THESIS

**BREEDING OF SOYBEAN *(Glycine max* (L.) Merrill*)*
FOR FIELD WEATHERING RESISTANCE
BY PEDIGREE METHOD**

PHAN THI THANH

**GRADUATE SCHOOL, KASETSART UNIVERSITY
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THESIS

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The present study was conducted to breed soybean variety which could resist to field weathering and gave high seed yielding using pedigree method of selection. Hybridization was made between commercial but susceptible variety (CM60) and two field weathering resistant varieties (SJ1 and GC2796) in 2003. The F_1 hybrid plants were grown in the greenhouse at Kasetsart University, Bangkok. The F_2 progenies were planted in the field at National Corn and Sorghum Research Center, Pakchong district, Nakhon Ratchasima province. Sixty one and sixty eight F_2 plants from the crosses CM60/GC2796 and CM60/SJ1 were selected for field weathering resistance evaluated by accelerated aging test and good agronomic characters. The selection of the F_3 and F_4 progenies was conducted at National Corn and Sorghum Research Center using pedigree method for lines manifested field weathering resistance and good agronomic characters. Field weathering resistance of soybean lines was evaluated by seed germiability after accelerated aging test, seed vigor estimated from electrical conductivity of the seed leakage, percentage of seed coat and seed coat thickness. Twenty seven F3 lines and seventeen F_4 lines of the two crosses were selected. The seventeen F5 lines of two crosses were grown for yield test using randomized complete block design with 4 replications at National Corn and Sorghum Research Center in rainy season 2005. Seed yield (kg/ha) was calculated at 12 percent moisture content. Data of some agronomic characters and yield components were averaged on 10 plants/line. The field weathering resistance was also determined. Six advanced F_5 lines were selected based on high yielding, field weathering resistance and good agronomic characteristics. These promising lines will be further evaluated for field weathering resistance, seed yield and agronomic performance in different locations.

Student's signature	P. Sripichitt Thesis Advisor's signature	Jan / 12 / 2006

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INTRODUCTION

Soybean (*Glycine max* (L.) Merrill) has two important characteristics. Firstly, its seed is rich in nutrients, especially oil and protein contents. On an average, soybean seed contains 37-41% protein, 18-21% oil, 30-40% carbohydrate and 4-5 % ashes (Hulse, 1996). Secondly, it has a capacity to use the atmospheric nitrogen through biological nitrogen fixation process. Soybean is also the lowest-cost producer of vegetable oil. It is one of the world's leading sources of vegetable oil and plant protein both of which are very well adapted to nourishment of human beings (Scott and Aldrich, 1983).

Soybean is the third importance in production of grain after corn and wheat and second in value after corn. In the world, the United States produces 51% of the world's total production, other three soybean-producing countries, Brazil, the People's Republic of China, and Argentina, produce another 38%. The remaining production is scattered among various countries in Asia and South America (Poehlman and Sleper, 1995).

Historically, soybean was produced in the northern regions of the temperate climatic zones of the world, where environmental stresses were relatively minimal. However, as the world demand for vegetable oil and protein continues to increase, soybean production has been spread rapidly into the hot and humid areas, and more recently into the tropical regions (Moore, 1966; TeKrony *et al*., 1980). Rachie and Plarre (1974) pointed out that soybeans were already well established in the tropics at intermediate elevations and in the subtropics. However, whether or not soybeans can be established in low latitude and low elevation tropics depends upon the environmental conditions and good management practices developed.

A major obstacle to the expansion of soybean production to new areas of the tropics is the difficulty in producing high quality seed. Tropical conditions of high temperature and relative humidity during the final stages of seed maturation are not conducive to production of high quality seed necessary to establish acceptable stands (Paschal and Ellis, 1978). The process of deterioration in seed quality occurs between the stages of the post-maturation and pre-harvest period is referred to as field weathering.

Field weathering is a major problem in soybean production. The quality of soybean seeds at harvest time depends heavily on the field weathering conditions during the development, maturation and storage of the seeds on the plant. The severity and limitations of weathering imposed on seed quality generally increase from cool to warm areas. The worst situation is in the humid subtropics and tropics. The quality of seeds produced generally is low and seed deterioration continues at a rapid rate during the storage time because of high temperature and humidity of the environments. Seeds from such weather-ridden crop lose viability owing to pathogenic infestation and physiological deterioration (Bhatia *et al*., 1993).

Field weathering of soybean seeds can be overcome by adjusting the planting date to avoid raining period which may occur during the stage of physiological maturity and pre-harvest period or using the field weathering resistant variety. Specifically, field weathering resistant variety allows the farmers to grow soybean in both rainy and dry seasons. Pascal and Ellis (1978), Potts *et al*. (1978), Ndimande *et al*. (1981), Wien and Kueneman (1981) and Minor and Pascal (1982) reported that varietal differences have been identified for resistance to field weathering and to deterioration during storage. However, no report has dealt with the breeding of soybean for field weathering resistance.

OBJECTIVE

The objective of this study was to breed soybean variety which could resist to field weathering by hybridizing a commercial sensitive variety CM60 with two resistant varieties (SJ1 and GC2796) and selection using pedigree method.

LITERATURE REVIEW

Soybean is one of the oldest cultivated crops in the world. Soybean was first domesticated in the northeastern China about 2500 B.C. From the first areas of its origin, soybeans were spread to southern China, Korea, Japan and other countries in southeastern Asia. Soybean was introduced intermittently into the United States in the late 1700s, but it remained a very minor crop grown mostly for forage until 1920s and 1930s (Poehlman and Sleper, 1995). With the development of lodging and shatter resistant cultivars, soybeans had been changed from a forage crop to an oilseed crop. This change resulted in rapid rising in areas planted of soybean in the following years.

Soybean belongs to the family Leguminosae, subfamily Papilionoideae, tribe Phaseoleae and genus *Glycine*. The *Glycine* genus contains two subgenera, *Soja* and *Glycine* (Poehlman and Sleper, 1995). The cultivated soybean and its wild progenitor, *Glycine Soja*, (containing 2n = 40 chromosomes) are compatable for crossbreeding and carry similar genomes (Palmer *et al*., 1996; Shimamoto, 2001). There are more than 100,000 soybean accessions in germplasm bank mainly from USA, China, Japan, Korea, Russia, Australia, Brazil, Germany, Indonesia and some other countries in Asia and Europe (Chowdhury, 2001).

Soybean production in Vietnam

In Vietnam, soybean is considered as an important source of providing protein for human food and animal feed. Soybean is a short duration crop. It has been cultivating in Vietnam for a quite long time. Soybean is one of the most important leguminous crops grown in Vietnam. It is also a crop suitable for crop rotation, intercropping in multiple cropping systems and improving soil fertility. In recent years, soybean production in Vietnam has reached to about 100,000 - 150,000 mt/year or about 100,000 - 130,000 harvested ha (Vietnam Yearbook, 2003).

Soybean has been grown in more than thirty provinces of the country. The production distribution is approximatly 60 % in the North and 40 % in the South.

About 65% of soybean grown areas is in the upland areas with low soil fertile, 35% of the planted areas is in the deltas, Red River Delta in the North and Mekong River Delta in the South (Nguyen, 1995).

In Vietnam, soybean can be grown in many different cropping systems, geographic areas, and three cropping seasons, spring, summer and winter. At present, soybean is grown mainly in two cropping seasons, the spring crop in the North and the dry season in the Mekong River delta. The summer crop in the North is targeting for major soybean production expansion. The increase in soybean production can also be sought from the winter or dry season crops (Le, 1988).

Soybean produced in Vietnam is used mainly for human consumption. Traditionally, non-fermented foods including tofu, soymilk and soy-flour are the main products while lesser quantities products are used for soy-sauce, paste and cheese. Soybean oil production is between 3000 and 6000 mt per year accounting for about 20% of the total crop production. The residues of soybean oil producing processes are used for animal feed (Pham, 1996).

Soybean is seen as a main source of animal feed for an expansion of livestock industry with an estimated demand of 600,000 mt in 2003. The Government's Development Plan in the next five years (2006-2010) is to increase soybean production to reach the areas of at least 400,000 ha per year (Vietnam Yearbook, 2003).

The constraints to soybean production in Vietnam can be summaried as follows: (1) Lack of varieties with high and stable of yield; (2) Poor seed quality; (3) Pests and diseases; (4) The development of improved varieties and production methods has been limited by the availability of experienced researchers and by limited access to international programs providing expertise and germplasm; (5) A poor infrastructure for seed storage and distribution especially in the upland and remote areas limiting the availability of high quality seed for soybean production in these areas; (6) The application of new varieties has been limited due to limitation of fund for seed production and carrying out extension services (Nguyen, 1995).

Soybean production in Thailand

Soybean is also the most important grain leguminous crop in Thailand. It has been cultivated for over 70 years in the upper north of the country. Soybeans are usually grown after the rice crop is harvested. The first reference to soybean production was made in 1931 in the northern part of Thailand (Pratoomrattana, 1969; Benjasil *et al*., 1994). The planted area has expanded to lower parts of the northern region, and has recently extended to the northeastern region and central plains. Since 1970, soybean production has been not only for local food consumption, but also for modern oil extracting, food processing and animal feeding. From the statistics of the Office of the Agricultural Economics, about 60% of the total domestic soybean production was used for vegetable oil extraction industry, 30% was used by other industries, and 10% was used as seeds (Chainuvati *et al*., 1994).

In Thailand, about 75% of the total soybean production comes from rainfed uplands. Soybeans are grown in all three seasons and the early raining season accounts for 35% and dry season accounts for 23% (Shrivastava, 1997). The average planted area during 1988-1991 was 422,000 ha annually. The planted area decreased to 251,000ha per year during 1996-1999. The average annual soybean production during 1988-1991 was 539,000 mt. Due to the decreasing in planted area during 1996-2000, Thai soybean production decreased sharply and it could be able to meet only 20-30% of the domestic demand. To meet the demand of the country, Thai government had to import about 1.0-1.5 million mt of soybean cakes yearly with the cost approximately of 9,000-11,000 million Baths during 1997-1998 (Field Crops Research Institute, 2001). Although the importance of soybean has been realized by Thai government and farmers, soybean production in Thailand has been still facing a number of constraints, especially lacking of specific cultivars suitable for particular locations (Chowdhury, 2001).

The soybean production in Thailand often encounters with field-weathering damages due to the effects of tropical climates. The tropical weather conditions with high temperature and relative humidity prior to harvest stage often result in rapid decrease in germination and vigor of soybean seeds. It also results in decreasing the quality of seed produced, and not conducive to production of high quality seed necessary to establishment of acceptable stands in Thailand.

Seed development and maturation

Seed development is concerned with the various processes and stage occurring during the period from fertilization until the seed is fully formed and ready for harvest. Seed viability of soybean attained about the 12^{th} day after flowering (seed moisture content 77%, dry weight of seed about 45% of its final value). Seed color begins to change from green to yellow on the 18^{th} day. A drop in the percentage of germination capacity of the seed commences about 14 days after physiological maturity, indicating the development of hard seed.

In soybean, the seed development is noted by Delouche (1974) that seed dry weight increases slowly up to 20 to 30 day after flowering, reaches a maximum at 65-75 day after flowering and remains constant or decreases slightly thereafter.

The changes in moisture levels of seed during development and maturation also are important. Delouche (1974) observed that at maximum dry weight, seed contain 40 to 50 percent moisture, while Mondragon and Potts (1974) stated a value of 30 percent. About one week after physiological maturity, seed moisture dropped to about 15 percent.

Developmental processes during seed growth and maturation interact with the production environment to determine the planting quality of a seed population (Miles *et al*., 1988). Many investigators have reported that seed desiccation in the stage of maturity is related to the ability of immature legume seed to germinate and initiate seedling growth (Adam and Rinne, 1981; Adam *et al*., 1983; Dasgupta *et al*., 1982;

Kermode and Bewley, 1985; Long *et al*., 1981; Obendorf *et al*., 1980; Ozaki *et al*., 1956). The environment during seed development and maturation influences the degree of dormancy of the mature seed (Delouche, 1980). Koller (1962) showed that warm temperature during maturation of 'Grand Rapids' lettuce seed reduces dormancy. A drought during the seed development period usually interrupts seed development and results in light shriveled seed.

Physiological maturity (PM) is normally defined to occur when the seed reaches its maximum dry weight (Shaw and Loomis, 1950; Harrington, 1972), and PM should also represent maximum viability and vigor of planting seeds (Andrews, 1966; Delouche, 1974; Knittle and Burris, 1976). However, seed cannot be mechanically harvested at this stage because of the high level of moisture in the pods and seeds. Soybean seeds attain PM in which moisture content is about 50-55% (Delouche, 1980). Following maturation the seeds continue to dry down until they reach harvest maturity (12-14% moisture content). The seeds at this stage can be effectively threshed with mechanical harvest. The interval between physiological maturity and harvest, which may be a few days or several weeks, is actually a period of storage. Field conditions are seldom favourable for such storage. Climatic conditions during this post-maturation and pre-harvest period have a great influence on the quality of the seed harvested.

Seed deterioration

Soybean seeds deteriorated faster than those of most other crops (Priestley *et al*., 1985), especially under tropical condition (Delouche and Baskin, 1973). Prevailing high temperature and high relative humidity in the lowland humid tropics make the production of soybean seed of good viability and the maintenance of its viability during stogare, very difficult. Loss of seed viability and resultant poor stands were major constraints in Ghana (Mercer-Quarshie and Nsowah, 1975), India (Saxena, 1976) and Indonesia (Somatmaadja and Guhardja, 1976), and have been received major research emphasis on soybean breeding programs of India (Sexena, 1976), INTSOY (Paschal and Ellis, 1978) and IITA (IITA, 1977).

The causes of seed deterioration can be pathological, physiological, or mechanical. These causes frequently occur in combination and act synergistically to reduce seed vigor. It appears that pathogens frequently play a major role in seed deterioration from the period of physiological maturity to harvest (Kuenemam, 1982). Seed viability decreases even before harvesting when high temperatures and humidity during the maturation period interact with incidence of fungal pathogens to reduce the quality of maturing seed (Green *et al*., 1965; Hinson and Hartwig, 1977; Paschal and Ellis, 1978; Ndimande *et al*., 1981).

Field deterioration or weathering damage is a part of the deterioration process that occurs before the seeds are harvested. It is the most detrimental factor affecting soybean seed quality in the tropics (Franca Neto *et al*., 1994a). It is generally considered that deterioration starts when physiological maturity is reached (Delouche, 1973, Mondragon and Potts, 1974) and continues at varying rates after this growth stage. Under some conditions, field deterioration may begin before physiological maturity (Harrington, 1973). The detrimental effects of allowing soybean seeds to remain in the field after reaching physiological maturity have been known for many years. The rate of seed quality loss after physiological maturity depends on the degree of unfavorable environmental conditions surrounding the seeds. Exposure of seeds to field weathering is the major cause of seed quality loss after physiological maturity reached (Delouche, 1980; Nangju *et al*., 1980). Such weathering not only lowers seed germination but also increases susceptibility to mechanical damage (Green *et al*., 1966; Metzer, 1967), and disease infection (Wilcox *et al*., 1974; Tedia, 1976; Pashal and Ellis, 1978).

Deterioration of seed in the field prior to harvest (field weathering) begins when the seeds reach physiological maturity, and it continues until the seeds are harvested. Green *et al*. (1965 and 1966) reported that when raining delayed harvesting time after the seed moisture content had been initially declined to 13.5%, seed quality would be declined and substantial reductions in germination and field emergence were seen. Nangju (1979) reported that harvest delays were accompanied by an increase in purple stain and cracked, wrinkled, and discolored seed. He proposed the use of delay-harvest and rainfall to evaluate for resistance to field weathering. Paschal and Ellis (1978) obtained reduced seed germination and field emergence of 7 and 14 percent, respectively, by delaying harvest for two weeks. Andrews (1982) obtained highest seed quality when 95 percent of the pods were matured and seed quality dropped when harvesting was delayed for 14, 28 or 42 days after 95 percent maturity. Paschal and Ellis (1978) grew 24 soybean lines in Peurtro Rico to determine the incidence and effect of fungal infection on seed viability under tropical condition. Seeds were harvested at maturity and two and four weeks later. The incidence of fungi has increased from 9 percent on seed harvested at maturity to 45 percent for seed harvested four weeks later. Tekrony *et al.* (1980) reported the similar declines in vigor when seeds were harvested at 30 days after maturity, especially if hot and humid conditions prevailed. They also indicated that soybean seed quality was reduced by environmental factors such as temperature, precipitation, relative humidity and strong wind during maturation period. Field weathering has certain negative effects on soybean seed quality.

Futhermore, seed deterioration under storage condition has been a major constraint to successful soybean production. Under the hot and humid conditions, soybean seed germination is generally low at harvest. Even when germination is high, its viability rapidly decreased during the storage resulted to the poor planting materials by the next sowing season (Popinigis, 1984). Soybean seed normally subjected to the field weathering before harvesting or severely damaged during harvest if it does not store quite well (Delouche and Rodda, 1976). Unfavourable condition of high temperature and relative humidity during storage will promote seed deterioration. The length of storage period had much more drastic effect than the two weeks delay in harvesting on the percent emergence of the lines when they were planted in the field (Wien and Kueneman, 1981). Eight months of ambient storage reduce the lines with poorest storability to nearly zero emergence and all cultivars had good field emergence after storage periods of four months or less. Wien and Kueneman (1981) also reported that the effect of delayed harvesting was generally severe with prolong storage. Cultivar differences in rate of deterioration before harvesting (Green and Pinnell, 1968) and during storage (Paschal and Ellis, 1978) have recently been reported. Franca Neto *et al*. (1994b) compared the effects of two initial levels of seed moisture and storage environment on the quality of seeds of the cultivar produced and stored in a tropical region of Bazil. Seed vigor and germination significantly decreased after 45 days in open storage. After three months, the incidence of *Aspergillus spp*. was above 50 percent and standard germination and vigor were severely affected.

Field weathering of soybean seed

Among the constraints for soybean production expansion, poor seed quality is a very important one in the humid tropics and subtropics (Horlings *et al*., 1994). Nangju *et al*. (1980) suggested that the reason for poor soybean seed quality in the tropics is due to environmental condition such as hot and humid climate, which may not be suitable for growing soybean. Several researchers have reported that soybean attains its highest seed quality at physiological maturity (maximum seed dry weight) (Wahab and Burris, 1971; Delouche, 1974). The seed vigor and viability reach a peak at physiological maturity (Ching *et al*., 1972). Unfortunately, due to high moisture content, seeds cannot be harvested commercially at this growth stage and they must remain in storage on the plants throughout a desiccation period. This period may vary from a few days to over 3 weeks before seed reaches a harvestable moisture level (harvest maturity). Soybean seed quality can be reduced by a wide range of environmental factors during this period (Delouche, 1974; TeKrony *et al*., 1980).

Climatic conditions during the post-maturation and pre-harvest periods have a great influence on the quality of harvested seed (Delouche, 1980). Mondragon and Potts (1974) reported that fluctuations in temperature and relative humidity determine the degree of soybean seed weathering. Moore (1971) proposed that exposure of mature soybean seeds to alternate wetting and drying in the field resulted in embryo destruction and lower quality. Metzer (1967) concluded that laboratory weathering of the seeds in pods at high or alternating (high and low) relative humidity for 14 days following harvest maturity increased susceptibility to mechanical injury and lowered seed quality. Delouches (1974) had documented many instances of poor seed quality of soybeans and strongly contended that adverse weather conditions during the post-maturation and pre harvest periods caused moderate to severe seed quality problem.

Environmental moisture of significance in subtropical and tropical soybean growing region takes the form of heavy early morning fog, dew, or rain. Under these conditions, relative humidity varies considerably but usually remains high during the warm, humid growing season. Additionally, as the fogs lift, dew dries, and rains cease, a hot, penetrating sun bears down upon the developing seed. Soybean seeds are very susceptible to such extremes of wetting and drying. Such cycles, particularly during the latter stages of seed maturation, are quite detriment to seed quality and in fact cause rapid deterioration. As early as 1950, Moorse *et al*. reported that exposure to periods of dampness caused soybean seeds to deteriorate. In evaluating the effects of various field environments upon soybean seed quality, Mondragon and Potts (1974) and Burdette (1977) determined that supplemental water sprays, either daily or once or twice weekly, increased the rate and degree of field deterioration. Deterioration was retarded either by protecting the maturing seeds from the ambient field environment or by removing them completely from it. Tropical and subtropical climate with high rainfall and temperature are also to obviously lead to a reduction in seed quality.

The environment plays a significant role in affecting the quality of soybean seeds. High temperature coupled with high humidity exerts severe stresses upon developing soybean seeds. Moorse *et al*. (1950) stated that hot weather during seed maturation often resulted in seed coat wrinkling which reduced germination. Andrews (1982) evaluated 18 soybean lines in Brazil, he found that an alternation of rain and hot weather accelerated deterioration, and high temperature during final stages of seed maturation caused the development of green seeds of low quality. Nicholson and Sinclair (1971) had reported that the incidence and severity of fungal invasion of seed was increased by weathering which lowered seed quality. The loss in seed quality was due to increased incidence of *Phomopsis. sojae* and other fungi when soybean harvest was delayed (Wilcox, 1974).

Field weathering resistance

Successful cultivation of soybean in the tropic requires the availability of high quality of planting seed. Local production of such seed requires cultivars capable of enduring adverse climatic condition usually presents during the later stages of production and throughout most of the storage period (Ferraz de Toledo *et al*., 1994).

There is large variation in seed quality among soybean cultivars (Dassou and Kueneman, 1984; Minor and Paschal, 1982; Paschal and Ellis, 1978). Studies have shown that viability is maintained longer in smaller than in larger seed (Delouche, 1975; Wien and Kueneman, 1981). Some seed characteristics were found to be very beneficial under tropical conditions (resistant to field weathering), such as hard seed coat (Potts *et al*., 1978; Hartwig and Potts, 1987), small seed size (Pashal and Ellis, 1978; Nangju, 1979; Dassou and Kueneman, 1984 and Horling *et al*., 1994), black seed coat (Dassou and Kueneman, 1984 and Horlings *et al*., 1994) and hardseed (Delouche, 1975 and Wien and Kueneman, 1981).

Burchett *et al*. (1975) and TeKrony *et al*. (1980) found that one of the main factor appear to contribute to the low vigor soybean seeds is the highly permeable seed coat through which soybeans absorb moisture easily, and thus tend to be more susceptible to weathering in the field as well as to humid tropical environment under open storage conditions. Kueneman (1982) reported that the mechanisms of resistance to deterioration may be associated with the seed coat. The hard seed coat helps to prevent viability loss by limiting the exchange water and gas between the seed and the environment. The seed coat also has a relevant role in preventing the entry of pathogenic micro-organisms.

Seed size and quality relationships have been extensively studied in soybean. Cultivars with small seed size appear to be better adapted to some tropical climates (Paschal and Ellis, 1978). Edwards and Hartwig (1971) compared germination and emergence of 3 nearly isogenic lines of soybean differing in seed size and found that seed of the small seeded line germinated and emerged most rapidly in a Sharky soil.

Small and medium-seeded near isogenic lines showed quicker emergence and greater root development than large-seeded lines, which was confirmed by Green et al. (1965). Ferraz de Toledo *et al*. (1994) showed that lines with small seed seemed to retain their quality better than those with large seed. Seed size was negatively correlated with field emergence and positively correlated with incidence of fungi. The smaller seeded genotypes had higher emergence percentages and less internally seedborne fungi (Paschal and Ellis, 1978). The small-seed size was controlled by Se (in pure line of PI 196.176) and L_1L_2 (in pure line of PI 85.505) genes (Bernard and Weiss, 1973). Dassou and Keuneman (1984) concluded that nearly all large-seeded genotypes were highly susceptible to both weathering and deterioration in storage while small-seeded genotypes having high percentage of hard seeds could resist to field weathering and deterioration in storage.

Several studies have suggested that hard seededness can provide protection against seed deterioration (IITA, 1977; Potts *et al*., 1978). Hard seededness was beneficial in maintaining the viability of seeds remaining in the field for up to 9 weeks after seed moisture initially declined to 20 percent. Hard seed coats restrict the entry of water into the seed and prevent or greatly reduce seed deterioration (Potts et al., 1978). Hartwig and Potts (1987) found germination of hardseeded strains to remain above 90 percent when left in the field up to 42 days after maturity. Dassou and Keuneman (1984) observed that there is a closely correlation coefficient between seedling emergence following field weathering and percentage of hard seed. They also reported that the percentage of hard seed was correlated with seedling emergence following incubator weathering and accelerated aging of unweathering seed.

Black seed coat color is one of the seed characteristics associated with resistance to weathering. Nagai (1921) showed that a single gene pair controlling black seed coat (*RR*) was completely dominant to brown seed coat (*rr*). He also described a second locus (*C*-*c*) with a recessive allele that altered black seed coat to imperfect black and brown to buff. Bernard and Weiss (1973) showed that there was a pleiotropic effect of the *T*-*t* gene pair for pubescence and seed coat color. Thus, tawny pubescence varieties have black or brown pigment in the seed whereas gray pubescent varieties have imperfect black or buff pigment. Dassou and Keuneman (1984) found that the mean emergence scores for 16 black-seeded genotypes after incubator weathering, field weathering and ambient storage were 47, 69 and 82% respectively compared to 9, 52 and 54% for the 19 yellow-seeded genotypes.

Genotypic differences in resistance to field weathering have been observed (Green and Pinnell, 1968; Pashal and Ellis, 1978; Potts *et al*., 1978). Some soybean cultivars appeared to be inherently more susceptible to field deterioration than others. Lassim (1975) compared the rate of field deterioration of 3 soybean varieties (Mack, Dare and Forrest) and indicated that the seed of Mack decreased much more rapidly in germination than other varieties. The poor weathering resistance of Mack soybean is well known to seedsmen.

Pedigree method of breeding

The pedigree method was first outlined by Love (1927) and Hays and Garber (1927). It has been subsequently discussed in all the plant breeding textbooks. It essentially consists of selecting promising plants in segregating generations of planned crosses commencing with F2 plants and progenies of each selected plant reselected in succeeding generations maintaining detailed pedigree until genetic purity is reached. A progeny is bulked and considered to be a pure breeding line as soon as all the plants appear to be uniform for easily observed morphological and seed characters.

During the period 1951 to 1960, about 95 percent of the varieties and during 1961 to 1974, almost 100 percent of the varieties developed were selected from the advanced segregating generations of planned crosses and backcrosses. The methods of handling the segregating generations have been pedigree, bulk and modified pedigree. However, most of the varieties have originated by pedigree method (Brim, 1973).

The earliest soybean lines were derived by the pedigree method (Zhu *et al*. 1995). This method is generally preferred in soybean as it permits rigorous selection for height, maturity, resistance to shattering and diseases, and plant type in F2 segregating population. This reduces number of plants that would otherwise be taken to advanced generations (Singh, 1976).

A number of workers have compared the effectiveness of the bulk, pedigree and modified pedigree methods of breeding in soybeans. Raeber and Weber (1953) evaluated bulk and pedigree methods of breeding in four crosses of soybeans and indicated that the phenotypic superior selections from F5 bulk populations were equally successful as pedigree selection. They also suggested that the greatest genetic advance in selecting for yield could be made by a combination of pedigree testing and concurrent phenotypic selection. Torrie (1958) compared the bulk and pedigree methods of breeding in soybeans with F6 lines in six soybean crosses. He found that the lines developed by bulk method were a bit later in maturity than those developed by the pedigree method. Luedders *et al*. (1973) evaluated the lines selected from six populations advanced by the pedigree method, early generation testing and bulk method in F6 and F7 generations. Highly significant differences in yield were observed among selections within method in all the six populations but no significant difference was observed due to methods of generation advance.

The pedigree method was also applied for selecting other crops. Hargrove (1978) informed that there were 31 rice breeders at 21 research centers in ten Asian countries, 68 percent of these used the pedigree method in breeding, and 94% of varieties was selected by this method in combination with other methods.

Selection for seed yield is one of the most important and difficult challenges of plant breeding. Pedigree method of selection can be used to identify superior genotypes for seed yield in cultivars development program. However, concomitantly with high yielding, cultivation soybean in the tropics requires high quality of planting seed. Genetic variability for soybean seed quality does exist. Several sources of high seed quality were identified, which confirmed the possibility of selecting for improving seed quality among soybean lines (Krzyzanowski, 1998).

The mechanism of resistance to field weathering in soybean may be associated with pod-wall permeability (Tully, 1982), seed-coat characteristics (Kueneman, 1982) and it has a relevant role in preventing the entry of pathogenic micro-organisms into the seed (Miranda, 1997). Brurris *et al.* (1973) had reported of seed size influencing seed vigor in soybean, wheat and several vegetable crops and they also suggested that the breeder should select for genotypes that produce high proportion of acceptable small seed size.

METERIALS AND METHODS

1. Materials and Equipments

1.1. Plant materials

Chiangmai 60 (CM60) was released by the Department of Agriculture, Ministry of Agriculture and Co-operatives in 1987. It possessed average yield of 2,460 kg/ha (Srisombun, 2000), plant height of 87cm, growing period from 90-95 days and one hundred-seed weight of 18g. Seed composition includes 20.2% oil and 43.8% protein. It has determinate growth habit. It is widely grown in Thailand. However, it is susceptible to field weathering (Kaowanant, 2003).

SJ1 was released by the Department of Agriculture, Ministry of Agriculture and Co-operatives in 1965. It has the yield of 1,662 kg/ha (Srisombun, 2000), plant height of 116.4cm, growing period from 98-100 days and one hundred-seed weight of 14.5 g. It shows indeterminate growth habit (Noiburi, 2004). It is resistant to field weathering (Kaowanant, 2003).

GC2796 possesses the plant height of 35.2cm. It has the yield of 1,450.7 kg/ha, growing period from 80-83 days, one hundred-seed weight of 16.3g. It has determinate growth habit (Noiburi, 2004). It is resistant to field weathering (Kaowanant, 2003).

1.2. Equipments

1.2.1. Equipments for hybridization: forcep, scissor.

1.2.2. Equipments for soybean planting: pots, fertilizers, insecticides and fungicide.

1.2.3. Equipments for field weathering evaluation: balance, electrical conductivity meter, incubator, tray, plastic box, beaker, razor blade, digital vernier and rolled paper towel.

2. Methodology

The experiments were conducted from 2003 to 2005. Hybridization was done in greenhouse at Agronomy Department, Faculty of Agriculture, Kasetsart University, Bangkok. The F_2, F_3, F_4 progenies and yield test of F_5 lines were conducted at the National Corn and Sorghum Research Center, Pakchong, Nakhon Ratchasima province. Field weathering of soybean plants/lines was evaluated at the Department of Agronomy, Faculty of Agriculture, Kasetsart University, Bangkok.

2.1 Hybridization and selection

- **Season 1**

CM60, SJ1 and *GC2796* were planted in the greenhouse as susceptible and resistant parents for crossing. The pollination was done when the female susceptible parent *(CM60)* and male resistant parents (*SJ1* and *GC2976*) were flowering. F_1 hybrid seeds were collected from female parent.

- **Season 2**

The F_1 hybrid seeds obtained were grown in the greenhouse. The F_2 seeds from F_1 plants were harvested at maturity.

- **Season 3**

The F_2 seeds obtained from F_1 hybrid plants were grown in the field. The pods were harvested from each of the F_2 plants at physiological maturity for field weathering determination by accelerated aging test (AA test). The F_2 plants having field weathering resistance and good plant performance were selected for the next generation.

- **Season 4**

The F_3 progenies were grown as plant to row in the field. Some agronomic characters including plant height, number of days to 50 percent flowering, number of days to maturity, number of pods/plant, number of seeds/pod, stem termination type and lodging of each soybean line were recorded. The pods were harvested at physiological maturity for field weathering evaluation by AA test, electrical conductivity test and percentage of seed coat and seed coat thickness. Selection was done for the lines and plants within the lines possessing field weathering resistance and good agronomic characters.

- **Season 5**

The F_4 lines were grown in the field. Some agronomic characters of each line as mentioned in season 4 were investigated. The pods were harvested at physiological maturity for field weathering evaluation as stated in season 4. Selection was done for the lines and plants within the lines having field weathering resistance and good agronomic characters.

- **Season 6**

The F_5 lines were grown in the field for yield test using randomized complete block design with 4 replications. Some agronomic characters of each line as described in season 4 were determined. At physiological maturity, pods were harvested for evaluation of field weathering evaluation as described in season 4. Selection based on the lines having high yield, field weathering resistance and good agronomic characters.

2.2 Evaluation of field weathering

Field weathering of soybean seeds was evaluated using 3 following tests.

2.2.1 Accelerated aging test (AOSA, 1983)

Pods in yellow color were separated from plants at physiological maturity and air dried until the pods turn brown and dry. The seeds were threshed by hand from the pods and air dried for 1-2 days (about 12% moisture content). Two replications of seed were formed in which each replication contained fifty seeds in number. They were placed in a screen 4 cm above the water surface and incubated at 40^0C and 100% relative humidity for 3 days. After incubation, seed germinability was evaluated by standard germination test (ISTA, 2003).

Germination test was conducted by using rolled paper towel method. The seeds of two replications in which each replication contained fifty seeds were placed on paper towels which were moistened with distilled water. The towels were rolled, placed in a plastic bag and then kept at $25^0 \pm 1^0$C in darkness for 5 days. Germination percentage were calculated according to ISTA (2003).

2.2.2 Electrical conductivity test

Twenty five seeds from 2.2.1 were weighed and soaked in 75ml deionized water in 200ml beaker with two replications. Control treatment was done by adding only 75ml deionized water into 200ml beaker. The beakers were covered with aluminum foil and incubated at 20^0C for 24 hours. The electrical conductivity (EC) of mixture (leakage from seeds and water) and deionized water (control treatment) was measured after incubation by electrical conductivity meter (Consort, C830). The EC of the leakage from seeds was determined by substracting the EC of deionized water from the EC of mixture (leakage from seed and deionized water). The EC of the leakage from seed was recorded in microSeimen (μS) per cm per gram of seed.

2.2.3 Measurement of seed coat thickness and percentage of seed coat

Ten seeds from 2.2.1 were soaked in distilled water and incubated at 5^0C for 15 – 16 hours with two replications. Seed coat was separated from seed using razor blade. Both seed (without seed coat) and seed coat were dried in hot air oven at 105^0C for 24 hours. After drying, the seed (without seed coat) and seed coat were weighed. The seed coat thickness (mm) was measured by using digital vernier.

The percentage of the seed coat was calculated by the formula of Huo (1989) as follows:

$$\% \text{ Seed coat} = \frac{\text{Seed coat dry weight}}{\text{Seed and seed coat dry weight}} \times 100$$

2.3. Determination of agronomic characters

The agronomic characters of soybean lines were determined according to the description given by Field Crop Research Institute (1997).

- Plant height was measured from the base of main stem to the terminal node (cm).

- Number of days to 50% flowering was the number of days from emergence to 50% of plants having first flowering.

- Number of days to maturity was the number of days from emergence to 95-100% of pods turning brown.

- Stem termination type was classified into determinate and indeterminate growth habit by using flowering period (Foley *et al*., 1986).

Determinate: plant having flowering period less than 14 days
Indeterminate: plant having flowering period more than 15 days

- Lodging from vertical line was scored on mature row of soybean plants with scale ranged from 1 to 5 levels (Gates et al.,1959).

1 = All plants were erect.
2 = 1-25% of plants in row were prostrate.
3 = 25-50% of plants in row were prostrate.
4 = 51-75% of plants in row were prostrate.
5 = > 75% of plants in row were prostrate.

- Yield (kg/ha) at 12% seed moisture content was calculated as follows:

Yield = (100 –B) x A / (100 – 12)
A = Total seed weight
B = Seed moisture measured by standard moisture meter

- Yield component includes:

1) Number of pods per plant
2) Number of seeds per plant
3) One hundred-seed weight (at 12% moisture content)

- Seed coat color was divided into 8 groups:

1 = Yellowish white
2 = Yellow
3 = Green

4 = Buff

5 = Reddish

6 = Gray

7 = Imperfect black shading to buff

8 = Black

2.4 Data analysis

Analysis of seed yield and seed characteristics attributed for field weathering was done by IRRISTAT program with significant differences at $P \leq 0.01$ or $P \leq 0.05$.

RESULTS AND DISSCUSION

Evaluation of field weathering reristance in F_2 progenies

Selection of soybean for field weathering resistance was conducted for two crosses between commercial variety CM60 which was susceptible to field weathering and field weathering resistant varieties (GC2796 and SJ1) using pedigree method from F_2 to F_5 generation. The F_2 progenies were evaluated for field weathering resistance by seed germination percentage following accelerated aging test (AA test). The F_2 plants of two soybean crosses were divided into two groups, resistance and susceptibility to field weathering. The plants showing seed germination percentage after AA test more than 80% were considered to be resistant to field weathering as suggested by Vieira *et al.* (2004). The segregation of F_2 plants for field weathering resistance was presented in Table 1. There were 273 and 278 resistant plants from the crosses CM60/GC2796 and CM60/SJ1, respectively. The frequency of resistant plants of the cross CM60/GC2796 (77.12%) was higher than that of the cross CM60/SJ1 (49.64%). This data implied that field weathering resistant trait of the male parent GC2796 was inherited to progenies more than that of the SJ1 male parent.

Table 1 Segregation of plants for field weathering resistance in the F_2 progenies of two soybean crosses.

Crosses	Total F_2 plants	Field weathering			
		Resistance		Susceptibility	
		No. of plant	%	No.of plant	%
CM60/GC2796	354	273	77.12	81	22.88
CM60/SJ1	560	278	49.64	282	50.36
Total	914	551	60.28	363	39.72

Sixty one and sixty eight F_2 plants from the two crosses which showed seed germination percentage higher than 94%, and number of pods per plant greater than 64 pods and 90 pods in the crosses CM60/GC2796 and CM60/SJ1, respectively, were selected for evaluation of field weathering and agronomic characters in the F_3 generation (Appendix Table 1).

Selection for field weathering resistance in F_3 generation

Field weathering resistance of the F_3 lines was evaluated from some seed characteristics including seed germination percentage after AA test, seed vigor estimated from the EC value of seed leakages, percentage of seed coat and seed coat thickness. Actual data of seed charactersistics attributed for field weathering of F_3 lines were given in Appendix Table 2. The distribution of some seed characters including seed germination percentage, EC value and seed coat percentage of the F_3 lines were displayed graphically in Figure 1, 2 and 3. After accelerated aging test, seed germination percentage of the F_3 lines ranged from 56 to 100% and 58 to 100% in the crosses CM60/GC2796 and CM60/SJ1 while the sensitive parental variety CM60 showed germination percentage of 72.1%. The EC values varied from 52.16 to 120.12µS $cm^{-1}g^{-1}$and from 49.11 to 148.66µS $cm^{-1}g^{-1}$ in the crosses CM60/GC2796 and CM60/JS1 whereas the EC value of the sensitive variety CM60 was 100.2 µS $cm^{-1}g^{-1}$. The soybean lines having EC values ranged from 60 to 70µS $cm^{-1}g^{-1}$ and 70 and 80µS $cm^{-1}g^{-1}$ were considered to be highly and intermediary vigor seed (Vieira *et al.*, 1999) whereas those possessing EC value higher than 150 µS $cm^{-1}g^{-1}$ were classified as low vigor seed lots and assumed to be inadequate for sowing (Vieira *et al.*, 2004). According to the previously described classification, the F_3 lines having EC value extended from 49.11 to 148.66 µS$cm^{-1}g^{-1}$ were assessed to be highly and intermediary vigor seed.

Seed coat percentage of the F_3 lines extended from 6.05 to 8.14% and from 6.04 to 8.53% in the crosses CM60/GC2796 and CM60/SJ1 while the sensitive variety CM60 possessed 6.08 percent of seed coat. Seed coat thickness varied from 0.075 to 0.105 mm and from 0.075 to 0.112 mm in the crosses CM60/GC2796 and CM60/SJ1 whereas the sensitive variety CM60 had seed coat thickness of 0.083 mm. It was observed that the F_3 lines presenting low EC value or high seed vigor tended to possessed high weight and thickness of seed coat.

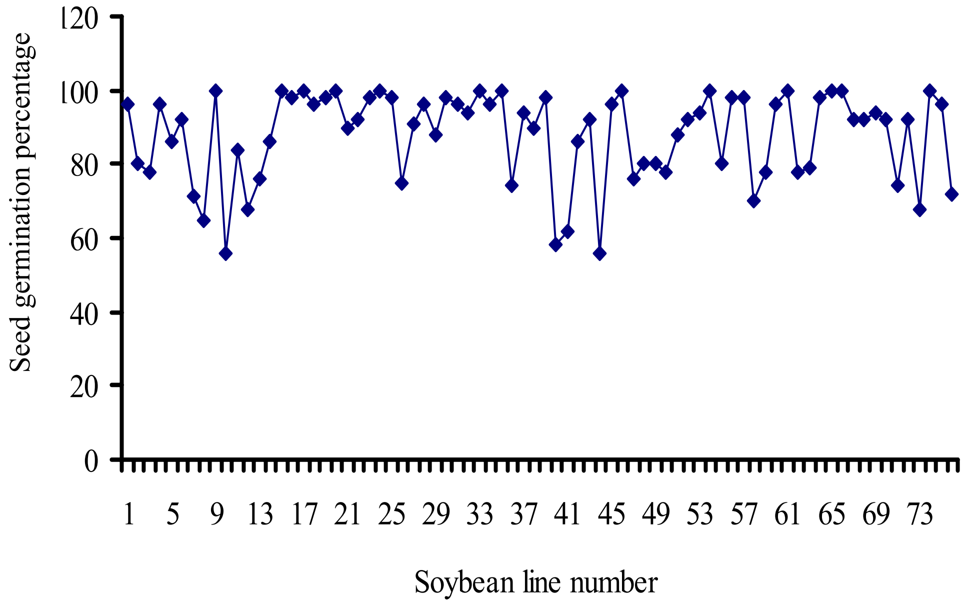

Figure 1 Seed germination percentage after AA test of the 73 F_3 lines of two soybean crosses and three check varieties (GC2796, SJ1 and CM60).

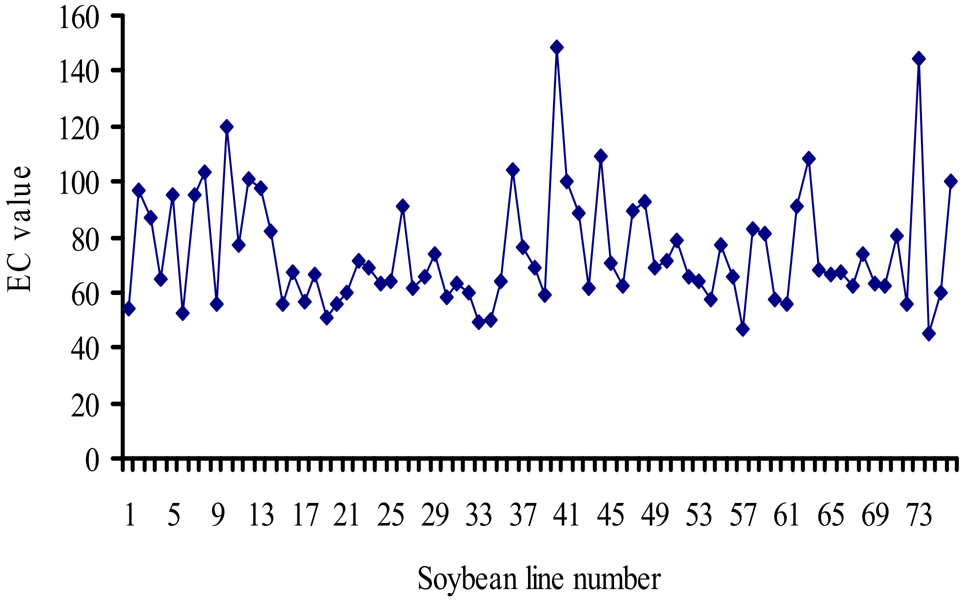

Figure 2 EC value of the 73 F_3 lines of two soybean crosses and three check varieties (GC2796, SJ1 and CM60).

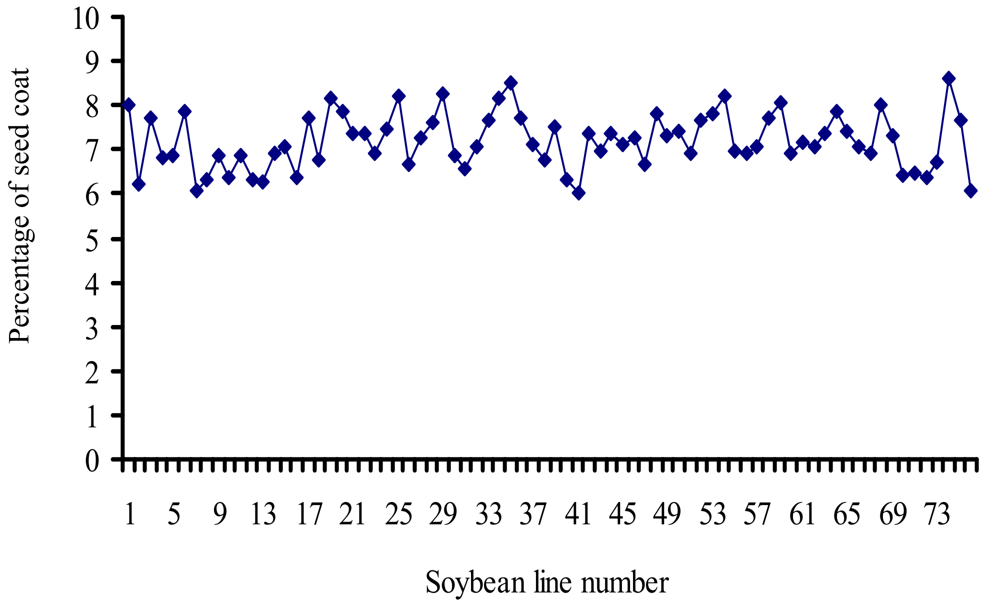

Figure 3 Seed coat percentage of the 73 F_3 lines of two soybean crosses and three check varieties (GC2796, SJ1 and CM60).

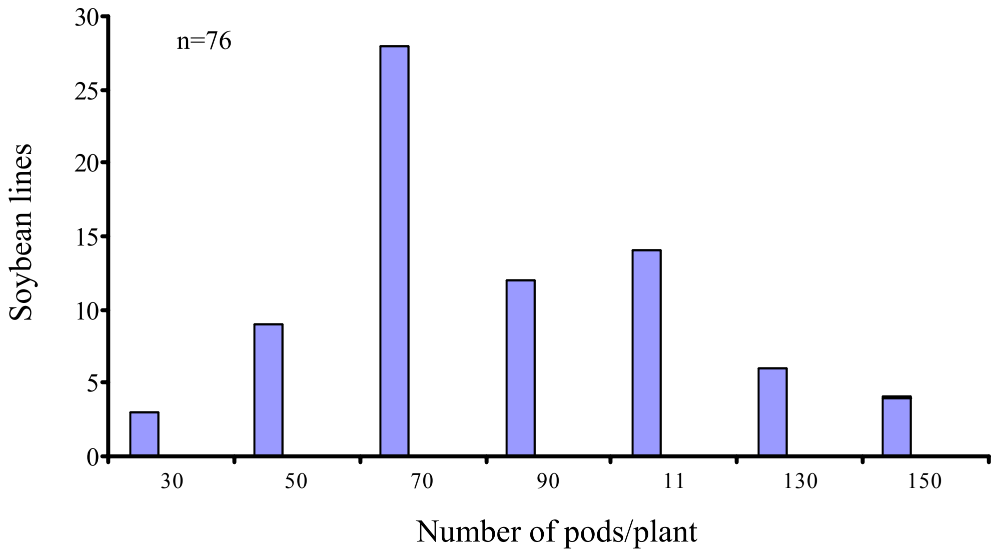

Figure 4 Distribution of pod number/plant of the 73 F_3 lines of two soybean crosses and three check varieties.

Evaluation for agronomic characters of soybean lines was necessary to identify the promising lines that might give high seed yield. Some agronomic characters of soybean lines were determined including number of days to flowering, number of days to maturity, flower color, plant height, lodging score and stem termination type. The data of agronomic characters of the F_3 lines of two soybean crosses were shown in the Appendix Table 3.

The number of days to 50% flowering ranged from 35 to 40 days and 39 to 45 days in the crosses CM60/GC2796 and CM60/SJ1 whereas that of parental variety CM60 was 39 days. The number of days to harvest varied from 85 to 90 days and from 90 to 98 days in the crosses CM60/GC2796 and CM60/SJ1, respectively while CM60 was harvested at 92 days after planting. The F_3 lines of the cross CM60/SJ1 were harvested later than those of the cross CM60/GC2796 because some of them possessed indeterminate growth habit which was contributed from their male parent SJ1.

Plant height of the F_3 lines expanded from 35 to 59 cm and from 42 to 94 cm in the crosses CM60/GC2796 and CM60/SJ1 whereas CM60 has the plant height of 59cm. All F_3 lines of the cross CM60/GC2796 possessed short and determinated stem type which was obtained from their male parent GC2796. Nevertheless, F_3 lines of the cross CM60/SJ1 exhibited variation in plant height from short to tall and stem type from determinate to indeterminate which were inherited from both of their parents CM60 and SJ1. All F_3 lines of the cross CM60/GC2796 had erect stem type (lodging score 1) while those of the cross CM60/SJ1 varied in stem type from erect to lodging at score 3. It was noticed that the lines with indeterminate stem type lodged more than the determinated stem lines. Similarly, Cooper (1971) had reported that cultivars with indeterminate growth habit were generally taller and lodging more than that of the determinate cultivars.

The variation in soybean yield was mainly due to the variation in number of seeds per unit area (Shibles *et al.*, 1975). Therefore, evaluation of the number of pods per plant in the early generation could predict soybean line producing high yielding in the next generation. The number of pods per plant of the F_3 lines extended from 34 to 87 pods and from 67 to 166 pods in the crosses CM60/GC2796 and CM60/SJ1 while that of the commercial variety CM60 was 77 pods. Most of the F_3 lines in the cross CM60/SJ1 exhibited higher number of pods per plant than F_3 lines of the cross CM60/GC2796 because the number of pods per plant of the male parent SJ1 (80 pods) was higher than that of the male parent GC2795 (30 pods). The distribution of the F_3 lines for number of pods per plant was illustrated in Figure 4. The selection for number of pods per plant was done with the lines presenting number of pods per plant greater than 70 pods.

Twenty seven F_3 soybean lines which showed seed germination percentage higher than 90%, EC values less than 70µS $cm^{-1}g^{-1}$, percentage of seed coat and seed coat thickness higher than those of the susceptible variety CM60 and good agronomic characters were selected (Table 2 and Table 3).

Table 2 Some seed characteristics attributed to field weathering resistance of the F_3 selected lines of two soybean crosses (dry season, 2004).

Line no.	Pedigree	Seed germination[2/] (%)	EC ($\mu S\ cm^{-1}g^{-1}$)	Percentage of seed coat	Seed coat thickness (mm)	Seed coat color
1	CM60/GC2796-23-2	96	54.14	8.02	0.105	Yellow
2	CM60/GC2796-200-26	92	52.16	7.84	0.088	Yellow
3	CM60/GC2796-225-34	100	55.73	6.85	0.080	Yellow
4	CM60/GC2796-302-50	100	55.39	7.07	0.085	Yellow
5	CM60/GC2796-312-52	100	56.80	7.70	0.091	Yellow
6	CM60/GC2796-331-57	98	50.93	8.14	0.098	Yellow
7	CM60/GC2796-337-59	90	60.13	7.37	0.098	Yellow
8	CM60/SJ1-9-2	100	63.12	7.48	0.089	Yellow
9	CM60/SJ1-32-5	91	61.79	7.26	0.091	Yellow
10	CM60/SJ1-34-6	96	65.88	7.63	0.092	Yellow
11	CM60/SJ1-47-9	98	57.88	6.89	0.093	Yellow
12	CM60/SJ1-113-16	100	64.32	8.53	0.108	Yellow
13	CM60/SJ1-135-21	98	59.17	7.51	0.097	Yellow
14	CM60/SJ1-171-25	92	61.58	6.97	0.080	Yellow
15	CM60/SJ1-209-29	96	70.86	7.10	0.082	Yellow
16	CM60/SJ1-209-29	100	62.35	7.25	0.086	Yellow
17	CM60/SJ1-232-32	90	68.92	7.30	0.085	Yellow
18	CM60/SJ1-276-38	94	64.25	7.81	0.103	Yellow
19	CM60/SJ1-305-42	100	57.35	8.23	0.112	Yellow
20	CM60/SJ1-314-45	98	65.82	6.93	0.080	Yellow
21	CM60/SJ1-315-46	98	46.43	7.05	0.092	Yellow
22	CM60/SJ1-350-49	96	57.67	6.91	0.082	Yellow
23	CM60/SJ1-356-50	100	56.19	7.18	0.091	Yellow
24	CM60/SJ1-401-55	98	67.77	7.84	0.103	Yellow
25	CM60/SJ1-413-56	100	66.11	7.41	0.093	Yellow
26	CM60/SJ1-414-57	100	67.60	7.05	0.088	Yellow
27	CM60/SJ1-449-61	94	63.46	7.31	0.091	Yellow
28	CG2796[1/]	100	45.25	8.60	0.112	Yellow
29	SJ1[1/]	96	59.61	7.67	0.098	Yellow
30	CM60[1/]	72	100.17	6.08	0.083	Yellow

[1/] Parents used as check varieties; [2/] From accelerated aging test

Table 3 Some agronomic characters of the F_3 selected lines of two soybean crosses.

Line no.	Pedigree	Days to 50% flowering	Days to harvest	Plant height (cm)	Stem ternination type	Lodging score	No. of pods/ plant
1	CM60/GC2796-23-2	40	90	56	Det.	1	84
2	CM60/GC2796-200-26	38	88	43	Det.	1	87
3	CM60/GC2796-225-34	40	90	40	Det.	1	81
4	CM60/GC2796-302-50	40	87	47	Det.	1	74
5	CM60/GC2796-312-52	38	85	49	Det.	1	77
6	CM60/GC2796-331-57	40	85	44	Det.	1	76
7	CM60/GC2796-337-59	38	85	42	Det.	1	70
8	CM60/SJ1-9-2	42	90	69	Mix	1	115
9	CM60/SJ1-32-5	42	90	61	Det.	1	83
10	CM60/SJ1-34-6	43	92	81	Mix	1	110
11	CM60/SJ1-47-9	42	98	66	Indet.	1	136
12	CM60/SJ1-113-16	42	98	81	Indet.	1	156
13	CM60/SJ1-135-21	41	97	72	Mix	1	84
14	CM60/SJ1-171-25	43	90	77	Det.	1	91
15	CM60/SJ1-209-29	43	90	60	Det.	1	106
16	CM60/SJ1-209-29	39	90	75	Det.	1	112
17	CM60/SJ1-232-32	42	90	81	Det.	1	154
18	CM60/SJ1-276-38	43	98	68	Indet.	1	145
19	CM60/SJ1-305-42	42	94	67	Mix	1	104
20	CM60/SJ1-314-45	41	96	73	Indet.	1	88
21	CM60/SJ1-315-46	43	90	71	Det.	1	121
22	CM60/SJ1-350-49	45	92	62	Det.	1	125
23	CM60/SJ1-356-50	41	90	65	Det.	1	125
24	CM60/SJ1-401-55	43	90	74	Mix	1	101
25	CM60/SJ1-413-56	45	98	67	Indet.	1	114
26	CM60/SJ1-414-57	43	90	46	Det.	1	88
27	CM60/SJ1-449-61	43	95	59	Mix	1	126
28	CG2796[1/]	32	82	30	Det.	1	40
29	SJ1[1/]	42	98	80	Indet.	3	144
30	CM60[1/]	39	92	59	Det.	1	77

[1/] Parents used as check varieties

Selection for field weathering resistance in F_4 generation

The data of some seed characteristics attributed to field weathering resistance and agronomic characters of the F_4 lines were displayed in the Figure 5, 6, 7, 8 and Appendix Table 4 and 5. The total 27 F_4 lines of the two crosses showed differences in seed germination percentage from 86 to 100%, EC values from 39.94 to 77.68µS $cm^{-1}g^{-1}$, percentage of seed coat from 7.07 to 8.41% and seed coat thickness from 0.080 to 0.106 mm. All of the F_4 lines presented seed characters which contributed to higher field weathering resistance than the susceptible variety CM60 which exhibited the lowest seed germination percentage (66%), the highest EC value (90.09µS $cm^{-1}g^{-1}$), the lowest weight (6.96%) of seed coat and low thickness (0.085 mm) of seed coat.

For the agronomic characters, the F_4 lines manifested variation in the number of days to flowering from 40 to 45 days, number of days to harvest from 88 to 96 days, plant height from 36 to 82 cm and number of pods per plant from 47 to 174 pods whereas the female parent CM60 exhibited the number of days to flowering and harvest of 43 and 90 days, plant height of 42 cm and pod number of 62 pods per plant. There were two types of stem termination in the F_4 lines where all of the indeterminate lines had higher number of pods per plant and showed longer days to harvest than the determinate lines.

The selection for field weathering resistance in the F_4 generation was done based on high seed germination percentage, low EC values, high percentage and thickness of seed coat, and good agronomic characters involving the high number of pods per plant and lodging resistance. Seventeen F_4 lines were selected for yield trial in the F_5 generation (Table 4 and Table 5).

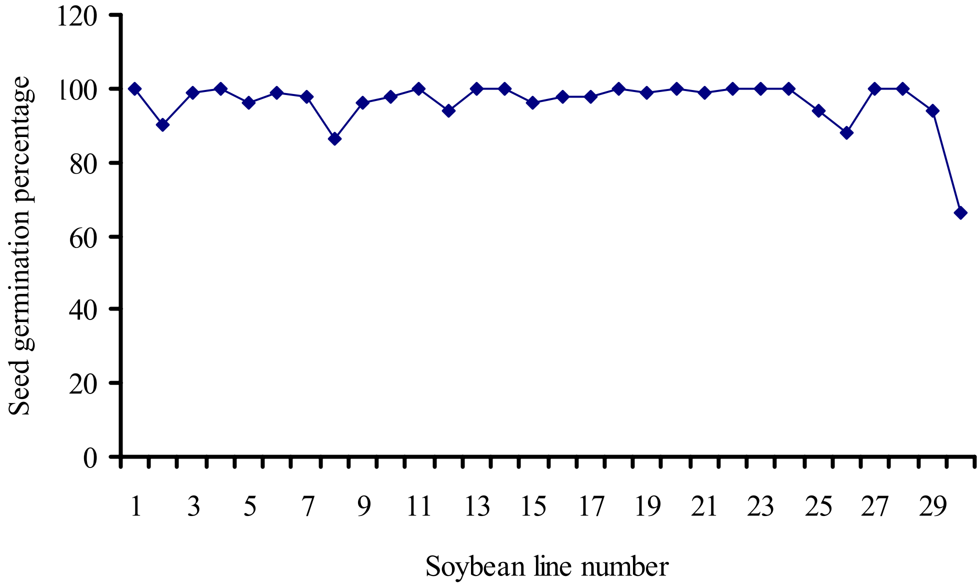

Figure 5 Seed germination percentage after AA test of the 27 F_4 lines of two soybean crosses and three check varieties (GC2796, SJ1 and CM60).

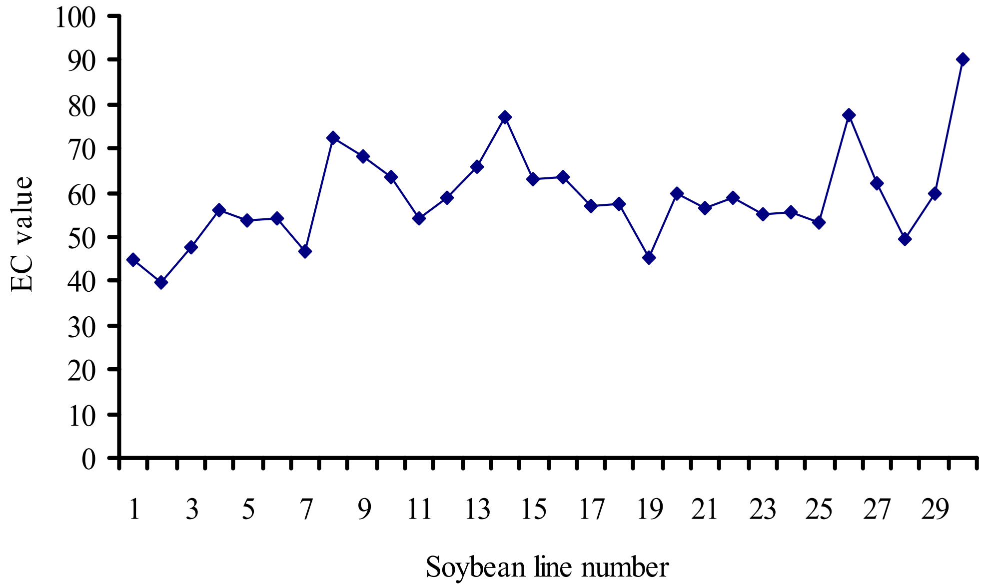

Figure 6 EC value of the 27 F_4 lines of two soybean crosses and three check varieties (GC2796, SJ1 and CM60).

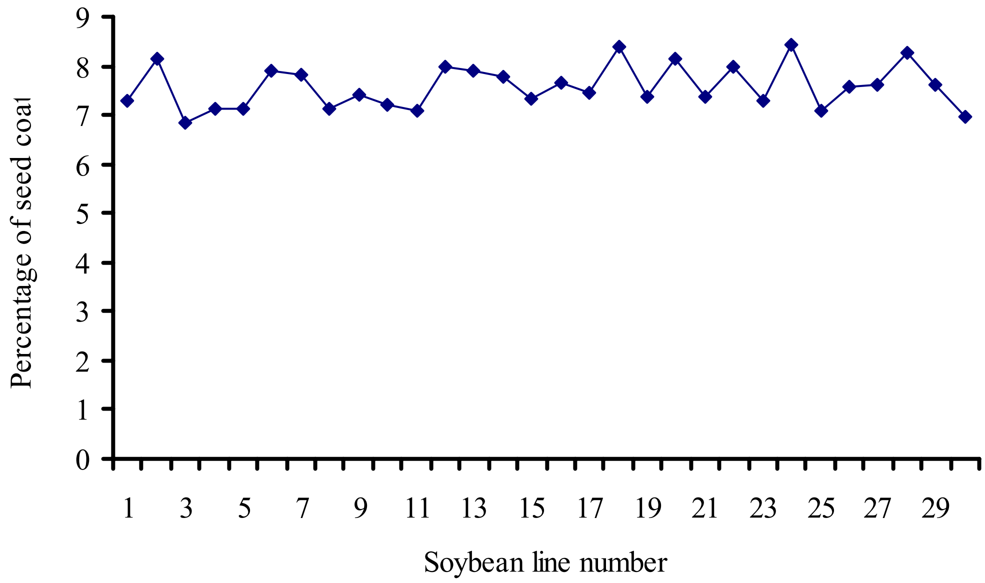

Figure 7 Seed coat percentage of the 27 F_4 lines of two soybean crosses and three check varieties (GC2796, SJ1 and CM60).

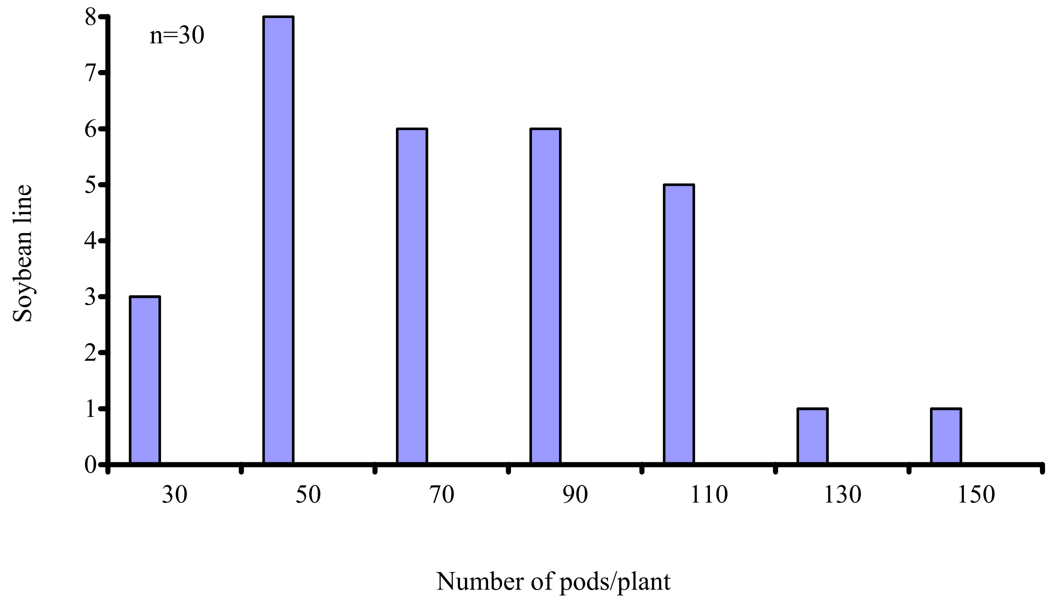

Figure 8 Distribution of pod number/plant of the 27 F_4 lines of two soybean crosses and three check varieties.

Table 4 Some seed characteristics attributed to field weathering reisistance of the F_4 selected lines of two soybean crosses (dry season, 2004)

Line no.	Pedigree	Seed germination[2/] (%)	EC ($\mu S\ cm^{-1}g^{-1}$)	Percentage of seed coat	Seed coat thickness (mm)	Seed coat color
1	CM60/GC2796-23-2-1	100	44.97	7.29	0.098	Yellow
2	CM60/GC2796-200-26-2	90	39.94	8.13	0.105	Yellow
3	CM60/GC2796-225-34-3	99	60.84	7.16	0.084	Yellow
4	CM60/SJ1-34-6-3	98	63.41	7.22	0.087	Yellow
5	CM60/SJ1-47-9-4	100	54.21	7.07	0.096	Yellow
6	CM60/SJ1-135-21-6	100	47.81	7.92	0.097	Yellow
7	CM60/SJ1-209-29-8	96	62.94	7.34	0.090	Yellow
8	CM60/SJ1-209-29-9	98	63.40	7.67	0.094	Yellow
9	CM60/SJ1-232-32-10	98	57.02	7.44	0.097	Yellow
10	CM60/SJ1-276-38-11	100	57.62	8.39	0.103	Yellow
11	CM60/SJ1-305-42-12	99	45.23	7.39	0.091	Yellow
12	CM60/SJ1-314-45-13	100	59.74	8.16	0.087	Yellow
13	CM60/SJ1-315-46-14	99	56.43	7.39	0.082	Yellow
14	CM60/SJ1-350-49-15	100	59.04	7.98	0.098	Yellow
15	CM60/SJ1-356-50-16	100	55.36	7.28	0.097	Yellow
16	CM60/SJ1-401-55-17	100	55.61	8.41	0.106	Yellow
17	CM60/SJ1-449-61-20	100	62.29	7.63	0.093	Yellow
18	GC2796[1/]	100	49.52	8.25	0.108	Yellow
19	SJ1[1/]	94	60.03	7.62	0.094	Yellow
20	CM60[1/]	66	90.09	6.96	0.085	Yellow

[1/] Parents used as check varieties; [2/] From accelerated aging test

Table 5 Some agronomic characters of the F_4 selected lines of two soybean crosses.

Line no.	Pedigree	Days to		Plant height (cm)	Stem termination type	Lodging score	No. of pods/ plant
		50% flowering	harvest				
1	CM60/GC2796-23-2-1	40	88	41	Det.	1	65
2	CM60/GC2796-200-26-2	41	88	45	Det.	1	63
3	CM60/GC2796-225-34-3	43	90	37	Det.	1	79
4	CM60/SJ1-34-6-3	43	90	54	Det.	1	90
5	CM60/SJ1-47-9-4	43	96	71	Indet.	1	110
6	CM60/SJ1-135-21-6	41	90	51	Det.	1	93
7	CM60/SJ1-209-29-8	45	90	65	Det.	1	123
8	CM60/SJ1-209-29-9	41	90	80	Det.	1	112
9	CM60/SJ1-232-32-10	41	90	82	Det.	1	95
10	CM60/SJ1-276-38-11	43	95	78	Indet.	1	174
11	CM60/SJ1-305-42-12	43	90	52	Det.	1	119
12	CM60/SJ1-314-45-13	43	95	65	Indet.	1	134
13	CM60/SJ1-315-46-14	43	93	57	Det.	1	81
14	CM60/SJ1-350-49-15	45	90	54	Det.	1	107
15	CM60/SJ1-356-50-16	43	90	51	Det.	1	92
16	CM60/SJ1-401-55-17	41	90	62	Det.	1	88
17	CM60/SJ1-449-61-20	43	90	67	Det.	1	93
18	GC2796[1/]	35	75	28	Det.	1	29
19	SJ1[1/]	43	95	60	Indet.	2	74
20	CM60[1/]	43	90	42	Det.	1	62

[1/] Parents used as check varieties

Yield trial of the F_5 lines

The F_5 lines were tested in yield trial at the National Corn and Sorghum Research Center in rainy season 2005. Seventeen lines were compared in this experiment. Three varieties were used as check varieties involving CM60 which is commercial variety but susceptible to field weathering and two field weathering resistant varieties GC2796 and SJ1. Some agronomic characters of the F_5 lines were investigated. The number of days to 50% flowering of the F_5 lines ranged from 43 to 46 days and from 38 to 45 days in the crosses CM60/GC2796 and CM60/SJ1, respectively (Table 6). The F_5 lines of the cross CM60/SJ1 flowered earlier and showed larger variation in the number of days to 50% flowering than those of the cross CM60/GC2796. The number of days to harvest extended from 89 to 92 days and from 92 to 110 days in crosses CM60/GC2796 and CM60/SJ1, respectively. Although the F_5 lines of the cross CM60/SJ1 flowered earlier than those of the cross CM60/GC2796, they were harvested later because three of them possessed indeterminate growth habit which was transmitted from their male parent SJ1.

The F_5 lines of the cross CM60/GC2796 exhibited very narrow variation in plant height (90 to 91 cm) while those of the cross CM60/SJ1 showed wide variation in plant height (78 to 121 cm). All F_5 lines of the cross CM60/GC2796 possessed higher plant stature than their parents. The tall plant height of some F_5 lines from the cross CM60/SJ1 was caused by their indeterminate stem termination type which was inherited from their male parent SJ1.

All F_5 lines of the cross CM60/GC2796 had erect stem type whereas those of the cross CM60/SJ1 varied in stem type from erect to lodging at level 4. The lodging of soybean plants was caused by tall plant height which was resulted from stem indetermination. This result was supported by the high correlation (r) between plant height and lodging score which was estimated to be 0.9140 (Figure 9a). Similarly, Foley *et al.* (1986) had reported that determinate genotypes were shorter and lodging less than the indeterminate ones.

Table 6 Some agronomic characters of the seventeen F_5 lines grown at National Corn and Sorghum Research Center in rainy season 2005.

Line no.	Pedigree	Days to		Plant height (cm)	Stem termination type	Lodging score
		50% flowering	harvest			
1	CM60/GC2796-23-2-1	45	89	90	Det.	1
2	CM60/GC2796-200-26-2	43	92	91	Det.	1
3	CM60/GC2796-225-34-3	46	89	90	Det.	1
4	CM60/SJ1-34-6-3	43	96	90	Det.	1
5	CM60/SJ1-47-9-4	43	105	121	Indet.	4
6	CM60/SJ1-135-21-6	43	92	85	Det.	1
7	CM60/SJ1-209-29-8	41	96	94	Det.	1
8	CM60/SJ1-209-29-9	43	96	84	Det.	1
9	CM60/SJ1-232-32-10	38	98	108	Det.	2
10	CM60/SJ1-276-38-11	41	110	115	Indet.	3
11	CM60/SJ1-305-42-12	45	95	98	Det.	1
12	CM60/SJ1-314-45-13	44	109	114	Indet.	4
13	CM60/SJ1-315-46-14	43	98	92	Det.	1
14	CM60/SJ1-350-49-15	43	96	91	Det.	1
15	CM60/SJ1-356-50-16	43	95	89	Det.	1
16	CM60/SJ1-401-55-17	43	95	111	Det.	3
17	CM60/SJ1-449-61-20	43	95	78	Det.	1
18	GC2796[1/]	35	82	32	Det.	1
19	SJ1[1/]	43	110	137	Indet.	4
20	CM60[1/]	43	98	70	Det.	1

[1/] Parents used as check varieties

Yield and yield components of the 17 F_5 lines of the two crosses were determined. The F_5 lines manifested the variation in number of pods per plant from 87.65 to 102.07 and from 82.75 to 133.4 in the cross CM60/GC2796 and CM60/SJ1, respectively (Table 7). Seven of them had higher number of pods per plant than the commercial variety CM60 which beared 113.67 pods per plant. The line no. 15 produced the greatest number of pods per plant (133.4 pods) while the line no. 5 produced the least number of pods per plant (82.75 pods) ($P < 0.05$).

The number of seeds per pod of the 17 F_5 lines ranged from 2.07 to 2.37 whereas the check variety CM60 produced 2.07 seeds per pod. All of the F_5 lines generated higher number of seeds per pod than CM60 except line no. 1 which gave equal number of seeds per pod as CM60.

The average 100 seed weight of the F_5 soybean lines expanded from 13.0 to 19.58 g while that of the commercial variety CM60 was 19.11 g. The line no. 3 and 11 produced higher seed weight than the CM60. However, the remaining lines showed the lower seed weight.

Seed yield of the F_5 lines varied from 2652.5 to 4601.5 kg/ha. Five of the 17 lines gave higher seed yield than the commercial variety CM60 (3500.9 kg/ha) especially the line no. 15 presented the highest yield of 4601.5 kg/ha. Apparently, the lowest yield of 2652.5 kg/ha was obtained from line no. 12 while the seed yield of two field weathering resistant varieties, GC2796 and SJ1, were 1459.7 and 3239.9 kg/ha, respectively.

Correlation between yield and yield components was shown in Figure 9b and c. High yielding of the soybean lines was caused by the high number of pods per plant which was comfirmed by high correlation between yield and the number of pods per plant ($r = 0.8133$). This observation is in agreement with the work of Verawudh (1974) and Shrivastava (1977) who reported that the highest yielding cultivar of soybean was derived from the cultivar producing highest number of pods per plant. Correlation between yield and 100 seeds weight was relatively low ($r = 0.5568$) so

Table 7 Yield and yield components of the seventeen F_5 lines grown at National Corn and Sorghum Research Center in rainy season 2005.

Line no.	Pedigree	No. of pods/plant	No. of seeds/pod	100-seed weight (g)	Yield (kg/ha)
1	CM60/GC2796-23-2-1	87.65 gh[2/]	2.07 gh	18.77 abc	2916.7 fg
2	CM60/GC2796-200-26-2	102.07 d-h	2.22 a-f	18.42 abc	3822.5 bcd
3	CM60/GC2796-225-34-3	95.92 gh	2.16 c-h	19.58 a	3110.5 efg
4	CM60/SJ1-34-6-3	122.85 a-d	2.32 ab	15.85 e-h	3874.2 bcd
5	CM60/SJ1-47-9-4	82.75 h	2.12 e-h	14.39 g-i	2983.2 efg
6	CM60/SJ1-135-21-6	119.60 a-e	2.24 a-e	17.05 b-f	4111.0 ab
7	CM60/SJ1-209-29-8	96.08 gh	2.16 c-h	16.87 c-f	3089.8 efg
8	CM60/SJ1-209-29-9	99.75 e-h	2.2 b-h	18.45 abc	3415.3 def
9	CM60/SJ1-232-32-10	107.82 b-g	2.27 a-d	18.41 abc	3964.9 bc
10	CM60/SJ1-276-38-11	95.42 gh	2.18 b-h	15.39 f-i	3007.1 efg
11	CM60/SJ1-305-42-12	119.67 a-e	2.21 b-g	19.27 a	4078.5 ab
12	CM60/SJ1-314-45-13	90.00 gh	2.32 ab	13.08 j	2652.5 g
13	CM60/SJ1-315-46-14	122.50 a-d	2.14 d-h	18.93 abc	4095.1 ab
14	CM60/SJ1-350-49-15	124.50 abc	2.09 fgh	16.03 d-h	4203.9 ab
15	CM60/SJ1-356-50-16	133.40 a	2.16 c-h	17.99 a-d	4601.5 a
16	CM60/SJ1-401-55-17	118.17 a-f	2.37 a	13.49 ij	2854.8f g
17	CM60/SJ1-449-61-20	96.75 fgh	2.25 a-e	17.89 a-e	3180.5 efg
18	GC2796[1/]	55.17 i	2.24 a-e	16.27 d-g	1459.7 h
19	SJ1[1/]	127.50 ab	2.29 abc	14.03 hij	3239.9 ef
20	CM60[1/]	113.67 c-h	2.07 h	19.11 ab	3500.9 cde
	Mean	105.56	2.20	17.06	3408.1
	C.V.%	12.80	3.90	7.60	10.1

[1/] Parents used as check varieties; [2/] Means within a column followed by a common letter are not significantly different at 95% level of confidence by DMRT.

that yield was slightly affected by seed weight. Similar observation has been made by Egli *et al.* (1978); Weber *et al.* (1966) who found that soybean yield was not closely related to seed size or weight but it was highly associated with seed number.

The data of seed characteristics attribited to field weathering of two soybean crosses were presented in the Table 8. Significant differences were observed for seed germination percentage after AA test among the F_5 lines ($P < 0.05$). All of the F_5 lines showed higher percentage of seed germination (70.5 to 92.5%) than the check variety CM60 (68.5%) which is susceptible to field weathering. The seed germination percentage of the the resistant varieties, GC2796 and SJ1 were 95.0 and 90.0%, respectively.

There was highly significant difference in EC value among the F_5 lines ($P < 0.01$). All of the F_5 lines except line no. 3 had lower EC value (53.01 to 76.98µS $cm^{-1}g^{-1}$) than the check variety CM60 (84.93µS $cm^{-1}g^{-1}$). Seed coat percentage of all lines (6.07 to 8.82%) were higher than that of the check variety CM60 (6.03%). The lines having low EC value or high seed vigor tended to manifest high weight and thickness of seed coat as verified the negative correlation between EC value and seed coat percentage ($r = -0.8219$) and seed coat thickness ($r = -0.6671$) (Figure 9d, e). The negative correlation between seed germination percentage and EC value found in this experiment ($r = -0.7634$) (Figure 9f) implied that the seed exhibiting high seed germination percentage showed high vigor as well. Soybean lines presenting high seed germination percentage and vigor, high weight and thickness of seed coat were considered to be field weathering resistance.

Fourteen of the 17 F_5 lines were classified to have field weathering resistance higher than CM60, however thiers were not higher than the resitant check variety (GC2796). Among them the soybean line no. 1, 2, 4, 14 and 16 (CM60/GC2796-23-2-1, CM60/GC2796-200-34-3, CM60/SJ1-34-6-3, CM60/SJ1-350-49-15, CM60/SJ1-401-55-17) were the top five highest field weathering resistant lines.

Table 8 Some seed characteristics attributed to field weathering resistance of the seventeen F_5 lines grown at National Corn and Sorghum Research Center in rainy season 2005.

Line no.	Pedigree	Seed germination[2/] (%)	EC ($\mu S\ cm^{-1}g^{-1}$)	Percentage of seed coat	Seed coat thickness (mm)	Seed coat color
1	CM60/GC2796-23-2-1	92.0 abc[3/]	56.44 fgh	8.38 a-d	0.158 a	Yellow
2	CM60/GC2796-200-26-2	88.5 abc	60.35 efg	8.13 b-e	0.119 bc	Yellow
3	CM60/GC2796-225-34-3	70.5 d	87.67 a	6.07 h	0.090 cd	Yellow
4	CM60/SJ1-34-6-3	89.5 abc	57.00 fgh	8.54 ab	0.124 abc	Yellow
5	CM60/SJ1-47-9-4	83.0 c	75.01 c	6.92 g	0.101 bc	Yellow
6	CM60/SJ1-135-21-6	92.5 ab	64.45 dfg	7.89 b-e	0.102 bc	Yellow
7	CM60/SJ1-209-29-8	88.5 abc	68.23 cde	7.74 de	0.118 bc	Yellow
8	CM60/SJ1-209-29-9	88.0 abc	76.98 bc	7.83 cde	0.131 ab	Yellow
9	CM60/SJ1-232-32-10	84.0 bc	62.12 d-g	8.44 abc	0.125 abc	Yellow
10	CM60/SJ1-276-38-11	84.5 bc	63.88 def	8.12 b-e	0.116 bc	Yellow
11	CM60/SJ1-305-42-12	95.5 a	61.62 d-g	7.63 ef	0.120 bc	Yellow
12	CM60/SJ1-314-45-13	85.5 bc	62.72 d-g	7.76 de	0.120 bc	Yellow
13	CM60/SJ1-315-46-14	84.5 bc	71.93 cd	7.07 fg	0.118 bc	Yellow
14	CM60/SJ1-350-49-15	92.5 ab	61.90 d-g	8.82 a	0.114 bc	Yellow
15	CM60/SJ1-356-50-16	89.0 abc	60.82 d-g	7.98 b-e	0.109 bc	Yellow
16	CM60/SJ1-401-55-17	90.0 abc	53.01 gh	8.15 b-e	0.128 ab	Yellow
17	CM60/SJ1-449-61-20	92.0 abc	64.00 def	7.56 ef	0.120 bc	Yellow
18	GC2796[1/]	95.0 a	50.05 h	8.29 a-d	0.129 ab	Yellow
19	SJ1[1/]	90.0 abc	64.35 def	7.84 cde	0.115 bc	Yellow
20	CM60[1/]	68.5 d	84.93 ab	6.03 h	0.090 d	Yellow
	Mean	87.53	65.37	7.76	0.117	-
	C.V.%	9.9	6.4	5.1	18.4	-

[1/] Parents used as check varieties; [2/] From accelerated aging test; [3/] Means within a column followed by a common letter are not significantly different at 95% level of confidence by DMRT

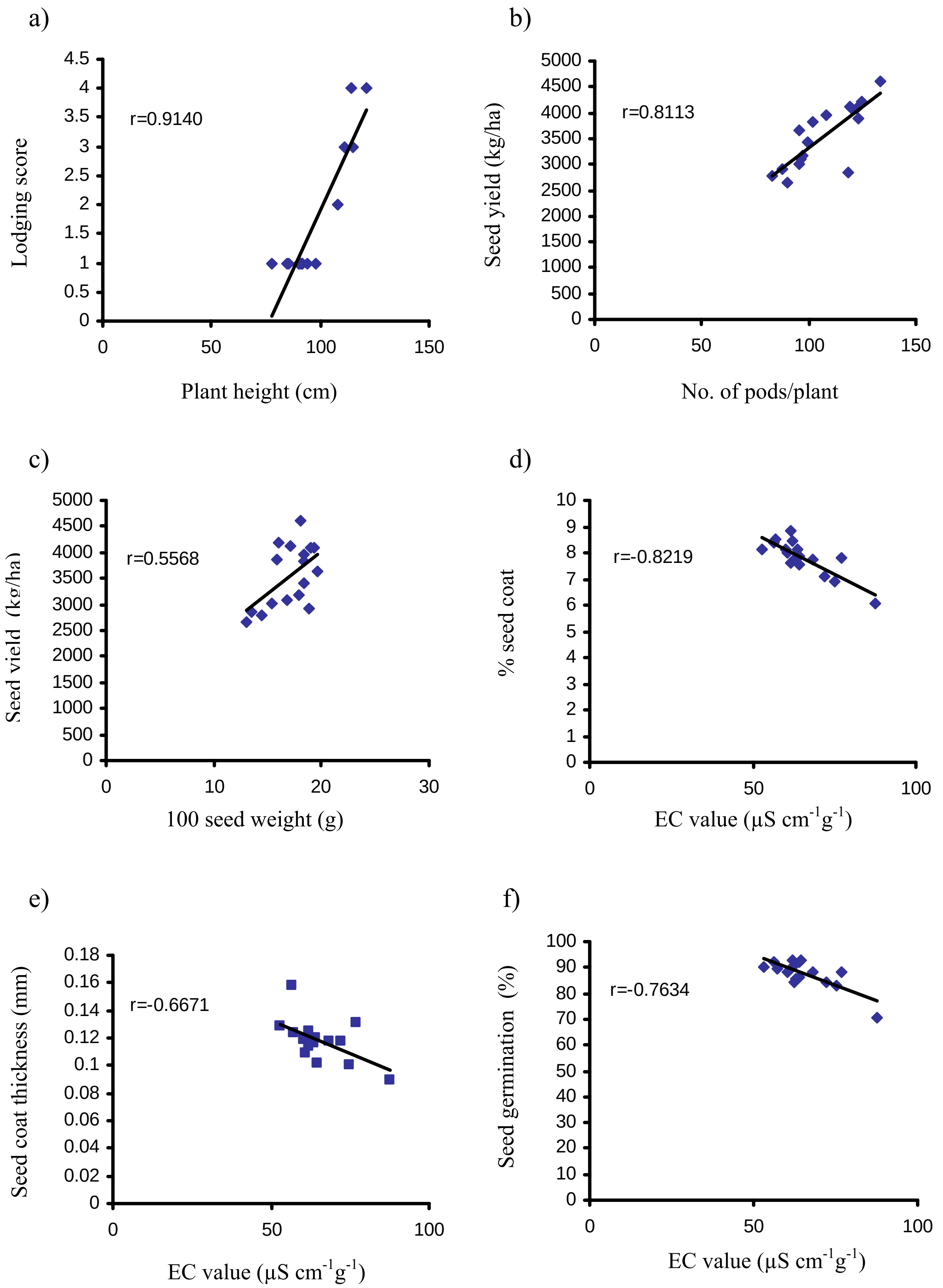

Figure 9 The correlation between some characteristics of 17 F_5 soybean lines: a) plant height and lodging score b) number of pods/plant with seed yield c) and 100 seed weight with seed yield d) EC value and percentage of seed coat e) EC value and seed coat thickness f) EC value and seed germination percentage.

General discussion

- **Hybridization and selection**

The soybean breeder must be aware of the agronomic and market conditions under which soybean is to be produced, understand the main problems and set the clearly defined objectives. Usually, the main objectives in soybean breeding are to increase yield and stability. The classical approach is selection for yield and incorporation of genes that reduce the effects of limiting factors such as disease, flowering under short-day condition and seed quality. Therefore, new programmes of breeding mainly attempt to reduce the effects of limiting factors and put more emphasis on increasing yield.

The present study was performed to develop soybean lines having good seed quality with emphasis on field weathering resistance. Hybridization was made between a commercial variety CM60 which was susceptible to field weathering and two field weathering resistant varieties (GC2796 and SJ1). Pedigree method was applied for selection of soybean plants/lines for field weathering resistance, good agronomic characters and high seed yield from F_2 to F_5 generation. Pedigree selection is a scheme of among and within family or line selection where selected plants or entry families are kept in isolation designated by a pedigree number so that any progeny plant in any generation can be traced back to the original plant. Thus the pedigree method of breeding permits more opportunity than any other method for evaluating meterials of a cross (Singh, 1976).

Pedigree selection is usually on single plant basis from F_2 generation and continues in succeeding generation until genetic purity is reached. Modification of the pedigree selection procedure may be employed such as introducing yield trials as early as the F_3 or the F_4 generation (Poehlman and Sleper, 1995). In this experiment the selection was started on F_2 generation for field weathering resistant plants. Selection for field weathering reistance and good agonomic characters were continued in F_3 and F_4 generations. Yield test was conducted with 17 F_5 lines. Six promissing F_5

lines having high seed yield, field weathering resistance and good agronomic characters were recovered. The advantages of pedigree method was reported by Briggs and Knowles (1967) that this method permited the early elimination of types of no future value of qualitative characters such as resistance to disease, earliness, height, flower color. It was the way to conserve space and time for materials of promise. Moreover, Raeber and Weber (1953) found that the greatest genetic advance could be made by growing F_3 lines in both replicated yield trials and a separate space planted nursery. They suggested that agronomic performance in the replicated yield trials would identify the superior lines in nursery.

Extensive evaluation is required to predict the performance of new lines. Evaluation of lines should be carried out in any generation of inbreedings (Perraz de Toledo *et al*., 1994). Some characteristics of the soybean are considered necessary and others undesirable. Resistance to lodging and prevalent disease, adequate plant canopy and stem termination, sufficient height for mechanical harvesting are essential traits. The lines showing a relatively high uniformity for agronomic charactesistics could be predicted to be the revealing of good lines.

Lodging could be a limitation to maximum seed yield in stem indeterminated soybean lines that was caused by reducing harvest efficiency and increasing harvest losses. Lodging of soybean occurs before or during the early pod-filling stage, it can reduce yield by limiting pod set and seed filled. The effects of plant height and early lodging on seed yield had been reported by Lin and Nelson (1988) who found that the cultivars having short plant height showed erect stem type and produced higher seed yield. The lodging score of F_5 lines ranged from 1 to 4 while the taller varieties were more susceptible to lodging. The indeterninate cultivars are generally taller and lodging more than determinate ones in highly produtive environments. Therefore, some breeding efforts have been directed towards the development of short-stature, determinate cultivar to reduce lodging (Cooper, 1976; Cooper, 1981; Beaver and Johnson, 1981). Determinate cultivars were short in plant height which prevented lodging, but sometimes the yields of these cultivars were less than the indeterminate ones because there was a positive association between seed yield and plant height and the taller plant had a greater number of nodes for pod set (Green *et al*., 1977; Beaver and Johnson, 1981).

The stem determinate F_5 lines of the two soybean crosses exhibited the days to harvest from 89 to 98 days. Among them the lines having the longer duration to harvest ranged from 95 to 98 days produced higher seed yield than the other lines with shorter duration to harvest. This observation was in good agreement with the study of Cooper (1981) who had reported that full-season varieties had higher yield potential than early varieties because they maximized the use of available light. On the other hand, Chang *et al.* (1982) found that short-season varieties were useful for avoiding stress conditions. The early maturity cultivar might be needed to avoid yield losses from early frost especially when planting is delayed in the spring. Therefore, maturity is an important character to be considered when selecting soybean lines. Varying crop maturity could be employed to distribute the use of labor and other valuable resources more optimally throughout the cropping season. It could also spread the risk associated with climatic and pest conditions.

Number of pods per plant is the key component of the final seed yield. The highest yielding F_5 line was obtained from the line which produced the highest number of pods per plant. Seed weight was also an important component for obtaining higher seed yield (Verawudh, 1974 and Shrivastava, 1997). However, seed yield of the F_5 lines were slightly affected by seed weight. This observation was in agreement with the work of Yang and Wang (2000) who found highly correlation between seed yield and pod number per plant but the association between yielding and seed weight was relatively low. Similarly, Hartwig and Edward (1970) reported that soybean lines having large seed size or high seed weight produced fewer seeds and pods per plant which resulted in lower seed yield.

- **Evaluation of field weathering resistance of soybean seed**

Weather-damages of soybean seeds are unsuitable for the production of high quality of planting seeds. The breeding of resistant cultivars requires an understanding of the weathering process and the use of suitable criteria for measuring the degree of weathering damage. Part of this research was to describe the effect of weathering on the seed deterioration evaluation by the exposure of seeds to high temperature and relative humidity in accelerated aging test, electrical conductivity of leakage from exposed seeds, percentage of seed coat and seed coat thickness, and to verify this technique as a means for discriminating the levels of weathering damage.

Accelerated aging test incorporates many of the important traits desired in a vigor test. Initially it was proposed as a method to evaluate seed storability. The accelerated aging test subjects unimbibed seeds to conditions of high temperature (41^{0}C) and relative humidity (around 100%) for a short period (72 hours) (AOSA, 1983). The two environmental variables, high temperature and high humidity cause rapid deterioration of the exposed seed. High vigor seed lots will withstand these extreme stress conditions and deteriorate at a slower rate than low vigor seed lots. Although aging temperature and seed moisture have the greatest influence on tested results, several other factors which modify the results must be controlled during the test.

The AA test does not provide an absolute vigor or field emergence score, but simply records germination (percentage of normal seedlings) after a period of stress under the conditions of high temperature and moisture. Seed germination percentage after AA test of the F_5 lines ranged from 70.5 to 95.5%, while that of the sensitive variety, CM60, was 68.5%. All of the F_5 lines showing seed germination rate higher than 80% were considered to be high vigor seed following the classification of Torres *et al.* (2004). Similary, Egli and TeKrony (1995) studied on seed germination, vigor and field emergence and indicated that soybean seed lots with germination rate higher than 80% after AA test manifested high probability of producing adequate seedling emergence under severe environmental conditions. When the germination of seeds after accelerated aging is compared with the standard germination of the same seed lot prior to aging, the germination of aged seeds will be either similar to standard germination (high vigor seed) or less than standard germination (medium to low vigor seed). The germination of aged seeds is associated with vigor and can be used to predict the storability and field emergence of each seed lot at planting (Delouche and Baskin, 1973).

An alternative way, vigor of soybean seeds can be evaluated by measuring the electrical conductivity (EC) of the leakage from seeds after soaking in deionized water. The EC of seed leakage has been satisfactorily used to determine the physiological quality of soybean seed (AOSA, 1983). The EC test is a fast and practical procedure, allowing to obtain an objective information. It is also easy to conduct in most seed analysis laboratories and does not require expensive equipmens (Loeffler *et al*., 1988).

Seed leakage is directly related to the cellular membrane integrity (Vieira *et al*., 2004). Disorganized membranes are associated to the seed deterioration process and consequently affected by insects infestation, mechanical injury and a long storage period (Bewley and Black, 1994).

The EC of seed leakage is generally increased with increasing visual damage and decreasing viability of seeds. The EC values of the F_5 lines varied from 53.01 to 87.67µS $cm^{-1}g^{-1}$ while the resistant varieties, GC2796 and SJ1 showed the values of 50.5 and 64.35µS $cm^{-1}g^{-1}$, respectively. Certain ranges of EC values are not difined to evaluate the level of soybean seed vigor. However, all of the F_5 lines except lines no.3 manifested the EC values lower than 80 µS $cm^{-1}g^{-1}$ which were classified as highly and intermediary seed vigor according to the suggestion of Vieira *et al*. (2004).

The seed coat is one of the main determinants of seed germination, seed vigor and longevity potential (Dubbern de Souza and Marcos-Filho, 2001). Therefore, in recent years, a growing interest in the genetic incorporation of specific seed coat trait associated with imbibition control in soybean genotype breeding occurred with the aim of increasing seed storage potential and reducing field deterioration (Potts *et al*., 1978).

Vigor and viability correlated negatively with the amount of water absorped by seed (Sauza and Marcos-Filho, 1993). Field deterioration often occurs due to water absorption from the atmosphere by mature, permeable seed before harvest. An intact seed coat was capable of regulating the speed of water absorption protecting embryo from injuries which might be otherwise rerulted from rapid imbibition. (Chachalis and Smith, 2000). The ratio between seed coat weight and total seed weight was proposed for prediction of seed longevity in soybean cutivars since high ratio was found to be associated with high seed longevity (Tiwari and Hariprasad, 1997). Thus, soybean cutivars with seed coat capable of delaying imbibition, instead of impeding it, were suggested as better alternatives.

The field weathering resistant F_5 lines which had high seed germiability and vigor exhibited higher percentage of seed coat than the sensitive variety CM60. Kuo (1989) reported that soybean seed possessing higher specific weight of testa showed lower membrane permeability. Consequently, high seed vigor of soybean lines might be resulted from the delayed permeability of the seed coat when the seeds exposed to field weathering. This finding opens up the possibility of breeding soybean cultivars resistant to field weathering by improvement seed which produces high proportion of seed coat with delayed permeability.

CONCLUSIONS

1. Field weathering resistance and high yieding soybean lines were developed by pedigree selection from the two crosses CM60/GC2976 and CM60/SJ1 since F_2 to F_5 generation. Six promising F_5 lines including CM60/GC2796-200-26-2, CM60/SJ1-34-6-3, CM60/SJ1-135-21-6, CM60/SJ1-305-42-12, CM60/SJ1-350-49-15 and CM60/SJ1-356-50-16 gave higher seed yield, field weathering resistance and good agronomic characters.

2. Accelerated aging test, electrical conductivity test and measurement of seed coat percentage and seed coat thickness were efficient tests for evaluating field weathering of soybean seeds. These test could be applied in combination for assisting selection of soybean plants/lines exhibiting high seed germinability and vigor, and high weight and thickness of seed coat which were attributed to field weathering resistance.

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APPENDICES

Appendix Table 1 Some agronomic characteristics and seed germination percentage of the F_2 selected plants of two soybean crosses.

Plant no.	Pedigree	Plant height (cm)	Flower color	No. of pods/ plant	Seed germination[1/] (%)	Seed coat color
1	CM60/GC2796-4	61	Light Purple	77	96	Yellow
2	CM60/GC2796-23	47	Purple	68	100	Yellow
3	CM60/GC2796-35	63	Purple	73	96	Yellow
4	CM60/GC2796-56	60	Dark Purple	59	96	Yellow
5	CM60/GC2796-76	52	Purple	64	96	Yellow
6	CM60/GC2796-79	60	Purple	68	96	Yellow
7	CM60/GC2796-80	57	Light Purple	59	100	Yellow
8	CM60/GC2796-89	38	White	68	98	Yellow
9	CM60/GC2796-92	56	Light Purple	55	98	Yellow
10	CM60/GC2796-105	52	Light Purple	68	94	Yellow
11	CM60/GC2796-111	65	White	82	96	Yellow
12	CM60/GC2796-116	54	Purple	82	100	Yellow
13	CM60/GC2796-124	51	White	82	97.3	Yellow
14	CM60/GC2796-127	48	White	70	98	Yellow
15	CM60/GC2796-133	52	Light Purple	91	98	Yellow
16	CM60/GC2796-136	56	Purple	95	96	Yellow
17	CM60/GC2796-138	47	White	65	98	Yellow
18	CM60/GC2796-152	59	Light Purple	64	100	Yellow
19	CM60/GC2796-164	60	White	97	100	Yellow
20	CM60/GC2796-172	49	Light Purple	23	94	Yellow
21	CM60/GC2796-184	53	Purple	82	96	Yellow
22	CM60/GC2796-185	63	Light Purple	100	96	Yellow
23	CM60/GC2796-190	56	White	91	100	Yellow
24	CM60/GC2796-192	52	Light Purple	82	94	Yellow
25	CM60/GC2796-199	51	Purple	91	98	Yellow
26	CM60/GC2796-200	67	Purple	105	96	Yellow
27	CM60/GC2796-209	60	Purple	85	96	Yellow
28	CM60/GC2796-210	50	Purple	102	96	Yellow
29	CM60/GC2796-218	64	White	95	96	Yellow
30	CM60/GC2796-219	64	Light Purple	64	98	Yellow
31	CM60/GC2796-221	52	Light Purple	68	100	Yellow
32	CM60/GC2796-223	56	White	73	98	Yellow
33	CM60/GC2796-224	69	White	64	98	Yellow
34	CM60/GC2796-225	64	Light Purple	68	100	Yellow
35	CM60/GC2796-233	57	White	68	96	Yellow
36	CM60/GC2796-242	60	White	73	98	Yellow
37	CM60/GC2796-243	66	Light Purple	68	96	Yellow
38	CM60/GC2796-249	54	Light Purple	68	96	Yellow
39	CM60/GC2796-252	77	White	91	100	Yellow
40	CM60/GC2796-259	53	Light Purple	73	98.7	Yellow
41	CM60/GC2796-270	45	Purple	55	68	Yellow

[1/] From accelerated aging test

Appendix Table 1 Continued.

Plant no.	Pedigree	Plant height (cm)	Flower color	No. of pods/ plant	Seed germination (%)	Seed coat color
42	CM60/GC2796-282	45	White	64	100	Yellow
43	CM60/GC2796-287	58	White	68	100	Yellow
44	CM60/GC2796-288	52	Purple	77	100	Yellow
45	CM60/GC2796-289	44	Light Purple	68	98	Yellow
46	CM60/GC2796-291	48	Purple	68	100	Yellow
47	CM60/GC2796-292	49	White	64	96	Yellow
48	CM60/GC2796-295	47	Light Purple	82	100	Yellow
49	CM60/GC2796-298	50	Purple	68	100	Yellow
50	CM60/GC2796-302	54	White	64	100	Yellow
51	CM60/GC2796-309	59	Purple	77	96	Yellow
52	CM60/GC2796-312	46	White	68	100	Yellow
53	CM60/GC2796-319	33	Light Purple	136	100	Yellow
54	CM60/GC2796-321	53	Light Purple	127	100	Yellow
55	CM60/GC2796-325	47	Light Purple	87	100	Yellow
56	CM60/GC2796-329	49	Purple	76	100	Yellow
57	CM60/GC2796-331	47	White	64	96	Yellow
58	CM60/GC2796-336	58	White	73	100	Yellow
59	CM60/GC2796-337	46	Light Purple	89	100	Yellow
60	CM60/GC2796-342	51	Purple	84	96	Yellow
61	CM60/GC2796-350	58	Light Purple	91	98	Yellow
62	CM60/SJ1-5	65	White	154	100	Yellow
63	CM60/SJ1-9	68	Purple	137	95	Yellow
64	CM60/SJ1-10	79	Purple	143	98	Yellow
65	CM60/SJ1-29	70	Purple	173	96	Yellow
66	CM60/SJ1-32	75	Purple	222	94	Yellow
67	CM60/SJ1-34	75	Purple	132	100	Yellow
68	CM60/SJ1-40	76	Purple	223	100	Yellow
69	CM60/SJ1-43	75	White	210	100	Yellow
70	CM60/SJ1-47	71	Purple	119	100	Yellow
71	CM60/SJ1-49	79	White	135	100	Yellow
72	CM60/SJ1-54	77	Purple	178	98	Yellow
73	CM60/SJ1-57	75	Purple	172	96	Yellow
74	CM60/SJ1-65	63	Purple	196	98	Yellow
75	CM60/SJ1-102	75	Purple	180	94	Yellow
76	CM60/SJ1-110	54	Purple	120	100	Yellow
77	CM60/SJ1-113	82	Purple	235	98	Yellow
78	CM60/SJ1-124	77	Purple	191	96	Yellow
79	CM60/SJ1-126	69	Purple	134	100	Yellow
80	CM60/SJ1-132	55	White	127	100	Yellow
81	CM60/SJ1-134	80	Purple	207	98	Yellow
82	CM60/SJ1-135	70	White	200	96	Yellow
83	CM60/SJ1-138	65	White	124	96	Yellow
84	CM60/SJ1-144	77	Purple	120	100	Yellow

<u>Appendix Table 1</u> Continued.

Plant no.	Pedigree	Plant height (cm)	Flower color	No. of pods/ plant	Seed germination (%)	Seed coat color
85	CM60/SJ1-167	65	Purple	140	100	Yellow
86	CM60/SJ1-171	44	Purple	126	98	Yellow
87	CM60/SJ1-176	67	Purple	107	98	Yellow
88	CM60/SJ1-178	80	Purple	160	100	Yellow
89	CM60/SJ1-199	77	Purple	101	100	Yellow
90	CM60/SJ1-209	56	Purple	114	100	Yellow
91	CM60/SJ1-211	83	Purple	203	98	Yellow
92	CM60/SJ1-229	50	Purple	127	98	Yellow
93	CM60/SJ1-232	83	Purple	164	100	Yellow
94	CM60/SJ1-233	62	Purple	122	100	Yellow
95	CM60/SJ1-234	69	Purple	126	100	Yellow
96	CM60/SJ1-245	55	White	122	98	Yellow
97	CM60/SJ1-263	65	White	156	96	Yellow
98	CM60/SJ1-266	55	Purple	136	100	Yellow
99	CM60/SJ1-276	73	Purple	132	96	Yellow
100	CM60/SJ1-288	68	Purple	120	100	Yellow
101	CM60/SJ1-294	75	Purple	187	98	Yellow
102	CM60/SJ1-295	71	Purple	171	94	Yellow
103	CM60/SJ1-305	76	Purple	163	96	Yellow
104	CM60/SJ1-308	74	Purple	129	98	Yellow
105	CM60/SJ1-309	80	Purple	144	100	Yellow
106	CM60/SJ1-314	70	Purple	131	98	Yellow
107	CM60/SJ1-315	70	White	118	100	Yellow
108	CM60/SJ1-335	73	Purple	150	98	Yellow
109	CM60/SJ1-337	71	Purple	124	100	Yellow
110	CM60/SJ1-350	65	Purple	112	100	Yellow
111	CM60/SJ1-356	60	White	138	94	Yellow
112	CM60/SJ1-381	73	Purple	111	94	Yellow
113	CM60/SJ1-387	53	Purple	90	100	Yellow
114	CM60/SJ1-388	65	Purple	129	96	Yellow
115	CM60/SJ1-399	63	White	155	100	Yellow
116	CM60/SJ1-401	76	White	221	94	Yellow
117	CM60/SJ1-413	75	Purple	174	100	Yellow
118	CM60/SJ1-141	49	Purple	195	100	Yellow
119	CM60/SJ1-418	70	Purple	152	100	Yellow
120	CM60/SJ1-422	46	Purple	134	100	Yellow
121	CM60/SJ1-442	60	Purple	128	100	Yellow
122	CM60/SJ1-449	74	Purple	257	94	Yellow
123	CM60/SJ1-460	61	Purple	106	100	Yellow
124	CM60/SJ1-190	77	White	209	98	Yellow
125	CM60/SJ1-492	75	Purple	146	100	Yellow
126	CM60/SJ1-493	72	Purple	138	96	Yellow
127	CM60/SJ1-511	70	Purple	116	98	Yellow
128	CM60/SJ1-524	71	Purple	120	96	Yellow
129	CM60/SJ1-546	70	White	130	96	Yellow

Appendix Table 2 Some seed characteristics attributed to field weathering resistance of the F_3 lines of two soybean crosses.

Line no.	Pedigree	Seed germination (%)	EC ($\mu S\ cm^{-1}g^{-1}$)	Percentage of seed coat	Seed coat thickness (mm)	Seed coat color
1	CM60/GC2796-23-2	96	54.14	8.02	0.105	Yellow
2	CM60/GC2796-89-8	80	96.99	6.23	0.078	Yellow
3	CM60/GC2796-92-9	78	87.18	7.73	0.090	Yellow
4	CM60/GC2796-184-21	96	64.88	6.82	0.081	Yellow
5	CM60/GC2796-199-25	86	95.29	6.89	0.081	Yellow
6	CM60/GC2796-200-26	92	52.16	7.84	0.088	Yellow
7	CM60/GC2796-209-27	71	95.00	6.05	0.075	Yellow
8	CM60/GC2796-224-33	65	103.00	6.32	0.078	Yellow
9	CM60/GC2796-225-34	100	55.73	6.85	0.080	Yellow
10	CM60/GC2796-252-39	56	120.12	6.37	0.080	Yellow
11	CM60/GC2796-259-40	84	77.47	6.87	0.082	Yellow
12	CM60/GC2796-287-43	68	101.00	6.30	0.079	Yellow
13	CM60/GC2796-288-44	76	98.00	6.28	0.078	Yellow
14	CM60/GC2796-292-47	86	81.81	6.91	0.080	Yellow
15	CM60/GC2796-302-50	100	55.39	7.07	0.085	Yellow
16	CM60/GC2796-309-51	98	67.14	6.38	0.082	Yellow
17	CM60/GC2796-312-52	100	56.80	7.70	0.091	Yellow
18	CM60/GC2796-329-56	96	66.58	6.78	0.085	Yellow
19	CM60/GC2796-331-57	98	50.93	8.14	0.098	Yellow
20	CM60/GC2796-336-58	100	56.12	7.85	0.092	Yellow
21	CM60/GC2796-337-59	90	60.13	7.37	0.098	Yellow
22	CM60/GC2796-350-61	92	71.34	7.35	0.089	Yellow
23	CM60/SJ1-5-1	98	68.94	6.90	0.085	Yellow
24	CM60/SJ1-9-2	100	63.12	7.48	0.089	Yellow
25	CM60/SJ1-10-3	98	63.64	8.23	0.110	Yellow
26	CM60/SJ1-29-4	75	90.74	6.65	0.079	Yellow
27	CM60/SJ1-32-5	91	61.79	7.26	0.091	Yellow
28	CM60/SJ1-34-6	96	65.88	7.63	0.092	Yellow
29	CM60/SJ1-40-7	88	73.88	8.26	0.121	Yellow
30	CM60/SJ1-47-9	98	57.88	6.89	0.093	Yellow
31	CM60/SJ1-54-11	96	62.77	6.58	0.085	Yellow
32	CM60/SJ1-57-12	94	60.05	7.06	0.085	Yellow
33	CM60/SJ1-65-13	100	49.11	7.68	0.890	Yellow
34	CM60/SJ1-102-14	96	50.07	8.14	8.105	Yellow
35	CM60/SJ1-113-16	100	64.32	8.53	0.108	Yellow
36	CM60/SJ1-124-17	74	103.96	7.73	0.090	Yellow
37	CM60/SJ1-126-18	94	76.03	7.09	0.085	Yellow

Appendix Table 2 Continued.

Line no.	Pedigree	Seed germination (%)	EC (µS $cm^{-1}g^{-1}$)	Percentage of seed coat	Seed coat thickness (mm)	Seed coat color
38	CM60/SJ1-132-19	90	68.64	6.76	0.089	Yellow
39	CM60/SJ1-135-21	98	59.17	7.51	0.097	Yellow
40	CM60/SJ1-138-22	58	148.66	6.33	0.079	Yellow
41	CM60/SJ1-144-23	62	100.00	6.04	0.075	Yellow
42	CM60/SJ1-167-24	86	88.33	7.38	0.089	Yellow
43	CM60/SJ1-171-25	92	61.58	6.97	0.080	Yellow
44	CM60/SJ1-176-25	56	108.82	7.38	0.091	Yellow
45	CM60/SJ1-209-29	96	70.86	7.10	0.082	Yellow
46	CM60/SJ1-209-29	100	62.35	7.25	0.086	Yellow
47	CM60/SJ1-211-30	76	89.76	6.65	0.082	Yellow
48	CM60/SJ1-229-31	80	92.81	7.81	0.095	Yellow
49	CM60/SJ1-232-32	90	68.92	7.30	0.085	Yellow
50	CM60/SJ1-234-34	78	71.76	7.39	0.085	Yellow
51	CM60/SJ1-245-35	88	78.52	6.92	0.080	Yellow
52	CM60/SJ1-263-36	92	65.86	7.65	0.089	Yellow
53	CM60/SJ1-276-38	94	64.25	7.81	0.103	Yellow
54	CM60/SJ1-305-42	100	57.35	8.23	0.112	Yellow
55	CM60/SJ1-308-43	80	77.14	6.97	0.079	Yellow
56	CM60/SJ1-314-45	98	65.82	6.93	0.080	Yellow
57	CM60/SJ1-315-46	98	46.43	7.05	0.092	Yellow
58	CM60/SJ1-335-47	70	83.19	7.73	0.096	Yellow
59	CM60/SJ1-337-48	78	81.21	8.04	0.098	Yellow
60	CM60/SJ1-350-49	96	57.67	6.91	0.082	Yellow
61	CM60/SJ1-356-50	100	56.19	7.18	0.091	Yellow
62	CM60/SJ1-388-53	78	91.24	7.04	0.089	Yellow
63	CM60/SJ1-399-54	79	108.35	7.35	0.091	Yellow
64	CM60/SJ1-401-55	98	67.77	7.84	0.103	Yellow
65	CM60/SJ1-413-56	100	66.11	7.41	0.093	Yellow
66	CM60/SJ1-414-57	100	67.60	7.05	0.088	Yellow
67	CM60/SJ1-418-58	92	62.42	6.90	0.082	Yellow
68	CM60/SJ1-422-59	92	73.66	8.00	0.099	Yellow
69	CM60/SJ1-449-61	94	63.46	7.31	0.091	Yellow
70	CM60/SJ1-492-64	92	62.71	6.40	0.082	Yellow
71	CM60/SJ1-493-65	74	80.42	6.47	0.086	Yellow
72	CM60/SJ1-524-67	92	55.49	6.39	0.082	Yellow
73	CM60/SJ1-546-68	68	144.25	6.71	0.089	Yellow
74	GC2796	100	45.25	8.60	0.112	Yellow
75	SJ1	96	59.61	7.67	0.098	Yellow
76	CM60	72	100.2	6.08	0.083	Yellow

Appendix Table 3 Some agronomic characters of the F3 lines of two soybean crosses.

Line no.	Pedigree	Days to		Plant height (cm)	Stem tenination type	Lodging score	No. of pods/ plant
		50% flowering	harvest				
1	CM60/GC2796-23-2	40	90	56	Det.	1	84
2	CM60/GC2796-89-8	35	88	42	Det.	1	47
3	CM60/GC2796-92-9	38	88	46	Det.	1	83
4	CM60/GC2796-184-21	40	85	39	Det.	1	69
5	CM60/GC2796-199-25	39	90	48	Det.	1	87
6	CM60/GC2796-200-26	38	88	43	Det.	1	87
7	CM60/GC2796-209-27	39	88	35	Det.	1	52
8	CM60/GC2796-224-33	35	90	48	Det.	1	35
9	CM60/GC2796-225-34	40	90	40	Det.	1	81
10	CM60/GC2796-252-39	40	86	50	Det.	1	51
11	CM60/GC2796-259-40	38	86	41	Det.	1	75
12	CM60/GC2796-287-43	35	86	39	Det.	1	34
13	CM60/GC2796-288-44	35	86	39	Det.	1	55
14	CM60/GC2796-292-47	39	86	59	Det.	1	78
15	CM60/GC2796-302-50	40	87	47	Det.	1	74
16	CM60/GC2796-309-51	39	90	52	Det.	1	68
17	CM60/GC2796-312-52	38	85	49	Det.	1	77
18	CM60/GC2796-329-56	38	85	43	Det.	1	67
19	CM60/GC2796-331-57	40	85	44	Det.	1	76
20	CM60/GC2796-336-58	39	85	50	Det.	1	64
21	CM60/GC2796-337-59	38	85	42	Det.	1	70
22	CM60/GC2796-350-61	40	90	39	Det.	1	62
23	CM60/SJ1-5-1	42	90	78	Indet.	3	104
24	CM60/SJ1-9-2	42	90	69	Mix	1	115
25	CM60/SJ1-10-3	42	95	73	Indet.	3	87
26	CM60/SJ1-29-4	43	95	71	Indet.	1	157
27	CM60/SJ1-32-5	42	90	61	Det.	1	83
28	CM60/SJ1-34-6	43	92	81	Mix	1	110
29	CM60/SJ1-40-7	44	92	67	Indet.	1	67
30	CM60/SJ1-47-9	42	98	66	Indet.	1	136
31	CM60/SJ1-54-11	42	98	74	Indet.	2	140
32	CM60/SJ1-57-12	43	95	82	Indet.	3	73
33	CM60/SJ1-65-13	43	90	55	Det.	1	113
34	CM60/SJ1-102-14	43	92	71	Mix	1	131
35	CM60/SJ1-113-16	42	98	81	Indet.	1	156
36	CM60/SJ1-124-17	42	98	60	Indet.	2	119
37	CM60/SJ1-126-18	43	98	64	Indet.		77

Appendix Table 3 Continued.

Line no.	Pedigree	Days to		Plant height (cm)	Stem ternination type	Lodging score	No. of pods/ plant
		50% flowering	harvest				
38	CM60/SJ1-132-19	41	90	56	Det.	1	71
39	CM60/SJ1-135-21	41	97	72	Mix	1	84
40	CM60/SJ1-138-22	41	95	68	Indet.	1	101
41	CM60/SJ1-144-23	43	95	70	Indet.	1	74
42	CM60/SJ1-167-24	43	90	77	Det.	1	110
43	CM60/SJ1-171-25	43	90	77	Det.	1	91
44	CM60/SJ1-176-25	43	90	86	Det.	1	93
45	CM60/SJ1-209-29	43	90	60	Det.	1	106
46	CM60/SJ1-209-29	39	90	75	Det.	1	112
47	CM60/SJ1-211-30	45	96	94	Indet.	3	70
48	CM60/SJ1-229-31	45	90	60	Det.	1	116
49	CM60/SJ1-232-32	42	90	81	Det.	1	154
50	CM60/SJ1-234-34	42	90	70	Det.	1	136
51	CM60/SJ1-245-35	42	90	47	Det.	1	93
52	CM60/SJ1-263-36	43	90	57	Det.	1	120
53	CM60/SJ1-276-38	43	98	68	Indet.	1	145
54	CM60/SJ1-305-42	42	94	67	Mix	1	104
55	CM60/SJ1-308-43	41	98	75	Indet.	1	110
56	CM60/SJ1-314-45	41	96	73	Indet.	1	88
57	CM60/SJ1-315-46	43	90	71	Det.	1	121
58	CM60/SJ1-335-47	43	96	62	Indet.	1	98
59	CM60/SJ1-337-48	45	98	62	Indet.	1	85
60	CM60/SJ1-350-49	45	92	62	Det.	1	125
61	CM60/SJ1-356-50	41	90	65	Det.	1	125
62	CM60/SJ1-388-53	41	90	59	Det.	1	89
63	CM60/SJ1-399-54	43	96	73	Indet.	1	166
64	CM60/SJ1-401-55	43	90	74	Mix	1	101
65	CM60/SJ1-413-56	45	98	67	Indet.	1	114
66	CM60/SJ1-414-57	43	90	46	Det.	1	88
67	CM60/SJ1-418-58	45	96	62	Indet.	1	84
68	CM60/SJ1-422-59	43	90	42	Det.	1	87
69	CM60/SJ1-449-61	43	95	59	Mix	1	126
70	CM60/SJ1-492-64	42	98	75	Indet.	2	74
71	CM60/SJ1-493-65	42	97	83	Indet.	3	102
72	CM60/SJ1-524-67	45	97	70	Indet.	2	87
73	CM60/SJ1-546-68	42	97	82	Indet.	3	120
74	CG2796	32	82	30	Det.	1	40
75	SJ1	42	98	80	Indet.	3	144
76	CM60	39	92	59	Det.	1	77

Appendix Table 4 Some seed charactersistics attributed to field weathering resistance of the F_4 lines of two soybean crosses.

Line no.	Pedigree	Seed germination (%)	EC ($\mu S\ cm^{-1}g^{-1}$)	Percentage of seed coat	Seed coat thickness (mm)	Seed coat color
1	CM60/GC2796-23-2-1	100	44.97	7.29	0.098	Yellow
2	CM60/GC2796-200-26-2	90	39.94	8.13	0.105	Yellow
3	CM60/GC2796-225-34-3	99	60.84	7.16	0.084	Yellow
4	CM60/GC2796-302-50-4	100	56.27	7.14	0.081	Yellow
5	CM60/GC2796-312-52-5	96	53.89	7.14	0.081	Yellow
6	CM60/GC2796-331-57-6	99	54.17	7.91	0.098	Yellow
7	CM60/GC2796-337-59-7	98	46.67	7.83	0.090	Yellow
8	CM60/SJ1-9-2-1	86	72.52	7.14	0.080	Yellow
9	CM60/SJ1-32-5-2	96	68.00	7.43	0.082	Yellow
10	CM60/SJ1-34-6-3	98	63.41	7.22	0.087	Yellow
11	CM60/SJ1-47-9-4	100	54.21	7.07	0.096	Yellow
12	CM60/SJ1-113-16-5	94	58.96	7.98	0.097	Yellow
13	CM60/SJ1-135-21-6	100	47.81	7.92	0.097	Yellow
14	CM60/SJ1-171-25-7	100	77.03	7.79	0.085	Yellow
15	CM60/SJ1-209-29-8	96	62.94	7.34	0.090	Yellow
16	CM60/SJ1-209-29-9	98	63.40	7.67	0.094	Yellow
17	CM60/SJ1-232-32-10	98	57.02	7.44	0.097	Yellow
18	CM60/SJ1-276-38-11	100	57.62	8.39	0.103	Yellow
19	CM60/SJ1-305-42-12	99	45.23	7.39	0.091	Yellow
20	CM60/SJ1-314-45-13	100	59.74	8.16	0.087	Yellow
21	CM60/SJ1-315-46-14	99	56.43	7.39	0.082	Yellow
22	CM60/SJ1-350-49-15	100	59.04	7.98	0.098	Yellow
23	CM60/SJ1-356-50-16	100	55.36	7.28	0.097	Yellow
24	CM60/SJ1-401-55-17	100	55.61	8.41	0.106	Yellow
25	CM60/SJ1-413-56-18	94	53.10	7.08	0.086	Yellow
26	CM60/SJ1-414-57-19	88	77.68	7.58	0.089	Yellow
27	CM60/SJ1-449-61-20	100	62.29	7.63	0.093	Yellow
28	GC2796	100	49.52	8.25	0.108	Yellow
29	SJ1	94	60.03	7.62	0.094	Yellow
30	CM60	66	90.09	6.96	0.085	Yellow

Appendix Table 5 Some agronomic characters of the F_4 lines of two soybean crosses.

Line no.	Pedigree	Days to		Plant height (cm)	Stem termination type	Lodging score	No. of pods/ plant
		50% flowering	harvest				
1	CM60/GC2796-23-2-1	40	88	41	Det.	1	65
2	CM60/GC2796-200-26-2	41	88	45	Det.	1	63
3	CM60/GC2796-225-34-3	43	90	37	Det.	1	79
4	CM60/GC2796-302-50-4	40	86	41	Det.	1	47
5	CM60/GC2796-312-52-5	41	86	40	Det.	1	56
6	CM60/GC2796-331-57-6	42	86	42	Det.	1	60
7	CM60/GC2796-337-59-7	41	86	36	Det.	1	62
8	CM60/SJ1-9-2-1	42	93	53	Mix	1	66
9	CM60/SJ1-32-5-2	43	86	43	Det.	1	49
10	CM60/SJ1-34-6-3	43	90	54	Det.	1	90
11	CM60/SJ1-47-9-4	43	96	71	Indet.	1	110
12	CM60/SJ1-113-16-5	43	96	53	Indet.	1	81
13	CM60/SJ1-135-21-6	41	90	51	Det.	1	93
14	CM60/SJ1-171-25-7	41	90	43	Det.	1	90
15	CM60/SJ1-209-29-8	45	90	65	Det.	1	123
16	CM60/SJ1-209-29-9	41	90	80	Det.	1	112
17	CM60/SJ1-232-32-10	41	90	82	Det.	1	95
18	CM60/SJ1-276-38-11	43	95	78	Indet.	1	174
19	CM60/SJ1-305-42-12	43	90	52	Det.	1	119
20	CM60/SJ1-314-45-13	43	95	65	Indet.	1	134
21	CM60/SJ1-315-46-14	43	93	57	Det.	1	81
22	CM60/SJ1-350-49-15	45	90	54	Det.	1	107
23	CM60/SJ1-356-50-16	43	90	51	Det.	1	92
24	CM60/SJ1-401-55-17	41	90	62	Det.	1	88
25	CM60/SJ1-413-56-18	43	95	52	Indet.	1	55
26	CM60/SJ1-414-57-19	44	90	35	Det.	1	61
27	CM60/SJ1-449-61-20	43	90	67	Det.	1	93
28	GC2796	35	75	28	Det.	1	29
29	SJ1	43	95	60	Indet.	2	74
30	CM60	43	90	42	Det.	1	62