Selection for Quality Traits in Vegetable Soybean

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Abstract

The quality of vegetable soybean is judged by both morphological and chemical traits. The objectives of the present study were to estimate the 1. genotype-environment (GxE) interactions and 2. the broad-sense heritabilities of graded pod yield, days to harvest, 100-green bean weight, sugar content and pod color value in vegetable soybean. This information will be useful for breeding adapted vegetable soybeans in Taiwan. F_6- and F_7-derived lines were evaluated in replicated trial in spring, summer and autumn seasons from 1996 to 1999. Lines evaluated in trials differed among years. Results showed that variation in graded pod yield, days to harvest, sugar content and pod color value were mostly due to season and season by genotype (SxG) interactions. However, variation due to genotype accounted for most variation in certain sets of selections and years. Most of the variation in 100 green bean weight was due to genotype. Broad sense-heritability estimates for 100 green bean weight (0.58 to 0.93), days to harvest (0.52 to 0.92) and sugar content (0.24 to 0.86) were fairly high, while heritability estimates for graded pod yield, and pod color values were low. A highly significant negative correlation of –0.50*** between sugar content and oil content was found. This is the first report of such a relationship in vegetable soybean. The correlation between protein content and sugar content was also largely negative but quite variable with seasons and years. Highly significant negative correlation was also found between sugar content and protein plus oil (-0.52***). Plant breeder can expect rapid progress from selection for 100 green bean weight and days to harvest. Selection for low oil content would result in higher sugar content.

Key words: Vegetable soybean, quality traits, sugar content, pod color, 100 green bean weight

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毛豆品質性狀的選育

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摘 要

毛豆外銷日本的規格必須符合毛豆莢外觀及豆仁及品質上的要求。本試驗的目的在決定1）基因型和環境間的交感作用，2）合格莢產量、收穫期、鮮百粒重、糖份及莢色等性狀的廣義遺傳率，以利於毛豆品種選育上的應用。由 F_6 及 F_7 中挑選所得的優良品系，在85至88年間進行兩重覆，每年三季的品交產量比較試驗調查合格莢產量、播種期、毛豆收穫期、鮮百粒重、種仁含糖量及莢色等性狀。結果顯示合格莢產量、含糖量及莢色的總變異量主要來自季節及季節和品系間的交感作用；鮮百粒重的總變異量則來自品系。相對於鮮百粒重，毛豆收穫期及含糖量的高遺傳率估值，合格莢產量和莢色的遺傳率估值則較低。含糖量和油份間有顯著的負相關，而蛋白質和含糖量間的負相關則在不同季節或年度有不同程度的顯著性。所以，在育種上可進行鮮百粒重及收穫期的有效選拔，而進行低油份品系的選拔則可獲得高含糖量的品系。

關鍵詞：毛豆、品質性狀、含糖量、莢色、百粒重

Introduction

Vegetable soybean export from Taiwan to Japan began in 1971. Prior to 1971 vegetable soybeans in Taiwan were normally shelled and marketed as fresh beans (Cheng 1991). Until 1990 Taiwan was the major exporter of vegetable soybeans to Japan. But due to increased labor cost, higher land value and appreciation of the Taiwan currency, the volume of vegetable soybean exported from Taiwan to Japan gradually decreased. To remain competitive and retain a reasonable share of the export market and expand the domestic market in Taiwan researchers at the Asian Vegetable Research and Development Center and the Taiwan National Agricultural Research System staff developed vegetable soybean production strategies in consultation with the processing and trading companies. The first was to reduce the cost of production by mechanizing the planting and harvesting operations. The second was to improve the quality of vegetable soybean from Taiwan. Therefore, the research focus for vegetable soybean varietal improvement since 1995 was improvement of quality traits and adaptation to mechanical harvest.

Vegetable soybean in Japan is consumed as a snack to go with drinks. Vegetable soybean quality in Japan can be broadly divided into two major areas, namely 1) morphological characters and 2) chemical composition. The morphological characters include large pod size; fresh, bright green pod color; gray pod pubescence and high percentage of two and three seed pods. The chemical composition can be divided into two areas, 1) eating quality and 2) nutrients. The eating quality consists of sweetness (high sugar content), good taste (called "umami" in Japanese and may be due to amino acid content), flavor, and texture. (Masuda, 1991; Shanmugasundaram et. al. 1991; Takahashi, 1991; Tsou and Hong, 1991). Vegetable soybeans have high total sugar, (sucrose, glucose and fructose) compared to grain soybean on a dry weight basis (Tsou and Hong 1991).

The objectives of the present study were to: 1) estimate the genotype x environment interaction and, 2) to estimate broad-sense heritabilities of graded pod yield, days to harvest, 100-green bean weight, sugar content and pod color in vegetable soybean. This information will be useful in breeding adapted vegetable soybeans.

Materials and Methods

Field Evaluation

Two hundred F_4 and F_5 lines each from 32 crosses were selected at random. The parents used in each cross from 1996 to 1999 are given in Table 1. Single F_6 or F_7 plants were selected and the lines derived from them were evaluated in pedigree rows. Each line represented a random sample of the population. Varying number of lines was included in a replicated evaluation trial in spring, summer and autumn seasons in 1996-1999. The details of number of lines, dates of planting and number of cross combinations from which the lines were made are given in Table 2. The lines evaluated differed among years. Due to continuous rain in 1999 summer (July and August) the summer crop could not be planted (Fig. 1).

All the experiments were conducted at the AVRDC experimental farm in Shanhua, Tainan, Taiwan. The plot size was 2m x 2m and the harvest plot size was 2m x 1m. Raised beds were made with a spacing of 1m from center of one bed to the center of next bed. Two rows were planted on each bed. Between row spacing was about 40cm and within row between plant spacing was 10cm. In spring and summer seasons two seeds were planted in each hill while in the autumn 3 seeds were planted per hill. The trials were conducted using a RCBD with two replications. AVRDC's suggested cultural practices were used in growing the crop (Shanmugasundaram and Yan 1998, unpublished).

The green pods were harvested at $R_{6.5}$ (Fehr et. al. 1971). The harvest date was recorded as the days to harvest from sowing. The two or more seeded good quality pods were separated and weighed as graded pod. From each replication, 100 green beans were randomly picked and weighed to get the 100-green bean weight.

Table 1. Parents of crosses from which lines were selected for evaluation.

Year	Cross No.	Parents
1996	GC 91032	KS 3 x [KS 1 x (Tzuzunoko x AGS 129)]
	GC 91033	KS 3 x (KS 1 x AGS 129)
	GC 91034	KS 3 x OCB
	GC 91035	Ryokkoh x SRE-D-14B
	GC 91036	Ryokkoh x OCB

	GC 91050	KS 1 x [(Vesoy 2 x PI 6302) x D62-7815]
	GC 92003	SRE-D-14B x TVB-5
	GC 92005	KS 1 x Neu Ta Pien 1
	GC 92006	OCB x Neu Ta Pien 1
1997	GC 91032	KS 3 x [KS 1 x (Tzuzunoko xc AGS 129)]
	GC 92005	KS 1 x Neu Ta Pien 1
	GC 93006	Ryokkoh x (Neu Ta Pien 1 x KS 3)
	GC 93012	Ryokkoh x (OCB x Neu Ta Pien 1)
	GC 93029	(Ryokkoh x Mikawashima) x KN 123
	GC 91033	KS 3 x (KS 1 x AGS 129)
	GC 91034	KS 3 x OCB
	GC 91035	Ryokkoh x SRE-D-14B
	GC 91036	Ryokkoh x OCB
	GC 91053	KS 3 x SRE-D-14B
	GC 92003	SRE-D-14B x TVB-5
	GC 93014	Ryokkoh x [(Ryokkoh x KS 8) x (Tanbaguro x Tzuzunoko)]
1998	GC 92004	SRE-D-14B x Kinshu
	GC 92005	KS 1 x Neu Ta Pien 1
	GC 93012	Ryokkoh x (OCB x Neu Ta Pien 1)
	GC 93028	(Ryokkoh x Mikawashima) x Tashu
	GC 93029	(Ryokkoh x Mikawashima) x KN 123
	GC 93037	[KS 1 x G 2120.M8(20-4)] x Kahori
	GC 94015	Ryokkoh x (OCB x Neu Ta Pien 1)
	GC 94016	TVB-5 x (Ryokkoh x OCB)
	GC 94017	KS 1 x [(Tzuzunoko x PI 157424) x Blue Side]
	GC 94019	(Ryokkoh x KS 8) x [(Tzuzunoko x PI 157424) x Blue Side]
	GC 94020	(Ryokkoh x KS 8) x (OCB x Neu Ta Pien 1)
	GC 94015	Ryokkoh x (OCB x Neu Ta Pien 1)
	GC 94016	TVB-5 x (Ryokkoh x OCB)
	GC 94017	KS 1 x [(Tzuzunoko x PI 157424) x Blue Side]
	GC 94018	KS 1 x (SRE-D-14B x TVB-5)
	GC 94019	(Ryokkoh x KS 8) x [(Tzuzunoko x PI 157424) x Blue Side]
	GC 94020	KS 2 x (OCB x Neu Ta Pien 1)
	GC 94025	(Ryokkoh x SRE-D-14B) x KS 1
	GC 94027	(Ryokkoh x SRE-D-14B) x KS 1
	GC 94028	(Ryokkoh x SRE-D-14B) x KS 1
1999	GC 94015	Ryokkoh x (OCB x Neu Ta Pien 1)
	GC 94016	TVB-5 x (Ryokkoh x OCB)
	GC 94018	KS 1 x (SRE-D-14B x TVB 5)
	GC 94019	(Ryokkoh x KS 8) x [(Tzuzunoko x PI 157424) x Blue Side]
	GC 94020	KS 2 x (OCB x Neu Ta Pien 1)
	GC 94022	KS 3 x {KS 1 x [(Vesoy 2 x PI 6302) x D62-7812]}
	GC 94027	(Ryokkoh x SRE-D-14B) x KS 1
	GC 95001	{KS 2 x {KS 1 x [(Vesoy 2 x PI 6302) x D62-7812]}} x KS 1
	GC 95004	[(Tzuzunoko x PI 157424) x Blue Side] x KS 1
	GC 95005	KS 2 x [(Ryokkoh x Mikawashima) x Blue Side]
	GC 95007	KS 2 x TS 82-02V

Fig. 1. Temperature and rainfall pattern from 1996 to 1999 at AVRDC

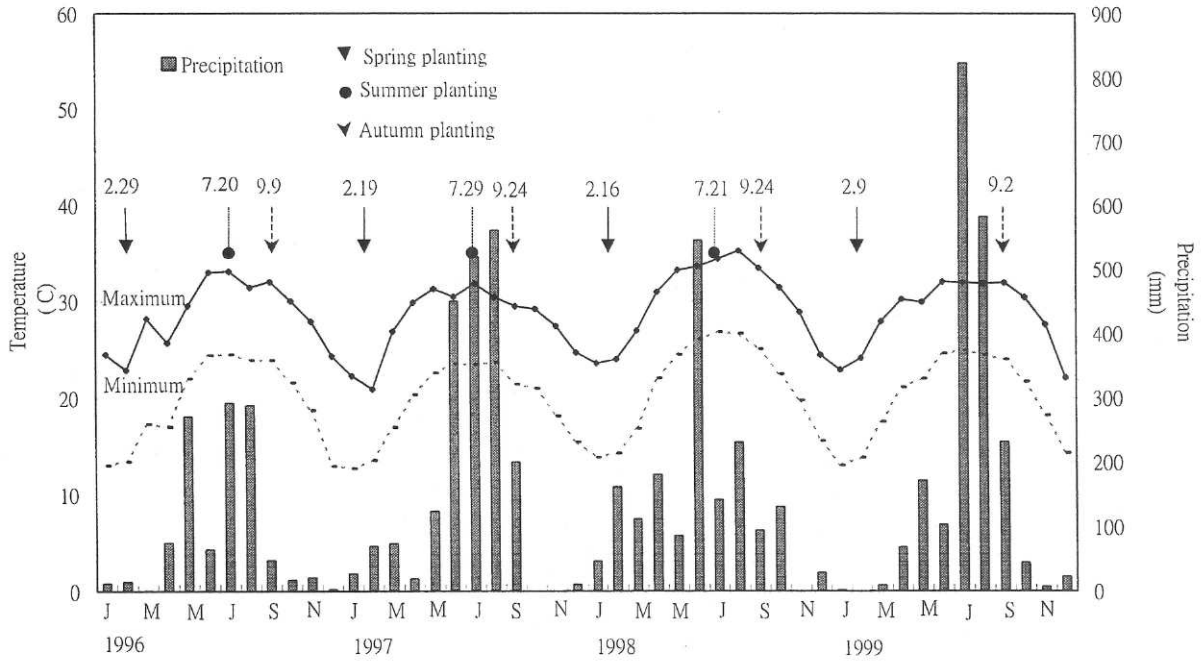


Table 2. Evaluation of lines from different crosses in 1996-1999.

Trial	Year	No. of entries	Season	Date planted	No. of cross combinations
1	1996	44	Spring	29 Feb. 1996	9
			Summer	20 July 1996	
			Autumn	9 Sept. 1996	
2	1997	20	Spring	19 Feb. 1997	1
			Summer	29 July 1997	
			Autumn	24 Sept. 1997	
3	1997	20	Spring	19 Feb. 1997	4
			Summer	30 July 1997	
			Autumn	24 Sept. 1997	
4	1997	20	Spring	19 Feb. 1997	7
			Summer	30 July 1997	
			Autumn	24 Sept. 1997	
5	1998	22	Spring	16 Feb. 1998	11
			Summer	21 July 1998	
			Autumn	24 Sept. 1998	
6	1998	22	Spring	17 Feb. 1998	9
			Summer	21 July 1998	
			Autumn	24 Sept. 1998	
7	1999	24	Spring	9 Feb. 1999	11
			Autumn	2 Sept. 1999	

Chemical

From each replication, 250 g sample of graded pods was taken at random. The pods were blanched at 95°C for 90 seconds in 2.4% salt water. After blanching, the pods were removed from the boiling water and passed through ice water, and instantly frozen (IQF) at –40°C using IQF equipment from Daiwa Industries Ltd. in Japan. The frozen pods were thawed for an hour and were rated visually for pod color using a color chart of Mitsubishi Company. Five pods were rated for each replication and the average rating was determined. The lower the color rating the darker and brighter the preferred color and vice versa.

To determine the sugar content, sample pods from IQF were thawed at room temperature for one hour and then oven dried at 45°C for 2 days. Each sample was ground to obtain the dry powder. Using a pre-calibrated near infrared reflectance spectroscopy (NIRS) the sugar content was estimated.

Statistical Analysis

Data from the spring, summer and autumn seasons in each year were subjected to statistical analysis using the SAS ANOVA (SAS, 1992). Sums of squares from the analysis of variance were used to indicate the relative importance of different sources of variation (Byth et.al. 1976). Variance components associated with these sources of variation were estimated using the PROCVARCOMP program of SAS. The total variance among genotype means [σ^2 (A), representing additive, dominance and epistatic variance was estimated by using the formula σ^2 (G) + σ^2 (G x S)/S + σ^2 (Error)/RS. Broad-sense heritability, H^2 was estimated by σ^2 (G)/ σ^2 (A) (Johnson, et al. 1955).

Results

The pooled analysis of variance of the data across three seasons for the trials in 1996, 1997, 1998 and 1999 are given in Tables 3 to 9. Significant mean squares for seasons (S) and genotypes (G) and SxG were found for all traits in most years. In 1996 and 1999, 50 and 59 percent respectively of the variation in graded pod yield was due to genotype but much lower in other years. Effect of season on graded pod yield in 1996 and 1999 accounted for only 1.9 and 10.1% of the variation respectively (Tables 3 and 9). The variation due to SxG interaction was higher in 1996 compared to 1999. However, in all the other years, most of the variation in graded pod yield (about 60%) was due to season and the SxG interaction accounted for 14 to 20% of the variation (Tables 4 to 8).

Table 3. Pooled ANOVA of vegetable soybean data over seasons in 1996.

Source	DF	Graded pod yield	100 GBWT	DH	Sugar	Color Value
		MS (10^6)	MS	MS	MS	MS
Season (S)	2	10.7*** (1.9)[1]	2271.12*** (20.2)	2783.0*** (63.2)	23.46*** (11.8)	2.94*** (13.4)
Rep.(S)	3	1.7 (0.5)	18.76 (0.3)	0.91 (0.03)	0.50 (0.4)	0.33* (2.3)
Genotype (G)	43	13.1*** (50.0)	346.63*** (66.4)	35.99*** (17.6)	4.45*** (48.1)	0.23*** (22.3)
S x G	86	4.1*** (31.2)	23.14*** (8.9)	17.16*** (16.7)	1.44*** (31.1)	0.17** (33.8)
Error	129	1.4 (16.4)	7.29 (4.2)	1.70 (2.5)	0.26 (8.6)	0.10 (28.3)

[1]Value in parenthesis is percent of total sum of squares.

100 GBWT: 100 green bean weight; DH: days to harvest.

Table 4. Pooled ANOVA of vegetable soybean data over seasons in 1997.

Source	DF	Graded pod yield	100 GBWT	DH	Sugar	Color Value
		MS (10^6)	MS	MS	MS	MS
Season (S)	2	331.29*** (60.4) [1]	1308.95*** (42.6)	1056.76*** (59.5)	39.95*** (32.1)	13.20*** (66.4)
Rep.(S)	3	1.36 (0.4)	7.65 (0.4)	0.14 (0.0)	1.65 (2.0)	0.14** (1.1)
Genotype (G)	19	6.20*** (10.7)	87.15*** (27.0)	62.95*** (33.7)	3.04*** (23.3)	0.37*** (17.6)
S x G	38	5.54*** (19.2)	32.90*** (20.4)	5.14*** (5.5)	1.34 (20.4)	0.11*** (10.3)
Error	457	1.79 (9.3)	10.44 (9.7)	0.79 (1.3)	0.97 (22.3)	0.03 (4.6)

[1]Values in parenthesis are percent of total sum of squares.

100 GBWT: 100 green bean weight; DH: days to harvest.

Table 5. Pooled ANOVA of vegetable soybean data over seasons in 1997.

Source	DF	Graded pod yield MS (10^6)	100 GBWT MS	DH MS	Sugar MS	Color Value MS
Season (S)	2	302.95*** (61.9)	2582.70*** (58.2	713.36*** (56.4	18.19*** (38.6)	6.88*** (38.0)
Rep.(S)	3	0.23 (0.1)	12.14 (0.4)	0.72 (0.1)	0.14 (0.4)	0.05 (0.4)
Genotype (G)	19	5.88** (11.4)	109.02*** (23.3	37.83*** (28.4)	2.01*** (40.5)	0.44** (22.9)
S x G	38	3.48 (13.5)	28.23*** (12.1	6.53*** (9.8)	0.28*** (11.1)	0.10 (10.3)
Error	57	2.25 (13.1)	9.31 (6.0)	2.33 (5.3)	0.15 (9.4)	0.18 (28.4)

[1]Values in parenthesis are percent of total sum of squares.

100 GBWT: 100 green bean weight; DH: days to harvest.

Table 6. Pooled ANOVA of vegetable soybean data over seasons in 1997.

Source	DF	Graded pod yield MS (10^6)	100 GBWT MS	DH MS	Sugar MS	Color Value MS
Season (S)	2	300.96*** (53.7)	2221.16*** (28.1)	791.28*** (48.5)	41.14*** (35.7)	8.91*** (42.2)
Rep.(S)	3	1.94 (0.5)	8.38 (0.2)	0.08 (0.0)	3.31* (4.3)	0.42 (3.0)
Genotype (G)	19	7.69** (13.0)	450.82*** (54.1)	72.11*** (42.0)	2.10* (17.3)	0.27 (12.2)
S x G	38	5.19* (17.6)	57.98*** (13.9)	6.82*** (7.9)	1.15 (18.9)	0.23 (21.1)
Error	57	2.97 (15.1)	10.33 (3.7)	0.87 (1.5)	0.97 (23.9)	0.16 (21.5)

[1]Values in parenthesis are percent of total sum of squares.

100 GBWT: 100 green bean weight; DH: days to harvest.

Table 7. Pooled ANOVA of vegetable soybean data over seasons in 1998.

Source	DF	Graded pod yield MS (10^6)	100 GBWT MS	DH MS	Sugar MS	Color Value MS
Season (S)	2	357.06*** (59.8)	268.41*** (8.5)	1084.73*** (57.6)	92.11*** (63.8)	20.67*** (58.7)
Rep.(S)	3	6.86** (1.7)	17.86*** (0.8)	0.48 (0.0)	0.43 (0.4)	0.04 (0.2)
Genotype (G)	21	7.32*** (12.9)	158.18*** (52.6)	55.15*** (30.8)	2.15*** (15.7)	0.61*** (18.1)
S x G	42	5.45*** (19.1)	47.79*** (31.8)	9.68*** (10.8)	1.11*** (16.1)	0.29*** (17.0)
Error	63	1.23 (6.5)	6.25 (6.2)	0.48 (0.8)	0.18 (4.0)	0.07 (6.0)

[1]Values in parenthesis are percent of total sum of squares.
100 GBWT: 100 green bean weight; DH: days to harvest.

Table 8. Pooled ANOVA of vegetable soybean data over seasons in 1998.

Source	DF	Graded pod yield MS (10^6)	100 GBWT MS	DH MS	Sugar MS	Color Value MS
Season (S)	2	267.24*** (53.4)	289.79*** (7.5)	1162.96*** (54.6)	114.88*** (75.6)	27.50*** (55.1)
Rep.(S)	3	1.93 (0.6)	8.14 (0.3)	1.28*** (0.1)	0.13 (0.1)	0.03 (0.1)
Genotype (G)	21	8.62*** (18.1)	175.34*** (47.7)	59.39*** (29.3)	1.25*** (8.6)	1.39*** (29.3)
S x G	42	5.46*** (22.9)	74.18*** (40.4)	16.12*** (15.9)	0.95*** (13.1)	0.29*** (12.4)
Error	63	0.79 (5.0)	4.92 (4.0)	0.04 (0.1)	0.13 (2.6)	0.05 (3.3)

[1]Values in parenthesis are percent of total sum of squares.
100 GBWT: 100 green bean weight; DH: days to harvest.

Table 9. Pooled ANOVA of vegetable soybean data over seasons in 1999.

Source	DF	Graded pod yield	100 GBWT	DH	Sugar	Color Value
		MS (10^6)	MS	MS	MS	MS
Season (S)	1	31.51*** (10.1)	320.11*** (7.1)	1666.67*** (65.7)	32.31*** (21.5)	3.88*** (15.0)
Rep.(S)	2	0.69 (0.4)	20.46 (0.9)	0.0 (0.0)	0.32 (0.4)	0.34* (2.6)
Genotype (G)	23	8.04*** (59.1)	140.29*** (71.4)	32.67*** (29.6)	3.80*** (58.2)	0.47*** (41.5)
S x G	23	2.01*** (14.7)	27.50*** (14.0)	4.04*** (3.7)	0.66* (10.2)	0.31*** (27.7)
Error	46	1.06 (15.6)	6.48 (6.6)	0.54 (1.0)	0.32 (9.7)	0.07 (13.1)

[1]Values in parenthesis are percent of total sum of squares.

100 GBWT: 100 green bean weight; DH: days to harvest.

With the exception of two trials in 1997 most of the variation in all the other trials for 100 green bean weight was due to genotype (about 50 to 70%). Most of the variation in days to harvest, and color value, estimated from the pooled analysis of variance of the respective value in each data set was due to season as shown by the high percent of total sum of squares for season (Tables 3 to 9). In 1996, 1997 and 1999, the percent total sum of squares for sugar content for genotype was fairly high (about 50%). But in other years the variation was predominantly due to season.

The estimates for broad-sense heritability for graded pod yield, 100 green bean weight, days to harvest, sugar content and color value are given in Table 10. Heritability estimates were high for 100 green bean weight (0.58 to 0.93)and days to harvest (0.52 to 0.92) and lower for graded pod yield (0.11 to 0.75). Except for one estimate in 1998 the estimates for sugar content were fairly high. However, color value estimates were quite variable.

The mean graded pod yields by season over years of the check cultivars, Kaohsiung No. 1 and Ryokkoh are given in Table 11. For both varieties, spring season yields exceeded summer and autumn season yields. In four out of seven trials in the spring season a total of 6 lines had significantly higher graded pod yield than the checks. In the summer season from all 6 trials a total of 12 lines had significantly higher graded pod yield than the checks. In the autumn season 14 lines from 6 out of 7 trials had significantly higher graded pod yield than the checks (Table 11).

The 100 green bean weights by season over years of Kaohsiung No.1 and Ryokkoh are given in Table 12. For both varieties, spring season seed size was larger than summer and autumn season seed size. In 1996, 1997 and 1998 from 3 trials a total of 23 lines had significantly larger 100 green bean weight than the checks (Table 12).

The sugar contents by season over years of Kaohsiung No.1and Ryokkoh are given in Table 13. Sugar content was highest in the autumn for Kaohsiung No. 1 while it was highest in the spring season for Ryokkoh. In 1997 and 1998 from three trials in the autumn season 9 lines had significantly higher sugar content than the checks. The highest sugar content was 14.1 percent in 1999 spring season (Table 13).

The color values by season over years of Kaohsiung No.1 and Ryokkoh are given in Table 14. None of the new lines had significantly better color value than the checks (Table 14).

Table 10.Heritability of graded pod yield and other traits estimated from variance components in 1999.

Year	Trial No.	Graded pod yield	100 green bean wt.	Days to harvest	Sugar content	Color value
1996	1	0.688	0.933	0.523	0.677	0.242
1997	2	0.107	0.622	0.918	0.56	0.707
	3	0.326	0.871	0.905	0.453	0.137
	4	0.408	0.741	0.828	0.862	0.775
1998	5	0.214	0.698	0.824	0.486	0.529
	6	0.367	0.577	0.729	0.241	0.789
1999	7	0.751	0.804	0.876	0.825	0.332

Table 11. Graded pod yield (t/ha) of check cultivars and selections in different seasons and in different years.

Trial No.	Year/season	Check		Selections		Overall
		KS #1	Ryokkoh	Max.	No.[1/]	Mean + SD
1	1996 SP	10.7	7.3	9.5	0	6.9 ± 1.93
	1996 SU	7.7	7.0	13.1	2	6.5 ± 1.80
	1996 AU	9.5	8.4	11.1	1	7.2 ± 1.93
2	1997 SP	10.1	9.6	13.8	2	11.7 ± 1.69
	1997 SU	3.2	2.2	10.6	3	6.5 ± 2.31
	1997 AU	7.2	6.6	7.7	0	7.1 ± 0.67
3	1997 SP	11.3	8.7	14.8	1	10.7 ± 1.59
	1997 SU	2.2	2.1	7.7	3	5.4 ± 2.20
	1997 AU	7.0	5.9	9.1	2	6.8 ± 1.30
4	1997 SP	12.8	10.0	11.2	0	10.3 ± 1.29
	1997 SU	2.5	2.7	7.1	2	4.9 ± 1.90
	1997 AU	6.4	5.6	7.9	3	6.5 ± 1.08
5	1998 SP	11.1	10.0	13.0	2	10.6 ± 1.54
	1998 SU	15.0	8.6	15.0	1	10.4 ± 2.31
	1998 AU	5.9	4.6	8.4	4	5.6 ± 1.18
6	1998 SP	10.5	10.5	11.0	0	9.7 ± 1.61
	1998 SU	12.3	9.4	13.2	1	9.1 ± 2.52
	1998 AU	6.0	4.7	6.9	3	5.1 ± 0.91
7	1999 SP	10.0	8.8	12.4	1	9.1 ± 1.71
	1999 AU	8.4	8.1	10.6	1	8.0 ± 1.45
Mean	SP	10.9 ± 0.95	9.3 ± 1.09			
	SU	7.2 ± 5.48	5.3 ± 3.38			
	AU	7.2 ± 1.33	6.3 ± 1.52			

[1/]Number of selections significantly higher yielding than Kaohsiung #1.

Table 12. One hundred green bean weight (gm) of check cultivars and selections in different seasons and in different years.

Trial No.	Year/season	Check		Selections		Overall Mean
		KS #1	Ryokkoh	Highest	No.[1/]	
1	1996 SP	72	74	81	1	65 ± 7.3
	1996 SU	59	64	76	3	56 ± 8.9
	1996 AU	74	76	87	2	65 ± 7.9
2	1997 SP	69	83	76	0	71 ± 6.2
	1997 SU	49	57	65	0	59 ± 4.3
	1997 AU	66	76	70	0	66 ± 4.4
3	1997 SP	71	86	102	3	81 ± 10.7
	1997 SU	48	55	80	3	66 ±10.0
	1997 AU	67	74	95	3	73 ± 8.4
4	1997 SP	74	84	70	0	70 ± 6.0
	1997 SU	49	55	59	0	54 ± 4.5
	1997 AU	69	75	65	0	64 ± 5.2
5	1998 SP	69	80	88	2	72 ± 6.4
	1998 SU	67	73	81	2	72 ± 6.2
	1998 AU	60	67	87	3	68 ± 6.9
6	1998 SP	65	74	82	1	72 ± 7.6
	1998 SU	63	72	70	0	68 ± 8.7
	1998 AU	59	72	67	0	67 ± 5.3
7	1999 SP	58	87	79	0	71 ± 7.2
	1999 SU	68	75	79	0	67 ± 5.7
Mean	SP	68 ± 5.3	81 ± 5.4			
	SU	58 ± 8.8	64 ± 8.9			
	AU	66 ± 5.6	73 ± 3.4			

[1/]Number of selections significantly larger than Kaohsiung No. 1 and Ryokkoh.

Table 13. Sugar content (%) of check cultivars and selections in different seasons and in different years.

Trial No.	Year/season	Check		Selections		Overall Mean
		KS #1	Ryokkoh	Highest	No.[1/]	
1	1996 SP	12.8	11.5	12.2	0	11.0 ± 0.87
	1996 SU	11.7	12.0	12.9	0	10.7 ± 1.64
	1996 AU	10.8	10.1	11.5	0	10.0 ± 0.48
2	1997 SP	12.0	11.7	10.2	0	10.0 ± 0.79
	1997 SU	11.1	9.7	9.6	0	9.3 ± 1.27
	1997 AU	13.1	10.4	11.5	0	11.3 ± 0.79
3	1997 SP	11.9	11.0	11.6	0	10.3 ± 0.72
	1997 SU	10.6	9.9	9.9	0	9.3 ± 1.07
	1997 AU	12.8	11.3	12.9	3	11.3 ± 0.73
4	1997 SP	11.0	10.9	10.1	0	10.0 ± 0.80
	1997 SU	10.6	10.1	9.8	0	10.0 ± 0.52
	1997 AU	12.9	11.2	11.5	0	11.2 ± 0.61
5	1998 SP	11.3	10.7	11.3	0	10.7 ± 0.86
	1998 SU	10.0	9.3	9.8	0	9.4 ± 0.99
	1998 AU	12.7	11.4	13.1	3	12.3 ± 0.68
6	1998 SP	11.4	10.5	11.3	1	10.8 ± 0.84
	1998 SU	8.7	8.9	10.5	1	9.4 ± 0.58
	1998 AU	12.9	11.9	13.9	3	12.6 ± 0.73
7	1999 SP	10.2	13.3	14.1	1	10.9 ± 1.10
	1999 SU	13.4	13.1	13.7	0	12.1 ± 1.01
Mean	SP	11.5 ± 0.83	11.4 ± 0.95			
	SU	10.5 ± 1.03	10.0 ± 1.08			
	AU	12.7 ± 0.85	11.3 ± 0.99			

[1/]Number of selections significantly higher than Kaohsiung No. 1 and Ryokkoh.

Table 14. Color value of check cultivars and selections in different seasons in different years.

Trial No.	Year/season	Check		Selections		Overall Mean
		KS #1	Ryokkoh	Lowest	No.[1/]	
1	1996 SP	3.3	2.8	2.4	0	2.9
	1996 SU	3.3	2.8	2.9	0	3.2
	1996 AU	3.7	3.2	3.1	0	3.2
2	1997 SP	3.6	2.9	3.6	0	3.8
	1997 SU	3.5	3.3	3.9	0	3.9
	1997 AU	2.9	2.7	2.7	0	2.8
3	1997 SP	3.2	2.8	2.6	0	3.5
	1997 SU	3.8	4.3	3.5	0	3.9
	1997 AU	2.9	2.6	2.3	0	2.9
4	1997 SP	3.4	2.7	3.0	0	3.5
	1997 SU	3.4	3.4	3.5	0	3.7
	1997 AU	2.8	2.8	2.7	0	2.9
5	1998 SP	3.3	2.5	3.0	0	3.2
	1998 SU	4.9	4.0	3.9	0	4.3
	1998 AU	3.2	2.7	3.1	0	3.1
6	1998 SP	3.3	2.7	3.4	0	3.6
	1998 SU	5.1	4.1	3.8	0	4.7
	1998 AU	3.1	2.6	3.3	0	3.2
7	1999 SP	3.2	3.0	2.9	0	3.4
	1999 SU	4.0	2.9	3.4	0	3.8
Mean	SP	3.3 + 0.14	2.8 + 0.16			
	SU	4.0 + 0.79	3.7 + 0.58			
	AU	3.2 + 0.45	2.8 + 0.21			

[1/]Number of selections significantly lower color value than Kaohsiung No. 1 and Ryokkoh.

Discussion

As shown in Fig.1 the environmental conditions for spring, summer and autumn season within each year and between years were different.

Results from pooled analysis of three seasons data for each set of lines in each year indicated that graded pod yield was strongly influenced by season and SxG (Tables 3 to 9). However, high variation due to genotype and high estimates of heritability for graded pod yield in 1996 and 1999 indicated that it may be possible to select genotypes with broad adaptation from either specific combinations or by evaluating them in specific environments (Tables 3 and 9).

Most of the variation in 100 green bean weight was due to genotype and the interaction component was much less. It is also reflected in the high estimates of heritability for 100 green bean weight (Table 10). Therefore, it should be possible to make good progress in selecting for large seed size regardless of seasons. This is in agreement with selection for seed size in grain soybeans (Burton, 1987).

In contrast, the variation due to season and SxG was important for days to harvest, sugar content and color value (Tables 3 to 9). Nevertheless, heritability estimates for days to harvest were high (Table 10). For sugar content and color value, the heritability

estimates differed depending upon the set of genotypes used and the seasons evaluated. As suggested by Dudley and Moll, (1969) the heritability estimates are specific for the set of genotypes evaluated and for the specific environment under which they are evaluated. The estimates of heritability relates to seven different sets of genotypes and 12 different sets of environments (four years and 3 seasons in each year). The low heritability estimate for graded pod yield is similar to the estimates for grain yield in soybean reported by others (Burton, 1987). However, higher estimates of heritability observed in 1996 and 1999 suggest that rapid progress can be made in some populations or in some seasons.

The heritability estimates for 100 green bean weight and days to harvest are in agreement with the 100 grain weight and days to maturity for grain soybean (Burton, 1987). The heritability estimates for sugar content varied with year and the set of genotypes used. Except for one trial in 1998 in which the estimate was very low, other heritability estimates for sugar content were from 0.45 to 0.86. Therefore, there is good scope for making progress in selection for high sugar content. In grain soybean, Openshaw and Hadley (1981) found a significant positive correlation between oil content and percent sugar in the seed. The correlation between protein content and percent sugar was also significant but negative. In the present study as shown in Table 15, highly significant negative correlation between sugar content and oil were found in 15 out of 20 trials. This is the first report establishing such a relationship between sugar content and oil in vegetable soybean. In addition the correlation between sugar content and protein was also largely negative but significant only in 6 out of 20 cases. An analysis of the pooled data from all the trials confirmed the correlation between sugar content and oil as –0.50 (0.0001) and that of sugar content and protein was –0.15 (0.0005). In both cases N=514. A highly significant negative correlaltion between sugar content and protein plus oil was also found [-0.52 (0.0001) N=514]. Akazawa et. al. in 1997 reported that vegetable soybeans contain higher amounts of water soluble nitrogen than grain soybeans. Whether higher amount of water soluble nitrogen is also associated with higher sugar content also needs to be investigated.

Graded pod yield as shown by the check cultivars as well as the selections in general are high in the spring season than in the summer or autumn seasons. Summer season is the most variable for graded pod yield (Table 11). One hundred green bean weight is higher in spring followed by autumn and summer. Seed size, similar to graded pod yield, also varied more in the summer due to unpredictable typhoon and heavy rains (Table 12). The sugar content was higher in autumn followed by spring and summer season (Table 13). The pod color was darker green in spring and autumn seasons than in the summer (Table 14).

Based on graded pod yield, 100 green bean weight and sugar content four genotypes adapted to spring and autumn seasons and one genotype adapted to all three seasons have been selected for further evaluation (Table 16).

Table 15.Phenotypic correlations between protein, oil and sugar content in different seasons and different years.

Trial	Year	Season	Protein and sugar	Oil and sugar content
1	1996	SP	- 0.33	- 0.86 (0.0001)
2		SU	-0.19	-0.63 (0.0001)
3		AU	-0.28	-0.45 (0.002)
4	1997	SP	- 0.50 (0.02)	-0.82 (0.0001)
5		SP	-0.51 (0.02)	-0.47 (0.03)
6		SP	0.24	-0.86 (0.0001)
7		SU	0.008	-0.23
8		SU	0.30	-0.21
9		SU	0.05	-0.68 (0.001)
10		AU	-0.38	-0.69 (0.0008)
11		AU	-0.45 (0.04)	-0.48 (0.04)
12		AU	-0.33	-0.50 (0.02)
13	1998	SP	-0.35	-0.65 (0.001)
14		SP	-0.43 (0.04)	-0.69 (0.004)
15		SU	-0.20	-0.80 (0.0001)
16		SU	0.02	-0.46 (0.02)
17		AU	0.13	-0.30
18		AU	-0.31	0.34
19	1999	SP	-0.74 (0.0001)	-0.66 (0.0005)
20		AU	-0.60 (0.002)	-0.32
	Pooled data (N=514)		-0.15 (0.0005)	-0.50(0.0001)

Table 16. Promising selections adapted to two or three seasons.

Year	Season	Entry	Graded Pod yield (kg/ha)	100 green bean wt. (g)	Sugar (% on dry weight basis)
1997	SP	GC 92005-77-2-1	14,750	89.4	11.62
	AU	GC 92005-77-2-1	9,100	82.8	12.94
	SP	GC 93006-1-1-3-3	12,100	102.2	10.02
	AU	GC 93006-1-1-3-3	6,300	95.2	11.66
1998	SP	GC 92005-120-1-3-1	11,400	86.8	11.34
	AU	GC 92005-120-1-3-1	8,350	87.1	12.85
	SP	GC 94016-10-1	10,750	81.5	10.33
	SU	GC 94016-10-1	13,200	64.4	10.54
	AU	GC 94016-10-1	6,850	67.4	13.10
1999	SP	GC 94015-1-2-1	10,625	78.7	14.05
	AU	GC 94015-1-2-1	10,625	78.5	13.73

Note: Parentage of crosses:
GC 92005 = Kaohsiung No. 1 x Neu Ta Pien 1
GC 93006 = Ryokkoh x F5 [Neu Ta Pien 1 x (PI 157424 x KS #8)]
GC 94015 = (Ryokkoh x SRE-D-14B) x AGS 292
GC 94016 = TVB 5 x (Ryokkoh x OCB)

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