SHORT REPORT
doi: 10.2306/scienceasia1513-1874.2007.33.229

Yield Improvement of Early Maturing Soybeans by Selection for Late Flowering and Early Maturity

Thitiporn Machikowa[a], Aree Waranyuwat[a], Joseph W. Burton[b] and Paisan Laosuwan[a*]

[a] School of Crop Production Technology, Institute of Agricultural Technology, Suranaree University of Technology, Nakhon Ratchasima 30000, Thailand.
[b] USDA-ARS, Department of Crop Science, North Carolina State University, Raleigh, NC 27695-7631, USA.

* Corresponding author, E-mail: paisan@sut.ac.th

Received 6 Jan 2006
Accepted 28 Nov 2006

ABSTRACT: In Thailand, soybean varieties classified as early, medium and late maturing can be harvested in about 85, 100 and 115 days, respectively. The early maturing varieties generally have small plant stature, flower in about 30 days after planting and produce lower yield than others. Breeding to increase days to flowering of early maturing varieties while keeping their days from flowering to maturity intact or reducing them might indirectly increase seed yield. To test this hypothesis, three crosses were made between early maturing varieties (NS1, CM2) and a late maturing variety (CB1) and a late maturing line (LJ4). These crosses, CB1 × NS1, LJ4 × NS1 and LJ4 × CM2, were used to produce advanced populations. The three populations were subjected to two methods of inbreeding, conventional single-seed descent (CSSD) without selection and modified single-seed descent (MSSD) which included early generation selection for late flowering and early maturing plants. In the MSSD F_2 and F_3 generations, a single seed was taken from late flowering and early maturing plants. With CSSD, single seeds were sampled from all plants without selection. In the F_6 generation, regardless of the number of tested lines, 17 lines, which flowered three days or more later and matured earlier than or on similar date to their respective early parent were selected from all three populations and both CSSD and MSSD methods of selection. These lines were evaluated for yield, days to flowering, days to maturity, seed size, nodes per plant, branches per plant, pods per plant, seeds per plant and plant height. It was found that in the F_7 generation for all crosses the CSSD method gave a higher number early maturing lines outyielding their respective early parents (CM2, NS1) and the location check (SJ5) than the MSSD method. These lines flowered later than their respective early parents but matured on a similar date to their early parents. Therefore, this study showed that breeding early maturing soybeans for later days to flowering while keeping days to maturity intact or reducing them resulted in increased yield.

KEYWORDS: Late flowering, early maturity, indirect selection, single seed descent.

INTRODUCTION

The traditional system for soybean production in Thailand has been sequential cropping after rice and other field crops. Early maturing varieties which require less than 85 days to maturity are needed for this system to exploit available moisture in the late rainy season and be harvested before the next crop. The existing early maturing varieties recommended to farmers are not popular due to their small plant stature and low yield potential[1]. Higher yielding medium and late maturing varieties presently grown by farmers, mature in 100 and 115 days, respectively, after planting. Therefore, they are not suitable in the current cropping system due to their late maturity. Thus, it is important that new early maturing soybean varieties with higher yield potential be developed, which will be suited to present day and future crop production systems of Thailand.

Hartwig[2] suggested that a minimum number of 45 days from emergence to blooming is needed for sufficient vegetative growth to produce moderate yields. Later flowering has been reported to be associated with higher soybean yield[3]. Therefore, the extension of days to flowering of current early varieties, as well as the development of new varieties with a longer vegetative period, may result in higher yielding varieties. A number of studies have shown that days to flowering and days to maturity have relatively high heritability[4].

Many selection procedures have been employed effectively in the improvement of soybean varieties[4]. Empig and Fehr[5] evaluated single seed descent (SSD), cross bulk, restricted cross bulk and maturity-group bulk methods for soybean improvement. Mean yields of lines did not differ among methods, but the single seed descent (SSD) method was more effective in maintaining early lines and was less time consuming. Byron and Orf[6] compared three selection procedures for early maturity in soybean: pedigree, single seed descent and single seed descent with early maturity selection in populations created by crossing parents from MG 00 and 0 with parents from MG II and III. The results indicated no differences among selection procedures for maturity and yield.

The objectives of this research were (1) to select soybean lines with later flowering and early maturity using early × late variety crosses and (2) to evaluate the efficiency of two single seed descent methods, one conventional and one which included early generation selection for later flowering and early maturity.

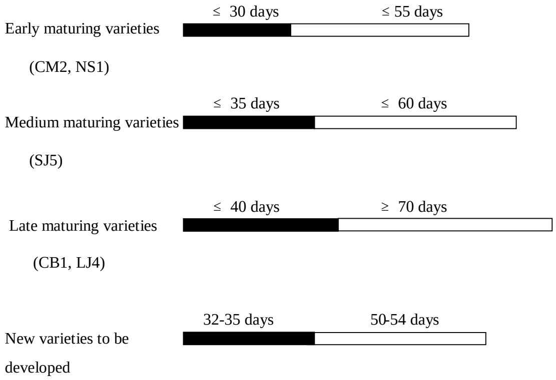

Fig 1. Comparison of approximate days to flowering and days to maturity of early, medium and late maturing varieties grown in Thailand and desired new varieties to be developed.

Materials and Methods

Crossing between Early and Late Maturing Varieties

This study was conducted on the Suranaree University of Technology experimental farm (SUT farm), Nakhon Ratchasima, in the northeast region of Thailand (lat 16° N) during 2000 through 2003. Four soybean varieties, two early and two late maturing, were used as parents. At this location, the growth period of existing varieties averaged over all planting dates was less than 85 days for early varieties and over 110 days for late varieties (Fig 1). Chiangmai 2 (CM2) and Nakhonsawan 1 (NS1) were early while Chakkrabhandhu 1 (CB1) and Long Juvenile 4 (LJ4) were late varieties. All of these parents, except LJ4, were high yielders with good agronomic quality and were being grown as commercial varieties. LJ4 was a late maturing line developed by the Thailand Department of Agriculture (DOA) by selection among progeny from a cross between soybean line ATF-11 (introduced from Brazil) and a recommended variety, Sukhothai 1. Line ATF-11 carried a long juvenile gene (DOA, personal communication). Three crosses were made in 2000 between maturity groupings: CB1 × NS1, LJ4 × NS1 and LJ4 × CM2.

Selection in Advanced Populations

F_2 seeds from each cross were planted in rows spaced 50 cm apart in June, 2001 at the seeding rate of 10 seeds m^{-1}. Three checks, which included two early parents and SJ5, a medium well-adapted variety, were planted every 10th row for reference. These populations were advanced, using the conventional single seed descent (CSSD) procedure as described by Brim[7] and a

Table 1. Number of plants/lines of three populations of soybean crosses in the F_2 through F_5 generations that flowered later and matured earlier than their respective early parents.

Selection method[†]	F_2[‡] Number of plants grown	PFL[¶] (%)	PME[§] (%)	F_3 Number of plants grown	PFL (%)	PME (%)	F_4 Number of plants grown	PFL (%)	PME (%)	F_5 Number of plants selected	PFL (%)	PME (%)
CB1 × NS1												
CSSD	624	45	39	586	47	40	504	48	45	56	91	89
MSSD	624	45	39	160	73	67	70	89	70	30	90	87
LJ4 × NS1												
CSSD	870	51	44	752	54	48	670	58	52	71	94	92
MSSD	870	51	44	180	77	68	84	82	73	42	95	90
LJ4 × CM2												
CSSD	960	54	41	868	58	51	742	60	55	85	94	91
MSSD	960	54	41	190	75	63	80	80	71	47	91	87
Days to flowering (DF) and Days to maturity (DM) of checks												
		DF	DM		DF	DM		DF	DM		DF	DM
CM2		30	83		28	81		27	79		30	83
NS1		30	85		29	83		28	80		31	85
SJ5		38	98		36	95		35	91		37	97

[†] Conventional single seed descent (CSSD) and modified single seed descent (MSSD).
[‡] Planting dates: F_2 - June, 2001; F_3 - Sept, 2001; F_4 - Jan, 2002 and F_5 - June, 2002.
[¶] Proportions of plants that flowered later and matured earlier or the same day as early parents.
[§] Proportions of plants that matured earlier than early maturing parent.

modification of single seed descent (MSSD). For CSSD, one random seed per plant was harvested from each plant and in the F_2 and subsequent generations without selection. After each harvest, the seeds were bulked and planted in the same manner as previously described. From F_2 through F_5, the number of plants was recorded for those that flowered later and matured earlier than the respective early parent to ensure the possibility of obtaining such plants from selection in later generations. Days to flowering was recorded when the first flower bloomed, and maturity was recorded when ≥95% of the pods had turned brown. No selection was made until the F_4 generation. The MSSD involved certain restrictions for selection and was made in two steps. In the first step, F_2 plants which flowered later than the early parent were selected and tagged. In the second step, the plants selected in the first step were reselected in the same generation for maturity not later than the early parent. A random seed was harvested from each selected plant. These selection procedures were practiced again for MSSD in the F_3 generation.

The F_3-CSSD and MSSD seeds plus the same checks were planted in September (late rainy season), 2001 at the same location and seeding rate as F_2. The F_4 seeds for CSSD and MSSD for the three populations plus the same checks were grown in the same fashion as in earlier generations in January (dry season) 2002. Any F_4 plants that flowered later than the early parents for at least two days were marked, but only those which matured earlier or on the same date as the early parent were selected, harvested and threshed separately. For the CSSD method, about 10% of plants were selected visually for desirable growth period, large plant stature, high number of pods per plant and large seed size. About 50% of plants were selected by MSSD. The number of lines selected is shown in Table 1.

The $F_{4:5}$ lines of each population were planted in plant-to-row in the early rainy season of 2002 using their respective checks and SJ5 planted every 10th row. The rows were spaced 50 cm apart with a seeding rate of 10 seeds m^{-1}. Data taken in this generation were days to flowering, days to maturity and plant height. Selection was made in the field for good agronomic traits and desirable days to flowering and days to maturity. The selected rows were harvested in bulk. Only those which outyielded the early parent of each cross were retained for further testing. For the CSSD method, the respective number of $F_{4:6}$ lines selected from the CB1 × NS1, LJ4 ×NS1 and LJ4 × CM2 populations were 28, 34 and 38 lines, whereas those selected from these populations for the MSSD method were 20, 24 and 21 lines, respectively. These selected lines from each population were tested separately on the SUT farm in the late rainy season of 2002 using a group-balanced block design with three replications and the common checks being the respective early parents and SJ5. The methods of selection were in the main plots and lines within each population were in the sub plots. The soil type at the site was a Chatturat clay loam (Typic Haplustalfs). Each plot consisted of five 5-m rows spaced 50 cm between rows and 20 cm between hills with two plants per hill. Recommended pesticides were applied according to timings. Data were recorded for seed yield, days to flowering, days to maturity, seed size, number of nodes, branches, pods and seeds per plant, and plant height.

Seventeen early maturing $F_{4:7}$ lines with long vegetative periods and acceptable maturity that were selected with each method in each population and evaluated at two locations in the late rainy season of 2003. The first location was at the Suranaree University of Technology. The second location was at the National Corn and Sorghum Research Center, Pak Chong, about 120 km west of Suranaree University of Technology. The soil type of this site was Pak Chong Series (Oxic Paleustults). The lines from the three crosses were planted in a group balanced block design with three replications. Two selection methods were used, the main plots, and lines from each method within crosses which were in the sub-plots. A total of 102 entries plus three checks were evaluated. Each plot consisted of four 5-m rows spaced 50 cm apart. Within each row, the hills were spaced 20 cm apart with two plants per hill (i.e. 20 plants m^{-2}). Recommended herbicides were used to suppress weeds. Diseases and insects were controlled by regular application of fungicide and insecticide. Overhead sprinkler irrigation was applied once a week at both locations, as there was no rain in the planting season.

Data were collected at both locations for days to flowering, days to maturity and plant height. Seed harvested from each plot was recorded for seed size (100 seed weight) and seed yield. Ten plants were selected at random from the interior portion of the center two rows for determination of nodes per plant, branches per plant, pods per plant and seeds per plant.

Results and Discussion

Comparison of Selection Methods

The number of plants grown from each population and proportions of plants that flowered later and matured earlier than the respective early maturing parents in each generation from F_2 through F_5 are shown in Table 1. There was no selection for late flowering-early maturing plants in F_2 through F_4 using CSSD. In MSSD, selection for late flowering and early maturing was initiated in F_2. After selection among F_4 plants, the CSSD method produced more lines with the desired phenotypes, late flowering and higher yield, than the MSSD method (Table 1). By the F_6 generation,

Table 2. Mean yield and other agronomic characters of $F_{4:6}$ soybean lines of three populations selected by two selection procedures.

Selection method†	No. of lines	Yield kg/ha	Days to Flower/no.	Days to Maturity/no.	Seed Size g/100 seeds	Nodes	Branches	Pods	Seeds	Plant height cm.
						number / plant				
					CB1 × NS1					
CSSD	28	2,784	34	83	18.85	10	2	32	64	54
MSSD	20	2,610	33	83	17.77	10	2	28	55	51
$LSD_{0.05}$		89	1	1	0.31	1	1	4	7	6
					LJ4 × NS1					
CSSD	34	2,813	35	84	19.87	11	3	34	68	53
MSSD	24	2,701	34	84	18.90	11	3	30	61	52
$LSD_{0.05}$		97	1	1	0.45	1	1	4	6	5
					LJ4 × CM2					
CSSD	38	2,848	35	84	17.78	11	3	37	73	56
MSSD	21	2,695	34	84	17.19	11	2	32	67	54
$LSD_{0.05}$		86	1	1	0.48	1	1	4	6	5
CM2		2,517	31	81	17.40	10	2	28	60	44
NS1		2,496	31	82	20.45	10	2	26	53	46
SJ5		2,753	36	97	17.66	14	3	36	76	57

† Conventional single seed descent (CSSD) and modified single seed descent (MSSD).

nearly all the selected lines from both methods of selection flowered 2-4 days later than their respective early parents (Table 2). From both methods means, for days to maturity were about 1-2 days later than the early parents but there were lines that matured earlier than the early checks (data not shown). Selection resulted in lines being maturing about 10 days before their late parents which usually matured in about 110 days for CB1 and 140 days for LJ4. The mean yields of the CSSD lines of all populations was significantly higher than the mean yields of the MSSD lines. The selection for late flowering-early maturing plants made in the F_2 generation by MSSD may have resulted in the loss of favorable genes before suitable genetic recombinations were obtained. Thus, the CSSD was more effective than MSSD for yield selection as it was observed that lines selected by the CSSD method gave higher numbers of pods and seeds per plant than the MSSD method, which resulted in the higher yield of the former method (Table 2). Moreover, mean yields of lines selected by both methods were higher than those of their respective early maturing parents, and some individual lines were even higher yielding than SJ5.

Although for each selection method means for days to maturity were one or two days later than their respective early parents, more than 50% of lines matured the same day or earlier than their checks. This opened an ample opportunity for selection of early maturing lines. Among yield component traits, pods per plant and seeds per plant tended to be higher for CSSD than MSSD and their respective early parental checks. Average plant heights were not significantly different, but these selected lines were taller than their respective early parents (Tables 2 and 4).

Comparison among Populations

Comparing among the 17 lines of three populations evaluated in the F_7 generation, LJ4×NS1 and LJ4×CM2 gave a higher number of lines outyielding the early parent and SJ5 than CB1 × NS1 (Table 3). This may be

Table 3. Number of $F_{4:7}$ lines from total 17 lines for early population that yielded statistically higher than their respective early parents (CM2 and NS1) and a location check (SJ5).

Population	Selection method†	Lines yielding higher than: Early parent/ no.	SJ5/ no.	Late flowering lines‡/ no.	Early maturing lines¶/ no.
CB1 × NS1	CSSD	13	5	12	4
	MSSD	6	0	10	2
LJ4 × NS1	CSSD	15	10	12	6
	MSSD	10	4	11	3
LJ4 × CM2	CSSD	15	9	16	5
	MSSD	12	2	16	3

† Conventional single seed descent (CSSD) and modified single seed descent (MSSD).
‡ Number of lines flowered 3 to 4 days later than their respective early parent.
¶ Number of lines matured the same day or before the respective early parent.

Table 4. Means for yield and other characters over locations of the two best F_7 lines of each selection method of three populations.

Selection method†	Yield kg/ha	Days to Flower/no.	Days to Maturity/no.	Seed Size g/100 seeds	Nodes	Branches	Pods	Seeds	Plant height cm.
					number / plant				
				CB1 × NS1					
CSSD-1115	2,779	34	82	18.73	11	2	31	55	48
CSSD-1117	2,874	34	83	18.91	11	2	28	57	55
NS1	2,561	31	82	19.21	10	2	26	49	46
SJ5	2,757	36	99	16.50	13	3	35	72	68
$LSD_{0.05}$	159	1	1	1.1	1	1	6	10	8
MSSD-1211	2,663	34	82	17.61	11	2	30	54	57
MSSD-1216	2,742	34	84	16.76	11	2	34	63	61
NS1	2,559	31	82	18.70	10	2	27	50	48
SJ5	2,777	36	100	16.72	13	3	33	66	71
$LSD_{0.05}$	174	1	1	1.3	1	1	5	7	7
				LJ4 × NS1					
CSSD-2104	2,976	33	81	19.97	10	2	31	58	57
CSSD-2109	2,903	34	81	19.25	10	2	29	56	60
NS1	2,570	31	81	20.02	10	2	26	51	46
SJ5	2,703	36	99	17.20	13	3	33	65	67
$LSD_{0.05}$	148	1	1	1.3	1	1	5	9	8
MSSD-2206	2,807	34	82	19.82	10	2	27	57	53
MSSD-2208	2,882	33	83	17.32	11	2	36	78	74
NS1	2,608	31	81	19.84	10	2	24	45	46
SJ5	2,737	36	98	16.51	13	3	39	74	62
$LSD_{0.05}$	162	1	1	1.2	1	1	4	8	7
				LJ4 × CM2					
CSSD-3105	2,818	34	81	15.63	11	2	28	55	65
CSSD-3108	2,870	33	80	17.88	11	2	31	59	69
CM2	2,572	30	80	16.74	11	2	26	52	42
SJ5	2,730	36	100	17.62	13	3	38	72	63
$LSD_{0.05}$	165	1	1	1.2	1	1	4	7	8
MSSD-3211	2,818	33	83	17.92	11	2	27	57	58
MSSD-3217	2,888	33	82	16.83	11	3	29	56	66
CM2	2,549	30	81	16.44	10	2	24	45	41
SJ5	2,769	36	98	17.22	13	3	44	81	67
$LSD_{0.05}$	156	1	1	1.3	1	1	5	8	8

† Conventional single seed descent (CSSD) and modified single seed descent (MSSD).

due to greater genetic diversity between the parents of the former two crosses than between the latter two parents. The LJ4 × CM2 population gave a higher number of lines that flowered 3 and 4 days later than CM2, the early parent, than CB1 ×NS1 and LJ4×NS1. However, from these late flowering lines, only 2-6 lines matured the same day or before the respective early parents.

Line Evaluation in F_7 Generation

The means for yield and other characters of the two top yielding lines from each method of selection and each population are shown in Table 4. With the exception of line MSSD-1211, all lines significantly outyielded their respective early parents. Two outstanding lines, CSSD-2104 and CSSD-2109, gave a higher yield than SJ5, the location check, even though they matured 17 days earlier. Other lines gave similar yields to SJ5. All these lines flowered 2-3 days later than their early parents and some matured on the same date or 1-2 days later. However, all lines were much earlier than SJ5. Over all methods of selection in all populations, there was a tendency for the number of nodes per plant of the selected lines to be greater than node number of their early parents but branches per plant were the same. The superiority of the selected lines to their early parents was due to their having more pods and seeds per plant. Studies have shown that the number of pods per plant is an important yield component of soybean [8,9]. These selected lines were also taller than their early parents.

Conclusion

Two methods of selection, CSSD and MSSD, were both effective in selection for late flowering and early maturing lines from soybean crosses, although the former was more favorable than the latter. The populations subjected to CSSD contained a higher number of high yielding lines. However, the MSSD was the most economical method of selection for days to flowering and maturity because a large number of plants were discarded as early as the F_2 generation. This would permit the inclusion of more crosses in a breeding program.

The results from both methods of selection in three soybean crosses showed that the selection for later flowering than their respective early parent with the number of days to maturity similar to such a parent was possible. Our results suggest that there may be different genes responsible for days to flowering and days to maturity as both characters seemed to be independent in our selected lines. It was apparent from this study that the yield improvement of early soybean varieties can be effectively made by indirect selection for a longer vegetative period and faster rate of photosynthetic accumulation and translocation to seed after flowering.

Acknowledgements

The authors appreciate the Chiang Mai Field Crops Research Center for kindly providing seeds of soybean variety CM2 and line LJ4 for this experiment. This research was supported financially by the Thailand Research Fund (TRF).

References

1. Department of Agriculture (1994) Field crop production. Kurutsapa Ladpraow, Bangkok, Thailand (in Thai).
2. Hartwig EE (1970) Growth and reproductive characteristics of soybean [*Glycine max* (L) Merr.] grown under short-day conditions. *Trop Sci* **12**, 47-53.
3. Dunphy EJ Hanway JJ and Green DE (1979) Soybean yields in relation to days between specific developmental stages. *Agron J* **71**, 917-20.
4. Burton JW (1987) Quantitative genetics: Results relevant to soybean breeding. In: J.R. Wilcox (Eds.). Soybeans: Improvement, production, and uses. American Society of Agronomy Inc., Wisconsin, USA.
5. Empig LT and Fehr WR (1971) Evaluation of methods for generation advance in bulk hybrid soybean populations. *Crop Sci* **11**, 51-4.
6. Byron DF and Orf JH (1991) Comparison of three selection procedures for development of early-maturing soybean lines. *Crop Sci* **31**, 656-60.
7. Brim CA (1966) A modified pedigree method of selection in soybeans. *Crop Sci* **6**, 220.
8. Board JE Kang MS and Harville BG (1997) Path analyses indirect selection criteria for yield of late-planted soybean. *Crop Sci* **37**, 879-84.
9. Carpenter AC and Board JE (1997) Branch yield components controlling soybean yield stability across plant populations. *Crop Sci* **37**, 885-91.