Registration of the High-Yielding Soybean Germplasm Line LG04-6000

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ABSTRACT
The soybean [Glycine max (L.) Merr.] germplasm line LG04-6000 (Reg. No. GP-379, PI 664025) was developed and released by the USDA-ARS and the Illinois Agricultural Experiment Station at Urbana. LG04-6000 was derived from an F₃ plant from the cross of HS93-4118 × LG97-9912. LG97-9912 was derived from LG90-4181 × A3322. LG90-4181 is from PI 436682 × ‘Lawrence’ (PI 518673). PI 436682 is the Chinese cultivar ‘Jilin 15’, and LG04-6000 is the first germplasm released in the United States that has Jilin 15 as a progenitor. LG04-6000 is classified in early maturity group IV. In tests at 8 locations in 2006 conducted cooperatively with commercial soybean breeding companies, LG04-6000 yielded 127 kg ha⁻¹ more than LD00-3309. In tests at 22 locations in the Uniform Test IV in 2007 and 2008, LG04-6000 was the highest-yielding entry in the test in both years, exceeding the yield of LD00-3309, the highest-yielding check cultivar in both years, by an average of 8%. LG04-6000 is known to be susceptible to race 4 and resistant to race 7 of Phytophthora sojae Kaufmann & Gerdemann. LG04-6000 is the first example of germplasm derived from exotic parents adapted to the northern United States that has demonstrated a yield potential significantly higher than that of the best cultivars from public institutions. The combination of high yield and unique pedigree makes this line an exceptional new source of genetic diversity to improve the yield of U.S. cultivars.

The average soybean yield in the United States has been increasing at a linear rate of approximately 22 kg ha⁻¹ yr⁻¹ according to data obtained from the National Agricultural Statistics Service (http://www.nass.usda.gov/Data_and_Statistics/; verified 2 Mar. 2011). This linear trend began before scientific soybean breeding was established (Carter et al., 2004) and has continued through the application of the modern technology of plot mechanization, computer data analyses, and marker-assisted selection (Orf et al., 2004), including transgenic cultivars (Parrot and Clemente, 2004). There are many possible explanations why the rate of progress has not increased with the application of additional technology and include the lack of genetic diversity in the currently used commercial gene pool. Just 26 ancestors account for nearly 90% of the total ancestry, and 5 ancestors account for more than 55% of the public cultivars released between 1947 and 1988 (Gizlice et al., 1994). Only a few lines not previously in the pedigrees of released cultivars have made large contributions to a single cultivar or to the overall genetic base during the past 35 yr (Gizlice et al., 1994; Sneller, 1994, 2003). Although cultivars developed by commercial companies currently occupy most of the soybean production area, the evidence indicates that the shift to proprietary cultivars has not changed the genetic base (Sneller, 2003; Mikel et al., 2010). The development of high-yielding experimental lines derived from exotic germplasm could provide new genetic diversity to enrich the commercially used gene pool, which theoretically could increase the rate of yield increase in future cultivars. This research reports on one such line.

Soybean germplasm line LG04-6000 (Reg. No. GP-379, PI 664025) was developed and released by the USDA-ARS and the Illinois Agricultural Experiment Station at Urbana. LG04-6000 is from the cross of HS93-4118 × LG97-9912. LG04-6000 is classified as early maturity group IV. In the USDA Uniform Test IV in both 2007 and 2008, LG04-6000 was significantly (P = 0.05) higher yielding than the highest-yielding check cultivar, LD00-3309. This is the first germplasm release or cultivar in the United States with PI 436682 (USDA-ARS, NGRP, 2011) as a progenitor. This line will be useful in breeding programs as a parent line to provide new genetic diversity to improve the yield of U.S. cultivars.

Materials and Methods
Parental Selection and Pedigree
LG04-6000 is the progeny of an F₃ plant from the cross of HS93-4118 × LG97-9912 with 12% of its pedigree derived from Jilin 15 (PI 436682). HS93-4118 (St. Martin et al., 2001) is in maturity group IV. LG97-9912 was derived from

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LG90-4181 × A3322. A3322 [A4268 × ('Williams' [PI 548631] × 'Mack' [PI 559370])] is in maturity group III and was released by the Asgrow Seed Company in 1989. LG90-4181 is from PI 436682 × ‘Lawrence’. Lawrence (Bernard and Creemans, 1988) is in maturity group IV. PI 436682 is the Chinese cultivar ‘Jilin 15’, which was released by the Jilin Academy of Agricultural Sciences in 1978. In the United States, it is classified as maturity group I. The ancestry of Jilin 15 traces to three Chinese landraces that originated in the province of Jilin, China. (Cui et al., 1999). Neither Jilin 15 nor any of its progenitors have contributed to any U.S. cultivars or germplasm releases.

Jilin 15 was introduced into the USDA Soybean Germplasm Collection in 1979 from the Jilin Academy of Agricultural Sciences, Gongzhuling, Jilin (http://www.ars-grin.gov/npgs/; verified 6 Oct. 2011). In germplasm evaluations conducted at the Crop Sciences Research and Education Center, University of Illinois, Urbana in 1982 and 1983, the mean yield of PI 436682 was 3980 kg ha⁻¹. U.S. soybean cultivars of similar maturity that were included in the same test had mean yields between 3980 and 4180 kg ha⁻¹ (Nelson et al., 1988).

When evaluated at five locations during 2 yr in the Soybean Asian Germplasm Evaluation in 1998 and 1999 with other maturity group I lines, the mean yield of PI 436682 was 2795 kg ha⁻¹ compared with 3520 kg ha⁻¹ for the highest-yielding publicly developed cultivar, ‘Parker’ (Orf and Kennedy, 1994), and 3211 kg ha⁻¹ for the highest exotic entry PI 391594, Jilin No. 8 (Carter et al., 1999).

**Breeding-Line Development**

HS93-4118 was crossed with LG97-9912 in Urbana in the summer of 1999, and five F₁ plants were grown in the greenhouse the following winter. The F₁ population of approximately 500 plants was grown in the field in 2000, and 35 single plants were selected and in 2001 advanced for yield testing in unreplicated one-row plots that were 2.5 m long and spaced 1 m apart. LG01-5827 was the highest yielding of the 35 entries, with a seed yield 40% higher than that of HS93-4118 and was 1 d later in maturity. It was among 14 entries from that cross selected for testing in four-row plots with two replications at Urbana in 2002. In that limited testing, LG01-5827 was 2 d later in maturity and yielded 323 kg ha⁻¹ more than HS93-4118, which was significantly higher at the 0.05 probability level (LSD = 255 kg ha⁻¹). In 2003, single F₂ plants were harvested from within LG01-5827, and progenies from 20 plants were tested in one-row yield plots in 2004 as described above. In that test, LG04-6000 yielded 28% more than the check cultivar, LN97-15076, but it was 8 d later in maturity.

**Plot Technique and Trait Evaluation**

LG04-6000 was first tested in multiple locations in a cooperative test with the commercial soybean breeding companies Pioneer Hi-Bred International (Johnston, IA), Syngenta Seeds (Minnetonka, MN), and Dairyland Seed (West Bend, WI) at eight locations in 2006 in Missouri and Illinois. The entries were arranged in a randomized complete block design with either one or two replications. Both two- and four-row plots were used but only two rows were harvested for yield. The date of maturity was recorded at seven locations, lodging data was collected at six locations, and plant heights were measured at five locations.

LG04-6000 was entered into the USDA Uniform Group IV Test Northern States in 2007 and 2008. Row widths varied from 41 to 76 cm but the most common row width was 76 cm. Plots were four rows wide with the two center rows of each plot used for data, except for those in 41-cm row widths that had six rows planted and four rows harvested. The length of harvested rows varied from 3.0 to 4.9 m. Approximately half of the tests were end-trimmed before harvest and half were planted to the harvested length. Traits evaluated included seed yield, date of maturity, plant height, lodging, 100-seed weight, seed quality, seed protein and oil concentrations, and selected disease resistance scores.

The number of locations reporting each trait is listed in Table 1 (2007 USDA Uniform Group IV Test) and Table 2 (2008 USDA Uniform Group IV Test). Seed protein and oil content were analyzed using near-infrared spectroscopy (AACC method 39-21, [AACC, 1999]) at the National Center for Agricultural Utilization Research, USDA-ARS, Peoria, IL. LG04-6000 was evaluated for reaction to races 4 and 7 of Phytophthora sojae Kaufmann & Gerdemann in the 2007 and 2008 USDA Uniform Group IV Test Northern States (Abney and Crochet, 2007, 2008).

**Statistical Analysis**

All statistical analyses were done using PROC ANOVA in SAS Version 9.2 (SAS Institute, Cary, NC). The statistical model included genotypes as fixed factors and locations as random factors. With the analyses of variance data, least significant differences were calculated with α = 0.05 level of probability of a Type I error. All trait data used for analyses were the means of all replicates at each location so each environment was treated as a replication in the analysis of variance.

### Table 1. Means of agronomic and seed composition traits for LG04-6000 and LD00-3309, the highest yielding check cultivar, from the 2007 USDA Uniform Preliminary Group IV Test Northern States.

<table>
<thead>
<tr>
<th>Line</th>
<th>Yield</th>
<th>Maturity</th>
<th>Lodging</th>
<th>Height</th>
<th>Seed size</th>
<th>Seed quality</th>
<th>Protein</th>
<th>Oil</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>kg ha⁻¹</td>
<td>1 Sept. = day</td>
<td>1–5</td>
<td>cm</td>
<td>g 100 seed⁻¹</td>
<td>1–5</td>
<td>g kg⁻¹</td>
<td></td>
</tr>
<tr>
<td>LG04-6000</td>
<td>3756</td>
<td>25</td>
<td>1.6</td>
<td>99</td>
<td>13.2</td>
<td>1.7</td>
<td>405</td>
<td>191</td>
</tr>
<tr>
<td>LD00-3309</td>
<td>3507</td>
<td>20</td>
<td>1.4</td>
<td>89</td>
<td>11.3</td>
<td>1.7</td>
<td>400</td>
<td>195</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>241</td>
<td>2</td>
<td>0.4</td>
<td>4</td>
<td>0.6</td>
<td>0.4</td>
<td>8</td>
<td>5</td>
</tr>
<tr>
<td>No. of locations</td>
<td>11</td>
<td>13</td>
<td>13</td>
<td>13</td>
<td>13</td>
<td>13</td>
<td>8</td>
<td>8</td>
</tr>
</tbody>
</table>

1 = all plants erect; 5 = all plants prostrate.

1 = highest quality; 5 = lowest quality considering diseased seeds, wrinkled and cracked seed coat, and green coloration.
Table 2. Means of agronomic and seed composition traits for LG04-6000 and LD00-3309, the highest yielding check cultivar, from the 2008 USDA Uniform Group IV Test Northern States.

<table>
<thead>
<tr>
<th>Entry</th>
<th>Yield (kg ha⁻¹)</th>
<th>Maturity</th>
<th>Lodging</th>
<th>Height (cm)</th>
<th>Seed size (g 100 seed⁻¹)</th>
<th>Seed quality (1–5)</th>
<th>Protein (g kg⁻¹)</th>
<th>Oil (g kg⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LD00-3309</td>
<td>3837</td>
<td>25</td>
<td>1.4</td>
<td>79</td>
<td>13.4</td>
<td>1.8</td>
<td>397</td>
<td>202</td>
</tr>
<tr>
<td>LG04-6000</td>
<td>4172</td>
<td>28</td>
<td>2.0</td>
<td>86</td>
<td>13.9</td>
<td>1.8</td>
<td>397</td>
<td>202</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>254</td>
<td>1.5</td>
<td>0.4</td>
<td>4</td>
<td>0.6</td>
<td>0.3</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>No. of locations</td>
<td>11</td>
<td>12</td>
<td>13</td>
<td>13</td>
<td>13</td>
<td>12</td>
<td>6</td>
<td>6</td>
</tr>
</tbody>
</table>

1F = all plants erect; 5 = all plants prostrate.

2F = highest quality; 5 = lowest quality considering diseased seeds, wrinkled and cracked seed coat, and green coloration.

Seed Purification and Increase
LG04-6000 was initially derived from a single F₁ plant in 2003. In 2007 a seed increase plot was planted for seed purification and was carefully rogued to remove off-type plants for flower, pubescence, and pod-wall color as well as any other discernible phenotypic traits. The border rows and the plants at the ends of each row were not harvested to reduce the possibility of contamination by either pollen transfer or mechanical seed mixtures. Harvest was done with a plot combine that was thoroughly cleaned before use. These seeds are the primary source for LG04-6000.

Characteristics
Botanical Description and Seed Traits
LG04-6000 matures approximately 4 d later than LD00-3309 (Abney and Crochet, 2007, 2008) and is classified in early maturity Group IV. The plants are indeterminate in growth habit with white flowers, light tawny pubescence, and brown pods at maturity. Seeds have yellow seed coats and a black hilum.

In the combined analysis across 22 locations in the USDA Uniform Group IV Tests Northern States, LG04-6000 averaged 13.5 g 100 seed⁻¹ compared with 11.8 g 100 seed⁻¹ for LD00-3309 (Abney and Crochet, 2008). Data from the same two tests showed that LG04-6000 (401 g kg⁻¹ protein and 196 g kg⁻¹ oil) was nearly identical to the oil and protein concentrations of LD00-3309 (Abney and Crochet, 2008). LG04-6000 had an average maturity date that was 4 d later and a plant height that was 8 cm taller, and it lodged 0.4 units more than LD00-3309 (Table 2). In 2008, LG04-6000 was 3 d later in maturity and 8 cm taller and again lodged slightly more than LD00-3309 (Table 2). Only nine entries were in common for the 2007 and 2008 tests, so statistics were not calculated for the combined data. However, across 22 locations in 2007 and 2008, the yield of LD00-3309 was 296 kg ha⁻¹ greater than that of LD00-3309 (Abney and Crochet, 2008). LG04-6000 had a yield potential significantly higher than LD00-3309 (Table 2).

Agronomic and Disease Performance
In the 2006 cooperative test with private industry, LG04-6000 yielded a nonsignificant (P = 0.05) 127 kg ha⁻¹ more than LD00-3309 (Table 3) and was 1 d later in maturity. It was 3 cm taller than LD00-3309 and had a slightly higher lodging score (Table 3).

In the 2007 USDA Uniform Group IV Test Northern States (Abney and Crochet, 2007), the yield of LG04-6000 (3756 kg ha⁻¹) was significantly higher (P = 0.05) than LD00-3309 (3507 kg ha⁻¹), the highest-yielding check cultivar (Table 1). LG04-6000 was 5 d later in maturity and 10 cm taller, with a slightly higher lodging score when compared with LD00-3309 (Table 1). In the 2008 USDA Uniform Group IV Test Northern States (Abney and Crochet, 2008), the yield of LG04-6000 (4172 kg ha⁻¹) was again significantly higher (P = 0.05) than that of LD00-3309 (3837 kg ha⁻¹), which also repeated as the highest-yielding check cultivar (Table 2). In 2008, LG04-6000 was 3 d later in maturity and 8 cm taller and again lodged slightly more than LD00-3309 (Table 2). Only nine entries were in common for the 2007 and 2008 tests, so statistics were not calculated for the combined data. However, across 22 locations in 2007 and 2008, the mean yield of LG04-6000 was 296 kg ha⁻¹ greater than that of LD00-3309 (Abney and Crochet, 2008).

Table 3. Means of agronomic traits for LG04-6000 and LD00-3309 from tests grown at eight locations in 2006.

<table>
<thead>
<tr>
<th>Entry</th>
<th>Yield (kg ha⁻¹)</th>
<th>Maturity</th>
<th>Lodging</th>
<th>Height (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LG04-6000</td>
<td>3890</td>
<td>23</td>
<td>1.9</td>
<td>97</td>
</tr>
<tr>
<td>LD00-3309</td>
<td>3763</td>
<td>22</td>
<td>1.6</td>
<td>94</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>403</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. of locations</td>
<td>8</td>
<td>7</td>
<td>6</td>
<td>5</td>
</tr>
</tbody>
</table>

1F = all plants erect; 5 = all plants prostrate.

(3756 kg ha⁻¹) is an exceptional new source of genetic diversity to improve the yield of U.S. cultivars.

Availability
Seeds of LG04-6000 were deposited in the USDA Soybean Germplasm Collection. Small quantities of seed for research and breeding purposes, including the development and commercialization of new cultivars, may be obtained from the collection. We ask that appropriate recognition be made
if this germplasm line contributes to the development of a new breeding line or cultivar.

Acknowledgments
We thank the United Soybean Board for financial support for USB Project 9232, “Identification and utilization of exotic germplasm to improve soybean productivity,” which provided significant resources used in the development of this line.

References