APPENDIX A

Name of azuki bean parents, origin and reference

Name of Cultivar	Origin/Notes and Reference
Akatsuki dainagon	- Origin: Hokkaido - Noto shouzu x Wase dairyu 1, released in 1970. medium plant height (45-72.2 cm), highly branched (3.4-4.6 /plant), buff-colored pods, dark red seeds, large seed size (19.1-20 g/100 seeds), medium maturity (126 days), 36.9-46 pods/plant, 4.29 seeds/pod, 8.94 % seed testa/seed weight, harvest index 43.5-62.0 %, 2,520-2,960 kg/ha yield, very responsive to high planting densities (550,000 plants/ha), some *Ascochyta phaseolorum* and *Cercospora canescens* resistance but susceptible to viruses such as BCMV, CMV and BYMV.
Erimo	- Kotobuki azuki x Juiku 77 go, medium maturity, medium height (47-52 cm), sparsely branched, brown pods (34 pods/plant), small bright red seeds (11.7-13 g/100 seeds), 22.4 % protein, lodging resistant, cold tolerant, susceptible to *Phialophora gregata*, all 3 *Fusarium oxysporum* f.sp. *adzukicola* races, *Pseudomonas adzukicola* and virus infections, M.A.F.F., registration 1981.
Hondawase	- Native origin (Urahoro, Hokkaido)
Kamui dainagon	- Origin: Hokkaido - Toiku 106 x Tokei 207, largest seeds of any Hokkaido cultivar, virus resistant.

Sources: 1. Julsrigival *et al.* (2004)

2. Lumpkin and McClary (1994)

APPENDIX B

B1. Description of Inthanon, Khunpae and Pangda stations.

Stations	Description

Inthanon	- 1,280 metre above sea level, ASL
	- Highland areas, slope 10-60 percent
	- Average temperature
	  - High 24.9 ^{o}C
	  - Low 16.5 ^{o}C
	  - Mean 20.1 ^{o}C
	- Average rain fall 1,780.9 mm per year

Khunpae	- 1,200 metre ASL
	- Highland areas
	- Average temperature
	  - High 27.8 ^{o}C
	  - Low 14.5 ^{o}C
	  - Mean 24.0 ^{o}C
	- Average rain fall 1,200 mm per year

Pangda	- 700 metre ASL
	- Slope 5-35 percent
	- Average temperature
	  - High 29.2 ^{o}C
	  - Low 18.5 ^{o}C
	  - Mean 23.2 ^{o}C
	- Average rain fall 1,254.4 mm per year

Sources: 1. http://agronomy.agri.cmu.ac.th/meteo/royal_page.html (27 August 2007)

2. Division of Highland Agriculture Development. 1997. The data of Royal Development Centers in 1997. Ministry of Agriculture and Cooperatives.

B2. Temperature and rainfall data recorded at Pangda, Khunpae and Inthanon stations, in 2005 and 2006 growing seasons.

Month	Pangda station			Khunpae station			Inthanon station		
	Temperature (^oC)		Rain	Temperature (^oC)		Rain	Temperature (^oC)		Rain
	Max	Min	(mm)	Max	Min	(mm)	Max	Min	(mm)
				2005 growing season					
AUG	28.0	21.2	285.2	25.1	19.3	170.4	24.9	19.1	266.4
SEP	28.2	20.0	586.1	26.9	19.8	356.6	24.6	18.6	585.2
OCT	28.6	19.4	102.8	28.0	17.5	64.8	23.9	17.8	148.2
NOV	27.7	17.5	102.0	27.2	16.1	69.7	24.2	15.3	32.1
DEC	24.5	14.9	19.4	26.1	13.3	24.8	23.1	12.9	18.8
				2006 growing season					
AUG	28.3	21.3	243.1	27.6	18.4	164.5	24.6	19.5	238.9
SEP	28.4	20.5	304.2	29.2	18.3	304.3	24.1	18.4	574.7
OCT	28.5	19.2	203.6	29.0	18.5	145.7	25.7	16.9	207.2
NOV	28.7	15.2	0.0	28.7	16.9	0.0	24.9	14.4	0.0
DEC	25.9	12.4	0.0	26.6	12.5	0.0	22.9	12.3	0.0

APPENDIX C

Example of DIALLEL-SAS program for analyzing the diallel cross (Zhang and Kang, 2003). Data for seed yield per plant of azuki bean, grown on three highland locations in 2005 growing season.

```
data method2;title 'yield-2005';
input i j rep hybrid yield env;
drop n ni nj p;
p=4; *number of parental lines;
array gca(n) g1 g2 g3;
do n=1 to (p-1);
gca=((i=n)-(i=p))+((j=n)-(j=p));
end;
array sca(n) s11 s12 s13 s22 s23 s33;
n=0;
do ni=1 to (p-1);
do nj=ni to (p-1);
n+1;
if ni=nj then do;
sca=(i=ni)*((j=nj)-(j=p)*2)+(i=p)*(j=p);end;
else do;
sca=(i=ni)*(j=nj)-(j=p)*((i=ni)+(i=nj)-(i=p));
end;end;end;
cards;
```

1	1	1	1	9.66	1
2	2	1	2	6.61	1
1	2	1	3	22.43	1
3	3	1	4	14.19	1
1	3	1	5	10.72	1
4	4	1	6	11.56	1
1	4	1	7	23.32	1

2	3	1	8	15.69	1
2	4	1	9	19.70	1
3	4	1	10	17.25	1
1	1	2	1	9.38	1
2	2	2	2	7.49	1
1	2	2	3	16.29	1
3	3	2	4	11.37	1
1	3	2	5	16.29	1
4	4	2	6	10.14	1
1	4	2	7	17.45	1
2	3	2	8	14.05	1
2	4	2	9	19.70	1
3	4	2	10	21.44	1
1	1	3	1	7.94	1
2	2	3	2	7.90	1
1	2	3	3	16.34	1
3	3	3	4	11.00	1
1	3	3	5	15.30	1
4	4	3	6	11.59	1
1	4	3	7	27.20	1
2	3	3	8	8.77	1
2	4	3	9	20.19	1
3	4	3	10	20.32	1
1	1	4	1	6.42	1
2	2	4	2	7.35	1
1	2	4	3	19.02	1
3	3	4	4	11.26	1
1	3	4	5	13.28	1
4	4	4	6	9.51	1
1	4	4	7	27.77	1
2	3	4	8	10.29	1
2	4	4	9	19.01	1
3	4	4	10	19.73	1
1	1	1	1	13.89	2
2	2	1	2	13.54	2
1	2	1	3	15.23	2
3	3	1	4	15.13	2
1	3	1	5	16.82	2
4	4	1	6	14.04	2
1	4	1	7	27.12	2
2	3	1	8	16.53	2
2	4	1	9	20.18	2
3	4	1	10	21.81	2
1	1	2	1	16.36	2
2	2	2	2	13.40	2
1	2	2	3	15.01	2
3	3	2	4	19.59	2

1	3	2	5	16.54	2
4	4	2	6	17.51	2
1	4	2	7	28.83	2
2	3	2	8	16.91	2
2	4	2	9	37.48	2
3	4	2	10	14.19	2
1	1	3	1	17.62	2
2	2	3	2	17.62	2
1	2	3	3	26.65	2
3	3	3	4	19.22	2
1	3	3	5	23.42	2
4	4	3	6	15.59	2
1	4	3	7	23.83	2
2	3	3	8	18.68	2
2	4	3	9	22.62	2
3	4	3	10	26.50	2
1	1	4	1	16.23	2
2	2	4	2	17.32	2
1	2	4	3	26.41	2
3	3	4	4	20.50	2
1	3	4	5	17.42	2
4	4	4	6	17.81	2
1	4	4	7	29.75	2
2	3	4	8	24.14	2
2	4	4	9	18.77	2
3	4	4	10	27.07	2
1	1	1	1	9.23	3
2	2	1	2	9.31	3
1	2	1	3	17.94	3
3	3	1	4	11.74	3
1	3	1	5	17.11	3
4	4	1	6	6.20	3
1	4	1	7	13.67	3
2	3	1	8	15.29	3
2	4	1	9	12.98	3
3	4	1	10	19.33	3
1	1	2	1	10.63	3
2	2	2	2	10.89	3
1	2	2	3	18.51	3
3	3	2	4	11.28	3
1	3	2	5	13.00	3
4	4	2	6	8.91	3
1	4	2	7	21.18	3
2	3	2	8	13.19	3
2	4	2	9	16.13	3
3	4	2	10	17.90	3
1	1	3	1	10.01	3

```
2	2	3	2	11.36	3
1	2	3	3	17.78	3
3	3	3	4	12.70	3
1	3	3	5	15.99	3
4	4	3	6	8.63	3
1	4	3	7	17.73	3
2	3	3	8	13.31	3
2	4	3	9	13.82	3
3	4	3	10	16.60	3
1	1	4	1	11.41	3
2	2	4	2	11.39	3
1	2	4	3	16.68	3
3	3	4	4	12.47	3
1	3	4	5	22.52	3
4	4	4	6	8.32	3
1	4	4	7	15.70	3
2	3	4	8	11.56	3
2	4	4	9	16.54	3
3	4	4	10	17.58	3
;
proc sort;by rep env i j;
proc glm;class rep env hybrid;model yield=env rep(env)
hybrid hybrid*env;test h=hybrid e=hybrid*env;
lsmeans hybrid;
proc glm;class rep env hybrid;
model yield=env rep(env) g1 g2 g3 s11 s12 s13 s22 s23 s33
 g1*env g2*env g3*env s11*env s12*env s13*env s22*env
s23*env s33*env;
contrast 'gca' g1 1, g2 1, g3 1;
contrast 'sca' s11 1, s12 1, s13 1, s22 1, s23 1, s33 1;
estimate 'g1' g1 1;estimate 'g2' g2 1;estimate 'g3' g3 1;
estimate 'g4' g1 -1 g2 -1 g3 -1;
estimate 's11' s11 1; estimate 's12' s12 1; estimate 's13' s13 1;
estimate 's14' s11 -1 s12 -1 s13 -1;
estimate 's22' s22 1; estimate 's23' s23 1;
estimate 's24' s12 -1 s22 -1 s23 -1;
estimate 's33' s33 1;
estimate 's34' s13 -1 s23 -1 s33 -1;
```

```
estimate 's44' s11 1 s12 2 s13 2 s22 1 s23 2 s33 1;
contrast 'gca*env' g1*env 1 -1,g2*env 1 -1,g3*env 1 -1;
contrast 'sca*env' s11*env 1 -1,s12*env 1 -1,s13*env 1 -1,s22*env 1 -1,s23*env 1 -
1,s33*env 1 -1;
run;
```

Output

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The GLM Procedure

Class Level Information

Class	Levels	Values
rep	4	1 2 3 4
env	3	1 2 3
hybrid	10	1 2 3 4 5 6 7 8 9 10

Number of observations 120

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The GLM Procedure

Dependent Variable: yield

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	38	3086.329560	81.219199	8.62	<.0001
Error	81	763.573720	9.426836		
Corrected Total	119	3849.903280			

R-Square	Coeff Var	Root MSE	yield Mean
0.801664	19.00418	3.070315	16.15600

Source	DF	Type I SS	Mean Square	F Value	Pr > F
env	2	865.572560	432.786280	45.91	<.0001
rep(env)	9	116.331380	12.925709	1.37	0.2149
hybrid	9	1819.569263	202.174363	21.45	<.0001
env*hybrid	18	284.856357	15.825353	1.68	0.0605

Source	DF	Type III SS	Mean Square	F Value	Pr > F
env	2	865.572560	432.786280	45.91	<.0001
rep(env)	9	116.331380	12.925709	1.37	0.2149
hybrid	9	1819.569263	202.174363	21.45	<.0001
env*hybrid	18	284.856357	15.825353	1.68	0.0605

Tests of Hypotheses Using the Type III MS for env*hybrid as an Error Term

Source	DF	Type III SS	Mean Square	F Value	Pr > F
hybrid	9	1819.569263	202.174363	12.78	<.0001

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The GLM Procedure

Least Squares Means

hybrid	yield LSMEAN
1	11.5650000
2	11.1816667
3	19.0241667
4	14.2041667
5	16.5341667
6	11.6508333
7	22.7958333
8	14.8675000
9	19.7600000
10	19.9766667

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The GLM Procedure

Class Level Information

Class	Levels	Values
rep	4	1 2 3 4
env	3	1 2 3
hybrid	10	1 2 3 4 5 6 7 8 9 10

Number of observations 120

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The GLM Procedure

Dependent Variable: yield

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	38	3086.329560	81.219199	8.62	<.0001
Error	81	763.573720	9.426836		
Corrected Total	119	3849.903280			

R-Square	Coeff Var	Root MSE	yield Mean
0.801664	19.00418	3.070315	16.15600

Source	DF	Type I SS	Mean Square	F Value	Pr > F
env	2	865.572560	432.786280	45.91	<.0001
rep(env)	9	116.331380	12.925709	1.37	0.2149
g1	1	18.922500	18.922500	2.01	0.1604
g2	1	77.911045	77.911045	8.26	0.0052
g3	1	2.631230	2.631230	0.28	0.5987
s11	1	1001.355835	1001.355835	106.22	<.0001
s12	1	2.304641	2.304641	0.24	0.6223
s13	1	53.170605	53.170605	5.64	0.0199
s22	1	541.573340	541.573340	57.45	<.0001
s23	1	42.897852	42.897852	4.55	0.0359
s33	1	78.802216	78.802216	8.36	0.0049
g1*env	2	63.795863	31.897931	3.38	0.0388
g2*env	2	32.164542	16.082271	1.71	0.1880
g3*env	2	20.387604	10.193802	1.08	0.3440
s11*env	2	56.479453	28.239726	3.00	0.0556
s12*env	2	25.849052	12.924526	1.37	0.2597
s13*env	2	5.132453	2.566226	0.27	0.7624
s22*env	2	32.362162	16.181081	1.72	0.1862
s23*env	2	21.811804	10.905902	1.16	0.3196
s33*env	2	26.873425	13.436713	1.43	0.2464

Source	DF	Type III SS	Mean Square	F Value	Pr > F
env	2	865.5725600	432.7862800	45.91	<.0001
rep(env)	9	116.3313800	12.9257089	1.37	0.2149
g1	1	1.3222685	1.3222685	0.14	0.7090
g2	1	60.5472667	60.5472667	6.42	0.0132
g3	1	2.6312296	2.6312296	0.28	0.5987
s11	1	698.6278490	698.6278490	74.11	<.0001
s12	1	205.6390046	205.6390046	21.81	<.0001

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The GLM Procedure

Dependent Variable: yield

Source	DF	Type III SS	Mean Square	F Value	Pr > F
s13	1	2.9746440	2.9746440	0.32	0.5758
s22	1	343.9498800	343.9498800	36.49	<.0001
s23	1	1.7688244	1.7688244	0.19	0.6660
s33	1	78.8022156	78.8022156	8.36	0.0049
g1*env	2	7.4745481	3.7372741	0.40	0.6740
g2*env	2	16.1854111	8.0927056	0.86	0.4276
g3*env	2	20.3876037	10.1938019	1.08	0.3440
s11*env	2	35.3166252	17.6583126	1.87	0.1602
s12*env	2	34.2927050	17.1463525	1.82	0.1688
s13*env	2	28.7545111	14.3772555	1.53	0.2238
s22*env	2	24.0547706	12.0273853	1.28	0.2847
s23*env	2	2.5270762	1.2635381	0.13	0.8748
s33*env	2	26.8734252	13.4367126	1.43	0.2464

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
gca	3	99.464775	33.154925	3.52	0.0187
sca	6	1720.104488	286.684081	30.41	<.0001
gca*env	3	11.761738	3.920579	0.42	0.7420
sca*env	6	63.401818	10.566970	1.12	0.3576
[1/]gca*env	**6**	**116.348009**	**19.391335**	**2.06**	**0.0674**
[2/]sca*env	**12**	**168.508349**	**14.042362**	**1.49**	**0.1451**

Parameter	Estimate	Standard Error	t Value	Pr > |t|
g1	0.11736111	0.31336274	0.37	0.7090
g2	-0.79416667	0.31336274	-2.53	0.0132
g3	-0.16555556	0.31336274	-0.53	0.5987
g4	0.84236111	0.31336274	2.69	0.0087
s11	-4.82572222	0.56056032	-8.61	<.0001
s12	3.54497222	0.75900226	4.67	<.0001
s13	0.42636111	0.75900226	0.56	0.5758
s14	0.85438889	0.68654337	1.24	0.2169
s22	-3.38600000	0.56056032	-6.04	<.0001
s23	-0.32877778	0.75900226	-0.43	0.6660
s24	0.16980556	0.68654337	0.25	0.8053
s33	-1.62072222	0.56056032	-2.89	0.0049
s34	1.52313889	0.68654337	2.22	0.0293
s44	-2.54733333	1.37308675	-1.86	0.0672

[1/] **Actual contrast SS was calculated by formula:**

gca*env SS = g1*env + g2*env + g3*env (from type I SS)

[2/] **Actual contrast SS was calculated by formula:**

sca*env SS = s11*env + s12*env + s13*env +
s22*env + s23*env + s33*env (from type I SS)

APPENDIX D

Generation Mean Analysis

Example D.1

Generation mean analysis (additive-dominance model), using the Mather and Jinks (1982) method. Data for seed yield per plant of K x H cross, grown on Inthanon Station, (in 2005).

$M = J^{-1} \times S$

$J = B_1' \times B$

$S = B_1' \times C$

$V = D \times V_1$

$SE = \sqrt{V}$

Where, M is the matrix of the parameters

J is the information matrix

B is the matrix of parameter coefficients

B_1 is the matrix of weight

S is the matrix of score

C is the matrix of six generation means

V is the matrix of parameter variances

V_1 is the matrix of six generation variances

D is the matrix of squared elements of the matrix $[J^{-1} \times B_1']$

SE is the standard error of parameters

$$M = \begin{bmatrix} m \\ d \\ h \end{bmatrix}$$

$$B = \begin{bmatrix} 1 & 1 & 0 \\ 1 & -1 & 0 \\ 1 & 0 & 1 \\ 1 & 0 & 0.5 \\ 1 & 0.5 & 0.5 \\ 1 & -0.5 & 0.5 \end{bmatrix}$$

$$B_1 = \begin{bmatrix} 5.48 & 5.48 & 0.00 \\ 4.68 & -4.68 & 0.00 \\ 0.44 & 0.00 & 0.44 \\ 3.26 & 0.00 & 1.63 \\ 0.76 & 0.38 & 0.38 \\ 0.59 & -0.30 & 0.30 \end{bmatrix}$$

$$C = \begin{bmatrix} \overline{P}_1 \\ \overline{P}_2 \\ \overline{F}_1 \\ \overline{F}_2 \\ \overline{BC}_1 \\ \overline{BC}_2 \end{bmatrix} = \begin{bmatrix} 8.52 \\ 8.36 \\ 18.62 \\ 12.49 \\ 12.91 \\ 11.57 \end{bmatrix} ; \quad V_1 = \begin{bmatrix} V\overline{P}_1 \\ V\overline{P}_2 \\ V\overline{F}_1 \\ V\overline{F}_2 \\ V\overline{BC}_1 \\ V\overline{BC}_2 \end{bmatrix} = \begin{bmatrix} 0.18 \\ 0.21 \\ 2.27 \\ 0.31 \\ 1.32 \\ 1.68 \end{bmatrix}$$

$$J = B_1' \times B = \begin{bmatrix} 5.48 & 4.68 & 0.44 & 3.26 & 0.76 & 0.59 \\ 5.48 & -4.68 & 0.00 & 0.00 & 0.38 & -0.30 \\ 0.00 & 0.00 & 0.44 & 1.63 & 0.38 & 0.30 \end{bmatrix} \text{X} \begin{bmatrix} 1 & 1 & 0 \\ 1 & -1 & 0 \\ 1 & 0 & 1 \\ 1 & 0 & 0.5 \\ 1 & 0.5 & 0.5 \\ 1 & -0.5 & 0.5 \end{bmatrix}$$

$$J = \begin{bmatrix} 15.21 & 0.88 & 2.74 \\ 0.88 & 10.50 & 0.04 \\ 2.74 & 0.04 & 1.59 \end{bmatrix} \quad ; \quad J^{-1} = \begin{bmatrix} 0.10 & -0.01 & -0.17 \\ -0.01 & 0.10 & 0.01 \\ -0.17 & 0.01 & 0.91 \end{bmatrix}$$

$$S = B_1' \text{ x } C = \begin{bmatrix} 5.48 & 4.68 & 0.44 & 3.26 & 0.76 & 0.59 \\ 5.48 & -4.68 & 0.00 & 0.00 & 0.38 & -0.30 \\ 0.00 & 0.00 & 0.44 & 1.63 & 0.38 & 0.30 \end{bmatrix} \text{ x } \begin{bmatrix} 8.52 \\ 8.36 \\ 18.62 \\ 12.49 \\ 12.91 \\ 11.57 \end{bmatrix}$$

$$S = \begin{bmatrix} 151.31 \\ 9.02 \\ 36.85 \end{bmatrix}$$

$$M = J^{-1} \text{ x } S = \begin{bmatrix} 0.10 & -0.01 & -0.17 \\ -0.01 & 0.10 & 0.01 \\ -0.17 & 0.01 & 0.91 \end{bmatrix} \text{ x } \begin{bmatrix} 151.31 \\ 9.02 \\ 36.85 \end{bmatrix} = \begin{bmatrix} 8.37 \\ 0.12 \\ 8.72 \end{bmatrix}$$

$$J^{-1} \text{ x } B_1' = \begin{bmatrix} 0.10 & -0.01 & -0.17 \\ -0.01 & 0.10 & 0.01 \\ -0.17 & 0.01 & 0.91 \end{bmatrix} \text{ x } \begin{bmatrix} 5.48 & 4.68 & 0.44 & 3.26 & 0.76 & 0.59 \\ 5.48 & -4.68 & 0.00 & 0.00 & 0.38 & -0.30 \\ 0.00 & 0.00 & 0.44 & 1.63 & 0.38 & 0.30 \end{bmatrix}$$

$$J^{-1} \text{ x } B_1' = \begin{bmatrix} 0.49 & 0.48 & -0.03 & 0.04 & 0.01 & 0.01 \\ 0.48 & -0.48 & 0.00 & -0.01 & 0.03 & -0.03 \\ -0.85 & -0.82 & 0.33 & 0.95 & 0.22 & 0.17 \end{bmatrix}$$

$$D = \begin{bmatrix} 0.24 & 0.23 & 0.00 & 0.00 & 0.00 & 0.00 \\ 0.23 & 0.23 & 0.00 & 0.00 & 0.00 & 0.00 \\ 0.72 & 0.68 & 0.11 & 0.90 & 0.05 & 0.03 \end{bmatrix}$$

$$V = D \times V_1 = \begin{bmatrix} 0.24 & 0.23 & 0.00 & 0.00 & 0.00 & 0.00 \\ 0.23 & 0.23 & 0.00 & 0.00 & 0.00 & 0.00 \\ 0.72 & 0.68 & 0.11 & 0.90 & 0.05 & 0.03 \end{bmatrix} \text{X} \begin{bmatrix} 0.18 \\ 0.21 \\ 2.27 \\ 0.31 \\ 1.32 \\ 1.68 \end{bmatrix}$$

$$V = \begin{bmatrix} 0.10 \\ 0.10 \\ 0.91 \end{bmatrix} \quad ; \quad SE = \begin{bmatrix} 0.31 \\ 0.31 \\ 0.96 \end{bmatrix}$$

Example D.2

Generation mean analysis (non-allelic interaction model, six parameters, approach by Hayman, 1958). Data for seed yield per plant of A x E cross, grown on Pangda Station, (in 2005).

$$M = B^{-1} \times C$$
$$V = E \times V_1$$
$$SE = \sqrt{V}$$

Where, M is the matrix of the parameters

B is the matrix of parameter coefficients

C is the matrix of six generation means

V is the matrix of parameter variances

V_1 is the matrix of six generation variances

E is the matrix of squared elements of the matrix $[B^{-1}]$

SE is the standard error of parameters

$$M = \begin{bmatrix} m \\ d \\ h \\ i \\ j \\ l \end{bmatrix}$$

$$B = \begin{bmatrix} 1 & 1 & -0.5 & 1 & -1 & 0.25 \\ 1 & -1 & -0.5 & 1 & 1 & 0.25 \\ 1 & 0 & 0.5 & 0 & 0 & 0.25 \\ 1 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0.5 & 0 & 0.25 & 0 & 0 \\ 1 & -0.5 & 0 & 0.25 & 0 & 0 \end{bmatrix}$$

$$B^{-1} = \begin{bmatrix} 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & -1 \\ -0.5 & -0.5 & 1 & -4 & 2 & 2 \\ 0 & 0 & 0 & -4 & 2 & 2 \\ -0.5 & 0.5 & 0 & 0 & 1 & -1 \\ 1 & 1 & 2 & 4 & -4 & -4 \end{bmatrix}$$

$$C = \begin{bmatrix} \overline{P}_1 \\ \overline{P}_2 \\ \overline{F}_1 \\ \overline{F}_2 \\ \overline{BC}_1 \\ \overline{BC}_2 \end{bmatrix} = \begin{bmatrix} 11.62 \\ 9.30 \\ 17.64 \\ 12.92 \\ 20.70 \\ 15.04 \end{bmatrix} ; \quad V_1 = \begin{bmatrix} V\overline{P}_1 \\ V\overline{P}_2 \\ V\overline{F}_1 \\ V\overline{F}_2 \\ V\overline{BC}_1 \\ V\overline{BC}_2 \end{bmatrix} = \begin{bmatrix} 0.15 \\ 0.23 \\ 0.64 \\ 0.25 \\ 2.05 \\ 1.59 \end{bmatrix}$$

$$M = B^{-1} \times C = \begin{bmatrix} 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & -1 \\ -0.5 & -0.5 & 1 & -4 & 2 & 2 \\ 0 & 0 & 0 & -4 & 2 & 2 \\ -0.5 & 0.5 & 0 & 0 & 1 & -1 \\ 1 & 1 & 2 & 4 & -4 & -4 \end{bmatrix} \times \begin{bmatrix} 11.62 \\ 9.30 \\ 17.64 \\ 12.92 \\ 20.70 \\ 15.04 \end{bmatrix}$$

$$M = \begin{bmatrix} 12.92 \\ 5.66 \\ 26.95 \\ 19.77 \\ 4.50 \\ -35.02 \end{bmatrix}$$

$$E = \begin{bmatrix} 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 1 \\ 0.25 & 0.25 & 1 & 16 & 4 & 4 \\ 0 & 0 & 0 & 16 & 4 & 4 \\ 0.25 & 0.25 & 0 & 0 & 1 & 1 \\ 1 & 1 & 4 & 16 & 16 & 16 \end{bmatrix}$$

$$V = E \times V_1 = \begin{bmatrix} 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 1 \\ 0.25 & 0.25 & 1 & 16 & 4 & 4 \\ 0 & 0 & 0 & 16 & 4 & 4 \\ 0.25 & 0.25 & 0 & 0 & 1 & 1 \\ 1 & 1 & 4 & 16 & 16 & 16 \end{bmatrix} \times \begin{bmatrix} 0.15 \\ 0.23 \\ 0.64 \\ 0.25 \\ 2.05 \\ 1.59 \end{bmatrix}$$

$$V = \begin{bmatrix} 0.25 \\ 3.64 \\ 19.30 \\ 18.56 \\ 3.73 \\ 65.16 \end{bmatrix} \quad ; \quad SE = \begin{bmatrix} 0.50 \\ 1.91 \\ 4.39 \\ 4.31 \\ 1.93 \\ 8.07 \end{bmatrix}$$

Example D.3

Generation mean analysis, non-allelic interaction model, omitting parameter(s) were not significance differed from zero, calculated by least square method (Hayman, 1958). Data for seed yield per plant of K x A cross, grown on Inthanon Station, (in 2005).

$$M = (B' \times B)^{-1} \times (B' \times C)$$

$$V = F \times V_1$$

$$SE = \sqrt{V}$$

Where, M is the matrix of the parameters

B is the matrix of parameter coefficients

C is the matrix of six generation means

V is the matrix of parameter variances

V_1 is the matrix of six generation variances

F is the matrix of squared elements of the matrix $[(B' \times B)^{-1} \times (B')]$

SE is the standard error of parameters

$$M = \begin{bmatrix} m \\ d \\ h \\ i \\ l \end{bmatrix}$$

$$B = \begin{bmatrix} 1 & 1 & -0.5 & 1 & 0.25 \\ 1 & -1 & -0.5 & 1 & 0.25 \\ 1 & 0 & 0.5 & 0 & 0.25 \\ 1 & 0 & 0 & 0 & 0 \\ 1 & 0.5 & 0 & 0.25 & 0 \\ 1 & -0.5 & 0 & 0.25 & 0 \end{bmatrix}$$

$$B' = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & -1 & 0 & 0 & 0.5 & -0.5 \\ -0.5 & -0.5 & 0.5 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 & 0.25 & 0.25 \\ 0.25 & 0.25 & 0.25 & 0 & 0 & 0 \end{bmatrix}$$

$$C = \begin{bmatrix} \overline{P}_1 \\ \overline{P}_2 \\ \overline{F}_1 \\ \overline{F}_2 \\ \overline{BC}_1 \\ \overline{BC}_2 \end{bmatrix} = \begin{bmatrix} 7.79 \\ 10.56 \\ 14.37 \\ 9.39 \\ 11.46 \\ 15.12 \end{bmatrix} ; \quad V_1 = \begin{bmatrix} V\overline{P}_1 \\ V\overline{P}_2 \\ V\overline{F}_1 \\ V\overline{F}_2 \\ V\overline{BC}_1 \\ V\overline{BC}_2 \end{bmatrix} = \begin{bmatrix} 0.23 \\ 0.20 \\ 1.61 \\ 0.23 \\ 0.99 \\ 1.44 \end{bmatrix}$$

$$B' \times B = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & -1 & 0 & 0 & 0.5 & -0.5 \\ -0.5 & -0.5 & 0.5 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 & 0.25 & 0.25 \\ 0.25 & 0.25 & 0.25 & 0 & 0 & 0 \end{bmatrix} \times \begin{bmatrix} 1 & 1 & -0.5 & 1 & 0.25 \\ 1 & -1 & -0.5 & 1 & 0.25 \\ 1 & 0 & 0.5 & 0 & 0.25 \\ 1 & 0 & 0 & 0 & 0 \\ 1 & 0.5 & 0 & 0.25 & 0 \\ 1 & -0.5 & 0 & 0.25 & 0 \end{bmatrix}$$

$$B' \times B = \begin{bmatrix} 6 & 0 & -0.5 & 2.5 & 0.8 \\ 0 & 2.5 & 0 & 0 & 0 \\ -1 & 0 & 0.75 & -1 & -0.1 \\ 2.5 & 0 & -1 & 2.1 & 0.5 \\ 0.8 & 0 & -0.1 & 0.5 & 0.2 \end{bmatrix}$$

$$(B' \times B)^{-1} = \begin{bmatrix} 1 & 0 & -4 & -4 & 4 \\ 0 & 0.4 & 0 & 0 & 0 \\ -4 & 0 & 25.5 & 24 & -31 \\ -4 & 0 & 24 & 24 & -32 \\ 4 & 0 & -31 & -32 & 54 \end{bmatrix}$$

$$B' \times C = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & -1 & 0 & 0 & 0.5 & -0.5 \\ -0.5 & -0.5 & 0.5 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 & 0.25 & 0.25 \\ 0.25 & 0.25 & 0.25 & 0 & 0 & 0 \end{bmatrix} \times \begin{bmatrix} 7.79 \\ 10.56 \\ 14.37 \\ 9.39 \\ 11.46 \\ 15.12 \end{bmatrix}$$

$$B' \times C = \begin{bmatrix} 68.69 \\ -4.60 \\ -2.00 \\ 25.00 \\ 8.18 \end{bmatrix}$$

$$M = (B' \times B)^{-1} \times (B' \times C) = \begin{bmatrix} 1 & 0 & -4 & -4 & 4 \\ 0 & 0.4 & 0 & 0 & 0 \\ -4 & 0 & 25.5 & 24 & -31 \\ -4 & 0 & 24 & 24 & -32 \\ 4 & 0 & -31 & -32 & 54 \end{bmatrix} \times \begin{bmatrix} 68.69 \\ -4.60 \\ -2.00 \\ 25.00 \\ 8.18 \end{bmatrix}$$

$$M = \begin{bmatrix} 9.39 \\ -1.84 \\ 20.78 \\ 15.59 \\ -21.66 \end{bmatrix}$$

$$(B' \times B)^{-1} \times B' = \begin{bmatrix} 1 & 0 & -4 & -4 & 4 \\ 0 & 0.4 & 0 & 0 & 0 \\ -4 & 0 & 25.5 & 24 & -31 \\ -4 & 0 & 24 & 24 & -32 \\ 4 & 0 & -31 & -32 & 54 \end{bmatrix} \times \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & -1 & 0 & 0 & 0.5 & -0.5 \\ -0.5 & -0.5 & 0.5 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 & 0.25 & 0.25 \\ 0.25 & 0.25 & 0.25 & 0 & 0 & 0 \end{bmatrix}$$

$$(B' \times B)^{-1} \times B' = \begin{bmatrix} 0 & 0 & 0 & 1 & 0 & 0 \\ 0.4 & -0.4 & 0 & 0 & 0.2 & -0.2 \\ -0.5 & -0.5 & 1 & -4 & 2 & 2 \\ 0 & 0 & 0 & -4 & 2 & 2 \\ 1 & 1 & 2 & 4 & -4 & -4 \end{bmatrix}$$

$$F = \begin{bmatrix} 0 & 0 & 0 & 1 & 0 & 0 \\ 0.16 & 0.16 & 0 & 0 & 0.04 & 0.04 \\ 0.25 & 0.25 & 1 & 16 & 4 & 4 \\ 0 & 0 & 0 & 16 & 4 & 4 \\ 1 & 1 & 4 & 16 & 16 & 16 \end{bmatrix}$$

$$V = F \times V_1 = \begin{bmatrix} 0 & 0 & 0 & 1 & 0 & 0 \\ 0.16 & 0.16 & 0 & 0 & 0.04 & 0.04 \\ 0.25 & 0.25 & 1 & 16 & 4 & 4 \\ 0 & 0 & 0 & 16 & 4 & 4 \\ 1 & 1 & 4 & 16 & 16 & 16 \end{bmatrix} \times \begin{bmatrix} 0.23 \\ 0.20 \\ 1.61 \\ 0.23 \\ 0.99 \\ 1.44 \end{bmatrix}$$

$$V = \begin{bmatrix} 0.23 \\ 0.17 \\ 15.08 \\ 13.36 \\ 49.36 \end{bmatrix} \quad ; \quad SE = \begin{bmatrix} 0.48 \\ 0.41 \\ 3.88 \\ 3.66 \\ 7.03 \end{bmatrix}$$

APPENDIX E

Generation Variance Analysis

Example Generation variance analysis is evaluated by using Kearsey and Pooni (1996) method. Data from seed yield per plant of K x H cross grown on Inthanon Station, in 2005.

$$C = (A' \times A)^{-1} \times (A' \times B)$$

Where, A is the matrix of parameter coefficients

B is the matrix of six generation variances

C is the matrix of the parameter of variances

$$C = \begin{bmatrix} VE \\ VA \\ VD \\ VAD \end{bmatrix}$$

$$A = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 1 & 1 & 1 & 0 \\ 1 & 0.5 & 1 & -1 \\ 1 & 0.5 & 1 & 1 \end{bmatrix}$$

$$B = \begin{bmatrix} VP_1 \\ VP_2 \\ VF_1 \\ VF_2 \\ VBC_1 \\ VBC_2 \end{bmatrix} = \begin{bmatrix} 8.58 \\ 11.76 \\ 11.37 \\ 17.50 \\ 13.19 \\ 15.14 \end{bmatrix}$$

$$A' = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 \\ 0 & 0 & 0 & 1 & 0.5 & 0.5 \\ 0 & 0 & 0 & 1 & 1 & 1 \\ 0 & 0 & 0 & 0 & -1 & 1 \end{bmatrix}$$

$$A' \times A = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 \\ 0 & 0 & 0 & 1 & 0.5 & 0.5 \\ 0 & 0 & 0 & 1 & 1 & 1 \\ 0 & 0 & 0 & 0 & -1 & 1 \end{bmatrix} \times \begin{bmatrix} 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 1 & 1 & 1 & 0 \\ 1 & 0.5 & 1 & -1 \\ 1 & 0.5 & 1 & 1 \end{bmatrix}$$

$$A' \times A = \begin{bmatrix} 6 & 2 & 3 & 0 \\ 2 & 1.5 & 2 & 0 \\ 3 & 2 & 3 & 0 \\ 0 & 0 & 0 & 2 \end{bmatrix}$$

$$(A' \times A)^{-1} = \begin{bmatrix} 0.33 & 0 & -0.33 & 0 \\ 0 & 6 & -4 & 0 \\ -0.33 & -4 & 0.33 & 0 \\ 0 & 0 & 0 & 0.5 \end{bmatrix}$$

$$A' \times B = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 \\ 0 & 0 & 0 & 1 & 0.5 & 0.5 \\ 0 & 0 & 0 & 1 & 1 & 1 \\ 0 & 0 & 0 & 0 & -1 & 1 \end{bmatrix} \times \begin{bmatrix} 8.58 \\ 11.76 \\ 11.37 \\ 17.50 \\ 13.19 \\ 15.14 \end{bmatrix}$$

$$A' \times B = \begin{bmatrix} 77.55 \\ 31.67 \\ 45.84 \\ 1.95 \end{bmatrix}$$

$$C = (A' \times A)^{-1} \times (A' \times B) = \begin{bmatrix} 0.33 & 0 & -0.33 & 0 \\ 0 & 6 & -4 & 0 \\ -0.33 & -4 & 0.33 & 0 \\ 0 & 0 & 0 & 0.5 \end{bmatrix} \times \begin{bmatrix} 77.55 \\ 31.67 \\ 45.84 \\ 1.95 \end{bmatrix}$$

$$C = \begin{bmatrix} 10.57 \\ 6.67 \\ 0.27 \\ 0.98 \end{bmatrix}$$

CURRICULUM VITAE

Name: Mr. Weerapun Kunkaew

Birth: 14 November 1974, Nan Province, Thailand.

Academic record:

Degree/Certificate	Area of concentration	Year	Institution
Ph.D. (Agronomy)	Plant breeding†	2007	Chiang Mai University, Thailand
M.S. (Agriculture)	Plant breeding‡	2005	Chiang Mai University, Thailand
B.S. (Agriculture)	Agronomy	1996	Chiang Mai University, Thailand
High School	Science programme	1992	Srisawatwittayakarn School, Nan Province, Thailand

† Thesis title "Genetic Control of Yield and Yield Components in Azuki Bean Under Highland Growing Conditions"

‡ Thesis title " Heterosis and Combining Ability in Azuki Bean (*Vigna angularis* [Willd.] Ohwi and Ohashi) "

Work experiences:

1997-present, researcher, The Royal Project Foundation, Chiang Mai, Thailand

Publications and papers:

1. Weerapun Kunkaew, Suthat Julsrigival, Narong Boonkaew, Vimol Punsupa, and Chen Keng Feng. 2004. Yield stability of azuki bean grown under highland conditions. *Royal Project Journal* 8(5):6-9.

2. Weerapun Kunkaew, Suthat Julsrigival, Chuckree Senthong and Dumnern Karladee. 2006. Estimation of heterosis and combining ability in azukibean under highland growing conditions in Thailand. *Chiang Mai University Journal* 5(2):163-168.
3. Weerapun Kunkaew, Suthat Julsrigival, Chuckree Senthong and Dumnern Karladee. 2007. Combining ability analysis of yield and yield components in azukibean under highland conditions of northern Thailand. *Chiang Mai University Journal of Natural Sciences* 6(1):121-126.
4. Weerapun Kunkaew, Suthat Julsrigival, Chuckree Senthong and Dumnern Karladee. 2007. Inheritance of seed yield in azuki bean [*Vigna angularis* (Willd.) Ohwi and Ohashi]. *Chiang Mai University Journal of Natural Sciences* (In press).