Evaluation of Old and Modern Soybean Cultivars in Liaoning and Ohio

XIE Fu-ti [1], S. K. St. Martin[2], ZHANG Hui-jun[1], WANG Hai-ying[1], AO Xue[1]

(1. College of Agronomy, Shenyang Agricultural University, Shenyang 110866, Liaoning, China; 2. Department of Horticulture and Crop Science, The Ohio State University, Columbus, OH 43210-1086, USA)

Abstract: Future yield gains may depend on an understanding of the past changes made to soybean [*Glycine max* (L.) Merr] by breeding. The objective of this study was to use experiments in Ohio and Liaoning province to compare a set of older cultivars from Liaoning province with their modern counterparts derived from breeding programs in Liaoning and Ohio. Tested in Ohio, Ohio cultivars exceeded the older cultivars in yield by 78% and modern Liaoning cultivars exceeded their older counterparts by 22%. In Liaoning, both groups of modern cultivars exceeded the mean yield of older cultivars by about 50%. The Liaoning environment produced greater mean height and displayed more lodging. The worst lodging scores belonged to the older cultivars. Ohio cultivars were lower in protein but higher in oil than the other two groups. Both Chinese and USA breeders have selected successfully for improved yield, shorter plants, shorter internode length, greater lodging resistance, higher percentage of yield produced on main stem and higher ratio of seed yield/stem. Selection for soy food use in China resulted in large seed size and high protein, but those traits have been largely neglected in the USA. The results suggest mutual benefits from germplasm exchange.

Key words: Soybean [*Glycine max* (L.) Merr.]; Genetic gain; Breeding; Cultivars

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中国辽宁和美国俄亥俄新老大豆品种的比较研究

谢甫绨[1], S. K. St. Martin[2], 张惠君[1], 王海英[1], 敖 雪[1]

(1. 沈阳农业大学 农学院, 辽宁 沈阳 110866; 2. Department of Horticulture and Crop Science, The Ohio State University, Columbus, OH 43210-1086, USA)

摘 要: 未来的大豆产量获得将取决于对过去遗传改良的认识。在中国辽宁省和美国俄亥俄州布置试验比较研究 2 个地区育成的新老大豆品种，以了解这 2 个地区大豆遗传改良的一些进展。结果表明：在俄亥俄试验点，俄亥俄州立大学育成的新品种比老品种增产 78%，比辽宁新品种增产 22%。在辽宁省试验点，俄亥俄新品种和辽宁新品种均比老品种增产约 50%。在辽宁试验环境下，大豆植株生长较高大，倒伏也相对严重，尤其老品种倒伏更重。与辽宁新品种和老品种相比，俄亥俄新品种蛋白质含量较低，脂肪含量较高。两地的育种家对大豆的产量遗传改良成绩显著，同时植株得到矮化、节间缩短和抗倒伏能力提高，主茎籽粒产量比例提高、粒/茎比增加。辽宁育种家注重籽粒大小和蛋白含量的改良，但这 2 个性状没有引起俄亥俄育种家的重视，双方互换种质将有利于大豆的遗传改良。

关键词: 大豆; 遗传改良; 育种; 品种

1 Introduction

Soybean [*Glycine max* (L.) Merr.] has been produced in China for more than 3000 yr and in the USA for more than 200 yr[1]. Current soybean production in the Northern USA has its genetic base primarily in introductions from China[2]. Using molecular markers, Li et al. determined that there was a relatively small genetic distance between ancestors of modern Northeast Chinese soybean cultivars and ancestors of Northern U. S. cultivars. Working independently but from roughly similar genetic bases, breeders in Northeast China and North America have selected for adaptation to their respective environments, resulting in increased yield and improvements in other traits[3].

Mean yield of soybean in China has risen from 617 $kg \cdot ha^{-1}$ in 1949 to 1790 $kg \cdot ha^{-1}$ in 1999[4]. Fei et al used 21 early-maturing soybean cultivars released from 1981 to 2000 to study genetic gain in Heilongjiang, China, resulting in an estimated gain of 43 $kg \cdot ha^{-1} \cdot yr^{-1}$, with increased numbers of pods with 3 and 4 seeds, pods per plant, seed weight per plant,

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Corresponding author: XIE Fu-ti (1966-), male, PhD, professor, engaged in soybean breeding. E-mail: snsoybean@yahoo.com.cn.

plant height, number of branches and effective nodes[5]. Soybean yields in the USA increased 23 kg · ha^{-1} · yr^{-1} from 1924 to 1997, but in the last quarter century (1972 to 1997) have risen 40% faster, 31 kg · ha^{-1} · yr^{-1}[6]. The upward trend in yields is partly due to improved cultivars. In the USA, the annual gain in yield attributable to genetic improvement averaged about 15 kg · ha^{-1} yr^{-1} prior to the 1980s, but it is now averaging about 30 kg · ha^{-1} · yr^{-1}[6].

Genetic changes in physiological and morphological traits have been linked to yield gains in some research. In Georgia (USA), Boerma and Ashley determined that high canopy apparent photosynthesis was a property of recent, high-yielding soybean cultivars in comparison with older cultivars[7]. In Canada, Morrison et al. compared cultivars from seven decades ago. Seed yield, harvest index and photosynthetic rate were found to have increased by 0.5% per year, while leaf area index decreased by 0.4% per year. The increase in seed yield with year of release was significantly correlated with an increase in harvest index, photosynthesis and stomatal conductance and a decrease in leaf area index[8].

Future yield gains may depend on an understanding of the changes made to soybean cultivars by breeding and selection. It would be valuable to know whether selection in one environment (China or USA) has led to similar improvements in the other environment. Knowledge of how morphological traits have responded to selection may also provide insight into the nature of the genetic changes. Our objective was to compare, in both Liaoning (China) and Ohio (USA) environments, a set of older cultivars from Liaoning province with their modern counterparts derived from breeding programs in Liaoning and Ohio. We examined yield, agronomic and compositional traits in both locations and morphological traits in Liaoning.

2 Materials and methods

We compared 12 cultivars (Table 1), including 4 old cultivars that were introduced into the USA from Liaoning before extensive North American breeding efforts began[9]. The four older cultivars were named and released in the USA, but of these only Mukden was ever widely grown. Mukden is also the only cultivar of the four that contributes significantly as an ancestor of current USA cultivars, providing an estimated 4% of the Northern USA germplasm base[10]. The remaining 8 cultivars in our tests were developed recently at Liaoning province and Ohio State University[11-14] (Table 1).

Table 1 Origin of soybean cultivars compared in Liaoning and Ohio.

Cultivar	Representing	Origin
HS93-4118	Modern Ohio	Ohio State Univ. (St. Martin et al., 2001c)
Ohio FG1	Modern Ohio	Ohio State Univ. (St. Martin et al., 1996)
Darby	Modern Ohio	Ohio State Univ. (St. Martin et al., 2001b)
Kottman	Modern Ohio	Ohio State Univ. (St. Martin et al., 2001a)
Liaodou 11	Modern Liaoning	Liaoning Academy of Agric. Sciences, 1996
Liaodou 12	Modern Liaoning	Liaoning Academy of Agric. Sciences, 1998
Shennong 9411	Modern Liaoning	Shenyang Agric. Univ., 1997
Shendou 4	Modern Liaoning	Shenyang Academy of Agric. Sciences, 1997
Shingto	Old Liaoning	PI 21.079, fromTieling, Liaoning, 1907
Mukden	Old Liaoning	PI 50.523Q, fromShenyang, Liaoning, 1920
Harbinsoy	Old Liaoning	PI 54.606-3, fromBenxi, Liaoning, 1921
Boone	Old Liaoning	PI 54.563-3, fromTongjiangkou, Liaoning, 1921

We conducted all experiments in the field at latitudes approximately 40°N in Liaoning and Ohio. In Liaoning, the experiment was carried out at Shenyang during the 2004, 2005 and 2006 growing seasons. The design was a split-plot with three replications, arranged in randomized complete blocks. Cultivars were the main-plot factor, and the split-plot factor consisted of three levels of N-P fertilizer. Results of the fertilizer treatments will be discussed elsewhere, and this manuscript will concern itself with the main effects of cultivars. In Ohio, trials took place in 2004 and 2005 at three sites: the Mitchell farm at Plain City, the Manchester farm at Lakeview, and the Western Research Station of the Ohio Agricultural Research and Development Center at South Charleston, Ohio. The design in Ohio was a 3 × 4 rectangular lattice, with two replications per location. Cultivar means were adjusted for block effects where necessary.

In Liaoning plots consisted of 5 rows, spaced 60 cm and 5 m in length. The distance between plants within a row was 11 cm, and plant density was 150 000 plants · ha^{-1}. The plant density was achieved by overplanting and thinning. Seeds were planted in late April or early May. Two days after planting, herbicides were applied for weed control. Before harvesting, 10 consecutive plants in a row were selected from each plot for the analysis of agronomic and morphological traits. Each sampled plant was measured for plant height from the node of cotyledon to the tip of the stem and height of the lowest node bearing a pod. The nodes of the main stem and the number of branches were counted, and the seed yields of branches and main stem were measured separately. Seed yield of the main stem was divided by the combined seed yield of the main stem and branches to determine the percentage of yield produced on the main stem. Seed yield was divided by the total weight of straw and pod wall to determine the ratio of seed yield/stem. At maturity, a lodging score was assigned to each plot, based on a scale of 1 (erect) to 5 (prostrate). The 3-m long middle part of the inside 3 rows (3 m per row x 3 rows x 0.6 m = 5.4 m^2) was harvested for plot yield. Seeds were analyzed for protein and oil content using a Foss 1241 near-infrared analyzer.

In Ohio, plots consisted of 6 rows, spaced 38 cm apart, 4.9 m in length. Approximately 20 seeds · m^{-1} were planted in late April or early May. Pre-plant herbicides were applied for weed control. Plots were end-trimmed to 3.5 m length at approximately growth stage R1 [15]. Plant height, and lodging score were assessed as in Liaoning, and the date of maturity (when 95% of the pods had reached their mature color) was determined. In 2004 two samples of seed of each cultivar, one harvested at Plain City, the other at Lakeview, were analyzed for protein and oil content by near-infrared transmittance (with a Foss Model 1255 Infratec NIR food and feed analyzer) at the National Center for Agricultural Utilization Research, Peoria, Illinois.

Data from Liaoning and Ohio were analyzed separately. Years and (in Ohio) locations were regarded as random factors, and appropriate interactions between cultivar and these factors were used as error terms. Cultivar was a fixed factor. Where F-tests indicated significant differences among cultivars, the LSD (P = 0.05) was used to separate means. Means of the three groups of cultivars were compared using an LSD procedure, equivalent to contrasts.

3 Results

3.1 Yield and agronomic traits

The Ohio cultivars were, on average, 3 to 4 days later maturing than the other two groups of cultivars, but there was a range of maturities within each group (Table 2).

Plants reached a greater height in Liaoning than in Ohio (Table 2). Ohio cultivars showed a marked similarity in height and were among the shortest cultivars at each location. In Ohio, the modern Liaoning cultivars were similar to the Ohio cultivars in height, but averaged 22 cm taller than that of Ohio cultivars in Liaoning. In both Ohio and Liaoning, two of the old cultivars, Harbinsoy and Boone, were extremely tall.

The Liaoning environment, which produced greater mean height, also displayed more lodging (Table 2) than observed in Ohio. In Liaoning, three Ohio cultivars (Kottman, Darby, and HS93-4118) had the best standability. The worst lodging scores belonged to the older cultivars. Similar trends were evident in Ohio, although with a smaller degree of lodging overall. The tall, older cultivars Harbinsoy and Boone had the most lodging in Ohio and Liaoning.

Mean seed yield in Ohio showed a clear ranking, Ohio > modern Liaoning > old Liaoning, with little overlap between groups (Table 2). Ohio cultivars exceeded the older cultivars in yield by 78%, and modern Liaoning cultivars exceeded their older counterparts by 22%. In Liaoning Ohio cultivars exceeded the older cultivars in yield by 51%, and modern Liaoning cultivars exceeded their older counterparts by 44%, The difference between the two modern groups in Liaoning was not significant.

Table 2 Yield and agronomic traits of old and modern soybean cultivars evaluated in Ohio, USA, and Liaoning, China.

Group	Cultivar	Ohio							Liaoning		
		Date mature*	Lodging score**	Plant height/cm	Yield/Mg·ha⁻¹ S. Charleston	Plain City	Lakeview	Mean	Lodging score**	Plant height/cm	Yield /Mg·ha⁻¹
Modern Ohio	HS93-4118	28	1.3	81	4.45	4.88	4.94	4.76	2.3	101	2.69
	Ohio FG1	22	1.2	81	3.53	4.34	3.52	3.80	3.1	101	2.55
	Darby	19	1.1	83	4.10	4.49	4.09	4.23	1.7	102	2.67
	Kottman	23	1.1	81	4.15	4.66	4.74	4.52	1.6	97	2.61
	Mean	**23**	**1.2**	**81**	**4.06**	**4.59**	**4.32**	**4.32**	**2.2**	**100**	**2.63**
Modern Liaoning	Liaodou 11	19	1.4	83	2.39	3.49	2.60	2.83	3.3	113	2.63
	Liaodou 12	15	1.1	72	2.93	3.38	2.85	3.06	3.2	111	2.66
	Shennong 9411	28	1.9	92	2.84	3.14	3.08	3.02	3.4	124	2.32
	Shendou 4	17	1.7	93	2.97	3.14	2.96	3.02	3.3	140	2.40
	Mean	**20**	**1.5**	**85**	**2.78**	**3.29**	**2.87**	**2.98**	**3.3**	**122**	**2.50**
Old Liaoning	Shingto	11	2.1	87	1.99	2.37	2.19	2.18	3.5	124	1.82
	Mukden	12	1.7	84	2.37	2.57	2.81	2.58	3.5	115	1.94
	Harbinsoy	21	3.3	122	1.95	2.60	2.28	2.27	3.8	208	1.55
	Boone	31	3.0	112	2.27	3.17	2.68	2.71	3.8	157	1.66
	Mean	**19**	**2.5**	**101**	**2.14**	**2.68**	**2.49**	**2.44**	**3.7**	**151**	**1.74**
	$LSD_{0.05}$ (cultivars)	2.4	0.7	17				0.53	0.2	23	0.44
	$LSD_{0.05}$ (groups)	1.2	0.3	8				0.27	0.1	11	0.22

* days after 31 August.

** rated from 1 (erect) to 5 (prostrate).

3.2 Seed composition

Generally, Ohio cultivars were lower in protein but higher in oil than the other two groups (Table 3). Modern Liaoning cultivars were similar in oil content and lower in protein content when compared with older cultivars in the Liaoning environment, but they were similar in protein content and lower in oil content to older cultivars in Ohio. There were significant within-group differences for compositional traits, and groups overlapped. Cultivar Shendou 4 displayed high protein in both test environments.

Table 3 Seed protein and oil content of old and modern soybean cultivars evaluated in Ohio, USA (2004), and Liaoning, China (2004-2006).

Group	Cultivar	Ohio** Protein*/g·kg⁻¹	Ohio** Oil/g·kg⁻¹	Liaoning Protein/g·kg⁻¹	Liaoning Oil/g·kg⁻¹
Modern Ohio	HS93-4118	388	189	408	202
	Ohio FG1	424	183	427	201
	Darby	405	187	409	212
	Kottman	415	185	418	206
	Mean	**408**	**186**	**415**	**205**
Modern Liaoning	Liaodou 11	412	178	413	208
	Liaodou 12	427	182	433	203
	Shennong 9411	414	176	417	193
	Shendou 4	448	179	435	199
	Mean	**425**	**179**	**424**	**201**
Old Liaoning	Shingto	423	179	447	197
	Mukden	429	181	451	198
	Harbinsoy	412	185	429	197
	Boone	428	184	416	208
	Mean	**423**	**182**	**436**	**200**
	$LSD_{0.05}$ (cultivars)	15	5	11	5
	$LSD_{0.05}$ (groups)	8	3	5	3

* Protein and oil are tested on dry-weight basis.

** Mean of two samples of seed, one at Plain City, the other at Lakeview.

3.3 Morphological traits

In Liaoning, Ohio cultivars had more branches per plant than modern Liaoning culitivars (Table 4). Compared with the old Liaoning cultivars, modern Liaoning cultivars had fewer branches and a more uniform branch number among cultivars (Table 4). Ohio cultivars had a lower height of lowest pod than older cultivars and displayed uniformity (about 22 cm) among cultivars, but modern Liaoning cultivars had a similar height of lowest pod to the old cultivars (Table 4). Ohio cultivars had fewer nodes and shorter internode length than both modern and old Liaoning cultivars, and compared with the old Liaoning cultivars, both of modern Ohio and Liaoning cultivars had a shorter internode length. Ohio cultivars had the shortest internode length (Table 4), which is assumed to confer lodging resistance. The old cultivars Boone and Harbinsoy had greater length (6 to 8 cm) than other cultivars (4 to 6 cm). Grain weight per plant showed a pattern similar to that of yield, with smaller means for older cultivars.

Modern cultivars had a higher ratio of seed yield/stem than older Liaoning cultivars (Table 4), mainly because of the very low ratios of Harbinsoy and Boone. Modern cultivars, especially modern Liaoning cultivars, had a higher percentage of yield on main stem (Table 4), which might resulted from selection for ease of harvest.

Cultivar differences for 100-seed weight were expressed consistently across years. Modern Liaoning cultivars significantly exceeded the older cultivars in 100-seed weight (Table 4). Four modern Liaoning cultivars and the Ohio cultivar Ohio FG1 had significantly larger seed than the other entries. The larger seed of modern Liaoning cultivars is the result of deliberate selection for seed size, which is a desirable characteristic for many soy foods [16]. The large-seeded Ohio cultivar, Ohio FG1, was also selected for soy food applications.

Table 4 Morphological traits of old and modern soybean cultivars evaluated inLiaoning, China (2004-2006).

Group	Cultivar	Branches per plant	HLP/cm	Nodes per stem	Internode length/cm	GWPP/g	RSYS	PYPMS/%	100-seed weight/g
Modern Ohio	HS93-4118	2.8	21	23	4.4	19	1.1	67	15.1
	Ohio FG1	2.6	23	21	4.8	19	1.0	71	20.9
	Darby	2.3	21	25	4.2	18	1.0	85	13.5
	Kottman	2.0	22	23	4.3	17	1.0	82	14.9
	Mean	**2.4**	**22**	**23**	**4.4**	**18**	**1.0**	**76**	**16.1**
Modern Liaoning	Liaodou 11	1.7	23	23	4.9	19	0.9	78	20.2
	Liaodou 12	1.7	25	23	4.8	19	1.1	81	21.8
	Shennong 9411	1.1	31	26	4.8	21	0.9	87	20.8
	Shendou 4	1.8	24	28	4.9	23	0.9	84	17.0
	Mean	**1.6**	**26**	**25**	**4.9**	**21**	**1.0**	**82**	**20.0**
Old Liaoning	Shingto	1.9	21	23	5.4	16	0.9	82	14.6
	Mukden	1.6	23	22	5.2	17	0.9	81	14.9
	Harbinsoy	2.2	36	27	7.6	14	0.5	64	15.2
	Boone	4.1	33	26	6.1	17	0.7	45	14.4
	Mean	**2.5**	**28**	**24**	**6.1**	**16**	**0.7**	**68**	**14.8**
	$LSD_{0.05}$ (cultivars)	0.7	9	2	0.6	4	0.2	12	1.1
	$LSD_{0.05}$ (groups)	0.4	5	1	0.3	2	0.1	6	0.5

HLP = Height of lowest pod; GWPP = Grain weight per plant; RSYS = Ratio of seed yield/stem; PYPMS = Percentage of yield produced on main stem.

4 Discussion

The basis for the choice of older cultivars for this experiment was geographical rather than pedigree: the cultivars were collected in Liaoning and presumably grown there. Except for Mukden they are not ancestral to the Ohio cultivars, and there is no evidence that they were ancestral to modern Liaoning cultivars. We are assuming, however, that they phenotypically typify soybean germplasm grown in Liaoning 85 to 100 years ago.

Breeders in the U. S. and China have made significant improvements in yield and lodging resistance of cultivars. U. S. breeders have imposed selection pressure for ease of mechanical harvesting, which may explain why the Ohio cultivars exhibited greater resistance to lodging. In the U. S., soybeans are typically planted at higher seeding rates than in North China, making resistance to lodging an important consideration[17]. In our study, we used seeding rates typical of locale where the test was grown, i. e., 3 times greater in Ohio than in Liaoning (150 000 plants · ha^{-1}). Modern Liaoning cultivars tested in Ohio, and Ohio cultivars tested in Liaoning were exposed to different plant densities from those in which they were selected. The mix of tall and short cultivars formerly in use in Liaoning has given way to more uniformly short cultivars. The four modern Liaoning cultivars in our study are all semi-determinate, while short-stature indeterminate cultivars have been selected for Ohio.

A few trends for genetic gain are evident in comparing both sets of modern cultivars with the older cultivars. Modern cultivars from Liaoning and Ohio show improved yield, shorter plants, shorter internode length, greater lodging resistance, higher percentage of yield produced on main stem, and higher ratio of seed yield/stem. The different end uses for the crop (oil and meal in the USA vs. soy foods in China) account for selection for large seed size and high protein in China and neglect of those traits in the USA. Reduced branch number in Chinese cultivars may be related to selection occurring under lower stand densities than are used in the USA. Semi-determinate growth habit, in combination with reduced numbers of branches and higher plant height, favors high yield in Liaoning environments, which feature a relatively low seeding rate.

Unlike the US farmers who harvest soybeans by combine, farmers in Liaoning have harvested soybeans by hand and sickle continually. The different methods of harvest may be responsible for differences between modern Ohio and Liaoning cultivars in plant height, internode length, nodes/stem, and height of lowest pod.

Soybeans in Liaoning are primarily utilized for human consumption as tofu or other soy foods, and high protein is considered desirable for such products. By contrast, most U. S. soybeans are crushed to produce both protein-based products and oil, and there has been little selection in recent decades for protein. Also, protein and oil content are highly negatively correlated [18]. Thus it would not be surprising that the Ohio cultivars exhibited lower protein content and higher oil content than the other two groups, and this was indeed observed in both environments.

Our results, showing concurrent improvement in both USA and Chinese germplasm, suggest that breeders in the two countries may find each other's modern cultivars to be a good source of germplasm. In particular, USA breeders seeking high protein cultivars with large seed size and Chinese breeders seeking sources for high yield may benefit from germplasm exchange. As the soybean is sensitive to day length, exchange between breeders operating at the similar latitudes will benefit both breeding programs.

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