-	-	-
j ± SE	-	-	-	-	-	-
l ± SE	-	-	-	-	-	-
X^2 (df)	4.6929 (3)	0.4915 (3)	0.8019 (4)	0.4932 (3)	0.8807 (3)	6.1221 (3)
Probability	0.1957	0.9207	0.9381	0.9203	0.8300	0.1058
			Khunpae station			
m ± SE	18.48 ± 0.55**	19.32 ± 0.52**	18.58 ± 1.02**	23.43 ± 0.61**	20.80 ± 0.60**	18.30 ± 0.59**
d ± SE	-8.91 ± 2.39**	6.24 ± 2.44*	-	-2.84 ± 0.62**	-0.87 ± 0.61	5.00 ± 0.60**
h ± SE	-	-	19.18 ± 4.61**	1.93 ± 1.44	4.60 ± 1.40**	7.59 ± 1.47**
i ± SE	-	-	7.59 ± 2.98*	-	-	-
j ± SE	-6.43 ± 2.43**	9.53 ± 2.51**	-	-	-	-
l ± SE	-	-	-	-	-	-
X^2 (df)	1.3024 (3)	0.3483 (3)	0.9541 (3)	1.2301 (3)	0.5416 (3)	1.9063 (3)
Probability	0.7285	0.9507	0.8123	0.7457	0.9096	0.5920
			Pangda station			
m ± SE	18.46 ± 0.48**	20.62 ± 0.85**	24.23 ± 0.65**	27.56 ± 0.82**	23.41 ± 0.86**	22.49 ± 0.65**
d ± SE	-2.99 ± 0.49**	-4.59 ± 0.74**	-	-9.35 ± 3.82*	2.19 ± 0.69**	2.85 ± 0.65**
h ± SE	1.10 ± 1.19	34.24 ± 6.87**	14.10 ± 1.76**	8.89 ± 1.75**	30.84 ± 6.43**	9.48 ± 1.64**
i ± SE	-	25.85 ± 6.73**	-	-	20.73 ± 6.26**	-
j ± SE	-	-	-	-8.67 ± 3.87*	-	-
l ± SE	-	-40.09 ± 12.43**	-	-	-35.72 ± 11.41**	-
X^2 (df)	2.2688 (3)	0.3003 (1)	1.0859 (4)	0.8325 (2)	0.2525 (1)	0.1893 (3)
Probability	0.5185	0.5836	0.8965	0.6595	0.6153	0.9793

K = Kamuidainagon, H = Hondawase, A = Akatsukidainagon and E = Erimo variety.
SE is the standard error value.
*, ** Significantly different from zero at the P<0.05 and P<0.01 level, respectively.

in 2005, and K x H and K x E crosses showed significantly in 2006. For the l effect, only H x E cross showed significantly in the first year.

At Pangda station, m values ranged from 15.68-22.00 and 18.46-27.56 pods per plant in 2005 and 2006, respectively. The d effect for K x H and A x E crosses in the first year and all crosses (except K x E) in the second year was significantly observed. The h effect showed significantly in all crosses in both years (except the cross K x H in 2006). The i effect gave significantly for all crosses, except H x A cross in the first year and for two crosses, K x A and H x E in the second year. The j effect found in K x A and A x E crosses in the first year and H x A cross in the second year was significantly observed. For the l effect, it was found that four crosses, K x A, K x E, H x E and A x E in the first year and two crosses, K x E and A x E in the second year was significantly observed.

Results of joint-scaling test and genetic effect analysis indicated that non-additive gene effect (dominance and epistasis) was more important than additive gene effect in controlling number of pods per plant in azuki bean. The epistatic interaction showed predominantly of a duplicate type. These results are similar to the works of Kunkaew *et al.* (2006; 2007a).

4.3.5 Number of seeds per pod

Results of joint-scaling test for this trait are presented in Tables 23 and 25. Results showed that K x A cross fitted to the additive-dominance model for all locations in the first year. In the second year, K x H and H x A crosses fitted to the model at Inthanon, and K x A and H x E crosses fitted to the model at Khunpae station.

The estimation of gene effects for number of seeds per pod are presented in Tables 24 and 26. At Inthanon, m values ranged from 3.17-4.30 and 3.45-4.41 seeds per pod in 2005 and 2006, respectively. The d effect for all crosses was significant in both years (except K x H and H x A crosses in 2005, and A x E cross in 2006). The h effect for all crosses was significant in both years (except K x H and H x A in 2005, and K x A and K x E in 2006). The i effect gave significantly for K x E, H x E and A x E crosses in the first year and A x E cross in the second year. The j effect indicated that one cross, K x H and four crosses, K x A, K x E, H x A and A x E were significant in the first and second year, respectively. For the l, it was significantly observed in three crosses, K x H, H x E and A x E in the first year and one cross, A x E in the second year.

At Khunpae station, m values ranged from 4.17-5.00 and 3.67-4.53 seeds per pod in 2005 and 2006, respectively. The d effect showed significantly for K x A, K x E and A x E crosses in 2005, and K x A, H x A and H x E crosses in 2006. The h effect showed significantly for all crosses in the first year and three crosses, K x A, K x E and A x E in the second year. The i effect was found significantly for all crosses (except K x A) in the first year and two crosses, K x E and A x E, in the second year. The j effect was significantly observed in one cross, H x E, in the first year. For the l effect, it indicated that all crosses (except K x A and H x A) were significant in the first year.

At Pangda station, m values ranged from 3.94-4.78 and 4.36-5.17 seeds per pod in 2005 and 2006, respectively. The d effect showed significantly for H x E and A x E crosses in the first year and for K x A and K x E crosses in the second year. The h effect for K x H, K x A and K x E crosses in 2005, and K x A, K x E and A x E crosses in 2006 was significantly observed. The i effect showed significantly for K x H cross in 2005 and K x A and A x E crosses in 2006. The j effect was significantly observed in K x E cross in the first year and for all crosses (except K x H and H x A) in the second year. For the l effect, it showed significantly for one cross, K x H and two crosses (K x A and A x E) in the first year and second year, respectively.

Results of joint-scaling test and analysis of gene effect indicated that both additive and non-additive gene effects are important in controlling the number of seeds per pod in azuki bean. The negative additive gene effects indicating this effect was a decrease of the mean from mid-parent in this trait. In addition, the epistatic interaction showed predominantly of a duplicate type. These results are similar to the works reported by Kunkaew *et al.* (2006; 2007a).

Table 23 Generation means and joint-scaling test for number of seeds per pod in azuki bean crosses, grown at three highland locations in 2005 growing season.

Generations	K x H	K x A	K x E	H x A	H x E	A x E
			Inthanon station			
P1 ± SE	3.77±0.06(46)ab[1]	3.39±0.06(44)a	3.60±0.06(60)d	2.91±0.06(66)b	2.68±0.07(61)c	2.84±0.05(73)e
P2 ± SE	3.04±0.06(63)c	2.92±0.05(58)b	5.10±0.06(58)a	2.90±0.06(79)b	4.49±0.08(60)ab	4.92±0.07(54)a
F1 ± SE	3.57±0.09(7)b	3.60±0.11(13)a	4.85±0.11(19)b	3.12±0.10(25)ab	3.92±0.17(16)b	4.45±0.12(17)b
F2 ± SE	3.71±0.07(83)ab	3.49±0.05(94)a	4.19±0.07(93)c	3.22±0.08(105)ab	3.97±0.09(93)b	3.33±0.09(93)d
BC1±SE	3.87±0.14(13)ab	3.50±0.10(20)a	4.31±0.12(22)c	2.94±0.12(22)b	3.99±0.16(23)ab	3.76±0.19(12)c
BC2±SE	4.03±0.19(11)a	3.38±0.14(11)a	4.83±0.13(24)b	3.29±0.24(12)a	4.61±0.19(16)a	4.94±0.19(16)a
Joint-scaling test						
A ± SE	0.41 ± 0.29	0.02 ± 0.23	0.18 ± 0.26	-0.14 ± 0.27	1.39 ± 0.37**	0.23 ± 0.41
B ± SE	1.45 ± 0.40**	0.24 ± 0.31	-0.28 ± 0.29	0.57 ± 0.50	0.82 ± 0.43	0.51 ± 0.40
C ± SE	0.91 ± 0.36*	0.45 ± 0.31	-1.62 ± 0.36**	0.84 ± 0.40*	0.90 ± 0.50	-3.35 ± 0.44**
			Khunpae station			
P1 ± SE	4.19±0.07(42)b	4.43±0.07(48)a	4.29±0.07(53)e	3.87±0.05(69)b	3.90±0.06(66)d	3.91±0.05(64)c
P2 ± SE	3.77±0.06(54)c	3.91±0.06(62)b	6.00±0.08(62)a	3.86±0.05(73)b	6.11±0.07(45)a	6.26±0.07(52)a
F1 ± SE	4.60±0.11(14)a	4.40±0.14(12)a	5.53±0.17(18)bc	3.94±0.12(16)ab	5.67±0.20(11)ab	5.01±0.21(10)b
F2 ± SE	4.19±0.06(87)b	4.38±0.07(82)a	5.00±0.09(88)d	4.28±0.07(95)a	4.81±0.09(62)c	4.43±0.07(88)bc
BC1±SE	4.57±0.13(14)a	4.28±0.13(18)ab	5.07±0.16(21)cd	3.84±0.09(20)b	5.40±0.18(10)b	4.58±0.15(13)b
BC2±SE	4.57±0.11(21)a	4.27±0.19(12)ab	5.86±0.15(27)ab	4.00±0.16(17)b	5.77±0.18(14)ab	5.69±0.15(17)a
Joint-scaling test						
A ± SE	0.36 ± 0.29	-0.26 ± 0.30	0.32 ± 0.37	-0.12 ± 0.23	1.23 ± 0.43**	0.24 ± 0.37
B ± SE	0.78 ± 0.26**	0.24 ± 0.41	0.18 ± 0.36	0.19 ± 0.35	-0.26 ± 0.41	0.12 ± 0.37
C ± SE	-0.37 ± 0.34	0.39 ± 0.42	-1.35 ± 0.50**	1.50 ± 0.37**	-2.12 ± 0.55**	-2.48 ± 0.51**
			Pangda station			
P1 ± SE	4.39±0.06 (63)a	4.44±0.07(75)bc	4.14±0.07(71)c	4.15±0.06(74)a	4.11±0.05(51)c	4.27±0.07(72)d
P2 ± SE	4.15±0.05 (70)a	4.33±0.06(65)c	5.45±0.10(54)a	4.17±0.06(73)a	5.01±0.07(33)ab	5.35±0.08(61)a
F1 ± SE	4.63±0.10 (18)a	4.73±0.10(25)ab	4.95±0.13(30)ab	4.11±0.11(27)a	4.64±0.08(21)b	4.89±0.13(27)abc
F2 ± SE	4.45±0.06(109)a	4.43±0.07(109)bc	4.65±0.08(113)b	4.41±0.07(111)a	4.66±0.07(78)b	4.62±0.08(116)cd
BC1±SE	4.90±0.16 (9)a	4.40±0.12(28)bc	4.92±0.16(21)ab	4.15±0.11(27)a	4.32±0.11(19)c	4.67±0.16(17)bc
BC2±SE	4.54±0.13 (19)a	4.85±0.20(11)a	5.04±0.16(23)ab	4.39±0.15(25)a	5.13±0.12(18)a	5.23±0.16(24)ab
Joint-scaling test						
A ± SE	0.78 ± 0.33*	-0.37 ± 0.26	0.76 ± 0.36*	0.04 ± 0.25	-0.10 ± 0.25	0.18 ± 0.35
B ± SE	0.30 ± 0.29	0.63 ± 0.42	-0.31 ± 0.36	0.50 ± 0.32	0.61 ± 0.26*	0.22 ± 0.36
C ± SE	0.00 ± 0.32	-0.50 ± 0.36	-0.88 ± 0.42*	1.10 ± 0.36**	0.24 ± 0.33	-0.93 ± 0.41*

K = Kamuidainagon, H = Hondawase, A = Akatsukidainagon and E = Erimo variety.
In parenthesis, is the number of plant.
[1] Means within columns followed by the same letter are not significantly different based on Duncan's Multiple Range Test (p=0.05).
SE is the standard error value.
*, ** Significantly different from zero at the P<0.05 and P<0.01 level, respectively.

Table 24 Estimation of genetic effects for number of seeds per pod in azuki bean crosses, grown at three highland locations in 2005 growing season.

parameters	K x H	K x A	K x E	H x A	H x E	A x E
			Inthanon station			
m ± SE	3.87 ± 0.08**	3.17 ± 0.04**	4.30 ± 0.07**	3.22 ± 0.08**	3.97 ± 0.09**	3.33 ± 0.09**
d ± SE	-	0.23 ± 0.04**	-0.71 ± 0.05**	-0.35 ± 0.27	-0.85 ± 0.07**	-1.07 ± 0.06**
h ± SE	-	0.53 ± 0.09**	1.20 ± 0.26**	-0.20 ± 0.64	1.65 ± 0.63**	4.65 ± 0.66**
i ± SE	-	-	0.68 ± 0.19**	-0.41 ± 0.64	1.31 ± 0.60*	4.09 ± 0.65**
j ± SE	-0.37 ± 0.04**	-	-	-0.35 ± 0.27	-	-
l ± SE	-1.65 ± 0.37**	-	-	-0.02 ± 1.15	-3.53 ± 1.11**	-4.83 ± 1.16**
X^2 (df)	0.0175 (3)	2.5744 (3)	0.0139 (2)	-	0.0081 (1)	0.0018 (1)
Probability	0.9993	0.4620	0.9930	-	0.9282	0.9661
			Khunpae station			
m ± SE	4.19 ± 0.06**	4.17 ± 0.04**	5.00 ± 0.09**	4.18 ± 0.08**	4.81 ± 0.09**	4.43 ± 0.07**
d ± SE	-	0.25 ± 0.04**	-0.84 ± 0.06**	-	-	-1.16 ± 0.05**
h ± SE	2.13 ± 0.42**	0.28 ± 0.12*	2.24 ± 0.59**	-0.57 ± 0.29*	3.76 ± 0.65**	2.77 ± 0.55**
i ± SE	1.51 ± 0.42**	-	1.86 ± 0.57**	-0.63 ± 0.20**	3.09 ± 0.62**	2.85 ± 0.50**
j ± SE	-	-	-	-	1.11 ± 0.04**	-
l ± SE	-2.65 ± 0.77**	-	-2.36 ± 1.02*	-	-4.06 ± 1.16**	-3.21 ± 0.99**
X^2 (df)	0.0220 (2)	2.8476 (3)	0.0003 (1)	0.0120 (3)	0.0121 (1)	0.0002 (1)
Probability	0.9890	0.4157	0.9861	0.9996	0.9124	0.9887
			Pangda station			
m ± SE	4.45 ± 0.06**	4.36 ± 0.04**	4.78 ± 0.09**	4.41 ± 0.07**	3.94 ± 0.06**	4.75 ± 0.09**
d ± SE	-	0.03 ± 0.05	-	-0.24 ± 0.18	-0.62 ± 0.25*	-0.54 ± 0.06**
h ± SE	1.44 ± 0.47**	0.28 ± 0.10**	0.46 ± 0.15**	-0.60 ± 0.47	-	0.42 ± 0.32
i ± SE	1.08 ± 0.47*	-	0.28 ± 0.23	-0.56 ± 0.46	-	0.31 ± 0.22
j ± SE	-	-	0.65 ± 0.06**	-0.23 ± 0.19	0.29 ± 0.25	-
l ± SE	-2.16 ± 0.88*	-	-	0.01 ± 0.81	-	-
X^2 (df)	0.0205 (2)	6.3698 (3)	0.0134 (2)	-	0.1356 (3)	0.0114 (2)
Probability	0.9898	0.0949	0.9933	-	0.9872	0.9943

K = Kamuidainagon, H = Hondawase, A = Akatsukidainagon and E = Erimo variety.
SE is the standard error value.
*, ** Significantly different from zero at the P<0.05 and P<0.01 level, respectively.

Table 25 Generation means and joint-scaling test for number of seeds per pod in azuki bean crosses, grown at three highland locations in 2006 growing season.

Generations	K x H	K x A	K x E	H x A	H x E	A x E
			Inthanon station			
P1 ± SE	3.93±0.09(38)a[1]	3.83±0.12(39)b	3.89±0.12(41)c	3.15±0.09(55)b	2.79±0.11(54)c	3.27±0.07(56)b
P2 ± SE	3.20±0.08(41)b	3.14±0.09(53)cd	4.85±0.13(51)a	3.30±0.10(62)b	5.03±0.11(59)a	4.89±0.10(51)a
F1 ± SE	3.92±0.20(7)a	3.66±0.17(20)b	4.61±0.23(17)ab	3.68±0.19(18)ab	4.61±0.16(25)a	4.69±0.23(14)b
F2 ± SE	3.91±0.08(70)a	3.46±0.13(64)bc	4.12±0.12(69)bc	3.38±0.10(99)b	4.02±0.15(79)b	3.45±0.10(84)a
BC1±SE	4.04±0.13(22)a	2.88±0.25(13)d	3.78±0.32(8)c	3.30±0.18(22)b	3.91±0.23(21)b	5.12±0.25(10)a
BC2±SE	3.70±0.17(12)a	4.18±0.24(15)a	5.20±0.22(23)a	4.39±0.39(6)a	4.64±0.27(20)a	5.15±0.25(12)a
Joint-scaling test						
A ± SE	0.24 ± 0.34	-1.74 ± 0.54**	-0.93 ± 0.68	-0.24 ± 0.42	0.42 ± 0.50	2.29 ± 0.55**
B ± SE	0.28 ± 0.41	1.55 ± 0.51**	0.93 ± 0.51	1.78 ± 0.80*	-0.36 ± 0.57	0.72 ± 0.55
C ± SE	0.69 ± 0.52	-0.44 ± 0.63	-1.48 ± 0.70*	-0.30 ± 0.57	-0.97 ± 0.70	-3.73 ± 0.62**
			Khunpae station			
P1 ± SE	4.12±0.08(70)a	3.84±0.08(59)ab	3.92±0.10(64)d	3.27±0.09(67)b	3.51±0.08(72)d	3.36±0.09(72)d
P2 ± SE	3.13±0.08(60)b	3.56±0.06(72)b	5.41±0.11(55)a	3.47±0.08(76)b	5.39±0.10(68)a	5.24±0.10(68)a
F1 ± SE	4.06±0.13(20)a	4.22±0.13(18)a	5.17±0.14(23)ab	3.47±0.15(23)b	4.72±0.16(27)bc	4.55±0.21(16)bc
F2 ± SE	4.17±0.09(91)a	3.90±0.08(103)ab	4.53±0.10(102)c	4.00±0.10(102)ab	4.49±0.10(107)c	3.75±0.10(104)cd
BC1±SE	4.16±0.18(17)a	3.87±0.17(19)ab	4.94±0.19(19)b	3.34±0.15(25)b	4.28±0.19(20)c	4.52±0.25(14)b
BC2±SE	4.07±0.18(19)a	4.04±0.18(17)ab	5.45±0.19(26)a	4.49±0.52(4)a	5.15±0.21(22)ab	4.84±0.23(21)ab
Joint-scaling test						
A ± SE	0.15 ± 0.39	-0.32 ± 0.37	0.81 ± 0.42	-0.07 ± 0.35	0.33 ± 0.42	1.12 ± 0.55*
B ± SE	0.95 ± 0.39*	0.31 ± 0.39	0.33 ± 0.41	2.04 ± 1.05	0.18 ± 0.47	-0.12 ± 0.51
C ± SE	1.33 ± 0.46**	-0.23 ± 0.41	-1.54 ± 0.49**	2.32 ± 0.52**	-0.40 ± 0.52	-2.71 ± 0.60**
			Pangda station			
P1 ± SE	4.34±0.06(34)a	4.46±0.06(55)b	4.42±0.06(70)c	3.94±0.07(69)b	3.92±0.07(74)c	4.10±0.07(67)d
P2 ± SE	3.93±0.05(64)b	4.18±0.05(63)b	5.80±0.07(71)a	4.11±0.07(77)ab	5.86±0.07(69)a	5.74±0.07(64)a
F1 ± SE	4.24±0.09(18)a	4.26±0.07(24)b	5.46±0.12(26)a	4.39±0.12(26)ab	5.08±0.13(24)b	4.99±0.17(18)bc
F2 ± SE	4.51±0.05(104)a	4.39±0.06(97)b	4.96±0.07(112)b	4.48±0.08(114)ab	4.92±0.09(100)b	4.57±0.08(113)cd
BC1±SE	4.41±0.10(16)a	4.47±0.10(23)b	4.56±0.14(24)bc	4.23±0.15(24)ab	5.16±0.13(27)b	5.45±0.20(14)ab
BC2±SE	4.44±0.11(22)a	4.98±0.13(16)a	5.69±0.13(30)a	4.59±0.21(15)a	5.19±0.17(24)b	5.41±0.16(23)ab
Joint-scaling test						
A ± SE	0.25 ± 0.23	0.23 ± 0.22	-0.76 ± 0.31*	0.13 ± 0.34	1.33 ± 0.30**	1.81 ± 0.43**
B ± SE	0.71 ± 0.24**	1.53 ± 0.27**	0.12 ± 0.30	0.67 ± 0.43	-0.55 ± 0.38	0.09 ± 0.37
C ± SE	1.30 ± 0.29**	0.42 ± 0.28	-1.29 ± 0.38**	1.07 ± 0.41*	-0.27 ± 0.45	-1.55 ± 0.47**

K = Kamuidainagon, H = Hondawase, A = Akatsukidainagon and E = Erimo variety.
In parenthesis, is the number of plant.
[1] Means within columns followed by the same letter are not significantly different based on Duncan's Multiple Range Test (p=0.05).
SE is the standard error value.
*, ** Significantly different from zero at the P<0.05 and P<0.01 level, respectively.

Table 26 Estimation of genetic effects for number of seeds per pod in azuki bean crosses, grown at three highland locations in 2006 growing season.

parameters	K x H	K x A	K x E	H x A	H x E	A x E
			Inthanon station			
m ± SE	3.58 ± 0.06**	3.53 ± 0.07**	4.41 ± 0.08**	3.58 ± 0.09**	3.89 ± 0.07**	3.45 ± 0.10**
d ± SE	0.36 ± 0.06**	-1.30 ± 0.35**	-1.41 ± 0.38**	-1.09 ± 0.43*	-1.10 ± 0.08**	-
h ± SE	0.54 ± 0.15**	-	-	0.54 ± 0.18**	0.65 ± 0.16**	7.35 ± 0.84**
i ± SE	-	-	-	-	-	6.74 ± 0.80**
j ± SE	-	-1.65 ± 0.35**	-0.93 ± 0.39*	-1.01 ± 0.43*	-	0.81 ± 0.06**
l ± SE	-	-	-	-	-	-9.75 ± 1.53**
X^2 (df)	1.7668 (3)	0.0074 (3)	0.0317 (3)	0.0615 (2)	3.4320 (3)	0.0006 (1)
Probability	0.6221	0.9998	0.9985	0.9697	0.3296	0.9938
			Khunpae station			
m ± SE	4.17 ± 0.09**	3.69 ± 0.05**	4.53 ± 0.10**	3.67 ± 0.10**	4.45 ± 0.06**	3.75 ± 0.10**
d ± SE	0.10 ± 0.25	0.13 ± 0.05*	-	-0.31 ± 0.12**	-0.93 ± 0.06**	-
h ± SE	0.21 ± 0.64	0.49 ± 0.12**	3.18 ± 0.66**	-	0.25 ± 0.14	3.96 ± 0.80**
i ± SE	-0.23 ± 0.62	-	2.67 ± 0.66**	-	-	3.71 ± 0.79**
j ± SE	-0.40 ± 0.26	-	-	-	-	-
l ± SE	-0.86 ± 1.11	-	-3.81 ± 1.18**	-	-	-4.71 ± 1.48**
X^2 (df)	-	1.9008 (3)	0.2624 (2)	0.2341 (4)	1.8905 (3)	0.4226 (2)
Probability	-	0.5932	0.8770	0.9936	0.5954	0.8095
			Pangda station			
m ± SE	4.51 ± 0.05**	4.36 ± 0.06**	5.17 ± 0.05**	4.48 ± 0.08**	5.04 ± 0.05**	4.57 ± 0.08**
d ± SE	-0.03 ± 0.15	-0.51 ± 0.16**	-1.13 ± 0.19**	-0.36 ± 0.26	-	-
h ± SE	-0.24 ± 0.37	1.28 ± 0.41**	0.27 ± 0.11*	0.10 ± 0.61	0.22 ± 0.13	3.52 ± 0.62**
i ± SE	-0.35 ± 0.35	1.34 ± 0.40**	-	-0.27 ± 0.60	-	3.46 ± 0.59**
j ± SE	-0.23 ± 0.15	-0.65 ± 0.17**	-0.44 ± 0.20*	-0.27 ± 0.26	0.97 ± 0.05**	0.82 ± 0.05**
l ± SE	-0.61 ± 0.65	-3.09 ± 0.71**	-	-0.53 ± 1.10	-	-5.36 ± 1.11**
X^2 (df)	-	-	0.0159 (2)	-	0.0122 (3)	0.0001 (1)
Probability	-	-	0.9920	-	0.9996	0.9920

K = Kamuidainagon, H = Hondawase, A = Akatsukidainagon and E = Erimo variety.
SE is the standard error value.
*, ** Significantly different from zero at the P<0.05 and P<0.01 level, respectively.

4.3.6 100-seed weight

Results of joint-scaling test for this trait are presented in Tables 27 and 29. Results showed that only one cross of K x A fitted to additive-dominance model in 2005 at Inthanon. In 2006, one cross (H x E) at Inthanon, and two crosses (H x E and K x A) fitted to the model at Pangda.

The analysis of genetic effects of this trait is presented in Tables 28 and 30. At Inthanon, m values ranged from 15.18-19.72 and 15.15-21.48 g in 2005 and 2006, respectively. The d effect showed significantly for all crosses in both years (except, K x H and A x E in 2005, and K x A and A x E in 2006). The h effect gave significantly in two crosses, K x E and A x E and three crosses, K x E, H x E and A x E in the first and second year, respectively. The i effect showed significantly for K x E and A x E crosses in the first year and K x A, K x E and A x E crosses in the second year. The j effect revealed that H x A, H x E and A x E crosses were significant in the first year, and two crosses (H x A and A x E) were significant in the second year. For the l effect, significantly observed in three crosses (K x H, K x E and A x E) and all crosses (except H x A and H x E) in the first year and second year, respectively.

At Khunpae station, m values ranged from 14.64-19.74 and 11.73-16.29 g in 2005 and 2006, respectively. The d effect showed significantly for all crosses (except K x H) and three crosses (K x H, K x A and K x E) in the first and second year, respectively. The h and i effects were significant for all crosses in both years (except K x H, H x A in 2005 and H x E in 2006). The j effect showed significantly for K x H, K x E and H x A crosses in 2005 and for K x A, K x E and H x A crosses in 2006. For the l effect, it was significantly observed for all crosses in both years (except K x H and H x A crosses in the first year, and H x E cross in the second year).

At Pangda station, m values ranged from 12.17-17.07 and 10.02-15.27 g in 2005 and 2006, respectively. The d effect showed significantly for K x A, K x E and H x A crosses and all crosses (except K x H) in the first year and second year, respectively. The h and i effects suggested that all crosses were significant in both years, except H x A cross in the first year and K x A, H x A and H x E crosses in the second year. The j effect was significant in all crosses (except K x H and K x A) and for two crosses, K x H and K x E, in the first and second year, respectively. For the l effect, it was significantly observed for all crosses (except K x H and H x A) and two crosses (K x E and A x E) in the first year and second year, respectively.

Table 27 Generation means and joint-scaling test for 100-seed weight in azuki bean crosses, grown at three highland locations in 2005 growing season.

Generations	K x H	K x A	K x E	H x A	H x E	A x E
			Inthanon station			
P1 ± SE	20.79±0.28(38)a[1]	20.62±0.30(47)a	19.78±0.18(35)a	15.83±0.20(61)cd	14.00±0.20(36)c	18.28±0.17(65)a
P2 ± SE	15.17±0.25(68)b	17.70±0.26(59)c	14.64±0.11(67)d	19.02±0.18(67)a	14.27±0.14(57)c	14.37±0.16(65)d
F1 ± SE	18.39±0.63(8)a	18.98±0.52(12)b	18.18±0.21(21)b	16.81±0.34(29)bc	15.55±0.30(17)ab	16.17±0.29(19)c
F2 ± SE	19.21±0.34(79)a	19.63±0.25(103)ab	18.40±0.18(64)b	16.03±0.21(105)bcd	15.80±0.15(93)a	17.17±0.19(81)b
BC1±SE	20.47±0.57(13)a	19.71±0.47(24)ab	18.17±0.29(18)b	17.06±0.39(22)b	16.38±0.27(21)a	15.81±0.44(11)bc
BC2±SE	19.47±0.91(10)a	18.80±0.63(14)bc	15.98±0.26(24)c	15.19±0.52(14)d	15.07±0.35(16)b	15.96±0.37(19)c
Joint-scaling test						
A ± SE	1.77 ± 1.33	-0.17 ± 1.12	-1.61 ± 0.64*	1.48 ± 0.88	3.21 ± 0.65**	-2.82 ± 0.95**
B ± SE	5.38 ± 1.95**	0.92 ± 1.39	-0.86 ± 0.56	-5.45 ± 1.11**	0.31 ± 0.78	1.38 ± 0.81
C ± SE	4.11 ± 1.89*	2.26 ± 1.50	2.85 ± 0.85**	-4.34 ± 1.10**	3.81 ± 0.88**	3.71 ± 0.99**
			Khunpae station			
P1 ± SE	20.46±0.20(58)a	21.63±0.19(43)a	21.28±0.13(30)a	15.61±0.12(70)bc	15.50±0.09(66)a	17.35±0.13(54)a
P2 ± SE	15.38±0.22(66)d	17.34±0.15(62)c	12.59±0.09(53)f	17.33±0.14(76)a	12.54±0.10(58)d	12.78±0.11(65)d
F1 ± SE	18.31±0.35(14)c	19.32±0.31(12)b	16.01±0.17(12)d	16.20±0.24(20)b	14.03±0.26(13)c	14.64±0.29(11)c
F2 ± SE	19.50±0.23(87)b	19.74±0.22(75)b	19.24±0.22(22)b	15.35±0.14(103)bc	14.64±0.13(67)b	15.89±0.15(74)b
BC1±SE	19.60±0.46(16)b	19.21±0.45(12)b	17.55±0.22(12)c	16.25±0.23(21)b	14.13±0.23(16)bc	15.25±0.29(14)c
BC2±SE	19.00±0.42(22)bc	17.88±0.45(14)c	14.11±0.18(28)e	14.88±0.41(13)c	12.84±0.25(14)d	13.05±0.27(18)d
Joint-scaling test						
A ± SE	0.43 ± 1.01	-2.53 ± 0.97*	-2.18 ± 0.49**	0.69 ± 0.54	-1.27 ± 0.54*	-1.49 ± 0.66*
B ± SE	4.29 ± 0.93**	-0.89 ± 0.96	-0.38 ± 0.42	-3.77 ± 0.87**	-0.89 ± 0.58	-1.32 ± 0.62*
C ± SE	5.54 ± 1.21**	1.36 ± 1.08	11.08 ± 0.95**	-3.93 ± 0.77**	2.46 ± 0.73**	4.13 ± 0.84**
			Pangda station			
P1 ± SE	18.02±0.15(75)a	18.00±0.15(81)a	17.38±0.16(68)a	13.00±0.09(74)bcd	13.23±0.10(68)a	14.14±0.14(64)a
P2 ± SE	13.00±0.13(80)c	14.11±0.12(79)d	10.21±0.15(62)e	14.22±0.12(61)a	9.94±0.11(55)d	10.46±0.14(66)d
F1 ± SE	15.56±0.29(21)b	16.26±0.26(23)bc	13.68±0.25(28)c	13.30±0.18(29)bc	12.32±0.15(22)b	12.53±0.21(29)bc
F2 ± SE	17.26±0.18(113)a	16.60±0.15(100)b	15.65±0.28(114)b	12.82±0.12(109)cd	12.17±0.11(80)bc	13.25±0.13(116)b
BC1±SE	16.56±0.66(6)a	16.16±0.25(29)bc	14.19±0.34(23)c	13.73±0.26(18)b	11.70±0.19(22)bc	12.05±0.33(13)c
BC2±SE	15.58±0.51(13)b	15.12±0.40(13)c	11.61±0.15(28)d	12.82±0.22(26)d	11.44±0.21(18)c	11.82±0.29(22)c
Joint-scaling test						
A ± SE	-0.46 ± 1.37	-1.94 ± 0.58**	-2.67 ± 0.74**	1.16 ± 0.56*	-2.15 ± 0.41**	-2.57 ± 0.71**
B ± SE	2.60 ± 1.07*	-0.11 ± 0.86	-0.66 ± 0.41	-1.89 ± 0.50**	0.63 ± 0.46	0.64 ± 0.63
C ± SE	6.90 ± 0.94**	1.77 ± 0.83*	7.67 ± 1.24**	-2.55 ± 0.63**	0.86 ± 0.55	3.33 ± 0.70**

K = Kamuidainagon, H = Hondawase, A = Akatsukidainagon and E = Erimo variety.
In parenthesis, is the number of plant.
[1] Means within columns followed by the same letter are not significantly different based on Duncan's Multiple Range Test (p=0.05).
SE is the standard error value.
*, ** Significantly different from zero at the P<0.05 and P<0.01 level, respectively.

Table 28 Estimation of genetic effects for 100-seed weight in azuki bean crosses, grown at three highland locations in 2005 growing season.

parameters	K x H	K x A	K x E	H x A	H x E	A x E
			Inthanon station			
m ± SE	19.72 ± 0.38**	19.22 ± 0.19**	18.40 ± 0.18**	16.66 ± 0.13**	15.18 ± 0.10**	17.17 ± 0.19**
d ± SE	-	1.43 ± 0.19**	2.49 ± 0.12**	1.87 ± 0.65**	1.31 ± 0.44**	-
h ± SE	-	0.24 ± 0.45	-4.34 ± 1.07**	-	-	-5.31 ± 1.43**
i ± SE	-	-	-5.31 ± 1.05**	-	-	-5.15 ± 1.39**
j ± SE	-	-	-	3.46 ± 0.67**	1.45 ± 0.46**	-1.96 ± 0.12**
l ± SE	-6.41 ± 1.80**	-	7.78 ± 1.76**	-	-	6.60 ± 2.52**
X^2 (df)	0.9236 (4)	2.9504 (3)	0.0033 (1)	0.1295 (3)	0.2173 (3)	0.0006 (1)
Probability	0.9211	0.3993	0.9541	0.9880	0.9747	0.9804
			Khunpae station			
m ± SE	18.71 ± 0.13**	19.74 ± 0.22**	19.24 ± 0.22**	16.80 ± 0.07**	14.64 ± 0.13**	15.89 ± 0.15**
d ± SE	-	1.98 ± 0.16**	3.45 ± 0.29**	3.45 ± 0.29**	1.44 ± 0.09**	2.27 ± 0.10**
h ± SE	-	-4.94 ± 1.57**	-14.57 ± 1.07**	-	-4.62 ± 0.89**	-7.36 ± 1.03**
i ± SE	-	-4.78 ± 1.54**	-13.64 ± 1.05**	-	-4.63 ± 0.85**	-6.93 ± 0.98**
j ± SE	-2.54 ± 0.15**	-	-0.90 ± 0.30**	-0.90 ± 0.30**	-	-
l ± SE	-	8.20 ± 2.77**	16.21 ± 1.49**	-	6.80 ± 1.56**	9.74 ± 1.79**
X^2 (df)	0.1562 (4)	0.0142 (1)	-	0.5077 (3)	0.0010 (1)	0.0002 (1)
Probability	0.9971	0.9051	-	0.9172	0.9747	0.9887
			Pangda station			
m ± SE	17.07 ± 0.28**	16.60 ± 0.15**	15.65 ± 0.28**	13.10 ± 0.11**	12.17 ± 0.11**	13.25 ± 0.13**
d ± SE	-	1.77 ± 0.12**	2.58 ± 0.37**	0.91 ± 0.35*	-	-
h ± SE	-3.20 ± 0.73**	-3.62 ± 1.16**	-11.12 ± 1.37**	-	-1.64 ± 0.73*	-5.03 ± 1.05**
i ± SE	-3.21 ± 0.56**	-3.82 ± 1.12**	-11.00 ± 1.34**	0.53 ± 0.13**	-2.38 ± 0.71**	-5.26 ± 1.03**
j ± SE	-	-	-1.01 ± 0.39*	1.52 ± 0.35**	-1.65 ± 0.07**	-1.84 ± 0.10**
l ± SE	-	5.87 ± 2.06**	14.34 ± 1.94**	-	3.90 ± 1.25**	7.20 ± 1.90**
X^2 (df)	0.8510 (3)	0.0212 (1)	-	0.0094 (2)	0.0028 (1)	0.0023 (1)
Probability	0.8372	0.8842	-	0.9953	0.9578	0.9617

K = Kamuidainagon, H = Hondawase, A = Akatsukidainagon and E = Erimo variety.
SE is the standard error value.
*, ** Significantly different from zero at the P<0.05 and P<0.01 level, respectively.

Table 29 Generation means and joint-scaling test for 100-seed weight in azuki bean crosses, grown at three highland locations in 2006 growing season.

Generations	K x H	K x A	K x E	H x A	H x E	A x E
			Inthanon station			
P1 ± SE	22.54±0.33(43)a[1]	21.45±0.42(36)a	22.64±0.40(39)a	15.96±0.28(46)b	15.73±0.30(39)ab	18.82±0.24(46)a
P2 ± SE	14.12±0.30(52)c	18.47±0.38(44)bc	14.23±0.31(53)d	17.46±0.26(52)a	14.68±0.23(57)b	14.77±0.21(57)cd
F1 ± SE	19.60±0.62(12)b	21.72±0.53(21)a	17.37±0.29(17)c	15.67±0.55(13)b	16.39±0.32(29)a	15.44±0.47(9)c
F2 ± SE	21.33±0.45(72)ab	20.78±0.45(62)ab	19.79±0.41(63)b	15.53±0.25(91)b	15.50±0.27(76)ab	17.34±0.26(66)b
BC1±SE	23.86±0.43(22)a	19.62±0.87(11)abc	19.51±0.58(15)b	16.70±0.54(16)ab	16.06±0.46(20)ab	14.13±0.48(12)d
BC2±SE	19.26±1.01(15)b	18.17±0.86(15)c	14.22±0.66(24)d	13.32±0.84(7)c	15.03±0.50(19)ab	15.57±0.54(15)cd
Joint-scaling test						
A ± SE	5.59 ± 1.12**	-3.94 ± 1.88*	-0.98 ± 1.26	1.77 ± 1.24	-0.01 ± 1.02	-6.01 ± 1.09**
B ± SE	4.80 ± 2.14*	-3.86 ± 1.84*	-3.15 ± 1.39*	-6.50 ± 1.78**	-1.02 ± 1.08	0.92 ± 1.20
C ± SE	9.47 ± 2.24**	-0.23 ± 2.17	7.53 ± 1.81**	-2.65 ± 1.53	-1.21 ± 1.32	4.88 ± 1.45**
			Khunpae station			
P1 ± SE	16.86±0.23(72)a	16.94±0.19(47)a	17.80±0.17(51)a	11.76±0.16(64)b	12.33±0.12(58)a	12.92±0.17(66)a
P2 ± SE	12.25±0.20(61)d	13.25±0.16(73)c	10.85±0.15(59)d	13.58±0.17(72)a	11.04±0.11(71)c	10.52±0.14(70)b
F1 ± SE	15.74±0.33(21)ab	15.19±0.43(10)b	14.07±0.27(18)c	11.93±0.30(23)b	11.38±0.18(25)bc	10.83±0.25(16)b
F2 ± SE	16.29±0.28(98)ab	15.61±0.18(91)b	15.84±0.21(42)b	12.12±0.16(103)b	11.49±0.12(82)bc	12.35±0.17(105)a
BC1±SE	15.42±0.53(15)b	16.10±0.29(24)ab	13.95±0.29(17)c	11.53±0.31(23)bc	11.92±0.23(19)ab	10.99±0.41(12)b
BC2±SE	13.70±0.60(17)c	13.21±0.38(20)c	11.65±0.25(28)d	10.79±0.43(4)c	11.80±0.21(24)ab	10.68±0.34(21)b
Joint-scaling test						
A ± SE	-1.76 ± 1.14	0.08 ± 0.74	-3.97 ± 0.66**	-0.64 ± 0.71	0.12 ± 0.50	-1.77 ± 0.87*
B ± SE	-0.59 ± 1.26	-2.01 ± 0.89*	-1.62 ± 0.59**	-3.93 ± 0.93**	1.18 ± 0.47*	0.00 ± 0.73
C ± SE	4.56 ± 1.32**	1.89 ± 1.16	6.58 ± 1.01**	-0.72 ± 0.92	-0.18 ± 0.62	4.29 ± 0.86**
			Pangda station			
P1 ± SE	15.75±0.14(70)a	15.85±0.15(77)a	16.21±0.16(69)a	11.21±0.13(62)b	10.79±0.14(71)a	12.58±0.13(64)a
P2 ± SE	10.85±0.13(75)e	12.64±0.14(74)c	9.62±0.11(78)f	12.72±0.13(70)a	9.31±0.13(74)c	10.03±0.09(78)cd
F1 ± SE	13.03±0.23(16)d	14.46±0.26(22)b	12.94±0.28(23)c	11.77±0.22(25)b	10.53±0.18(33)ab	10.87±0.23(24)bc
F2 ± SE	15.26±0.16(111)ab	14.48±0.19(116)b	14.81±0.19(74)b	11.50±0.14(101)b	10.03±0.14(108)b	11.90±0.15(109)ab
BC1±SE	14.66±0.33(17)bc	14.90±0.29(33)b	12.28±0.29(23)d	11.65±0.27(19)b	10.56±0.26(25)ab	10.14±0.33(13)c
BC2±SE	13.81±0.32(22)cd	12.79±0.45(16)c	10.94±0.28(30)e	10.63±0.33(16)c	10.06±0.32(19)b	9.20±0.28(28)d
Joint-scaling test						
A ± SE	0.55 ± 0.72	-0.51 ± 0.65	-4.59 ± 0.67**	0.33 ± 0.60	-0.21 ± 0.56	-3.17 ± 0.71**
B ± SE	3.74 ± 0.69**	-1.52 ± 0.95	-0.66 ± 0.63	-3.23 ± 0.70**	0.28 ± 0.67	-2.49 ± 0.61**
C ± SE	8.37 ± 0.83**	0.53 ± 0.95	7.55 ± 0.97**	-1.46 ± 0.72*	-1.04 ± 0.70	3.24 ± 0.78**

K = Kamuidainagon, H = Hondawase, A = Akatsukidainagon and E = Erimo variety.
In parenthesis, is the number of plant.
[1] Means within columns followed by the same letter are not significantly different based on Duncan's Multiple Range Test (p=0.05).
SE is the standard error value.
*, ** Significantly different from zero at the P<0.05 and P<0.01 level, respectively.

Table 30 Estimation of genetic effects for 100-seed weight in azuki bean crosses, grown at three highland locations in 2006 growing season.

parameters	K x H	K x A	K x E	H x A	H x E	A x E
			Inthanon station			
m ± SE	21.48 ± 0.40**	19.87 ± 0.43**	19.79 ± 0.41**	15.77 ± 0.20**	15.15 ± 0.18**	17.34 ± 0.26**
d ± SE	4.29 ± 0.28**	-	4.42 ± 0.27**	3.38 ± 0.99**	0.55 ± 0.18**	-
h ± SE	-	-	-12.73 ± 2.44**	-	1.06 ± 0.35**	-11.32 ± 1.85**
i ± SE	-	-2.11 ± 0.60**	-11.67 ± 2.41**	-	-	-9.97 ± 1.78**
j ± SE	-	-	-	4.13 ± 1.01**	-	-2.03 ± 0.16**
l ± SE	-10.92 ± 1.89**	8.31 ± 2.62**	15.81 ± 3.96**	-	-	15.06 ± 3.23**
X^2 (df)	0.0610 (3)	0.3454 (3)	0.0281 (1)	0.1906 (3)	1.5156 (3)	0.0695 (1)
Probability	0.9960	0.9512	0.8668	0.9790	0.6786	0.7920
			Khunpae station			
m ± SE	16.29 ± 0.28**	15.61 ± 0.18**	15.84 ± 0.21**	12.12 ± 0.16**	11.73 ± 0.11**	12.35 ± 0.17**
d ± SE	2.19 ± 0.20**	2.89 ± 0.48**	2.30 ± 0.39**	-	-	-
h ± SE	-5.73 ± 1.98**	-3.73 ± 1.29**	-12.42 ± 1.17**	-4.60 ± 1.29**	-	-6.95 ± 1.26**
i ± SE	-6.91 ± 1.95**	-3.83 ± 1.21**	-12.17 ± 1.14**	-3.85 ± 1.24**	-	-6.06 ± 1.25**
j ± SE	-	1.05 ± 0.50*	-1.17 ± 0.40**	0.91 ± 0.12**	-	-
l ± SE	9.27 ± 3.47**	5.76 ± 2.24*	17.76 ± 1.84**	8.42 ± 2.32**	-0.60 ± 0.55	7.84 ± 2.29**
X^2 (df)	0.0095 (1)	-	-	0.0242 (1)	0.0859 (4)	0.2499 (2)
Probability	0.9223	-	-	0.8763	0.9991	0.8825
			Pangda station			
m ± SE	15.27 ± 0.18**	14.24 ± 0.10**	14.81 ± 0.19**	14.06 ± 0.19**	10.02 ± 0.09**	11.90 ± 0.15**
d ± SE	-	1.61 ± 0.10**	1.34 ± 0.40**	2.11 ± 0.53**	0.73 ± 0.09**	1.21 ± 0.11**
h ± SE	-4.47 ± 0.31**	0.16 ± 0.24	-12.79 ± 1.16**	-	0.39 ± 0.19*	-9.34 ± 1.08**
i ± SE	-4.20 ± 0.44**	-	-12.81 ± 1.12**	-	-	-8.91 ± 1.05**
j ± SE	-2.45 ± 0.09**	-	-1.96 ± 0.41**	0.50 ± 0.54	-	-
l ± SE	-	-	18.06 ± 1.88**	1.03 ± 0.87	-	14.57 ± 1.89**
X^2 (df)	0.0256 (2)	3.9629 (3)	-	0.0214 (2)	2.6671 (3)	0.0046 (1)
Probability	0.9872	0.2655	-	0.9893	0.4458	0.9459

K = Kamuidainagon, H = Hondawase, A = Akatsukidainagon and E = Erimo variety.
SE is the standard error value.
*, ** Significantly different from zero at the P<0.05 and P<0.01 level, respectively.

Results of joint-scaling test and analysis of gene effects indicated clearly that non-additive gene effects are more important in controlling of this 100-seed weight of azuki bean than additive gene effects. This non-additive gene effect was also affected by environmental conditions, especially at Khunpae and Pangda where epistasis (i, j and l) seemed to show greater effect than Inthanon station in both years. The results showed that both additive and non-additive gene effects were involved in controlling this trait which results are similar to the works reported by Kunkaew *et al.* (2006; 2007a). Almost additive gene effects are positive values, indicating that this gene effects increased the mean of seed size from mid-parent. In addition, the epistatic interaction showed predominantly of a duplicate type.

4.3.7 Seed yield per plant

Results of joint-scaling test for this trait are presented in Tables 31 and 33. Results showed that K x H and H x A crosses fitted to the additive-dominance model at Inthanon and Khunpae in 2005. In 2006, H x A and H x E crosses fitted to the model at Inthanon and Khunpae, and A x E cross fitted to the model at Pangda.

The results of genetic effects of seed yield per plant are presented in Tables 32 and 34. At Inthanon, m values ranged from 8.37-17.18 and 5.63-9.48 g per plant in 2005 and 2006, respectively. The d effect showed that K x A, H x A and A x E crosses and H x E cross were significant in the first year and second year, respectively. The h effect showed significantly for all crosses in both years, except K x H and H x A crosses in the second year. The i effect was significantly observed in two crosses, K x A and H x E in 2005. The j effect gave significantly for only one cross (A x E) in 2005. For the l effect, it was observed significantly for two crosses, K x A and H x E in 2005.

At Khunpae, m values ranged from 15.33-21.64 and 9.81-13.77 g per plant in 2005 and 2006, respectively. The d effect showed significantly for two crosses (K x A and A x E) and three crosses (K x A, H x A and H x E) in the first year and second year, respectively. The h effect gave significantly to all crosses in both years, except K x A and A x E crosses in 2005, and K x H in 2006. The i effect was observed significantly in two crosses (K x E and H x E) in 2005. The j effect showed significantly for K x A and A x E crosses and K x H, K x A and K x E crosses in the first and second year, respectively. The l effect gave significantly in two crosses, K x E and H x E in 2005.

At Pangda, m values ranged from 10.34-13.44 and 11.51-16.82 g per plant in 2005 and 2006, respectively. The d effect showed significantly for all crosses in both years, except K x A and H x A crosses in the first year, and K x H and K x E crosses in the second year. The h effect showed significantly for all crosses in both years, except K x H and K x E crosses in the second year. The i effect showed significantly for all crosses (except K x E) in the first year and K x A, K x E and H x E crosses in the second year. The j effect gave significantly for K x H, H x E and A x E crosses in the first year and all crosses (except A x E) in the second year. For the l effect, it was significantly observed for all crosses (except K x E) in the first year and K x A, K x E and H x E crosses in the second year.

For over-all estimating of genetic effects of these studied traits, it is important to investigate that dominance effects (h) are generally much higher than additive effect (d) for all traits, except 100-seed weight of azuki bean. This magnitude of gene effect was also observed in most crosses, all locations and both years. These similar results were reported in soybean (Kunta *et al*., 1997), azuki bean (Kunkaew *et al*., 2007a; 2007b) and in peanut (Jogloy *et al*., 1999) that dominance gene effects were always greater than additive gene effects if two diverse parents were crossed. In addition, epistatic interaction of additive x additive (i) as well as additive x dominance (j) and dominance x dominance (l) were integral components of the genetic formation of these traits. Hence, estimation and consideration of these gene effect components are so important for the manipulation of azuki bean breeding programme. As a consequence, if the higher magnitude of interaction of non-fixable gene effects were greater than fixable gene effects, it indicates that non-additive gene effects play the major role for controlling the traits. Such a condition, successful breeding methods will be those that accumulate the genes to form a specific genotype interacting in a favorable manner. A possible breeding programme is to do as a bi-parental or multiparental mating, followed by selection until desirable genotypes are observed. These breeding strategies are useful for exploitation of both fixable and non-fixable types of gene-action as recommended by many breeders (Hayman, 1958; Allard, 1960; Falconer, 1989; Kearsey and Pooni, 1996). This study also further demonstrated that the inheritance of seed yield per plant of azuki bean is quite affected by environmental factors, suggesting that an appropriate choice of the environments should be considered for improving on this trait.

Table 31 Generation means and joint-scaling test for seed yield per plant in azuki bean crosses, grown at three highland locations in 2005 growing season.

Generations	K x H	K x A	K x E	H x A	H x E	A x E
			Inthanon station			
P1 ± SE	8.52±0.43(47)c[1]	7.79±0.48(54)c	8.94±0.45(67)c	7.17±0.45(72)b	6.31±0.33(61)c	13.59±0.63(63)b
P2 ± SE	8.36±0.46(55)c	10.56±0.45(54)b	11.93±0.96(72)bc	12.16±0.63(75)a	9.62±0.48(56)c	10.61±0.52(66)b
F1 ± SE	18.62±1.51(5)a	14.37±1.27(6)a	24.45±1.99(20)a	11.88±0.96(28)a	20.05±1.47(6)ab	19.28±1.40(13)a
F2 ± SE	12.49±0.55(57)b	9.39±0.48(100)bc	13.59±0.94(100)bc	12.81±0.91(105)a	17.18±1.01(84)b	15.09±0.85(82)b
BC1±SE	12.91±1.15(10)b	11.46±1.00(16)b	17.20±1.61(23)b	11.54±1.18(22)a	22.64±1.85(12)a	12.50±1.79(6)b
BC2±SE	11.57±1.30(9)b	15.12±1.20(13)a	16.22±1.99(24)b	16.02±2.35(15)a	19.44±2.10(13)b	23.47±2.40(11)a
Joint-scaling test						
A ± SE	-1.32 ± 2.78	0.75 ± 2.41	1.01 ± 3.82	4.02 ± 2.58	18.92 ± 4.00**	-7.87 ± 3.89*
B ± SE	-3.84 ± 3.04	5.31 ± 2.75	-3.94 ± 4.55	8.00 ± 4.85	9.20 ± 4.48*	17.05 ± 5.04**
C ± SE	-4.16 ± 3.80	-9.53 ± 3.25**	-15.39 ± 5.56**	8.15 ± 4.19	12.69 ± 5.03*	-2.38 ± 4.49
			Khunpae station			
P1 ± SE	16.13±0.86(54)ab	16.37±0.58(49)b	15.58±0.67(53)c	15.05±0.57(69)b	16.11±0.82(70)b	21.13±0.66(51)b
P2 ± SE	14.68±0.85(55)b	17.72±0.60(50)b	15.52±0.64(64)c	16.70±0.65(69)ab	16.56±0.61(63)b	16.98±0.56(63)b
F1 ± SE	19.68±1.94(15)a	18.51±1.73(8)b	27.42±1.60(13)a	18.29±1.25(19)a	22.74±2.06(10)a	24.27±2.09(15)b
F2 ± SE	16.24±0.89(94)ab	18.07±0.67(68)b	16.73±0.75(88)c	16.73±0.73(105)ab	19.51±0.97(94)ab	19.62±0.94(93)b
BC1±SE	18.35±1.56(17)ab	24.59±1.39(12)a	20.27±1.30(20)b	18.40±1.60(16)ab	28.21±1.91(18)a	19.78±2.01(11)b
BC2±SE	18.44±1.90(22)ab	15.00±1.41(14)b	22.75±1.42(23)b	19.26±1.85(13)a	22.68±2.53(11)a	28.32±2.94(9)a
Joint-scaling test						
A ± SE	0.89 ± 3.77	14.31 ± 3.33**	-2.45 ± 3.12	3.46 ± 3.48	17.57 ± 4.43**	-5.83 ± 4.58
B ± SE	2.52 ± 4.34	-6.24 ± 3.36	2.55 ± 3.32	3.53 ± 3.97	6.06 ± 5.50	15.39 ± 6.27*
C ± SE	-5.19 ± 5.40	1.17 ± 4.47	-19.01 ± 4.47**	-1.43 ± 3.95	-0.10 ± 5.75	-8.15 ± 5.70
			Pangda station			
P1 ± SE	10.42±0.34(72)c	10.95±0.37(79)b	9.59±0.38(70)c	10.93±0.41(72)c	10.58±0.41(69)c	11.62±0.39(73)cd
P2 ± SE	10.82±0.32(69)c	11.88±0.40(70)b	8.42±0.42(57)c	12.52±0.45(67)bc	6.97±0.43(63)d	9.30±0.48(57)d
F1 ± SE	17.93±0.65(13)b	16.14±0.92(16)a	17.34±1.04(20)a	13.44±0.72(27)abc	14.60±0.77(20)ab	17.64±0.80(20)ab
F2 ± SE	11.39±0.39(113)c	11.82±0.39(101)b	12.56±0.50(106)b	12.03±0.48(113)bc	10.34±0.42(110)c	12.92±0.50(117)cd
BC1±SE	23.71±1.23(5)a	15.58±0.70(26)a	15.89±1.00(17)a	15.74±0.98(21)a	12.00±0.79(25)bc	20.70±1.43(10)a
BC2±SE	18.95±1.27(12)b	15.72±1.12(12)a	12.56±0.93(28)b	14.35±1.08(19)ab	15.35±1.16(12)a	15.04±1.26(17)bc
Joint-scaling test						
A ± SE	19.06 ± 2.56**	4.06 ± 1.71*	4.85 ± 2.29*	7.12 ± 2.13**	-1.18 ± 1.80	12.12 ± 3.00**
B ± SE	9.14 ± 2.64**	3.40 ± 2.46	-0.65 ± 2.18	2.74 ± 2.32	9.13 ± 2.48**	3.13 ± 2.69
C ± SE	-11.55 ± 2.09**	-7.82 ± 2.47**	-2.47 ± 2.95	-2.22 ± 2.49	-5.36 ± 2.37*	-4.51 ± 2.64

K = Kamuidainagon, H = Hondawase, A = Akatsukidainagon and E = Erimo variety.
In parenthesis, is the number of plant.
[1] Means within columns followed by the same letter are not significantly different based on Duncan's Multiple Range Test (p=0.05).
SE is the standard error value.
*, ** Significantly different from zero at the P<0.05 and P<0.01 level, respectively.

Table 32 Estimation of genetic effects for seed yield per plant in azuki bean crosses, grown at three highland locations in 2005 growing season.

parameters	K x H	K x A	K x E	H x A	H x E	A x E
			Inthanon station			
m ± SE	8.37 ± 0.31**	9.39 ± 0.48**	16.50 ± 0.68**	9.88 ± 0.38**	17.18 ± 1.01**	16.39 ± 0.65**
d ± SE	0.12 ± 0.31	-1.84 ± 0.41**	-	-2.54 ± 0.38**	-	-10.97 ± 3.02**
h ± SE	8.72 ± 0.95**	20.78 ± 3.88**	13.39 ± 1.78**	3.37 ± 0.93**	27.51 ± 6.91**	7.65 ± 1.30**
i ± SE	-	15.59 ± 3.66**	-	-	15.43 ± 6.91*	-
j ± SE	-	-	-	-	-	-12.46 ± 3.03**
l ± SE	-	-21.66 ± 7.03**	-	-	-43.56 ± 12.28**	-
X^2 (df)	2.0063 (3)	0.1728 (1)	1.1500 (4)	7.1631 (3)	0.9319 (2)	0.5292 (2)
Probability	0.5711	0.6776	0.8862	0.0668	0.6275	0.7675
			Khunpae station			
m ± SE	15.33 ± 0.58**	18.38 ± 0.47**	16.73 ± 0.75**	15.89 ± 0.42**	19.51 ± 0.97**	21.64 ± 1.29**
d ± SE	0.70 ± 0.59	9.59 ± 1.98**	-	-0.81 ± 0.43	-	-8.54 ± 3.56*
h ± SE	3.66 ± 1.50*	-	30.98 ± 4.89**	2.60 ± 1.09*	30.14 ± 7.46**	7.27 ± 4.88
i ± SE	-	-	19.10 ± 4.87**	-	23.73 ± 7.44**	1.55 ± 3.24
j ± SE	-	10.27 ± 2.02**	-	-	-	-10.61 ± 3.59**
l ± SE	-	-	-19.20 ± 8.90*	-	-47.36 ± 13.94**	-
X^2 (df)	2.2280 (3)	0.4346 (3)	0.1422 (2)	2.2583 (3)	0.6066 (2)	0.6401 (1)
Probability	0.5264	0.9330	0.9313	0.5205	0.7383	0.4236
			Pangda station			
m ± SE	11.39 ± 0.39**	11.82 ± 0.39**	13.44 ± 0.36**	12.03 ± 0.48**	10.34 ± 0.42**	12.92 ± 0.50**
d ± SE	4.76 ± 1.77*	-	1.14 ± 0.35**	-	-3.35 ± 1.40*	5.66 ± 1.91**
h ± SE	47.06 ± 3.92**	20.01 ± 3.08**	8.51 ± 0.93**	13.80 ± 3.51**	19.14 ± 3.38**	26.95 ± 4.39**
i ± SE	39.76 ± 3.86**	15.28 ± 3.07**	-	12.09 ± 3.50**	13.32 ± 3.28**	19.77 ± 4.31**
j ± SE	4.96 ± 1.78**	-	-	-	-5.15 ± 1.43**	4.50 ± 1.93*
l ± SE	-67.96 ± 7.37**	-22.75 ± 5.84**	-	-21.95 ± 6.35**	-21.27 ± 6.09**	-35.02 ± 8.07**
X^2 (df)	-	0.0392 (2)	0.3952 (3)	0.1729 (2)	-	-
Probability	-	0.9805	0.9412	0.9171	-	-

K = Kamuidainagon, H = Hondawase, A = Akatsukidainagon and E = Erimo variety.
SE is the standard error value.
*, ** Significantly different from zero at the P<0.05 and P<0.01 level, respectively.

Table 33 Generation means and joint-scaling test for seed yield per plant in azuki bean crosses, grown at three highland locations in 2006 growing season.

Generations	K x H	K x A	K x E	H x A	H x E	A x E
			Inthanon station			
P1 ± SE	6.70±0.48(49)ab[1]	5.85±0.42(26)b	7.81±0.65(37)ab	6.05±0.37(50)a	5.44±0.43(43)d	8.55±0.59(52)bc
P2 ± SE	5.78±0.47(53)ab	5.38±0.35(32)b	6.71±0.46(45)b	5.33±0.47(61)a	6.71±0.42(56)cd	6.83±0.49(63)c
F1 ± SE	6.32±0.91(14)ab	7.60±0.64(14)a	10.37±1.24(14)a	6.61±0.95(13)a	10.84±1.01(28)a	12.59±1.92(13)a
F2 ± SE	8.48±0.59(78)a	4.70±0.38(41)b	6.72±0.59(77)ab	5.42±0.41(100)a	8.88±0.71(79)ab	7.58±0.59(85)c
BC1±SE	8.17±0.94(22)ab	5.22±0.77(9)b	7.40±1.23(13)ab	6.68±0.88(21)a	8.40±1.23(22)abc	9.34±1.17(10)ab
BC2±SE	5.33±1.12(16)b	6.44±0.77(9)ab	9.08±1.16(19)ab	7.67±2.01(6)a	7.60±1.39(19)bc	9.74±1.09(13)bc
Joint-scaling test						
A ± SE	3.32 ± 2.14	-3.01 ± 1.72	-3.38 ± 2.82	0.70 ± 2.03	0.51 ± 2.70	-2.47 ± 3.08
B ± SE	-1.44 ± 2.46	-0.11 ± 1.71	1.09 ± 2.67	3.40 ± 4.15	-2.36 ± 2.99	0.06 ± 2.95
C ± SE	8.79 ± 3.05**	-7.64 ± 2.06**	-8.38 ± 3.50*	-2.92 ± 2.59	1.70 ± 3.52	-10.25 ± 4.58*
			Khunpae station			
P1 ± SE	11.18±0.49(63)ab	10.37±0.57(58)a	12.06±0.57(50)b	7.60±0.53(67)c	8.04±0.36(71)d	9.87±0.55(63)bc
P2 ± SE	8.15±0.51(61)b	10.93±0.57(65)a	8.46±0.44(55)c	11.82±0.61(68)ab	12.56±0.54(68)abc	7.61±0.41(69)c
F1 ± SE	13.24±1.57(9)a	12.31±0.98(13)a	18.98±1.15(12)a	11.06±1.24(17)bc	14.44±0.86(26)ab	13.80±1.08(16)a
F2 ± SE	10.63±0.57(97)ab	10.48±0.51(103)a	12.39±0.59(94)b	11.40±0.61(103)abc	11.60±0.54(108)bcd	9.61±0.48(102)bc
BC1±SE	8.89±1.14(17)ab	14.19±1.09(20)a	12.22±1.01(19)b	9.11±1.05(23)bc	10.13±1.20(16)cd	12.70±1.24(13)ab
BC2±SE	11.79±1.42(14)ab	10.60±1.41(12)a	14.41±1.13(23)b	14.82±3.15(4)a	15.28±1.31(17)a	11.17±1.04(20)abc
Joint-scaling test						
A ± SE	-6.65 ± 2.81*	5.70 ± 2.45*	-6.59 ± 2.40**	-0.44 ± 2.50	-2.21 ± 2.57	1.73 ± 2.76
B ± SE	2.18 ± 3.28	-2.05 ± 3.05	1.37 ± 2.58	6.77 ± 6.44	3.57 ± 2.80	0.93 ± 2.37
C ± SE	-3.32 ± 3.95	-3.99 ± 2.94	-8.92 ± 3.37**	4.07 ± 3.58	-3.08 ± 2.84	-6.62 ± 2.97*
			Pangda station			
P1 ± SE	12.88±0.55(56)a	11.62±0.48(71)d	14.36±0.64(61)bc	10.92±0.63(68)c	8.81±0.44(70)c	12.94±0.70(68)a
P2 ± SE	8.40±0.43(79)b	12.21±0.59(62)cd	9.87±0.48(78)d	12.75±0.61(66)bc	9.28±0.52(73)c	11.30±0.54(78)a
F1 ± SE	12.86±0.95(15)a	16.69±1.00(24)ab	23.59±1.13(18)a	20.23±1.21(22)a	17.71±0.95(22)a	17.53±1.67(17)a
F2 ± SE	12.64±0.52(111)a	13.45±0.63(112)bcd	16.83±0.69(99)b	12.88±0.68(111)bc	11.51±0.52(103)bc	15.06±0.68(113)a
BC1±SE	11.30±1.06(19)a	15.57±1.08(27)bc	12.84±1.20(24)c	10.19±1.20(21)c	18.06±1.06(20)a	16.85±1.73(14)a
BC2±SE	13.69±1.16(19)a	20.96±1.79(11)a	15.04±1.12(30)bc	17.24±2.12(11)ab	13.02±1.16(18)b	13.78±1.37(25)a
Joint-scaling test						
A ± SE	-3.14 ± 2.38	2.82 ± 2.43	-12.28 ± 2.73**	-10.76 ± 2.77**	9.60 ± 2.36**	3.23 ± 3.91
B ± SE	6.12 ± 2.54*	13.02 ± 3.77**	-3.39 ± 2.55	1.49 ± 4.45	-0.95 ± 2.56	-1.27 ± 3.26
C ± SE	3.54 ± 2.89	-3.44 ± 3.30	-4.12 ± 3.66	-12.61 ± 3.74**	-7.47 ± 2.89*	0.92 ± 4.40

K = Kamuidainagon, H = Hondawase, A = Akatsukidainagon and E = Erimo variety.
In parenthesis, is the number of plant.
[1] Means within columns followed by the same letter are not significantly different based on Duncan's Multiple Range Test (p=0.05).
SE is the standard error value.
*, ** Significantly different from zero at the P<0.05 and P<0.01 level, respectively.

Table 34 Estimation of genetic effects for seed yield per plant in azuki bean crosses, grown at three highland locations in 2006 growing season.

parameters	K x H	K x A	K x E	H x A	H x E	A x E
			Inthanon station			
m ± SE	8.48 ± 0.59**	6.00 ± 0.26**	8.25 ± 0.44**	5.63 ± 0.29**	6.09 ± 0.30**	9.48 ± 0.55**
d ± SE	2.84 ± 1.46	-	-	0.38 ± 0.29	-0.60 ± 0.30*	-
h ± SE	-6.83 ± 3.88	1.58 ± 0.63*	2.73 ± 1.14*	0.43 ± 0.74	4.86 ± 0.86**	4.46 ± 1.66**
i ± SE	-6.91 ± 3.76	-	-	-	-	-
j ± SE	2.38 ± 1.50	-	-	-	-	-
l ± SE	5.03 ± 6.60	-	-	-	-	-
X^2 (df)	-	0.5962 (4)	0.6434 (4)	2.9782 (3)	1.0878 (3)	0.7152 (4)
Probability	-	0.9634	0.9581	0.3950	0.7800	0.9494
			Khunpae station			
m ± SE	10.65 ± 0.43**	11.63 ± 0.41**	13.77 ± 0.40**	9.81 ± 0.39**	10.27 ± 0.31**	10.50 ± 0.61**
d ± SE	-	3.59 ± 1.80*	-	-2.19 ± 0.40**	-2.33 ± 0.32**	-
h ± SE	-	1.76 ± 0.96	8.15 ± 1.06**	2.11 ± 1.01*	3.72 ± 0.78**	7.49 ± 2.51**
i ± SE	-	-	-	-	-	2.20 ± 1.67
j ± SE	-1.51 ± 0.35**	3.87 ± 1.83*	-1.80 ± 0.36**	-	-	-
l ± SE	-	-	-	-	-	-
X^2 (df)	1.2326 (4)	0.2206 (2)	0.4819 (3)	2.5670 (3)	4.1129 (3)	0.6324 (3)
Probability	0.8727	0.8955	0.9228	0.4633	0.2495	0.8889
			Pangda station			
m ± SE	11.96 ± 0.34**	13.45 ± 0.63**	16.82 ± 0.61**	14.66 ± 0.54**	11.51 ± 0.52**	12.16 ± 0.43**
d ± SE	-	-5.39 ± 2.09*	-	-7.04 ± 2.45**	5.04 ± 1.57**	0.91 ± 0.43*
h ± SE	-	24.05 ± 4.99**	-	7.48 ± 1.16**	24.79 ± 3.89**	5.66 ± 1.19**
i ± SE	-	19.27 ± 4.88**	-11.48 ± 0.48**	-	16.12 ± 3.76**	-
j ± SE	-2.24 ± 0.35**	-5.10 ± 2.13*	-2.25 ± 0.40**	-6.13 ± 2.48*	5.28 ± 1.60**	-
l ± SE	-	-35.11 ± 9.00**	27.12 ± 4.49**	-	-24.78 ± 6.91**	-
X^2 (df)	0.6941 (4)	-	0.1735 (2)	0.6815 (2)	-	1.0425 (3)
Probability	0.9520	-	0.9169	0.7112	-	0.7909

K = Kamuidainagon, H = Hondawase, A = Akatsukidainagon and E = Erimo variety.
SE is the standard error value.
*, ** Significantly different from zero at the P<0.05 and P<0.01 level, respectively.

4.4 Heterosis

The evaluated values of heterosis (H) and heterobeltiosis (Hb) are shown in Tables 35 to 41 which indicated that each type of heterosis could be of either positive or negative values and might or might not be significantly different from zero. F1 hybrids exhibited positive and negative heterotic effects on seed yield per plant and yield components over their mid- and better-parents.

4.4.1 Plant height

In 2005, for plant height, it was found that H and Hb values averaged over locations were -13.50 to 42.38 percent and -15.64 to 37.38 percent, respectively. In the second year, H and Hb values averaged over locations were -18.07 to 20.40 percent and -27.28 to 15.72 percent, respectively. The H and Hb values gave differently from environment to environment. For example in 2005, at Khunpae station, K x E hybrid gave highest average positive of both mid-parent heterosis (H) and heterobeltiosis (Hb) which were 42.38 and 37.38 percent, respectively. In 2006, at Pangda station, H x E hybrid gave highest average positive mid-parent heterosis (20.40 percent) while this hybrid at Inthanon station gave the highest average positive heterobeltiosis (15.72 percent).

4.4.2 Number of nodes per plant

For number of nodes per plant, it was found that heterosis (H) and heterobeltiosis (Hb) values averaged over the test sites in 2005 ranged -2.01 to 26.61 percent and -9.06 to 19.73 percent, respectively. In 2006, H and Hb values averaged over the test sites were -4.79 to 25.31 percent and -7.82 to 22.15 percent, respectively. In the first year at Inthanon station, hybrid K x E and H x E gave the highest average positive H (26.61 percent) and heterobeltiosis (19.73 percent), respectively. In the second year, at Pangda station, hybrid H x A and A x E gave the highest resitive H (25.31 percent) and Hb (22.15 percent), respectively.

Table 35 Observed heterosis over mid-parent (H) and better-parent (Hb) values for plant height in azuki bean crosses, grown at three highland locations in two growing seasons, 2005 and 2006.

Locations	Crosses	2005		2006	
		H±SE	Hb±SE	H±SE	Hb±SE
Inthanon	K x H	9.67±1.16**	-0.74±1.18	-1.67±0.80*	-7.74±0.85**
	K x A	14.04±0.98**	1.28±1.01	-3.96±0.52**	-7.69±0.56**
	K x E	41.46±1.03**	36.84±1.09**	13.62±0.71**	10.17±0.77**
	H x A	-5.08±0.63**	-12.77±0.67**	-6.44±0.68**	-8.94±0.71**
	H x E	27.75±0.89**	22.28±0.96**	17.20±0.64**	15.72±0.70**
	A x E	26.53±1.10**	13.23±1.15**	-0.53±0.89	-8.22±0.93**
Khunpae	K x H	1.77±0.92	0.29±0.96	-11.42±0.89**	-11.84±0.93**
	K x A	5.92±0.71**	-1.26±0.75	0.36±0.88	-7.90±0.93**
	K x E	42.38±0.80**	37.38±0.85**	16.52±0.91**	15.30±1.00**
	H x A	6.14±0.71**	-0.03±0.76	-18.07±1.09**	-27.28±1.15**
	H x E	14.94±0.74**	13.25±0.79**	-0.05±0.71	-8.27±0.79**
	A x E	7.85±0.92**	-1.56±0.98	16.28±0.87**	12.37±0.92**
Pangda	K x H	-5.65±0.65**	-8.80±0.68**	-8.58±0.66**	-9.07±0.71**
	K x A	-13.05±0.68**	-15.64±0.73**	8.43±0.72**	-1.39±0.77
	K x E	9.62±0.82**	7.50±0.91**	12.29±0.93**	9.19±1.00**
	H x A	-3.59±0.48**	-6.12±0.56**	11.28±0.77**	3.02±0.83**
	H x E	5.25±0.82**	5.09±0.93**	20.40±0.79**	15.17±0.85**
	A x E	9.61±0.70**	7.44±0.73**	13.96±1.12**	13.65±1.18**

*, ** Significantly different from zero at the p<0.05 and p<0.01 level, respectively.

Table 36 Observed heterosis over mid-parent (H) and better-parent (Hb) values for number of nodes per plant in azuki bean crosses, grown at three highland locations in two growing seasons, 2005 and 2006.

Locations	Crosses	2005		2006	
		H±SE	Hb±SE	H±SE	Hb±SE
Inthanon	K x H	6.31±0.31**	-2.00±0.32**	4.44±0.31**	-2.22±0.34**
	K x A	12.77±0.30**	1.35±0.31**	-1.36±0.31**	-4.60±0.33**
	K x E	26.61±0.30**	19.15±0.32**	8.91±0.35**	5.47±0.37**
	H x A	2.63±0.21**	-2.68±0.23**	13.65±0.32**	8.39±0.34**
	H x E	21.79±0.35**	19.73±0.38**	7.64±0.30**	6.23±0.32**
	A x E	20.54±0.34**	14.01±0.35**	1.41±0.56*	-3.46±0.58**
Khunpae	K x H	-0.16±0.36	-3.70±0.39**	-4.79±0.39**	-7.25±0.42**
	K x A	12.09±0.31**	4.09±0.33**	5.72±0.34**	-3.63±0.36**
	K x E	23.60±0.34**	18.64±0.35**	14.47±0.36**	13.79±0.38**
	H x A	8.69±0.27**	7.05±0.29**	1.19±0.39**	-7.82±0.42**
	H x E	17.33±0.38**	15.61±0.39**	10.83±0.32**	5.66±0.34**
	A x E	6.00±0.33**	0.35±0.35	16.19±0.39**	3.34±0.42**
Pangda	K x H	11.37±0.19**	10.86±0.21**	11.05±0.33**	9.97±0.36**
	K x A	-2.01±0.32**	-9.06±0.34**	14.84±0.40**	5.51±0.43**
	K x E	21.41±0.32**	18.03±0.35**	23.92±0.40**	21.75±0.42**
	H x A	2.50±0.26**	0.31±0.30	24.89±0.37**	22.15±0.39**
	H x E	11.22±0.29**	11.14±0.32**	22.35±0.39**	18.98±0.41**
	A x E	17.01±0.30**	15.48±0.33**	25.31±0.46**	19.93±0.48**

*, ** Significantly different from zero at the p<0.05 and p<0.01 level, respectively.

4.4.3 Number of branches per plant

For the number of branches per plant, H and Hb values averaged over the test sites were -0.59 to 44.58 percent and -8.82 to 42.32 percent, respectively, in 2005. In 2006, averaged over the test sites were -1.39 to 44.17 percent for heterosis and -23.40 to 40.14 percent for heterobeltiosis. In 2005, at Inthanon station, hybrid H x E gave the highest positive heterosis (44.58 percent) and hybrid K x E gave the highest positive heterobeltiosis (42.32 percent) at Pangda station. In 2006, at Pangda station, hybrid H x E gave highest positive for H and Hb which were 44.17 and 41.14 percent, respectively.

4.4.4 Number of pods per plant

For the number of pods per plant, the values of H and Hb did not differ among locations and years. This trait almost gave positive values for both H and Hb. In the first year, average H and Hb ranged from 7.39 to 109.66 percent and -11.16 to 86.52 percent, respectively. In the second year, H and Hb ranged -17.33 to 83.41 percent and -34.88 to 77.53 percent, respectively. Hybrid K x H and K x E at Inthanon station gave highest positive for heterosis and heterobeltiosis which were 109.66 and 86.52 percent, respectively, in 2005. In 2006, at Pangda station, hybrid K x E gave highest both positive heterosis and heterobeltiosis which were 83.41 and 77.53 percent, respectively.

4.4.5Number of seeds per pod

For the number of seeds per pod in 2005, heterosis and heterobeltiosis values were -1.46 to 15.60 percent and -19.90 to 9.82 percent, respectively. In 2006, heterosis and heterobeltiosis values were -1.26 to 18.03 percent and -13.40 to 11.50 percent, respectively. In 2005, at Khunpae station, hybrid K x H gave highest both positive H and Hb which were 15.60 and 9.82 percent, respectively. In 2006, at Inthanon station, hybrid H x E gave highest positive H (18.03 percent) and H x A gave highest positive Hb (11.50 percent).

Table 37 Observed heterosis over mid-parent (H) and better-parent (Hb) values for number of branches per plant in azuki bean crosses, grown at three highland locations in two growing seasons, 2005 and 2006.

Locations	Crosses	2005		2006	
		H±SE	Hb±SE	H±SE	Hb±SE
Inthanon	K x H	38.99±0.33**	21.31±0.35**	-8.33±0.41**	-23.40±0.45**
	K x A	18.60±0.35**	1.93±0.36**	6.34±0.33**	0.61±0.36
	K x E	39.73±0.29**	34.80±0.33**	39.31±0.39**	31.14±0.41**
	H x A	13.24±0.25**	0.15±0.27	1.62±0.36**	1.03±0.38**
	H x E	44.58±0.33**	35.48±0.36**	29.91±0.33**	21.04±0.37**
	A x E	20.82±0.40**	5.45±0.43**	13.51±0.36**	-3.35±0.38**
Khunpae	K x H	0.72±0.38	-8.82±0.40**	-12.76±0.36**	-21.65±0.38**
	K x A	8.44±0.35**	-4.80±0.37**	13.45±0.38**	-0.73±0.43
	K x E	34.90±0.36**	30.04±0.39**	25.03±0.44**	21.68±0.46**
	H x A	13.96±0.29**	12.58±0.30**	-15.39±0.44**	-22.79±0.46**
	H x E	20.73±0.33**	11.14±0.35**	14.92±0.29**	12.62±0.33**
	A x E	9.57±0.43**	0.19±0.45	19.12±0.41**	0.81±0.44
Pangda	K x H	3.87±0.32**	0.76±0.34*	26.63±0.39**	20.50±0.41**
	K x A	-0.59±0.35	-4.29±0.37**	25.56±0.34**	10.62±0.39**
	K x E	42.87±0.32**	42.32±0.36**	37.33±0.47**	32.55±0.50**
	H x A	7.39±0.27**	4.85±0.31**	30.35±0.38**	27.30±0.41**
	H x E	15.20±0.35**	5.54±0.38**	44.17±0.39**	40.14±0.42**
	A x E	22.65±0.34**	14.56±0.36**	36.16±0.49**	25.41±0.52**

*, ** Significantly different from zero at the p<0.05 and p<0.01 level, respectively.

Table 38 Observed heterosis over mid-parent (H) and better-parent (Hb) values for number of pods per plant in azuki bean crosses, grown at three highland locations in two growing seasons, 2005 and 2006.

Locations	Crosses	2005		2006	
		H±SE	Hb±SE	H±SE	Hb±SE
Inthanon	K x H	109.66±2.18**	77.01±2.22**	-17.33±1.07**	-34.88±1.23**
	K x A	21.82±1.50**	-5.29±1.62**	10.43±1.23**	-4.15±1.33**
	K x E	103.37±2.06**	86.52±2.18**	68.76±1.25**	61.44±1.31**
	H x A	17.75±1.84**	-0.32±2.03	7.11±1.23**	-0.55±1.30
	H x E	39.71±1.67**	32.18±1.74**	78.13±1.19**	64.09±1.30**
	A x E	59.41±2.33**	29.82±2.50**	57.16±1.69**	29.42±1.79**
Khunpae	K x H	7.39±2.14**	-11.16±2.37**	22.18±1.93**	7.73±2.00**
	K x A	13.59±2.02**	-5.09±2.09*	-10.01±1.40**	-22.33±1.53**
	K x E	56.12±1.47**	43.67±1.56**	69.20±2.08**	54.89±2.15**
	H x A	21.40±2.17**	20.94±2.26**	6.02±1.74**	-5.28±1.83**
	H x E	20.93±2.86**	11.20±3.02**	21.29±1.59**	16.88±1.73**
	A x E	31.04±2.45**	12.64±2.61**	47.10±1.90**	15.93±2.06**
Pangda	K x H	39.35±1.06**	13.98±1.15**	11.14±1.52**	-4.34±1.62**
	K x A	29.36±1.32**	8.95±1.42**	43.47±1.40**	20.24±1.56**
	K x E	84.89±1.43**	75.23±1.54**	83.41±2.01**	77.53±2.12**
	H x A	15.96±1.42**	12.71±1.53**	41.79±1.89**	37.94±2.04**
	H x E	45.38±1.53**	21.81±1.61**	51.10±1.48**	41.27±1.61**
	A x E	51.43±1.35**	42.45±1.36**	41.07±2.12**	25.41±2.26**

*, ** Significantly different from zero at the p<0.05 and p<0.01 level, respectively.

Table 39 Observed heterosis over mid-parent (H) and better-parent (Hb) values for number of seeds per pod in azuki bean crosses, grown at three highland locations in two growing seasons, 2005 and 2006.

Locations	Crosses	2005		2006	
		H±SE	Hb±SE	H±SE	Hb±SE
Inthanon	K x H	4.67±0.10**	-5.53±0.11**	9.91±0.21**	-0.29±0.22
	K x A	13.89±0.11**	5.99±0.12**	5.12±0.19**	-4.30±0.21**
	K x E	11.40±0.11**	-5.02±0.12**	5.48±0.24**	-5.02±0.26**
	H x A	7.21±0.11**	7.04±0.12**	14.20±0.20**	11.50±0.21**
	H x E	9.25±0.18**	-12.84±0.19**	18.03±0.18**	-8.23±0.19**
	A x E	14.51±0.13**	-9.65±0.14**	14.99±0.24**	-4.04±0.25**
Khunpae	K x H	15.60±0.12**	9.82±0.13**	12.16±0.14**	-1.31±0.15**
	K x A	5.51±0.15**	-0.66±0.16**	14.17±0.14**	9.99±0.15**
	K x E	7.40±0.18**	-7.90±0.19**	10.85±0.16**	-4.41±0.18**
	H x A	2.07±0.13**	2.00±0.13**	3.10±0.16**	0.22±0.17
	H x E	13.35±0.21**	-7.20±0.22**	6.07±0.17**	-12.43±0.18**
	A x E	-1.46±0.21**	-19.90±0.22**	5.90±0.22**	-13.11±0.23**
Pangda	K x H	8.32±0.11**	5.32±0.12**	2.54±0.10**	-2.23±0.11**
	K x A	7.83±0.11**	6.57±0.13**	-1.26±0.08**	-4.38±0.09**
	K x E	3.15±0.14**	-9.20±0.16**	6.85±0.13**	-5.94±0.14**
	H x A	-1.10±0.12**	-1.43±0.13**	9.16±0.13**	6.90±0.14**
	H x E	1.70±0.09**	-7.45±0.11**	3.77±0.14**	-13.40±0.15**
	A x E	1.73±0.14**	-8.51±0.15**	1.41±0.17**	-13.06±0.18**

** Significantly different from zero at the p<0.01 level

4.4.6 100-seed weight

For 100-seed weight, there were few crosses (K x H, K x A and H x E) which gave the positive value for heterosis, but heterobeltiosis did not show in most hybrid crosses. In 2005, average heterosis and heterobeltiosis were -5.48 to 10.04 percent and -24.78 to 8.99 percent, respectively. In 2006, heterosis and heterobeltiosis ranged -8.05 to 8.84 percent and -23.27 to 4.18 percent, respectively. Hybrid H x E at Inthanon station gave highest both positive heterosis and heterobeltiosis in the first year which were 10.04 and 8.99 percent, respectively. In the second year, hybrid K x A and H x E gave highest both positive values of 8.84 and 4.18 percent, respectively.

4.4.7 Seed yield per plant

For seed yield per plant, it was found that most crosses gave high value of positive heterosis and heterobeltiosis. In the first year, heterosis and heterobeltiosis values ranged from 2.21 to 151.58 percent and -0.28 to 118.59 percent, respectively. In the second year, the value of heterosis and heterobeltiosis ranged from 1.29 to 95.78 percent and -6.47 to 90.83 percent, respectively. At Inthanon station, hybrid H x E and K x H gave highest positive heterosis and heterobeltiosis in 2005 which were 151.58 and 118.59 percent, respectively. At Pangda station in 2006, hybrid H x E gave highest both positive heterosis and heterobeltiosis of 95.78 and 90.83 percent, respectively.

For heterotic effect study on seed yield per plant and its yield components, it was found that both heterosis (H) and heterobeltiosis (Hb) were positive or negative values and might or might not be significantly different from zero. Most of F1 hybrids gave high values of H and Hb for seed yield per plant, number of branches per plant, number of pods per plant at Pangda station since environmental factors at this location, i.e., temperature, soil moisture and soil fertility were more favorable to promote F1's growth and development. At Inthanon station, only 100-seed weight showed high heterotic effect because temperature at this station was quite cool during grain-filling period and this factor is important for dry matter accumulation for seed yield. Heterozygous genotypes of F1 that showed high positive hybrid vigors of their traits to optimum environments were reported in many crops such as rice (Young and Virmani , 1990; Dwivedi *et al.*,1998), barley (Martinez and Foster, 1998), and soybean (Paschal and Wilcox, 1975; Kunta *et al.*, 1997). However, in specific case of experiment, Dwivedi *et al.* (1998) reported that F1 hybrids received from Indica x Indica and Japonica x Japonica showed better heterotic effects on seed yields when grown under stress conditions. These similar results were reported in pea crop by Sarawat *et al.* (1994). For studying of heterosis of seed yield per plant and yield components of azuki bean, it was found that heterotic effects for most traits were influenced greatly by environmental factors which resulted in varying of both H and Hb values from location to location and year to year. As well, heterotic values were also affected by genetic effects which play important roles in controlling of individual trait. More discussion of this genetic effects on heterotic values will be given in Chepter 5.

Table 40 Observed heterosis over mid-parent (H) and better-parent (Hb) values for 100-seed weight in azuki bean crosses, grown at three highland locations in two growing seasons, 2005 and 2006.

Locations	Crosses	2005		2006	
		H±SE	Hb±SE	H±SE	Hb±SE
Inthanon	K x H	2.29±0.66**	-11.54±0.69**	6.92±0.66**	-13.05±0.71**
	K x A	-0.91±0.56	-7.93±0.60**	8.84±0.60**	1.28±0.68
	K x E	5.64±0.23**	-8.08±0.28**	-5.76±0.38**	-23.27±0.49**
	H x A	-3.49±0.36**	-11.59±0.38**	-6.21±0.58**	-10.25±0.61**
	H x E	10.04±0.32**	8.99±0.33**	7.79±0.37**	4.18±0.44**
	A x E	-0.94±0.31**	-11.54±0.33**	-8.05±0.50**	-17.95±0.53**
Khunpae	K x H	2.19±0.38**	-10.48±0.40**	8.14±0.36**	-6.65±0.40**
	K x A	-0.82±0.33*	-10.65±0.36**	0.64±0.45	-10.33±0.47**
	K x E	-5.48±0.19**	-24.78±0.21**	-1.78±0.29**	-20.95±0.31**
	H x A	-1.63±0.26**	-6.52±0.28**	-5.89±0.33**	-12.19±0.35**
	H x E	0.05±0.26	-9.49±0.27**	-2.62±0.20**	-7.73±0.22**
	A x E	-2.82±0.30**	-15.62±0.32**	-7.58±0.27**	-16.16±0.30**
Pangda	K x H	0.33±0.30	-13.64±0.32**	-2.04±0.25**	-17.26±0.27**
	K x A	1.25±0.28**	-9.71±0.30**	1.47±0.28**	-8.81±0.30**
	K x E	-0.82±0.27**	-21.27±0.29**	0.16±0.29	-20.21±0.32**
	H x A	-2.28±0.20**	-6.46±0.22**	-1.61±0.24**	-7.46±0.25**
	H x E	6.37±0.16**	-6.87±0.18**	4.79±0.21**	-2.41±0.23**
	A x E	1.91±0.23**	-11.37±0.25**	-3.85±0.24**	-13.60±0.26**

*, ** Significantly different from zero at the $p<0.05$ and $p<0.01$ level, respectively.

Table 41 Observed heterosis over mid-parent (H) and better-parent (Hb) values for seed yield per plant in azuki bean crosses, grown at three highland locations in two growing seasons, 2005 and 2006.

Locations	Crosses	2005		2006	
		H±SE	Hb±SE	H±SE	Hb±SE
Inthanon	K x H	120.61±1.54**	118.59±1.57**	1.29±0.97	-5.66±1.03**
	K x A	56.53±1.31**	36.02±1.35**	35.46±0.70**	30.07±0.77**
	K x E	134.36±2.06**	104.99±2.21**	42.87±1.30**	32.80±1.40**
	H x A	2.21±1.04*	-0.28±1.15	16.06±1.00**	9.19±1.02**
	H x E	151.58±1.50**	108.31±1.55**	78.45±1.05**	61.54±1.09**
	A x E	59.36±1.46**	41.88±1.54**	63.79±1.96**	47.29±2.01**
Khunpae	K x H	27.76±2.03**	22.02±2.12**	37.04±1.61**	18.48±1.65**
	K x A	8.61±1.78**	4.45±1.84*	15.58±1.06**	12.61±1.13**
	K x E	76.39±1.66**	76.07±1.73**	85.00±1.21**	57.42±1.29**
	H x A	15.27±1.33**	9.58±1.41**	13.83±1.31**	-6.47±1.38**
	H x E	39.24±2.12**	37.32±2.15**	40.27±0.92**	15.03±1.02**
	A x E	27.38±2.13**	14.86±2.19**	57.94±1.13**	39.86±1.21**
Pangda	K x H	68.76±0.69**	65.65±0.73**	20.86±1.01**	-0.14±1.10
	K x A	41.42±0.96**	35.83±1.00**	40.09±1.07**	36.72±1.16**
	K x E	92.62±1.08**	80.84±1.10**	94.73±1.19**	64.28±1.29**
	H x A	14.61±0.78**	7.31±0.85**	70.91±1.29**	58.61±1.35**
	H x E	66.42±0.83**	38.02±0.87**	95.78±1.01**	90.83±1.08**
	A x E	68.63±0.86**	51.80±0.89**	44.63±1.72**	35.43±1.81**

*, ** Significantly different from zero at the p<0.05 and p<0.01 level, respectively.

4.5 Generation variance analysis

The analyzed values of generation variance components are shown in Tables 42 to 48. Results were analyzed from variance of six basic generations (P1, P2, F1, F2, BC1 and BC2) in order to identify the gene effects of additive, dominance or environment variances which are important for controlling seed yield and yield components of azuki bean.

4.5.1 Plant height

In 2005, additive variance (V_A) which was averaged from three test sites ranged from 1.68 to 18.33, averaged 7.37, dominance variance (V_D) was0.22-11.47, averaged 2.21, covariance (V_{AD}) was 0.03-5.75, averaged 1.56, and environment variance (V_E) was 5.53-15.04, averaged 9.89. Hybrid A x E, A x E and H x A gave highest V_A at Inthanon, Khunpae and Pangda stations for 18.33, 16.13 and 8.08, respectively while hybrid K x E, A x E and H x A gave V_D at Khunpae, Inthanon and Pangda stations for 11.47, 8.47 and 1.18, respectively. Hybrid K x H, K x E and A x E gave V_{AD} at Inthanon, Pangda and Khunpae stations for 5.75, 3.01 and 1.82, respectively. Hybrid K x E, H x E and A x E gave V_E at Inthanon, Pangda and Khunpae stations for 15.04, 13.26 and 12.45, respectively.

In 2006, additive variance (V_A) which was averaged from three test sites ranged from 2.94 to 21.34, averaged 7.44, dominance variance (V_D) was 0.06-6.31, averaged 1.49, covariance (V_{AD}) was 0.11-5.91, averaged 1.79, and environment variance (V_E) was 3.22-19.04, averaged 11.26. Hybrid K x E, K x E and H x A gave highest V_A at Pangda, Khunpae and Inthanon stations for 21.34, 10.52 and 10.29, respectively while hybrid H x E, H x A and H x E gave V_D at Pangda, Khunpae and Inthanon stations for 6.31, 4.53 and 1.85, respectively. Hybrid H x E, H x A and H x E gave V_{AD} at Pangda, Khunpae and Inthanon stations for 5.91, 3.04 and 2.35, respectively, and hybrid A x E, K x E and K x H gave V_E at Pangda, Khunpae and Inthanon stations for 19.04, 18.22 and 8.41, respectively.

4.5.2 Number of nodes per plant

In 2005, additive variance (V_A) which was averaged from three test sites ranged from 0.41 to 1.94, averaged 0.90, dominance variance (V_D) was 0.00-0.31, averaged 0.13, covariance (V_{AD}) was 0.02-0.43, averaged 0.16, and environment variance (V_E) was 0.68-

2.02, averaged 1.46. Hybrid K x E gave highest V_A at all locations, Inthanon, Khunpae and Pangda stations, for 1.94, 1.61 and 1.48, respectively while hybrid K x A, K x E and K x E gave V_D at Khunpae, Inthanon and Pangda stations for 0.31, 0.25 and 0.19, respectively. Hybrid K x H, K x E and K x E gave V_{AD} at Pangda, Khunpae and Inthanon stations for 0.43, 0.33 and 0.17, respectively, and hybrid K x E, K x H and A x E gave V_E at Pangda, Khunpae and Inthanon stations for 2.02, 1.82 and 1.69, respectively.

In 2006, additive variance (V_A) which was averaged from three test sites ranged from 0.61 to 1.73, averaged 1.20, dominance variance (V_D) was 0.01-1.14, averaged 0.23, covariance (V_{AD}) was 0.03-0.61, averaged 0.23, and environment variance (V_E) was 1.22-3.25, averaged 2.28. Hybrid K x E, H x E and K x A gave highest V_A at Pangda, Inthanon and Khunpae stations for 1.73, 1.59 and 1.54, respectively while hybrid A x E, K x E and H x E gave V_D at Pangda, Inthanon and Khunpae stations for 1.14, 0.56 and 0.22, respectively. Hybrid K x H, K x A and A x E gave V_{AD} at Pangda, Khunpae and Inthanon stations for 0.61, 0.46 and 0.41, respectively, and hybrid K x A, A x E and K x E gave V_E at Pangda, Inthanon and Khunpae stations for 3.25, 2.63 and 2.60, respectively.

4.5.3 Number of branches per plant

In 2005, additive variance (V_A) which was averaged from three test sites ranged from 0.61 to 3.01, averaged 1.21, dominance variance (V_D) was 0.05-0.33, averaged 0.17, covariance (V_{AD}) was 0.02-0.78, averaged 0.29, and environment variance (V_E) was 1.17-2.67, averaged 1.91. Hybrid K x E, K x H and H x A gave highest V_A at Inthanon, Pangda and Khunpae stations for 3.01, 1.63 and 1.55, respectively while hybrid H x E, A x E and H x E gave V_D at Inthanon, Khunpae and Pangda stations for 0.33, 0.32 and 0.29, respectively. Hybrid H x E, A x E and K x E gave V_{AD} at Khunpae, Pangda and Inthanon stations for 0.78, 0.71 and 0.61, respectively, and hybrid A x E, A x E and H x E gave V_E at Inthanon, Khunpae and Pangda stations for 2.67, 2.52 and 2.47, respectively.

In 2006, additive variance (V_A) which was averaged from three test sites ranged from 0.37 to 2.64, averaged 1.20, dominance variance (V_D) was 0.01-2.39, averaged 0.27, covariance (V_{AD}) was 0.10-1.10, averaged 0.25, and environment variance (V_E) was 1.56-3.58, averaged 2.48. Hybrid A x E, K x E and H x E gave highest V_A at Khunpae, Pangda and Inthanon stations for 2.64, 2.43 and 1.26, respectively while hybrid H x E, A x E and H x E gave V_D at Khunpae, Pangda and Inthanon stations for 2.39, 0.42 and 0.10, respectively. Hybrid K x E, K x H and K x H gave V_{AD} at Pangda, Khunpae and Inthanon

Table 42 Generation variance analysis for plant height in azuki bean crosses, grown at three highland locations in two growing seasons, 2005 and 2006.

Locations	Crosses	2005				2006			
		VA	VD	VAD	VE	VA	VD	VAD	VE
Inthanon	K x H	2.83	3.81	5.75	6.05	4.30	0.43	0.24	8.41
	K x A	4.77	0.28	0.42	9.09	3.10	0.13	1.44	3.22
	K x E	12.18	2.17	0.85	15.04	3.78	0.84	1.98	6.12
	H x A	10.89	1.70	4.40	8.84	10.29	0.70	1.71	7.47
	H x E	8.32	0.69	0.03	14.15	6.08	1.85	2.35	7.76
	A x E	18.33	8.47	2.14	14.82	3.06	0.06	1.26	7.61
	Average	**9.55**	**2.85**	**2.27**	**11.33**	**5.10**	**0.67**	**1.50**	**6.77**
Khunpae	K x H	5.53	1.11	1.72	10.16	2.94	2.14	1.82	9.89
	K x A	3.30	0.44	0.86	5.53	4.40	0.27	0.77	14.32
	K x E	4.41	11.47	0.64	9.15	10.52	3.69	0.11	15.78
	H x A	5.43	2.63	0.61	8.53	7.98	4.53	3.04	18.22
	H x E	6.46	1.51	1.51	7.50	8.64	1.77	2.98	13.64
	A x E	16.13	1.94	1.82	12.45	8.26	1.08	2.28	11.62
	Average	**6.88**	**3.18**	**1.19**	**8.89**	**7.12**	**2.25**	**1.83**	**13.91**
Pangda	K x H	1.68	0.22	0.11	5.66	7.88	0.21	0.71	6.80
	K x A	7.13	0.96	0.44	8.15	5.51	0.51	0.40	10.75
	K x E	4.57	0.35	3.01	12.94	21.34	1.17	5.91	15.53
	H x A	8.08	1.18	1.83	7.54	9.60	0.66	3.21	12.13
	H x E	7.10	0.34	0.11	13.26	8.41	6.31	0.98	14.38
	A x E	5.50	0.52	1.85	9.14	7.82	0.55	1.05	19.04
	Average	**5.68**	**0.60**	**1.23**	**9.45**	**10.09**	**1.57**	**2.04**	**13.11**
Average for all sites		***7.37***	***2.21***	***1.56***	***9.89***	***7.44***	***1.49***	***1.79***	***11.26***

Table 43 Generation variance analysis for number of nodes per plant in azuki bean crosses, grown at three highland locations in two growing seasons, 2005 and 2006.

Locations	Crosses	2005				2006			
		VA	VD	VAD	VE	VA	VD	VAD	VE
Inthanon	K x H	0.41	0.07	0.11	0.68	0.83	0.25	0.14	1.22
	K x A	0.59	0.15	0.15	0.94	1.38	0.01	0.11	1.32
	K x E	1.94	0.25	0.17	1.35	0.61	0.56	0.04	1.36
	H x A	0.55	0.10	0.15	0.89	0.91	0.04	0.19	1.94
	H x E	0.52	0.08	0.16	1.73	1.59	0.07	0.03	1.83
	A x E	1.18	0.23	0.06	1.69	1.25	0.18	0.41	2.63
	Average	**0.87**	**0.15**	**0.13**	**1.21**	**1.10**	**0.19**	**0.15**	**1.72**
Khunpae	K x H	0.99	0.10	0.07	1.82	0.68	0.10	0.06	2.23
	K x A	0.42	0.31	0.02	1.28	1.54	0.02	0.46	1.84
	K x E	1.61	0.18	0.33	1.60	1.01	0.02	0.23	2.60
	H x A	0.59	0.09	0.04	1.32	-	-	-	-
	H x E	1.32	0.03	0.19	1.61	0.90	0.22	0.13	2.41
	A x E	0.48	0.25	0.13	1.44	1.26	0.04	0.23	2.01
	Average	**0.90**	**0.16**	**0.13**	**1.51**	**1.08**	**0.08**	**0.22**	**2.22**
Pangda	K x H	0.50	0.08	0.43	0.80	1.70	0.03	0.61	1.73
	K x A	0.54	0.00	0.29	1.64	1.56	0.06	0.40	3.25
	K x E	1.48	0.19	0.12	2.02	1.73	0.21	0.19	3.18
	H x A	0.92	0.09	0.09	1.77	1.63	0.22	0.34	2.82
	H x E	1.24	0.04	0.34	1.87	1.04	0.69	0.18	3.21
	A x E	0.94	0.07	0.10	1.89	0.78	1.14	0.13	3.15
	Average	**0.94**	**0.08**	**0.23**	**1.67**	**1.41**	**0.39**	**0.31**	**2.89**
Average for all sites		***0.90***	***0.13***	***0.16***	***1.46***	***1.20***	***0.23***	***0.23***	***2.28***

Table 44 Generation variance analysis for number of branches per plant in azuki bean crosses, grown at three highland locations in two growing seasons, 2005 and 2006.

Locations	Crosses	2005				2006			
		VA	VD	VAD	VE	VA	VD	VAD	VE
Inthanon	K x H	0.99	0.16	0.11	1.33	0.75	0.08	0.29	1.95
	K x A	1.04	0.25	0.02	1.61	0.59	0.03	0.20	1.56
	K x E	3.01	0.27	0.61	1.70	0.52	0.05	0.07	1.57
	H x A	0.81	0.12	0.52	1.17	0.37	0.01	0.10	1.18
	H x E	1.65	0.33	0.34	2.36	1.26	0.10	0.13	2.43
	A x E	1.09	0.14	0.19	2.67	1.06	0.03	0.13	1.57
	Average	**1.43**	**0.21**	**0.30**	**1.81**	**0.76**	**0.05**	**0.15**	**1.71**
Khunpae	K x H	1.45	0.13	0.54	1.56	0.68	0.06	0.47	2.13
	K x A	0.71	0.05	0.15	1.71	1.64	0.07	0.26	2.99
	K x E	0.61	0.24	0.04	1.97	1.58	0.33	0.14	2.82
	H x A	1.55	0.02	0.15	1.49	-	-	-	-
	H x E	1.27	0.23	0.78	1.47	1.04	2.39	0.05	2.67
	A x E	1.21	0.32	0.12	2.52	2.64	0.06	0.18	2.74
	Average	**1.13**	**0.17**	**0.30**	**1.79**	**1.52**	**0.58**	**0.22**	**2.67**
Pangda	K x H	1.63	0.20	0.05	1.73	1.36	0.17	0.27	2.55
	K x A	1.09	0.10	0.19	1.93	0.48	0.34	0.17	2.79
	K x E	1.41	0.02	0.07	2.34	2.43	0.01	1.10	2.91
	H x A	0.61	0.13	0.23	2.00	1.35	0.02	0.26	3.34
	H x E	0.81	0.29	0.31	2.47	1.49	0.38	0.28	3.40
	A x E	0.79	0.11	0.71	2.27	1.16	0.42	0.10	3.58
	Average	**1.06**	**0.14**	**0.26**	**2.12**	**1.38**	**0.22**	**0.36**	**3.10**
Average for all sites		***1.21***	***0.17***	***0.29***	***1.91***	***1.20***	***0.27***	***0.25***	***2.48***

stations for 1.10, 0.47 and 0.29, respectively, and hybrid A x E, K x A and H x E gave V_E at Pangda, Khunpae and Inthanon stations for 3.58, 2.99 and 2.43, respectively.

4.5.4 Number of pods per plant

In 2005, additive variance (V_A) which was averaged from three test sites ranged from 6.55 to 82.45, averaged 37.32, dominance variance (V_D) was 0.10-22.36, averaged 5.35, covariance (V_{AD}) was 0.14-27.88, averaged 7.65, and environment variance (V_E) was 13.79-72.06, averaged 41.45. Hybrid A x E gave highest V_A at all locations, Inthanon, Khunpae and Pangda stations for 82.45, 62.09 and 41.94, respectively while hybrid H x E, H x A and H x A gave V_D at Khunpae, Inthanon and Pangda stations for 22.36, 17.11 and 12.66, respectively. Hybrid A x E gave V_{AD} at all locations, Inthanon, Khunpae and Pangda stations for 27.88, 22.87 and 8.96, respectively, and hybrid H x E, H x A and H x A gave V_E at Khunpae, Inthanon and Pangda stations for 72.06, 69.90 and 45.24, respectively.

In 2006, additive variance (V_A) which was averaged from three test sites ranged from 3.44 to 44.57, averaged 21.10, dominance variance (V_D) was 0.17-17.29, averaged 5.90, covariance (V_{AD}) was 0.32-18.15, averaged 4.60, and environment variance (V_E) was 14.72-69.24, averaged 36.58. Hybrid H x E, A x E and H x A gave highest V_A at Khunpae, Pangda and Inthanon stations for 44.57, 38.43 and 18.88, respectively while hybrid K x E, H x E and A x E gave V_D at Khunpae, Inthanon and Pangda stations for 17.29, 17.17 and 7.10, respectively. Hybrid K x H, K x H and K x E gave V_{AD} at Khunpae, Pangda and Inthanon stations for 18.15, 8.05 and 3.89, respectively, and hybrid H x A, H x E and A x E gave V_E at Pangda, Khunpae and Inthanon stations for 69.24, 55.75 and 23.06, respectively.

4.5.5 Number of seeds per pod

In 2005, additive variance (V_A) which was averaged from three test sites ranged from 0.11 to 0.47, averaged 0.23, dominance variance (V_D) was 0.00-0.07, averaged 0.02, covariance (V_{AD}) was 0.00-0.19, averaged 0.06, and environment variance (V_E) was 0.14-0.43, averaged 0.27. Hybrid H x A, A x E and H x A gave highest V_A at Inthanon, Pangda and Khunpae stations for 0.47, 0.28 and 0.21, respectively while hybrid K x E, A x E and H x A gave V_D at Khunpae, Inthanon and Pangda stations for 0.07, 0.05 and 0.02, respectively. Hybrid H x A gave V_{AD} at all locations, Inthanon, Khunpae and

Pangda stations for 0.19, 0.15 and 0.12, respectively, and hybrid K x E, K x E and H x E gave V_E at Pangda, Khunpae and Inthanon stations for 0.43, 0.42 and 0.42, respectively.

In 2006, additive variance (V_A) which was averaged from three test sites ranged from 0.09 to 1.05, averaged 0.31, dominance variance (V_D) was 0.01-0.21, averaged 0.07, covariance (V_{AD}) was 0.00-0.26, averaged 0.08, and environment variance (V_E) was 0.15-0.78, averaged 0.45. Hybrid H x E, H x A and H x E gave highest V_A at Inthanon, Khunpae and Pangda stations for 1.05, 0.49 and 0.35, respectively while hybrid A x E, H x A and H x E gave V_D at Khunpae, Pangda and Inthanon stations for 0.21, 0.10 and 0.09, respectively. Hybrid H x A, H x E and H x E gave V_{AD} at Khunpae, Inthanon and Pangda stations for 0.26, 0.17 and 0.13, respectively, and hybrid K x E, A x E and A x E gave V_E at Inthanon, Khunpae and Pangda stations for 0.78, 0.65 and 0.40, respectively.

4.5.6 100-seed weight

In 2005, additive variance (V_A) which was averaged from three test sites ranged from 0.35 to 5.40, averaged 1.32, dominance variance (V_D) was 0.01-0.76, averaged 0.15, covariance (V_{AD}) was 0.01-2.05, averaged 0.28, and environment variance (V_E) was 0.44-3.77, averaged 1.57. Hybrid K x H gave highest V_A at all locations, Inthanon, Khunpae and Pangda stations for 5.40, 2.38 and 1.33, respectively while hybrid K x H, K x A and K x A gave V_D at Pangda, Inthanon and Khunpae stations for 0.76, 0.72 and 0.50, respectively. Hybrid K x H, H x A and K x H gave V_{AD} at Inthanon, Khunpae and Pangda stations for 2.05, 0.55 and 0.38, respectively, and hybrid K x A, K x H and K x H gave V_E at Inthanon, Khunpae and Pangda stations for 3.77, 2.41 and 1.60, respectively.

In 2006, additive variance (V_A) which was averaged from three test sites ranged from 0.34 to 9.74, averaged 2.57, dominance variance (V_D) was 0.02-0.79, averaged 0.18, covariance (V_{AD}) was 0.06-5.60, averaged 0.83, and environment variance (V_E) was 0.81-6.23, averaged 2.36. Hybrid K x H, K x H and K x A gave highest V_A at Inthanon, Khunpae and Pangda stations for 9.74, 4.43 and 2.79, respectively while hybrid K x A, K x H and H x E gave V_D at Inthanon, Khunpae and Pangda stations for 0.79, 0.18 and 0.13, respectively. Hybrid K x H, K x H and A x E gave V_{AD} at Inthanon, Khunpae and Pangda stations for 5.60, 0.96 and 0.36, respectively, and hybrid K x A, K x H and K x A gave V_E at Inthanon, Khunpae and Pangda stations for 6.23, 2.81 and 1.51, respectively.

Table 45 Generation variance analysis for number of pods per plant in azuki bean crosses, grown at three highland locations in two growing seasons, 2005 and 2006.

Locations	Crosses	2005				2006			
		VA	VD	VAD	VE	VA	VD	VAD	VE
Inthanon	K x H	9.29	1.71	6.88	16.56	10.19	3.20	3.75	16.67
	K x A	25.63	4.63	2.17	27.26	3.44	4.45	1.07	18.30
	K x E	29.40	13.17	4.99	53.08	8.84	2.61	3.89	14.72
	H x A	76.66	17.11	13.18	69.90	18.88	0.19	1.90	18.70
	H x E	21.02	0.10	0.14	27.56	17.39	17.17	0.85	22.94
	A x E	82.45	0.43	27.88	59.42	12.50	0.58	1.23	23.06
	Average	**40.74**	**6.19**	**9.21**	**42.30**	**11.87**	**4.70**	**2.12**	**19.07**
Khunpae	K x H	38.21	3.87	13.78	57.19	18.93	10.42	18.15	32.27
	K x A	13.73	1.55	0.51	30.73	28.25	5.57	6.13	31.04
	K x E	40.89	1.29	6.61	27.34	14.20	17.29	4.98	42.73
	H x A	52.21	0.69	2.94	61.38	18.37	0.17	6.56	38.41
	H x E	57.83	22.36	11.08	72.06	44.57	7.55	5.64	55.75
	A x E	62.09	7.95	22.83	70.68	12.04	14.07	0.32	44.18
	Average	**44.16**	**6.29**	**9.63**	**53.23**	**22.73**	**9.18**	**6.96**	**40.73**
Pangda	K x H	6.55	0.62	1.52	13.79	15.28	4.54	8.05	31.62
	K x A	17.37	0.78	2.98	25.72	30.76	4.77	7.81	44.72
	K x E	38.81	3.24	3.28	29.30	35.57	1.81	0.91	54.69
	H x A	29.56	12.66	6.44	45.24	17.91	2.14	4.45	69.24
	H x E	28.15	1.78	1.45	30.51	34.33	2.64	5.24	39.33
	A x E	41.94	2.41	8.96	28.45	38.43	7.10	1.94	60.09
	Average	**27.06**	**3.58**	**4.11**	**28.84**	**28.71**	**3.83**	**4.73**	**49.95**
Average for all sites		***37.32***	***5.35***	***7.65***	***41.45***	***21.10***	***5.90***	***4.60***	***36.58***

Table 46 Generation variance analysis for number of seeds per pod in azuki bean crosses, grown at three highland locations in two growing seasons, 2005 and 2006.

Locations	Crosses	2005				2006			
		VA	VD	VAD	VE	VA	VD	VAD	VE
Inthanon	K x H	0.28	0.03	0.09	0.16	0.12	0.02	0.00	0.29
	K x A	0.13	0.00	0.02	0.14	0.41	0.09	0.01	0.53
	K x E	0.24	0.01	0.05	0.22	0.28	0.02	0.13	0.78
	H x A	0.47	0.02	0.19	0.25	0.39	0.05	0.09	0.56
	H x E	0.24	0.04	0.01	0.42	1.05	0.09	0.17	0.67
	A x E	0.45	0.05	0.07	0.23	0.28	0.01	0.06	0.52
	Average	**0.30**	**0.03**	**0.07**	**0.24**	**0.42**	**0.05**	**0.08**	**0.56**
Khunpae	K x H	0.11	0.01	0.01	0.19	0.35	0.02	0.03	0.38
	K x A	0.17	0.03	0.07	0.24	0.12	0.16	0.01	0.32
	K x E	0.19	0.07	0.04	0.42	0.24	0.11	0.09	0.58
	H x A	0.21	0.01	0.15	0.20	0.49	0.09	0.26	0.49
	H x E	0.16	0.01	0.05	0.30	0.42	0.05	0.15	0.60
	A x E	0.12	0.01	0.04	0.27	0.25	0.21	0.11	0.65
	Average	**0.16**	**0.02**	**0.06**	**0.27**	**0.31**	**0.11**	**0.11**	**0.50**
Pangda	K x H	0.13	0.00	0.06	0.21	0.09	0.01	0.05	0.15
	K x A	0.22	0.00	0.03	0.30	0.15	0.01	0.02	0.17
	K x E	0.27	0.01	0.02	0.43	0.16	0.09	0.03	0.32
	H x A	0.21	0.02	0.12	0.30	0.21	0.10	0.04	0.38
	H x E	0.21	0.01	0.00	0.14	0.35	0.03	0.13	0.38
	A x E	0.28	0.01	0.10	0.38	0.27	0.03	0.02	0.40
	Average	**0.22**	**0.01**	**0.06**	**0.29**	**0.21**	**0.05**	**0.05**	**0.30**
Average for all sites		***0.23***	***0.02***	***0.06***	***0.27***	***0.31***	***0.07***	***0.08***	***0.45***

Table 47 Generation variance analysis for 100-seed weight in azuki bean crosses, grown at three highland locations in two growing seasons, 2005 and 2006.

Locations	Crosses	2005				2006			
		VA	VD	VAD	VE	VA	VD	VAD	VE
Inthanon	K x H	5.40	0.04	2.05	3.53	9.74	0.18	5.60	4.69
	K x A	2.01	0.72	0.09	3.77	5.49	0.79	1.34	6.23
	K x E	1.01	0.03	0.05	0.99	5.75	0.67	2.76	4.24
	H x A	1.66	0.10	0.18	2.67	1.75	0.18	0.14	3.70
	H x E	0.77	0.03	0.22	1.35	2.23	0.21	0.28	3.22
	A x E	1.30	0.05	0.22	1.69	1.92	0.16	0.85	2.45
	Average	**2.03**	**0.16**	**0.47**	**2.33**	**4.48**	**0.37**	**1.83**	**4.09**
Khunpae	K x H	2.38	0.01	0.18	2.41	4.43	0.18	0.96	2.81
	K x A	1.65	0.50	0.20	1.32	1.27	0.05	0.46	1.78
	K x E	0.60	0.02	0.19	0.44	0.44	0.09	0.18	1.30
	H x A	0.79	0.10	0.55	1.18	-	-	-	-
	H x E	0.35	0.03	0.01	0.68	0.34	0.04	0.06	0.81
	A x E	0.68	0.02	0.08	0.88	1.45	0.10	0.17	1.37
	Average	**1.08**	**0.11**	**0.20**	**1.15**	**1.59**	**0.09**	**0.37**	**1.61**
Pangda	K x H	1.33	0.76	0.38	1.60	1.83	0.02	0.18	1.14
	K x A	0.74	0.05	0.18	1.51	2.79	0.08	0.27	1.51
	K x E	-	-	-	-	1.33	0.03	0.18	1.44
	H x A	0.74	0.07	0.03	0.81	0.65	0.09	0.16	1.13
	H x E	0.35	0.01	0.01	0.59	0.84	0.13	0.13	1.23
	A x E	0.67	0.05	0.18	1.25	1.47	0.02	0.36	1.02
	Average	**1.41**	**0.39**	**0.31**	**2.89**	**1.49**	**0.06**	**0.21**	**1.25**
Average for all sites		***1.32***	***0.15***	***0.28***	***1.57***	***2.57***	***0.18***	***0.83***	***2.36***

4.5.7 Seed yield per plant

In 2005, additive variance (V_A) which was averaged from three test sites ranged from 2.95 to 72.96, averaged 23.74, dominance variance (V_D) was 0.27-14.20, averaged 3.03, covariance (V_{AD}) was 0.28-26.34, averaged 7.81, and environment variance (V_E) was 7.10-52.86, averaged 21.94. Hybrid H x E, A x E and K x E gave highest V_A at Inthanon, Khunpae and Pangda stations for 72.96, 43.81 and 12.43, respectively while hybrid K x E, H x E and A x E gave V_D at Inthanon, Khunpae and Pangda stations for 14.20, 10.88 and 5.99, respectively. Hybrid H x A, K x H and K x H gave V_{AD} at Inthanon, Khunpae and Pangda stations for 26.34, 18.98 and 5.90, respectively, and hybrid K x E, K x H and K x E gave V_E at Inthanon, Khunpae and Pangda stations for 52.86, 45.32 and 13.81, respectively.

In 2006, additive variance (V_A) which was averaged from three test sites ranged from 1.08 to 22.90, averaged 12.49, dominance variance (V_D) was 0.04-15.40, averaged 2.87, covariance (V_{AD}) was 0.01-9.54, averaged 2.66, and environment variance (V_E) was 4.75-34.23, averaged 18.13. Hybrid K x E, K x E and K x H gave highest V_A at Pangda, Khunpae and Inthanon stations for 22.90, 15.84 and 14.83, respectively while hybrid H x E, H x E and K x E gave V_D at Inthanon, Khunpae and Pangda stations for 15.40, 4.19 and 2.77, respectively. Hybrid H x A, H x A and K x E gave V_{AD} at Pangda, Khunpae and Inthanon stations for 9.54, 7.12 and 2.96, respectively, and hybrid A x E, H x A and H x E gave V_E at Pangda, Khunpae and Inthanon stations for 34.23, 23.41 and 15.49, respectively.

Estimations of variance components which were calculated from variances of six basic generations (P1, P2, F1, F2, BC1 and BC2) indicated that additive (V_A), dominance (V_D) and environmental variance (V_E) were obviously involved in controlling seed yield and its yield components in azuki bean. Results of both combining ability study and generation mean analysis study as shown in Tables 4-5 and Tables 7 to 34 evidently supported these genetic effects for controlling these traits. It was found that additive variance (V_A) was generally higher than dominance variance (V_D) in most traits, indicating that variation of additive gene effects was higher than dominance effects. Ram *et al.* (1989) reported on 100-seed weight of rice that dominance genetic variance was negative and considered equal zero because additive and epistatic genetic variance were more important in controlling this trait. In contrast, results reported by González-García *et al.* (2000) indicated that dominance genetic variance had greater effect than additive genetic variance for controlling the erect glandular trichome density in diploid alfafa crop.

In most traits, environmental variance (V_E) was higher than additive and dominance variance, indicating that variation of traits were highly due to environmental effect. However, estimates of genetic variances ($V_G = V_A + V_D$) for some traits did not differ from environmental variance. These results were different from the work of Pacheco *et al.* (1995) who reported that flag leaf lamine area and flag leaf lamine green duration of wheat showed higher environmental variance than genetic variance.

The phenotypic variances (V_P) which were comprised of additive, dominance and environmental variance ($V_P = V_A + V_D + V_E$) of each trait was different from location to location and from year to year. For seed yield per plant, it was found that phenotypic variance of this trait at Khunpae was higher than Inthanon and Pangda station in the first year but in the second year, this phenotypic variance at Pangda was higher than Inthanon and Khunpae station (Table 48). Results of this study could be concluded that both genetic variance and phenotypic variance were influenced by environmental factors, especially temperature and moisture factors, which varied from location to location and year to year due to differences in altitudes. These similar results were reported by Martinez and Foster (1998), Pacheco *et al.* (1995) and González-García *et al.* (2000) who reported in barley, wheat and alfalfa, respectively.

Table 48 Generation variance analysis for seed yield per plant in azuki bean crosses, grown at three highland locations in two growing seasons, 2005 and 2006.

Locations	Crosses	2005				2006			
		VA	VD	VAD	VE	VA	VD	VAD	VE
Inthanon	K x H	6.67	0.27	0.98	10.57	14.83	0.79	0.30	11.56
	K x A	11.22	0.62	1.41	11.03	1.08	0.04	0.01	4.75
	K x E	20.64	14.20	17.48	52.86	7.80	3.20	2.96	15.44
	H x A	60.23	3.12	26.34	23.52	-	-	-	-
	H x E	72.96	2.02	8.25	10.80	8.42	15.40	1.55	15.49
	A x E	36.06	0.37	22.20	23.00	-	-	-	-
	Average	**34.63**	**3.43**	**12.78**	**21.96**	**8.03**	**4.86**	**1.21**	**11.81**
Khunpae	K x H	28.94	0.36	18.98	45.32	13.58	0.59	3.02	17.76
	K x A	10.79	0.64	2.28	19.44	6.02	3.37	0.22	17.39
	K x E	17.70	3.68	6.34	27.52	15.84	2.16	4.97	14.41
	H x A	26.76	2.05	1.87	27.32	11.64	3.25	7.12	23.41
	H x E	39.59	10.88	2.30	37.61	11.18	4.19	3.01	16.22
	A x E	43.81	3.37	16.69	35.85	5.95	1.33	0.78	16.42
	Average	**27.93**	**3.50**	**8.08**	**32.18**	**10.70**	**2.48**	**3.19**	**17.60**
Pangda	K x H	7.58	2.55	5.90	7.10	12.17	2.30	2.12	15.01
	K x A	2.95	0.50	1.24	11.92	21.11	2.10	1.96	20.73
	K x E	12.43	0.74	3.70	13.81	22.90	2.77	1.42	21.76
	H x A	10.15	2.80	0.94	13.32	22.87	0.64	9.54	27.87
	H x E	7.75	0.31	0.28	11.67	8.50	1.39	0.90	17.60
	A x E	11.10	5.99	3.31	12.23	16.00	2.34	2.62	34.23
	Average	**8.66**	**2.15**	**2.56**	**11.68**	**17.26**	**1.92**	**3.09**	**22.87**
Average for all sites		***23.74***	***3.03***	***7.81***	***21.94***	***12.49***	***2.87***	***2.66***	***18.13***

4.6 Heritability

Estimations of heritability for seed yield per plant and yield components of azuki bean are presented in Tables 49 to 55. Results of estimation for broad-sense heritability (h^2_b) and narrow-sense heritability (h^2_n) of each trait are as follow.

4.6.1 Plant height

The estimation of broad-sense (h^2_b) and narrow-sense (h^2_n) heritabilities revealed that average from crosses in all locations and years were 44.84 and 36.46 percent, respectively.

In 2005, broad-sense heritability (h^2_b), averaged from three test sites, ranged from 25.12 to 64.39 percent, averaged 46.39 percent and narrow-sense heritability (h^2_n) was 17.60-52.87 percent, averaged 36.23 percent. Hybrid A x E, K x E and H x A gave highest h^2_b at Inthanon, Khunpae and Pangda stations for 64.39, 63.44 and 55.13 percent, respectively while hybrid A x E, H x A and H x A gave h^2_n at Khunpae, Inthanon and Pangda stations for 52.87, 50.82 and 48.13 percent, respectively.

In 2006, broad-sense heritability (h^2_b), averaged from three test sites, ranged from 29.09 to 59.53 percent, averaged 43.28 percent and narrow-sense heritability (h^2_n) was 19.62-56.09 percent, averaged 36.68 percent. Hybrid H x A, K x E and K x E gave highest h^2_b at Inthanon, Pangda and Khunpae stations for 59.53, 59.17 and 47.39 percent, respectively while hybrid K x E, H x A and A x E gave h^2_n at Pangda, Inthanon and Khunpae stations for 56.09, 55.73 and 39.40 percent, respectively.

4.6.2 Number of nodes per plant

The estimation of h^2_b and h^2_n revealed that average from crosses in all locations and years were 39.68 and 33.98 percent, respectively.

In 2005, broad-sense heritability (h^2_b), averaged from three test sites, ranged from 24.91 to 61.85 percent, averaged 40.23 percent and narrow-sense heritability (h^2_n) was 22.20-54.75 percent, averaged 34.76 percent. Hybrid K x E gave highest h^2_b at all locations, Inthanon, Khunpae and Pangda for 61.85, 52.82 and 45.28 percent, respectively while hybrid K x E gave h^2_n at all locations, Inthanon, Khunpae and Pangda for 54.75, 47.39 and 40.10 percent, respectively.

Table 49 Heritability (%) estimates for plant height in azuki bean crosses, grown at three highland locations in two growing seasons, 2005 and 2006.

Locations	Crosses	2005		2006		Average for two years	
		h^2_b	h^2_n	h^2_b	h^2_n	h^2_b	h^2_n
Inthanon	K x H	52.32	22.26	35.98	32.72	44.15	27.49
	K x A	35.68	33.72	50.02	48.04	42.85	40.88
	K x E	48.82	41.43	43.02	35.24	45.92	38.34
	H x A	58.77	50.82	59.53	55.73	59.15	53.28
	H x E	38.92	35.94	50.56	38.75	44.74	37.35
	A x E	64.39	44.04	29.09	28.49	46.74	36.27
	Average	**49.82**	**38.04**	**44.70**	**39.83**	**47.26**	**38.94**
Khunpae	K x H	39.54	32.91	33.92	19.62	36.73	26.27
	K x A	40.38	35.61	24.59	23.14	32.49	29.38
	K x E	63.44	17.60	47.39	35.08	55.42	26.34
	H x A	48.58	32.72	40.70	25.96	44.64	29.34
	H x E	51.55	41.76	43.30	35.93	47.43	38.85
	A x E	59.21	52.87	44.54	39.40	51.88	46.14
	Average	**50.45**	**35.58**	**39.07**	**29.86**	**44.76**	**32.72**
Pangda	K x H	25.12	22.21	54.33	52.94	39.73	37.58
	K x A	49.84	43.91	35.92	32.85	42.88	38.38
	K x E	27.54	25.58	59.17	56.09	43.36	40.84
	H x A	55.13	48.13	45.83	42.89	50.48	45.51
	H x E	35.96	34.30	50.57	28.90	43.27	31.60
	A x E	39.74	36.30	30.55	28.53	35.15	32.42
	Average	**38.89**	**35.07**	**46.06**	**40.37**	**42.48**	**37.72**
Average for all sites		***46.39***	***36.23***	***43.28***	***36.68***	***44.84***	***36.46***

h^2_b = broad-sense heritability; h^2_n = narrow-sense heritability

Table 50 Heritability (%) estimates for number of nodes per plant in azuki bean crosses, grown at three highland locations in two growing seasons, 2005 and 2006.

Locations	Crosses	2005		2006		Average for two years	
		h^2_b	h^2_n	h^2_b	h^2_n	h^2_b	h^2_n
Inthanon	K x H	41.01	35.27	46.91	35.91	43.96	35.59
	K x A	44.24	35.26	51.51	51.02	47.88	43.14
	K x E	61.85	54.75	46.21	24.07	54.03	39.41
	H x A	41.82	35.57	32.63	31.36	37.23	33.47
	H x E	25.99	22.36	47.55	45.56	36.77	33.96
	A x E	45.61	38.07	35.28	30.82	40.45	34.45
	Average	**43.42**	**36.88**	**43.35**	**36.46**	**43.39**	**36.67**
Khunpae	K x H	37.48	34.07	25.78	22.55	31.63	28.31
	K x A	36.24	20.97	45.98	45.37	41.11	33.17
	K x E	52.82	47.39	28.40	27.79	40.61	37.59
	H x A	34.12	29.49	-	-	34.12	29.49
	H x E	45.62	44.63	31.67	25.47	38.65	35.05
	A x E	33.70	22.20	39.38	38.04	36.54	30.12
	Average	**40.00**	**33.13**	**34.24**	**31.84**	**37.12**	**32.49**
Pangda	K x H	41.71	35.99	49.98	49.05	45.85	42.52
	K x A	24.91	24.75	33.35	32.09	29.13	28.42
	K x E	45.28	40.10	37.82	33.75	41.55	36.93
	H x A	36.24	33.04	39.69	34.99	37.97	34.02
	H x E	40.67	39.37	35.06	20.98	37.87	30.18
	A x E	34.88	32.43	37.85	15.41	36.37	23.92
	Average	**37.28**	**34.28**	**38.96**	**31.05**	**38.12**	**32.67**
Average for all sites		***40.23***	***34.76***	***39.12***	***33.19***	***39.68***	***33.98***

h^2_b = broad-sense heritability; h^2_n = narrow-sense heritability

In 2006, broad-sense heritability (h^2_b), averaged from three test sites, ranged from 25.78 to 51.51 percent, averaged 39.12 percent and narrow-sense heritability (h^2_n) was 15.41-51.02 percent, averaged 33.19 percent. Hybrid K x A, K x H and K x A gave highest h^2_b at Inthanon, Pangda and Khunpae stations for 51.51, 49.98 and 45.98 percent, respectively while hybrid K x A, K x H and K x A gave h^2_n at Inthanon, Pangda and Khunpae stations for 51.02, 49.05 and 45.37 percent, respectively.

4.6.3 Number of branches per plant

The estimation of h^2_b and h^2_n revealed that average from crosses in all locations and years were 38.15 and 32.85 percent, respectively.

In 2005, broad-sense heritability (h^2_b), averaged from three test sites, ranged from 27.13 to 65.87 percent, averaged 41.24 percent and narrow-sense heritability (h^2_n) was 21.77-60.52 percent, averaged 36.06 percent. Hybrid K x E, K x H and H x A gave highest h^2_b at Inthanon, Pangda and Khunpae stations for 65.87, 51.34 and 51.24 percent, respectively while hybrid K x E, H x A and K x H gave h^2_n at Inthanon, Khunpae and Pangda stations for 60.52, 50.73 and 45.75 percent, respectively.

In 2006, broad-sense heritability (h^2_b), averaged from three test sites, ranged from 22.63 to 56.30 percent, averaged 35.05 percent and narrow-sense heritability (h^2_n) was 13.27-48.53 percent, averaged 29.64 percent. Hybrid H x E, K x E and A x E gave highest h^2_b at Khunpae, Pangda and Inthanon stations for 56.30, 45.62 and 41.09 percent, respectively while hybrid A x E, K x E and A x E gave h^2_n at Khunpae, Pangda and Inthanon stations for 48.53, 45.43 and 39.91 percent, respectively.

4.6.4 Number of pods per plant

The estimation of h^2_b and h^2_n suggested that average from crosses in all locations and years were 45.48 and 37.87 percent, respectively.

In 2005, broad-sense heritability (h^2_b), averaged from three test sites, ranged from 33.21 to 60.92 percent, averaged 48.57 percent and narrow-sense heritability (h^2_n) was 29.84-58.82 percent, averaged 43.07 percent. Hybrid A x E, K x E and A x E gave highest h^2_b at Pangda, Khunpae and Inthanon stations for 60.92, 60.68 and 58.24 percent, respectively while hybrid K x E, A x E and A x E gave h^2_n at Khunpae, Inthanon and Pangda stations for 58.82, 57.94 and 57.61 percent, respectively.

Table 51 Heritability (%) estimates for number of branches per plant in azuki bean crosses, grown at three highland locations in two growing seasons, 2005 and 2006.

Locations	Crosses	2005		2006		Average for two years	
		h^2_b	h^2_n	h^2_b	h^2_n	h^2_b	h^2_n
Inthanon	K x H	46.37	39.87	29.90	27.18	38.14	33.53
	K x A	44.50	35.77	28.40	26.82	36.45	31.30
	K x E	65.87	60.52	26.62	24.13	46.25	42.33
	H x A	44.11	38.62	24.51	23.55	34.31	31.09
	H x E	45.58	37.95	35.80	33.25	40.69	35.60
	A x E	31.46	27.97	41.09	39.91	36.28	33.94
	Average	**46.32**	**40.12**	**31.05**	**29.14**	**38.69**	**34.63**
Khunpae	K x H	50.28	46.11	25.70	23.63	37.99	34.87
	K x A	30.83	28.85	36.29	34.89	33.56	31.87
	K x E	30.13	21.77	40.49	33.45	35.31	27.61
	H x A	51.24	50.73	-	-	51.24	50.73
	H x E	50.71	42.85	56.30	17.06	53.51	29.96
	A x E	37.75	29.84	49.68	48.53	43.72	39.19
	Average	**41.82**	**36.69**	**41.69**	**31.51**	**41.76**	**34.10**
Pangda	K x H	51.34	45.75	37.45	33.38	44.40	39.57
	K x A	38.10	35.02	22.63	13.27	30.37	24.15
	K x E	37.85	37.40	45.62	45.43	41.74	41.42
	H x A	27.13	22.35	29.21	28.68	28.17	25.52
	H x E	30.76	22.73	35.50	28.24	33.13	25.49
	A x E	28.39	25.03	30.67	22.47	29.53	23.75
	Average	**35.60**	**31.38**	**33.51**	**28.58**	**34.56**	**29.98**
Average for all sites		***41.24***	***36.06***	***35.05***	***29.64***	***38.15***	***32.85***

h^2_b = broad-sense heritability; h^2_n = narrow-sense heritability

Table 52 Heritability (%) estimates for number of pods per plant in azuki bean crosses, grown at three highland locations in two growing seasons, 2005 and 2006.

Locations	Crosses	2005		2006		Average for two years	
		h^2_b	h^2_n	h^2_b	h^2_n	h^2_b	h^2_n
Inthanon	K x H	39.98	33.75	44.55	33.90	42.27	33.83
	K x A	52.61	44.56	30.14	13.14	41.38	28.85
	K x E	44.50	30.74	43.74	33.77	44.12	32.26
	H x A	57.29	46.84	50.49	49.97	53.89	48.41
	H x E	43.40	43.19	60.10	30.24	51.75	36.72
	A x E	58.24	57.94	36.19	34.59	47.22	46.27
	Average	**49.34**	**42.84**	**44.20**	**32.60**	**46.77**	**37.72**
Khunpae	K x H	42.39	38.49	47.63	30.72	45.01	34.61
	K x A	33.21	29.84	52.15	43.56	42.68	36.70
	K x E	60.68	58.82	42.43	19.13	51.56	38.98
	H x A	46.29	45.69	32.56	32.25	39.43	38.97
	H x E	52.67	37.98	48.32	41.32	50.50	39.65
	A x E	49.77	44.13	37.14	17.13	43.46	30.63
	Average	**47.50**	**42.49**	**43.37**	**30.69**	**45.44**	**36.59**
Pangda	K x H	34.19	31.25	38.53	29.71	36.36	30.48
	K x A	41.37	39.60	44.27	38.33	42.82	38.97
	K x E	58.94	54.40	40.60	38.63	49.77	46.52
	H x A	48.27	33.80	22.45	20.06	35.36	26.93
	H x E	49.52	46.57	48.45	44.99	48.99	45.78
	A x E	60.92	57.61	43.10	36.38	52.01	47.00
	Average	**48.87**	**43.87**	**39.57**	**34.68**	**44.22**	**39.28**
Average for all sites		***48.57***	***43.07***	***42.38***	***32.66***	***45.48***	***37.87***

h^2_b = broad-sense heritability; h^2_n = narrow-sense heritability

In 2006, broad-sense heritability (h^2_b), averaged from three test sites, ranged from 22.45 to 60.10 percent, averaged 42.38 percent and narrow-sense heritability (h^2_n) was 13.14-49.97 percent, averaged 32.66 percent. Hybrid H x E, K x A and H x E gave highest h^2_b at Inthanon, Khunpae and Pangda stations for 60.10, 52.15 and 48.45 percent, respectively while hybrid H x A, H x E and K x A gave h^2_n at Inthanon, Pangda and Khunpae stations for 49.97, 44.99 and 43.56 percent, respectively.

4.6.5 Number of seeds per pod

The estimation of h^2_b and h^2_n indicated that average from crosses in all locations and years were 45.87 and 40.16 percent, respectively.

In 2005, broad-sense heritability (h^2_b), averaged from three test sites, ranged from 32.61 to 68.02 percent, averaged 47.49 percent and narrow-sense heritability (h^2_n) was 28.36-63.07 percent, averaged 44.08 percent. Hybrid A x E, H x E and H x A gave highest h^2_b at Inthanon, Pangda and Khunpae stations for 68.02, 61.30 and 51.60 percent, respectively while hybrid H x A, H x E and H x A gave h^2_n at Inthanon, Pangda and Khunpae stations for 63.07, 59.55 and 49.92 percent, respectively.

In 2006, broad-sense heritability (h^2_b), averaged from three test sites, ranged from 27.18 to 63.01 percent, averaged 44.24 percent and narrow-sense heritability (h^2_n) was 20.70-58.10 percent, averaged 36.24 percent. Hybrid H x E, H x A and H x E gave highest h^2_b at Inthanon, Khunpae and Pangda stations for 63.01, 53.96 and 50.23 percent, respectively while hybrid H x E, K x H and H x E gave h^2_n at Inthanon, Khunpae and Pangda stations for 58.10, 46.64 and 46.38 percent, respectively.

4.6.6 100-seed weight

The estimation of h^2_b and h^2_n revealed that average from crosses in all locations and years were 47.75 and 43.89 percent, respectively.

In 2005, broad-sense heritability (h^2_b), averaged from three test sites, ranged from 34.24 to 61.89 percent, averaged 46.12 percent and narrow-sense heritability (h^2_n) was 32.11-60.17 percent, averaged 41.69 percent. Hybrid K x A, K x H and K x H gave highest h^2_b at Khunpae, Inthanon and Pangda stations for 61.89, 60.62 and 56.58 percent, respectively while hybrid K x H, K x E and H x A gave h^2_n at Inthanon, Khunpae and Pangda stations for 60.17, 56.52 and 45.63 percent, respectively.

Table 53 Heritability (%) estimates for number of seeds per pod in azuki bean crosses, grown at three highland locations in two growing seasons, 2005 and 2006.

Locations	Crosses	2005		2006		Average for two years	
		h^2_b	h^2_n	h^2_b	h^2_n	h^2_b	h^2_n
Inthanon	K x H	65.74	59.56	32.97	27.41	49.36	43.49
	K x A	47.67	47.17	48.87	39.83	48.27	43.50
	K x E	53.67	51.16	27.18	25.73	40.43	38.45
	H x A	66.28	63.07	44.09	38.91	55.19	50.99
	H x E	40.11	33.95	63.01	58.10	51.56	46.03
	A x E	68.02	61.63	36.26	34.64	52.14	48.14
	Average	**56.92**	**52.76**	**42.06**	**37.44**	**49.49**	**45.10**
Khunpae	K x H	39.26	37.26	49.18	46.64	44.22	41.95
	K x A	46.04	38.35	47.50	20.70	46.77	29.53
	K x E	39.21	28.36	37.65	26.16	38.43	27.26
	H x A	51.60	49.92	53.96	45.93	52.78	47.93
	H x E	36.80	34.45	43.97	39.19	40.39	36.82
	A x E	32.61	31.00	41.51	22.81	37.06	26.91
	Average	**40.92**	**36.56**	**45.63**	**33.57**	**43.28**	**35.07**
Pangda	K x H	37.82	36.86	39.35	36.25	38.59	36.56
	K x A	41.77	41.49	48.61	46.03	45.19	43.76
	K x E	40.04	37.96	43.54	27.54	41.79	32.75
	H x A	43.53	40.17	45.37	30.61	44.45	35.39
	H x E	61.30	59.55	50.23	46.38	55.77	52.97
	A x E	43.43	41.59	43.10	39.44	43.27	40.52
	Average	**44.65**	**42.94**	**45.03**	**37.71**	**44.84**	**40.33**
Average for all sites		***47.49***	***44.08***	***44.24***	***36.24***	***45.87***	***40.16***

h^2_b = broad-sense heritability; h^2_n = narrow-sense heritability

Table 54 Heritability (%) estimates for 100-seed weight in azuki bean crosses, grown at three highland locations in two growing seasons, 2005 and 2006.

Locations	Crosses	2005		2006		Average for two years	
		h^2_b	h^2_n	h^2_b	h^2_n	h^2_b	h^2_n
Inthanon	K x H	60.62	60.17	67.90	66.67	64.26	63.42
	K x A	41.98	30.87	50.22	43.92	46.10	37.40
	K x E	51.27	49.68	60.24	53.93	55.76	51.81
	H x A	39.66	37.51	34.37	31.11	37.02	34.31
	H x E	37.08	35.80	43.08	39.39	40.08	37.60
	A x E	44.33	42.73	45.89	42.43	45.11	42.58
	Average	**45.82**	**42.79**	**50.28**	**46.24**	**48.05**	**44.52**
Khunpae	K x H	49.78	49.50	62.07	59.69	55.93	54.60
	K x A	61.89	47.45	42.55	40.84	52.22	44.15
	K x E	58.68	56.52	28.86	23.80	43.77	40.16
	H x A	42.82	38.00	-	-	42.82	38.00
	H x E	36.27	33.16	32.10	28.35	34.19	30.76
	A x E	44.29	43.23	53.12	49.61	48.71	46.42
	Average	**48.96**	**44.64**	**43.74**	**40.46**	**46.35**	**42.55**
Pangda	K x H	56.58	36.10	61.74	61.21	59.16	48.66
	K x A	34.24	32.11	65.58	63.73	49.91	47.92
	K x E	-	-	48.63	47.40	48.63	47.40
	H x A	50.19	45.63	39.45	34.62	44.82	40.13
	H x E	37.95	36.50	44.09	38.10	41.02	37.30
	A x E	36.37	33.79	59.54	58.59	47.96	46.19
	Average	**43.07**	**36.83**	**53.17**	**50.61**	**48.12**	**43.72**
Average for all sites		***46.12***	***41.69***	***49.38***	***46.08***	***47.75***	***43.89***

h^2_b = broad-sense heritability; h^2_n = narrow-sense heritability

In 2006, broad-sense heritability (h^2_b), averaged from three test sites, ranged from 28.86 to 67.90 percent, averaged 49.38 percent and narrow-sense heritability (h^2_n) was 23.80-66.67 percent, averaged 46.08 percent. Hybrid K x H, K x A and K x H gave highest h^2_b at Inthanon, Pangda and Khunpae stations for 67.90, 65.58 and 62.07 percent, respectively while hybrid K x H, K x A and K x H gave h^2_n at Inthanon, Pangda and Khunpae stations for 66.67, 63.73 and 59.69 percent, respectively.

4.6.7 Seed yield per plant

The estimation of h^2_b and h^2_n indicated that average from crosses in all locations and years were 47.49 and 40.27 percent, respectively.

In 2005, broad-sense heritability (h^2_b), averaged from three test sites, ranged from 22.46 to 87.41 percent, averaged 50.93 percent and narrow-sense heritability (h^2_n) was 19.19-85.06 percent, averaged 44.78 percent. Hybrid H x E, K x H and H x E gave highest h^2_b at Inthanon, Pangda and Khunpae stations for 87.41, 58.77 and 57.30 percent, respectively while hybrid H x E, A x E and K x E gave h^2_n at Inthanon, Khunpae and Pangda stations for 85.06, 52.76 and 46.06 percent, respectively.

In 2006, broad-sense heritability (h^2_b), averaged from three test sites, ranged from 19.02 to 60.60 percent, averaged 44.04 percent and narrow-sense heritability (h^2_n) was 18.36-54.55 percent, averaged 35.75 percent. Hybrid H x E, K x E and K x E gave highest h^2_b at Inthanon, Khunpae and Pangda stations for 60.60, 55.54 and 54.11 percent, respectively while hybrid K x H, K x E and K x E gave h^2_n at Inthanon, Khunpae and Pangda stations for 54.55, 48.87 and 48.28 percent, respectively.

Table 55 Heritability (%) estimates for seed yield per plant in azuki bean crosses, grown at three highland locations in two growing seasons, 2005 and 2006.

Locations	Crosses	2005		2006		Average for two years	
		h^2_b	h^2_n	h^2_b	h^2_n	h^2_b	h^2_n
Inthanon	K x H	39.62	38.10	57.47	54.55	48.55	46.33
	K x A	51.78	49.08	19.02	18.36	35.40	33.72
	K x E	39.73	23.54	41.62	29.50	40.68	26.52
	H x A	72.93	69.34	-	-	72.93	69.34
	H x E	87.41	85.06	60.60	21.41	74.01	53.24
	A x E	61.30	60.68	-	-	61.30	60.68
	Average	**58.80**	**54.30**	**44.68**	**30.96**	**51.74**	**42.63**
Khunpae	K x H	39.27	38.78	44.39	42.54	41.83	40.66
	K x A	37.02	34.95	35.05	22.47	36.04	28.71
	K x E	43.72	36.20	55.54	48.87	49.63	42.54
	H x A	51.33	47.68	38.88	30.38	45.11	39.03
	H x E	57.30	44.95	48.65	35.38	52.98	40.17
	A x E	56.83	52.76	30.73	25.10	43.78	38.93
	Average	**47.58**	**42.55**	**42.21**	**34.12**	**44.90**	**38.34**
Pangda	K x H	58.77	43.99	49.08	41.27	53.93	42.63
	K x A	22.46	19.19	52.81	48.04	37.64	33.62
	K x E	48.82	46.06	54.11	48.28	51.47	47.17
	H x A	49.29	38.63	45.76	44.51	47.53	41.57
	H x E	40.83	39.27	35.99	30.92	38.41	35.10
	A x E	58.29	37.86	34.89	30.44	46.59	34.15
	Average	**46.41**	**37.50**	**45.44**	**40.58**	**45.93**	**39.04**
Average for all sites		***50.93***	***44.78***	***44.04***	***35.75***	***47.49***	***40.27***

h^2_b = broad-sense heritability; h^2_n = narrow-sense heritability

4.7 Genetic advance from selection (genetic gains) and response to selection

Estimations of genetic gains, top 5 percent selected, for seed yield per plant and yield components for different azuki bean crosses which were grown on three highland areas in 2005 and 2006 are presented in Tables 56 and 57, respectively.

4.7.1 Plant height

In 2005, genetic gains, averaged from three test sites, ranged from 1.3 to 6.0 cm (7.3-31.8 %) , averaged 3.3 cm (18.4 %). Hybrid A x E, A x E and H x A gave highest expected gains at Khunpae, Inthanon and Pangda stations for 6.0 (31.8 %), 5.9 (31.2 %) and 4.1 cm (19.9 %), respectively.

In 2006, genetic gains, averaged from three test sites, ranged from 1.6 to 7.1 cm (9.5-39.7 %), averaged 3.3 cm (21.9 %). Hybrid K x E, H x A and K x E gave highest expected gains at Pangda, Inthanon and Khunpae stations for 7.1 (39.7 %), 4.9 (44.2 %) and 4.0 cm (21.8 %), respectively.

4.7.2 Number of nodes per plant

In 2005, genetic gains, averaged from three test sites, ranged from 0.6 to 2.1 nodes (7.4-28.4 %), averaged 1.1 nodes (13.7 %). Hybrid K x E gave highest expected gains at all locations, Inthanon, Khunpae and Pangda stations for 2.1 (28.4 %), 1.8 (21.7 %) and 1.6 nodes (18.7 %), respectively.

In 2006, genetic gains, averaged from three test sites, ranged from 0.7 to 1.9 nodes (7.6-24.4 %), averaged 1.3 nodes (19.9 %). Hybrid K x H, H x E and K x A gave highest expected gains at Pangda, Inthanon and Khunpae stations for 1.9 (24.4 %), 1.8 (29.3 %) and 1.7 nodes (26.2 %), respectively.

4.7.3 Number of branches per plant

In 2005, genetic gains, averaged from three test sites, ranged from 0.8 to 2.8 branches (8.8-46.2 %), averaged 1.4 branches (19.0 %). Hybrid K x E, H x A and K x H gave highest expected gains at Inthanon, Khunpae and Pangda stations for 2.8 (46.2 %), 1.8 (22.3 %) and 1.8 branches (26.1 %), respectively.

In 2006, genetic gains, averaged from three test sites, ranged from 0.5 to 2.3 branches (7.1-33.3 %), averaged 1.2 branches (20.4 %). Hybrid A x E, K x E and H x E gave highest expected gains at Khunpae, Pangda and Inthanon stations for 2.3 (33.3 %), 2.2 (28.5 %) and 1.3 branches (28.2 %), respectively.

4.7.4 Number of pods per plant

In 2005, genetic gains, averaged from three test sites, ranged from 3.0 to 14.2 pods (18.9-57.3 %), averaged 8.0 pods (38.2 %). Hybrid A x E gave highest expected gains at all locations, Inthanon, Khunpae and Pangda stations for 14.2 (57.3 %), 10.8 (39.0 %) and 10.1 pods (46.1 %), respectively.

In 2006, genetic gains, averaged from three test sites, ranged from 1.4 to 8.8 pods (22.2-38.3 %), averaged 5.3 pods (31.3 %). Hybrid H x E, H x E and H x A gave highest expected gains at Khunpae, Pangda and Inthanon stations for 8.8 (38.3 %), 8.1 (34.6 %) and 6.3 pods (60.3 %), respectively.

4.7.5 Number of seeds per pod

In 2005, genetic gains, averaged from three test sites, ranged from 0.4 to 1.1 seeds (9.0-34.8 %), averaged 0.6 seeds (15.9 %). Hybrid H x A, H x A and H x E gave highest expected gains at Inthanon, Khunpae and Pangda stations for 1.1 (34.8 %), 0.7 (15.7 %) and 0.7 seeds (15.7 %), respectively.

In 2006, genetic gains, averaged from three test sites, ranged from 0.3 to 1.6 seeds (8.5-40.1 %), averaged 0.7 seeds (16.6 %). Hybrid H x E, H x A and H x E gave highest expected gains at Inthanon, Khunpae and Pangda stations for 1.6 (40.1 %), 1.0 (24.3 %) and 0.8 seeds (16.9 %), respectively.

4.7.6 100-seed weight

In 2005, genetic gains, averaged from three test sites, ranged from 0.7 to 3.7 gm (4.8-19.3 %), averaged 1.4 gm (8.5 %). Hybrid K x H gave highest expected gains at all locations, Inthanon, Khunpae and Pangda stations for 3.7 (19.3 %), 2.2 (11.4 %) and 1.4 gm (8.3 %), respectively.

In 2006, genetic gains, averaged from three test sites, ranged from 0.6 to 5.3 gm (5.6-24.6 %), averaged 2.1 gm (13.3 %). Hybrid K x H, K x H and K x A gave highest expected gains at Inthanon, Khunpae and Pangda stations for 5.3 (24.6 %), 3.4 (20.6 %) and 2.8 gm (19.0 %), respectively.

Table 56 Estimate of genetic gains (5% selected) for seed yield per plant and yield components in azuki bean crosses, grown at three highland locations in 2005 growing season.

Locations	Crosses	Plant height	No. of nodes per plant	No. of branches per plant	No. of pods per plant	No. of seeds per pod	100-seed weight	Seed yield per plant
Inthanon	K x H	1.6 (12.0)	0.8 (10.6)	1.3 (22.1)	3.7 (23.0)	0.8 (22.6)	3.7 (19.3)	3.3 (26.3)
	K x A	2.6 (17.5)	0.9 (13.2)	1.3 (21.5)	7.0 (51.0)	0.5 (14.6)	1.6 (8.3)	4.8 (51.5)
	K x E	4.6 (30.9)	2.1 (28.4)	2.8 (46.2)	6.2 (34.1)	0.7 (17.2)	1.5 (7.9)	4.5 (33.4)
	H x A	4.9 (27.1)	0.9 (11.5)	1.2 (16.2)	12.3 (50.5)	1.1 (34.8)	1.6 (10.2)	13.3 (103.9)
	H x E	3.6 (18.4)	0.7 (8.0)	1.6 (22.7)	6.2 (27.3)	0.6 (14.6)	1.1 (6.8)	16.2 (94.5)
	A x E	5.9 (31.2)	1.4 (17.0)	1.1 (14.7)	14.2 (57.3)	1.1 (32.7)	1.5 (8.9)	9.6 (63.9)
	Average	**3.9 (22.8)**	**1.1 (14.8)**	**1.5 (23.9)**	**8.3 (40.5)**	**0.8 (22.8)**	**1.8 (10.2)**	**8.6 (62.2)**
Khunpae	K x H	2.8 (16.6)	1.2 (15.1)	1.7 (24.3)	7.9 (39.6)	0.4 (10.3)	2.2 (11.4)	6.9 (42.5)
	K x A	2.2 (13.4)	0.6 (7.4)	0.9 (13.3)	4.2 (21.2)	0.5 (11.9)	1.8 (9.2)	4.0 (22.1)
	K x E	1.8 (11.1)	1.8 (21.7)	0.8 (10.7)	10.1 (52.4)	0.5 (9.6)	1.2 (6.2)	5.2 (26.4)
	H x A	2.8 (15.5)	0.9 (9.3)	1.8 (22.3)	10.1 (39.3)	0.7 (15.7)	1.1 (7.4)	7.4 (44.0)
	H x E	3.4 (17.4)	1.6 (15.8)	1.5 (17.0)	9.7 (32.9)	0.5 (10.2)	0.7 (4.8)	8.7 (44.5)
	A x E	6.0 (31.8)	0.7 (6.8)	1.2 (14.9)	10.8 (39.0)	0.4 (9.0)	1.1 (7.1)	9.9 (50.5)
	Average	**3.2 (17.6)**	**1.1 (12.7)**	**1.3 (17.1)**	**8.8 (37.4)**	**0.5 (11.1)**	**1.4 (7.7)**	**7.0 (38.3)**
Pangda	K x H	1.3 (7.3)	0.9 (11.5)	1.8 (26.1)	3.0 (18.9)	0.4 (9.9)	1.4 (8.3)	3.8 (33.0)
	K x A	3.6 (19.6)	0.8 (9.5)	1.3 (18.5)	5.4 (34.4)	0.6 (14.0)	1.0 (6.0)	1.6 (13.1)
	K x E	2.2 (11.5)	1.6 (18.7)	1.5 (20.3)	9.5 (53.1)	0.7 (14.2)	-	4.9 (39.3)
	H x A	4.1 (19.9)	1.1 (12.8)	0.8 (8.8)	6.5 (30.1)	0.6 (13.6)	1.2 (9.4)	4.1 (33.9)
	H x E	3.2 (16.5)	1.4 (16.8)	0.9 (11.6)	7.5 (38.0)	0.7 (15.7)	0.7 (6.1)	3.6 (34.7)
	A x E	2.9 (13.3)	1.1 (12.5)	0.9 (11.6)	10.1 (46.1)	0.7 (15.2)	1.0 (7.4)	4.2 (32.7)
	Average	**2.9 (14.7)**	**1.2 (13.6)**	**1.2 (16.1)**	**7.0 (36.8)**	**0.6 (13.7)**	**1.1 (7.4)**	**3.7 (31.1)**
Average for all sites		***3.3 (18.4)***	***1.1 (13.7)***	***1.4 (19.0)***	***8.0 (38.2)***	***0.6 (15.9)***	***1.4 (8.5)***	***6.4 (43.9)***

In parenthesis, is the percentage of genetic gains.

Table 57 Estimate of genetic gains (5% selected) for seed yield per plant and yield components in azuki bean crosses, grown at three highland locations in 2006 growing season.

Locations	Crosses	Plant height	No. of nodes per plant	No. of branches per plant	No. of pods per plant	No. of seeds per pod	100-seed weight	Seed yield per plant
Inthanon	K x H	2.4 (22.0)	1.1 (22.1)	0.9 (24.3)	3.8 (39.0)	0.4 (9.5)	5.3 (24.6)	5.9 (69.1)
	K x A	2.5 (24.3)	1.7 (40.1)	0.8 (25.3)	1.4 (22.2)	0.8 (24.3)	3.2 (15.4)	0.9 (19.6)
	K x E	2.4 (24.4)	0.8 (16.2)	0.7 (20.8)	3.6 (41.2)	0.6 (13.4)	3.6 (18.3)	3.1 (46.4)
	H x A	4.9 (44.2)	1.1 (21.4)	0.6 (13.4)	6.3 (60.3)	0.8 (23.7)	1.5 (9.8)	-
	H x E	3.2 (24.1)	1.8 (29.3)	1.3 (28.2)	4.7 (34.4)	1.6 (40.1)	1.9 (12.5)	2.8 (31.2)
	A x E	1.9 (14.5)	1.3 (22.2)	1.3 (25.0)	4.3 (29.3)	0.6 (18.6)	1.9 (10.7)	-
	Average	**2.9 (25.6)**	**1.3 (25.2)**	**1.0 (22.8)**	**4.0 (37.7)**	**0.8 (21.6)**	**2.9 (15.2)**	**3.2 (41.6)**
Khunpae	K x H	1.6 (9.5)	0.8 (12.3)	0.8 (14.3)	5.0 (31.2)	0.8 (19.9)	3.4 (20.6)	5.0 (46.6)
	K x A	2.1 (12.7)	1.7 (26.2)	1.6 (24.5)	7.2 (39.9)	0.3 (8.5)	1.5 (9.5)	2.4 (22.9)
	K x E	4.0 (21.8)	1.1 (15.7)	1.5 (23.9)	3.4 (19.9)	0.5 (11.5)	0.7 (4.2)	5.7 (46.3)
	H x A	3.0 (16.0)	-	-	5.0 (20.4)	1.0 (24.3)	-	3.9 (34.0)
	H x E	3.6 (21.0)	1.0 (13.4)	0.9 (12.1)	8.8 (38.3)	0.8 (18.5)	0.6 (5.6)	4.1 (35.3)
	A x E	3.7 (21.4)	1.4 (19.5)	2.3 (33.3)	3.0 (13.8)	0.5 (13.1)	1.8 (14.2)	2.5 (26.2)
	Average	**3.0 (17.0)**	**1.2 (17.4)**	**1.4 (21.6)**	**5.4 (27.2)**	**0.7 (15.9)**	**1.6 (10.8)**	**3.9 (35.2)**
Pangda	K x H	4.2 (25.2)	1.9 (24.4)	1.4 (20.2)	4.4 (24.0)	0.4 (8.4)	2.2 (14.3)	4.6 (36.6)
	K x A	2.8 (16.3)	1.5 (18.8)	0.5 (7.1)	7.1 (34.3)	0.5 (12.3)	2.8 (19.0)	6.6 (48.8)
	K x E	7.1 (39.7)	1.6 (19.8)	2.2 (28.5)	7.6 (36.0)	0.4 (8.7)	1.6 (11.0)	6.9 (40.7)
	H x A	4.2 (23.9)	1.6 (18.2)	1.3 (16.2)	3.9 (16.1)	0.5 (11.8)	1.0 (8.4)	6.6 (51.0)
	H x E	3.2 (18.5)	1.0 (11.0)	1.3 (17.1)	8.1 (34.6)	0.8 (16.9)	1.2 (11.6)	3.3 (29.0)
	A x E	3.1 (15.5)	0.7 (7.6)	1.1 (12.2)	7.7 (28.2)	0.7 (14.9)	1.9 (16.1)	4.6 (30.2)
	Average	**4.1 (23.2)**	**1.4 (16.6)**	**1.3 (16.9)**	**6.5 (28.9)**	**0.6 (12.2)**	**1.8 (13.4)**	**5.4 (39.4)**
Average for all sites		***3.3 (21.9)***	***1.3 (19.9)***	***1.2 (20.4)***	***5.3 (31.3)***	***0.7 (16.6)***	***2.1 (13.3)***	***4.3 (38.4)***

In parenthesis, is the percentage of genetic gains.

4.7.7 Seed yield per plant

In 2005, genetic gains, averaged from three test sites, ranged from 1.6 to 13.3 gm (13.1-103.9 %), averaged 6.4 gm (43.9 %). Hybrid H x A, A x E and K x E gave highest expected gains at Inthanon, Khunpae and Pangda stations for 13.3 (103.9 %), 9.9 (50.5 %) and 4.9 gm (39.3 %), respectively.

In 2006, genetic gains, averaged from three test sites, ranged from 0.9 to 6.9 gm (19.6-40.7 %), averaged 4.3 gm (38.4 %). Hybrid K x E, K x H and K x E gave highest expected gains at Pangda, Inthanon and Khunpae stations for 6.9 (40.7 %), 5.9 (69.1 %) and 5.7 gm (46.3 %), respectively.

4.7.8 Response to selection

Responses to selection based on selection of the superior 5 percent plants in F2 families for 100-seed weight and seed yield per plant are shown in Tables 58 and 59, respectively. For seed size, it was found that expected F3 generation mean was 18.08 gm per 100-seed (expected gain was 1.45 gm). In 2006, observed F3 mean of promising lines was 17.24 gm per 100-seed (actual gain was 0.61 gm). The expected and observed F3 generation means in this trait were not significant by χ^2-test (*P=0.9934*). The cross K x H showed highest expected gain at each location since this Kamuidainagon (K) variety performed as a good combiner for this trait (Table 6). In addition, additive gene effects were important in controlling of this trait, on which inheritance of this trait was quite stable to their progenies. These results suggest that selection for increasing seed size in azuki bean may be made effectively in early generations by using early-generation yield testing (EGT), or pedigree selection (PS) methods. (Boerma and Cooper, 1975).

For seed yield per plant, it was found that the average of expected F3 generation mean was 20.81 gm per plant (expected gain 6.45 gm) and ranged from 13.37 to 33.41 gm per plant (expected gain ranged from 1.55 to 16.23 gm). Observed mean of F3 promising lines was 17.43 gm per plant (actual gain was 3.07 gm) and ranged from 15.38 to 20.20 gm per plant (actual gain ranged from 1.55 to 16.23 gm). Observed and expected F3 generation means for seed yield per plant were significantly different by χ^2-test (*P=0.0304*). Since this trait was evidently controlled by dominance and epistatic gene effects, as shown in Tables 4, 5, 32 and 34, on which unfixable gene effects were greater than fixable gene effects, so that, in improving of seed yield per plant in azuki bean, it will be successful if breeding methods to be used are able to accumulate the gene to formulate a specific genotype interacting in a favorable manner. A possible breeding programme is to do a bi-parental or multiparental mating, followed by delaying selection until desirable genotypes are observed.

Response to selection of 100-seed weight suggested that average genetic gain (ΔG) was 1.45 gm and gave 18.08 gm and 17.24 gm for expected and observed means of F3 generation, respectively. This observed mean of 100-seed weight of F3 was not significantly different from expected mean, indicating that estimate of genetic gain and response of selection at 5 % for 100-seed weight was quite reliable and appropriate for predicting seed size trait in the advanced generations.

For seed yield per plant, it showed that average genetic gains (ΔG) was 6.45 gm per plant and gave 20.81 gm per plant and 17.43 gm per plant for expected and observed means for F3 generation, respectively. This observed mean of seed yield per plant of F3 generation was significantly different from expected mean (*P=0.0304*), indicating that genetic gain which was estimated at 5 % of selection might probably be over-estimated for this trait.

However, there were some crosses at some locations whose observed means were close to expected means, for example, A x E, H x A and K x H crosses at Pangda, K x A and K x E crosses at Inthanon station whereas some crosses showed large different values of observed and expected means, for example, H x A and H x E at Inthanon, K x A, K x H, H x A and H x E at Khunpae station

This discrepancy of observed and expected mean for seed yield per plant might probably be due to the use of 5 % of selection that gave large value of genetic gains for each cross at each location. The other reason might be due to h^2_n and standard deviation of F2 for seed yield per plant which were rather high values (Table 55) for some crosses which resulted in increased ΔG as well.

Table 58 Response to selection at 5% of selection for 100-seed weight in azuki bean.

Crosses	Locations	100-seed weight (gm)			
		ΔG	F2-mean (2005)	F3-mean (expected)	F3-mean (observed)
Inthanon	K x H	3.71	19.21	22.92	24.55
	K x A	1.62	19.63	21.25	22.84
	K x E	1.46	18.40	19.86	22.27
	H x A	1.63	16.03	17.66	19.48
	H x E	1.08	15.80	16.88	18.98
	A x E	1.53	17.17	18.70	19.73
Khunpae	K x H	2.23	19.50	21.73	16.32
	K x A	1.82	19.74	21.56	16.54
	K x E	1.20	19.24	20.44	18.55
	H x A	1.13	15.35	16.48	14.37
	H x E	0.70	14.64	15.34	13.14
	A x E	1.12	15.89	17.01	13.28
Pangda	K x H	1.43	17.26	18.69	17.40
	K x A	1.00	16.60	17.60	16.64
	K x E	-	-	-	-
	H x A	1.20	12.82	14.02	13.11
	H x E	0.74	12.17	12.91	12.56
	A x E	0.98	13.25	14.23	13.38
Average for all sites		***1.45***	***16.63***	***18.08***	***17.24***
			χ^2=5.3877, df=16, P=0.9934		

Table 59 Respond to selection at 5% of selection for seed yield per plant in azuki bean.

Crosses	Locations	Seed yield per plant (gm)			
		ΔG	F2-mean (2005)	F3-mean (expected)	F3-mean (observed)
Inthanon	K x H	3.28	12.49	15.77	17.31
	K x A	4.84	9.39	14.23	15.38
	K x E	4.54	13.59	18.13	17.65
	H x A	13.31	12.81	26.12	19.64
	H x E	16.23	17.18	33.41	17.90
	A x E	9.64	15.09	24.73	18.28
Khunpae	K x H	6.90	16.24	23.14	17.32
	K x A	4.00	18.07	22.07	15.82
	K x E	5.21	16.73	21.94	18.16
	H x A	7.36	16.73	24.09	16.71
	H x E	8.69	19.51	28.20	17.43
	A x E	9.90	19.62	29.52	16.52
Pangda	K x H	3.76	11.39	15.15	16.52
	K x A	1.55	11.82	13.37	17.19
	K x E	4.93	12.56	17.49	20.20
	H x A	4.08	12.03	16.11	15.83
	H x E	3.59	10.34	13.93	17.74
	A x E	4.22	12.92	17.14	18.16
Average for all sites		***6.45***	***14.36***	***20.81***	***17.43***
			χ^2=29.4730, df=17, P=0.0304		