ABSTRACT

A commercial variety of soybean, Chiangmai 60, which is susceptible to field weathering and two field weathering resistant varieties, GC 10848 and Kalitur, were grown and hybridized in the greenhouse at the Department of Agronomy, Kasetsart University. The F1 hybrid seeds and their parental varieties were planted in the greenhouse to produce F2 seeds. Parental varieties, F1 hybrids and F2 progenies were grown in an experimental field during the 2008 dry season at the National Corn and Sorghum Research Center, Pakchong District, Nakhon Ratchasima province. Individual plots were 3×3 m², with six rows, composed of two rows of parents and four rows of F1 hybrids or F2 progenies for each cross. The spacing between rows was 50 cm and between hills was 25 cm. At physiological maturity, soybean pods were harvested, threshed and subjected to tests for accelerated aging (AA) and electrical conductivity (EC), and the seed coat percentage was measured. Field weathering resistance of the parental plants, F1 hybrids and F2 progenies was evaluated using germination percentages after AA testing and EC values of seed leachate and seed coat percentages. Dominance percentages of F1 hybrids and the frequency distribution of F2 progenies for the germination percentages after AA testing and EC values of seed leachate and seed coat percentages of the two soybean crosses revealed that field weathering resistance was controlled by a polygene with partial dominance.

Keywords: soybean, inheritance, field weathering, seed vigor, accelerated aging test, electrical conductivity test

INTRODUCTION

Historically, soybean has been produced in the northern regions of the world’s temperate climatic zone, where environmental stresses are relatively minimal. However, as the world demand for vegetable oil and protein has continued to increase, soybean production has spread rapidly into the hot and humid areas, and more recently into the tropical regions (Moore, 1966). A major constraint to the expansion of soybean production into the tropics is the difficulty of producing high quality seed. Tropical conditions, involving high temperature and relative humidity during the seed
maturation period, are not conducive to the production of high quality seed, which is necessary to establish acceptable cops (Paschal and Ellis, 1978). Soybean seeds deteriorated faster than the seed of most other crops, especially under tropical conditions (Priestley et al., 1985). The process of deterioration in seed quality that occurs between the stages of post-maturation and pre-harvest is referred to as field weathering (TeKrony et al., 1980a).

Field weathering of soybean seeds can be minimized by enhancing field management, such as by carefully matching the maturity of the cultivar with rainfall patterns (Franca Neto et al., 1994), choosing a suitable latitude of the specific seed production region (TeKrony et al., 1980b) and using foliar fungicides and defoliants (Franca Neto et al., 1984). In addition, using a field weathering resistant variety can reduce seed deterioration. Specifically, a field weathering resistant variety allows farmers to grow soybean in both rainy and dry seasons (Wien and Kueneman, 1981). Varietal differences have been identified for resistance to field weathering and deterioration during storage (Ndimande et al., 1981).

Choosing a resistant variety is the most important and essential way to solve the field weathering problem. Generally, field weathering resistant varieties are low in grain yield and market demand. The hard seed coat that can contribute to field weathering resistance is not desired as commercial seed, because of non-uniform germination and emergence. Small seed size and a black seed coat for field weathering resistance are also not favored in the market, even though they have no influence on yield. Special care is needed when using these characteristics in a breeding program (Hill et al., 1986).

At present, field weathering breeding is limited by the lack of genetic information. Inheritance of field weathering resistance should be investigated to facilitate the breeding process for improving field weathering resistant varieties. Only a small amount of work has been done on the inheritance of field weathering resistance, such as the research by Unander et al. (1983), Dechkrong (2006) and Changrong et al. (2006, 2007). However, their work was not detailed. Therefore, it is necessary to study the inheritance of field weathering resistance of soybean for future breeding programs. The objective of this study was to determine the inheritance of field weathering resistance in some soybean varieties.

**MATERIALS AND METHODS**

**Planting the parental varieties and making crosses to produce F1 hybrids**

Chiangmai 60 (CM60), which is susceptible to field weathering (Kaowanant, 2003) and two field weathering resistant varieties, GC 10848 and Kalitur (Yupongchay, 2008), were grown in the greenhouse at the Department of Agronomy, Kasetsart University. Susceptible female parents were emasculated and hybridized with two resistant parents for two cross combinations, following the method described by Poehlman and Sleper (1995).

**Production of F2 seeds**

The F1 hybrid seeds were planted in the greenhouse to produce F2 seeds. The F1 plants were identified as real hybrids using hypocotyl color and flower color as morphological markers, as described by Bernard and Weiss (1973).

**Field test**

Parents, F1 hybrids and F2 progenies were grown in an experimental field during the 2008 dry season at the National Corn and Sorghum Research Center, Pakchong District, Nakhon Ratchasima province. Individual plots were 3×3 m², with six rows, composed of two rows of parents and four rows of F1 hybrids or F2 progenies for each cross. The spacing between
rows was 50 cm and between hills was 25 cm. At physiological maturity, the yellow pods were harvested from each plant of parents, F1 hybrids and F2 progenies for field weathering testing. At this stage, about 95% of the pods were yellow, but had not turned brown (Dassou and Kueneman, 1984). This stage was approximately R7.5, as described by Horlings et al. (1994).

**Field weathering test**

The yellow pods harvested from each plant of parental varieties, F1 hybrids and F2 progenies were air dried to approximately 12% moisture content and hand threshed. The seeds obtained were subjected to the following field weathering tests.

**Accelerated aging test**

Twenty-five seeds from each plant of parents (30, 30 and 30 plants), F1 hybrids (10 and 30 plants) and F2 progenies (239 and 359 plants) of the two crosses were put on wire-mesh trays. The trays were each sealed in a plastic box with 1 cm depth of water under the tray to ensure a high relative humidity (90-100%) during incubation. The boxes were then incubated at 41°C for 3 d (AOSA, 1983). The treated 25 seeds were germinated between wet paper at 25°C for 5 d.

The normal seedlings, abnormal seedlings, fresh un-germinated seeds, hard seeds and dead seeds were counted. Germination percentage was calculated, according to ISTA (1985).

**Electrical conductivity test**

Twenty-five seeds from each plant of parents (30, 30 and 30 plants), F1 hybrids (10 and 30 plants) and F2 progenies (239 and 359 plants) of the two crosses were weighed and soaked in 75 ml distilled water in a 200-ml beaker. A control treatment was used by adding only 75 ml of distilled water into the 200-ml beaker. The beakers were covered with aluminum foil and incubated at 20°C for 24 h (AOSA, 1983). Then, the electrical conductivity of the seed leachate was measured by a Cyberscan pc 510 digital meter and recorded in micro Siemen (µS) per cm per gram of seed.

**Measurement of seed coat percentage**

Ten seeds from each plant of parents (30, 30 and 30 plants), F1 hybrids (10 and 30 plants) and F2 progenies (239 and 359 plants) of the two crosses were soaked in distilled water and incubated at 5°C for 15-16 h. The seed coat was separated from the seed using a razor blade. The seed (without its seed coat) and seed coat were dried in a hot air oven at 105°C for 24 h. After drying, the seed and seed coat were weighed and the seed coat percentage was calculated (Kuo, 1989).

**Genetic analysis**

Field weathering resistance of soybean seeds from each plant of parents, F1 hybrids and F2 progenies of the two crosses was evaluated using the germination percentage after AA testing, the EC value of seed leachate and the seed coat percentage. The mean, standard error and the frequency distribution for these three parameters were calculated for the parents, F1 hybrids and F2 progenies. Mid-parent values and dominance percentages of the two crosses for the three parameters were also calculated and all the data were analyzed using the following formulas:

\[
\text{Mid – parent (MP)} = \frac{P_1 + P_2}{2} \quad \text{and dominance percentage} = \frac{F_1 - MP}{MP} \times 100
\]

**RESULTS AND DISCUSSION**

**Field weathering resistance manifested by germination percentage**

In the AA test, germination after aging was closely related to field emergence under adverse conditions (Delouche and Baskin, 1973). The two environmental variables in the AA test (high temperature and high humidity) caused rapid deterioration of the exposed seeds. High vigor seed lots can withstand these extreme stress conditions and deteriorate at a slower rate than low vigor seed lots (AOSA, 1983). The AA test is one of the most
frequently used for seed vigor evaluation. The seed lots with high germination percentages had high seed vigor, whereas those with low germination percentages had low seed vigor (Ferguson et al., 1990). Dassou and Kueneman (1984) reported that soybean genotypes with high germination percentages following weathering treatment were resistant to field weathering. Egli and TeKrony (1995) indicated that soybean seed lots with higher germination rates after AA testing manifested a high probability of producing adequate seedling emergence under severe environmental conditions. Furthermore, Marwanto (2003) reported that germination after weathering stress positively correlated with soybean seed quality. Phan et al. (2006) evaluated soybean lines and found that those with higher percentages of seed germination following AA testing were resistant to field weathering.

In this study, the range and mean of susceptible (CM60) and resistant (GC 10848 and Kalitur) parental varieties, F1 hybrids and F2 progenies of the two soybean crosses for germination percentages after AA testing were calculated (Table 1). Mid-parent values and dominance percentages were also determined. The mean germination percentages of CM60, GC 10848 and Kalitur were 43.20, 88.80 and 86.67%, respectively. Resistant parental varieties showed more than double the germination percentages of the susceptible varieties. For the CM60 × GC 10848 cross, the mean germination percentage of the F1 hybrid and mid-parent value were 70 and 66%, respectively, whereas the germination percentages of F2 segregating progenies ranged from 33 to 100%, with a mean value of 68.13%. For the CM60 × Kalitur cross, the mean germination percentage of the F1 hybrid and mid-parent value were 69.23 and 64.93%, respectively, whereas the germination percentages of F2 segregating progenies varied from 32 to 100%, with a mean value of 67.28%.

The frequency of the germination percentages of F2 segregating progenies of both crosses showed a continuous distribution and normal curves (Figures 1a and 1b). Therefore, the field weathering resistance in soybean identified by germination percentages after AA testing was controlled by a polygene. Furthermore, the mean germination percentages of the F1 hybrids of both crosses were intermediate between the parents and higher than the mid-parent value (Table 1). The dominance percentages of both crosses were 6.06 and 6.62%, which revealed that there was partial dominance of resistance to field weathering. The result was the same as the findings of Dechkrong (2006) and Changrong et al. (2006, 2007), who reported that field weathering resistance of soybean appeared to be a quantitative trait controlled by a polygene. Unander et al. (1983) considered that, like some other environmental stress resistance factors in plants, field weathering resistance of soybean may also be controlled by a polygene.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Range and mean (±standard error) for germination percentages after AA testing of parental varieties, F1 hybrids and F2 progenies in the two crosses of soybean.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population</td>
<td>CM60 × GC10848</td>
</tr>
<tr>
<td></td>
<td>Range</td>
</tr>
<tr>
<td>P1</td>
<td>24 - 60</td>
</tr>
<tr>
<td>P2</td>
<td>82 - 100</td>
</tr>
<tr>
<td>F1</td>
<td>65 - 75</td>
</tr>
<tr>
<td>F2</td>
<td>33 - 100</td>
</tr>
<tr>
<td>Mid-parent</td>
<td>66.00</td>
</tr>
<tr>
<td>Dominance (%)</td>
<td>6.06</td>
</tr>
</tbody>
</table>
Field weathering resistance identified by electrical conductivity value

The electrical conductivity (EC) of seed leachate has been used satisfactorily to determine the vigor of soybean seed (AOSA, 1983). Hampton and TeKrony (1995) reported that the membrane structure and cell leachate were usually associated with seed vigor. Highly vigorous seeds could re-establish their membrane integrity at a faster rate with less leachate (lower EC value) than those with low vigor. Furthermore, Chanprasert et al. (1996) found that the EC value of the seed leachate was correlated with seed quality, which included seed vigor during field deterioration (weathering). Phan et al. (2006) evaluated soybean lines with low EC values of seed leachate (higher seed vigor) and found that they were resistant to field weathering. Dechkrong (2006) reported that the F2 segregating progenies with low EC values were resistant, while those with high EC values were susceptible to field weathering. Win et al. (2009) demonstrated that soybean varieties/lines with lower EC values of seed leachate tended to be more resistant to field weathering.

In the current study, the range and mean EC values of seed leachate were analyzed for parents, F1 hybrids and F2 progenies of the two soybean crosses. Mid-parent values and dominance percentages were also calculated. The mean EC value of CM60, GC 10848 and Kalitur was 131.40, 78.05 and 85.20 µS/cm/g seed, respectively (Table 2). The EC values of resistant parent had much lower EC values than those of the susceptible parents. For the CM60 × GC 10848 cross, the mean EC values of F1 hybrids and mid-parent value were 113.99 and 104.72 µS/cm/g seed, whereas the EC values of F2 progenies ranged from 70.82 to 146.49 µS/cm/g seed with a mean value of 109.28 µS/cm/g seed. For the CM60 × Kalitur cross, the mean EC values of F1 hybrids and mid-parent were 119.04 and 108.30 µS/cm/g seed, whereas the EC values of F2 progenies varied from 62.33 to 150.09 µS/cm/g seed, with a mean value of 113.65 µS/cm/g seed.

The frequency of the EC values of F2 progenies of both crosses was also continuously distributed and had a normal curve (Figures 1c and 1d) suggesting that field weathering resistance in soybean evaluated by EC value was controlled by a polygene. Table 2 demonstrates that in the CM60 × Kalitur cross, the lowest EC value of some F2 progenies (62.33 µS/cm/g seed) was lower than that of the resistant parent, Kalitur (74 µS/cm/g seed) and the highest EC value of some F2 progenies (150.09 µS/cm/g seed) was higher than that of the susceptible parent, CM60 (140 µS/cm/g seed). This revealed that the character in this cross had transgressive segregation. This finding was consistent with the report of Dechkrong (2006) that field weathering resistance expressed by EC value was monitored by a polygene with transgressive segregation in F2 progenies. Moreover, Table 2 also shows that the mean EC values of F1 hybrids were intermediate between

### Table 2

<table>
<thead>
<tr>
<th>Population</th>
<th>CM60 × GC10848</th>
<th>CM60 × Kalitur</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Range</td>
<td>Mean ± S.E.</td>
</tr>
<tr>
<td>P1</td>
<td>123.00 - 140.00</td>
<td>131.40 ± 0.92</td>
</tr>
<tr>
<td>P2</td>
<td>64.09 - 91.09</td>
<td>78.05 ± 1.34</td>
</tr>
<tr>
<td>F1</td>
<td>105.49 - 123.49</td>
<td>113.99 ± 2.20</td>
</tr>
<tr>
<td>F2</td>
<td>70.82 - 146.49</td>
<td>109.28 ± 0.77</td>
</tr>
<tr>
<td>Mid-parent</td>
<td>104.72</td>
<td></td>
</tr>
<tr>
<td>Dominance (%)</td>
<td>8.85</td>
<td></td>
</tr>
</tbody>
</table>
Figure 1 Frequency distribution of parental varieties and F2 progenies of the two crosses of soybean CM60 × GC10848 and CM60 × Kalitur for germination percentages after AA test (a, b); EC values of seed leachate (c, d); and seed coat percentages (e, f).
those of parents and higher than the mid-parent value. The dominance percentages of both crosses were 8.85 and 9.92%, which implied partial dominance of susceptibility to field weathering. The partial dominance of susceptibility to field weathering might be affected by the maternal (CM60) tissue. Kilen and Hartwig (1978) studied the heritability of an impermeable seed coat and its association with EC value and concluded that the trait was controlled by maternal tissue, which supported the findings of the current study.

**Field weathering resistance revealed by seed coat percentage**

Kuo (1989) reported that soybean seed possessing higher specific weight of the testa showed lower membrane permeability. Consequently, high seed vigor of soybean lines might have resulted from the delayed permeability of the seed coat when the seeds were exposed to field weathering. This finding opens up the possibility of breeding soybean for resistance to field weathering by increasing the proportion of seed coat. Chanprasert et al. (1996) found that seed coat percentage and seed weight were correlated with seed quality during field deterioration (weathering). Phan et al. (2006) identified that the field weathering resistant soybean lines having high seed germination and vigor exhibited higher seed coat percentages than the susceptible ones. Dechkrong (2006) reported that F2 progenies having high seed coat percentages tended to be more resistant to field weathering than the ones with low seed coat percentages. Win et al. (2009) also found that soybean genotypes with low seed weight tended to have high seed coat percentage, which caused greater resistance to field weathering.

In the present study, the range and mean of seed coat percentage for parents, F1 hybrids, F2 progenies of the two soybean crosses are shown in Table 3. Mid-parent values and dominance percentages were also determined. The mean seed coat percentages of CM60, GC 10848 and Kalitur were 5.99, 7.60 and 8.34%, respectively. This indicated that resistant parent had higher seed coat percentages than susceptible parents. For the CM60 × GC 10848 cross, the mean seed coat percentage of F1 hybrids and the mid-parent value were 7.20 and 6.79 %, whereas the seed coat percentages of F2 progenies ranged from 3.70 to 9.30%, with a mean value of 6.92%. For the CM60 × Kalitur cross, the mean seed coat percentage of F1 hybrids and the mid-parent value were 7.88% and 7.16, while seed coat percentages of F2 progenies varied from 4.20 to 10.10%, with a mean value of 7.47%.

The frequencies of the seed coat percentages of F2 progenies of both crosses were continuously distributed and had a normal curve (Figures 1e and 1f), suggesting that field weathering resistance in soybean manifested by seed coat percentage was controlled by a polygene. Furthermore, the mean seed coat percentages of

<table>
<thead>
<tr>
<th>Table 3</th>
<th>Range and mean (±standard error) for seed coat percentages of parental varieties, F1 hybrids and F2 progenies in the two crosses of soybean.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population</td>
<td>CM60 × GC10848</td>
</tr>
<tr>
<td></td>
<td>Range</td>
</tr>
<tr>
<td>P1</td>
<td>5.20 - 6.90</td>
</tr>
<tr>
<td>P2</td>
<td>6.90 - 8.20</td>
</tr>
<tr>
<td>F1</td>
<td>6.60 - 7.80</td>
</tr>
<tr>
<td>F2</td>
<td>3.70 - 9.30</td>
</tr>
<tr>
<td>Mid-parent</td>
<td>6.79</td>
</tr>
<tr>
<td>Dominance (%)</td>
<td>6.04</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Population</th>
<th>CM60 × Kalitur</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range</td>
<td>Mean ± S.E.</td>
</tr>
<tr>
<td>P1</td>
<td>5.20 - 6.90</td>
</tr>
<tr>
<td>P2</td>
<td>7.40 - 9.50</td>
</tr>
<tr>
<td>F1</td>
<td>7.40 - 8.50</td>
</tr>
<tr>
<td>F2</td>
<td>4.20 - 10.10</td>
</tr>
</tbody>
</table>
F1 hybrids were intermediate between those of parents and higher than the mid-parent value. The dominance percentages of both crosses were 6.04 and 10.05% (Table 3), which revealed partial dominance of resistance to field weathering. Moreover, in both crosses, the lowest seed coat percentages of F2 progenies (3.70 and 4.20%) were lower than that of the susceptible parent CM60 (5.20%) and the highest seed coat percentages of F2 progenies (9.30 and 10.10%) were higher than those of the resistant parents, GC 10848 (8.20%) and Kalitur (9.50%). This implied that the character had transgressive segregation. The same result was reported by Dechkrong (2006).

CONCLUSION

Dominance percentages of F1 hybrids and the frequency distribution of F2 progenies for germination percentages after AA testing, EC values of seed leachate and seed coat percentages of the two soybean crosses revealed that field weathering resistance was controlled by a polygene with partial dominance.

To improve field weathering resistant varieties, selection can be carried out effectively from segregating progenies of the cross between a susceptible and resistant variety by pedigree or the single seed descent method. Emphasis in selection should be on field weathering resistant characters, including seed germination percentage after AA testing, the EC value of seed leachate and the seed coat percentage in the F2-F5 generations. From the F3 generation onwards, the performance of soybean plants/lines on good agronomic characters can be considered depending on the nature of responsible characters.

ACKNOWLEDGEMENTS

The authors wish to thank the Oil Crops Development Project, Myanmar for providing financial support for this research. The authors also would like to express thanks to the Laboratory of Seed Technology, Faculty of Agricultural Technology, King Mongkut’s Institute of Technology, Ladkrabang for providing laboratory equipment.

LITERATURE CITED


Dechkrong, P. 2006. Identification of DNA
Markers Linked to Genes Controlling Field Weathering Resistance in Soybean Cross CM60 × GC10848 by Bulk Segregants Analysis. M.S. thesis. Kasetsart University, Bangkok.


