8 Seed Production and Technology

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The efficient production of maximum soybean [*Glycine max* (L.) Merr.] yields requires adequate supplies of high-quality seed of improved cultivars. This large volume of planting seed is supplied primarily by a seed industry consisting of professional seed growers and seedsmen. Due to the uncertain quality and short longevity of soybean seed, however, nearly all of the seed planted must be produced and marketed on an annual basis. Traditionally, much of this seed was of publicly developed cultivars and was produced primarily through state seed certification agencies. With the passage of the Plant Variety Protection Act (PVPA) in 1970, however, a much greater proportion of the planting seed and the cultivars used have originated from private seed companies. This has resulted in a rapidly expanding seed industry which at times has had problems maintaining the quality of the seed produced.

Soybean seed ontogeny is a complicated biological process that begins with a fertilized ovule and continues until seed maturity. In the short period of 30 to 60 days that a seed is attached to the mother plant it must develop an embryonic axis and complete a complex series of biochemical and physiological events necessary for synthesis and storage of food reserves. At physiological maturity (maximum accumulation of seed dry weight) the seed reaches its maximum potential for germination and vigor. Unfortunately, this potential is short-lived compared to other grain crops and is often reduced prior to planting. This can result in poor field emergence and inadequate stands, especially under adverse soil conditions. Since the majority of the planting seed must be produced each year,

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if seed quality problems occur the farmer's demands can exceed the supply of high-quality seed of the most popular cultivars.

8–1 ATTRIBUTES OF SEED QUALITY

Seed quality is a multiple criterion that encompasses several important attributes. A seed scientist may be concerned with the quality characteristics of an individual seed while the seed trade usually considers the quality components of a seed lot. Each individual soybean seed possesses certain measurable quality characteristics which include genetic and chemical composition, physical condition, physiological viability and vigor, size, appearance, and presence of seedborne microorganisms. When seeds are combined into a seed lot, these characteristics are averaged across the population and may be altered by contamination by other crops, cultivars, weed seeds, or inert material. The quality components of a seed lot commonly include crop purity, cultivar purity, weed and crop contaminants, germination, vigor, uniformity, moisture content, and seedborne pathogens. The most chronic quality problems in soybean seeds relate to germination and vigor; however, cultivar purity and weed seed contamination are also serious problems in some production areas.

8–1.1 Individual Seed Quality

The ontogeny of a soybean seed begins with double fertilization of the egg and polar nuclei (chapter 4 in this book) and continues until death of the embryo. Seed growth and development follows a sequence of cytological and metabolic events (chapter 16 in this book) which ends when the seed reaches its maximum dry weight at physiological maturity (PM) (Delouche, 1974; Crookston and Hill, 1978; TeKrony et al., 1979). At PM the seed is completely yellow and is no longer connected to the vascular system of the plant (TeKrony et al., 1979). Seed moisture at PM, however, is approximately 550 g of water kg^{-1} of fresh seed weight (Crookston and Hill, 1978; TeKrony et al., 1979) and a period of desiccation is required for the seed to dry to a harvestable moisture content (TeKrony et al., 1980b). Harvest maturity has been defined as the first time that the seed reaches a moisture content of 140 g kg^{-1} (TeKrony et al., 1980a). A soybean seed at harvest is almost spherical in shape with a large, well-developed embryo surrounded by a thin testa (seed coat).

The soybean seed is capable of germination when about 30% of the maximum dry weight has been accumulated and reaches maximum germination potential about midway between anthesis and PM (Adams and Rinne, 1981; Ackerson, 1984). The maximum vigor potential of soybean seed, as measured by accelerated-aging, speed of germination and conductivity, does not occur, however, until much later when the seed has accumulated nearly 90% of its maximum dry weight (Miles et al., 1983). Thus, the maximum germination and vigor potential of a soybean seed is not reached until just prior to PM. The seed cannot be harvested commercially at PM, however, because of high seed moisture (ca. 550 g kg^{-1}) and must remain on the plant for approximately 2 or more weeks until the seed reaches harvest maturity.

8–1.2 Seed Lot Quality

The quality of a population of soybean seeds (seed lot) represents their collective planting performance potential. High quality seeds usually meet or exceed minimum quality standards for a number of important characteristics. These characteristics are not equal in relative importance, but in combination provide a measure of seed lot quality. The standard of performance for each quality characteristic is established by the seed grower, seed company, seed certification agency, or regulatory inspector. The minimum recommended standards for soybean seed followed by seed certification agencies in North America (AOSCA, 1983) are shown in Table 8–1. The procedures followed for measuring these components are outlined in the Rules for Testing Seeds published by the Association of Official Seed Analysts and the International Seed Testing Association (ISTA, 1976; AOSA, 1981). All official (state and federal) seed testing laboratories and the registered seed technologists in commercial seed laboratories follow these rules.

A laboratory test which measures any attribute of seed lot quality can only be as representative as the seed sample submitted. Regardless of the seed lot size or storage container (bag, bulk), the sample tested must represent the entire seed lot. This requires precise procedures for sampling following guidelines established by official seed testing associations (ISTA, 1976; AOSA, 1981).

Table 8–1. Soybean seed standards recommended by the Association of Official Seed Certifying Agencies (AOSCA, 1983).

Factor	Standards for each class		
	Foundation	Registered	Certified
	%		
Pure seed (minimum)	NS†	98.00	98.00
Inert matter (maximum)	NS	2.00	2.00
Weed seeds (maximum)‡	0.05	0.05	0.05
Objectionable weed seeds (maximum)§	None	None	None
Total other crop seeds (maximum)	0.20	0.30	0.60
Other cultivars	0.10	0.20	0.50
Other kinds¶	0.10	0.10	0.10
Germination and hard seed (minimum)	NS	80.00	80.00

†NS = No standard.
‡Total weed seed shall not exceed 10 per 454 g.
§Designated by each state certifying agency.
¶Not to exceed 3 per 454 g in any class except corn and sunflower seed where maximum is; foundation—NS, registered—None, and certified—1 per 454 g.

8-1.2.1 Crop Purity

The crop purity indicates how much material in a seed lot is intact soybean seed, other crop seed, and weed seed. It is determined by conducting a purity test on a small laboratory sample. The sample size evaluated for soybean seed purity is 500 g, which is approximately 2500 seeds. In the purity analysis, a physical hand separation of components is made and the results are reported as a percentage by weight for (i) pure seed, (ii) other crop seed, (iii) weed seed, and (iv) inert matter (AOSA, 1981).

Pure seed is the percentage of soybean seed for the cultivar stated that occurs in the seed lot being tested. Unless excessive physical seed breakage has occurred or the seed lot is severely contaminated with crop or weed seed, the purity for soybean seed should exceed 98.0%. Many seed producers and companies strive for a purity of 99.0% or higher for all seed sold. If seed of another crop or soybean cultivar exceeds 5.0% by weight, the seed lot would be designated as a mixture by state seed laws and the Federal Seed Act (USDA, 1975).

Other crop seed is the percentage of crop seeds other than soybeans present in the seed lot tested. The most common crop contaminant in soybean seed is corn (*Zea mays* L.); however, sunflower (*Helianthus annuus* L.), cowpea [*Vigna unguiculata* (L.) Walp.], field bean (*Phaseolus vulgaris* L.), and other crop seed can also occur. No other crop seed should occur in high quality soybean seed sold for planting purposes.

Weed seed are those seeds commonly recognized by laws, regulations, customs, or general usage as weeds in the state or region. Since weed seeds vary greatly in size, they should be expressed as the number found in the purity analysis (500 g) in addition to the percentage by weight (as required by seed laws). Each state has established lists of noxious weeds which are determined to be troublesome and objectionable. Such lists are usually defined in two categories, primary (prohibited) and secondary (restricted) noxious weed seed. Soybean seed cannot usually be sold if primary noxious weed seed are present, while sales are restricted if secondary noxious weed seeds exceed established levels.

Weed seeds that are classified as troublesome in soybean seed will vary from one region to another due to adaptation of plant species. Those weed seeds that cause the greatest problems for soybean seed producers, however, are those that are either difficult to control in the field or to separate from soybean seeds during routine seed conditioning. Examples include: common cocklebur (*Xanthium pensylvanicum* Wallr.), giant ragweed (*Ambrosia trifida* L.), purple moonflower (*Ipomoea turbinata* Lag.), common morningglory [*Ipomoea purpurea* (L.) Roth], ballonvine (*Cardiospernum halicacabum* L.), and Johnsongrass (*Sorghum halepense* Pers.). Even though weed contamination can cause problems in some soybean production fields, soybean seed should not be sold with noxious or other objectionable weed seed present. The present availability of herbicides and seed cleaning equipment make this a realistic goal.

Inert matter denotes the percentage of material in the seed lot tested that is not seed. It includes pods, stems, small stones, soil particles, and pieces of broken seeds that are one-half or less than the original size. Splits (soybean seeds that are split directly in half at the juncture of the two cotyledons with the embryonic axis) are also classified as inert matter. Thus, if soybean seed are harvested, handled, or conditioned at low seed moistures, physical damage will occur and the percent inert matter could increase to high levels. A low percentage of inert matter ($< 2.00\%$) is desirable and this objective is often met or exceeded by good seed producers.

8-1.2.2 Germination

Even though crop purity is important, it means nothing if the seeds are incapable of germination. Thus, the single most recognized and accepted index of seed quality is germination. The germination capacity of a soybean seed lot is the percentage of pure seed that will produce a normal seedling (pure live seed) under optimum laboratory testing conditions. The procedures (ISTA, 1976; AOSA, 1981) followed when conducting a germination test have been carefully evaluated and standardized for many years. Thus, a test conducted by an official or registered seed analyst is commonly referred to as the standard germination test. The definition of germination is "the emergence and development from the seed embryo of those essential structures which are indicative of the ability to produce a normal plant under favorable conditions" (AOSA, 1981).

The Rules for Testing Seeds specify the optimum temperature and substratum for the germination test as well as the sample size. The time recommended for a soybean germination test is 8 days, however, a preliminary count can be made at 3 to 5 days, especially if seedborne fungi which cause moldy, diseased seedlings are present. One of the most critical evaluations made by a seed analyst during the standard germination test is the determination of normal and abnormal seedlings. A normal soybean seedling must have at least one intact cotyledon, a healthy epicotyl, and vigorous primary radicle or secondary root system. Malformed seedlings that do not meet these criteria or are severely diseased or have hypocotyl breaks extending into the conducting tissue are classified as abnormal. This rather subjective evaluation of seedling development is the primary difference between a layman's interpretation of germination and the seed analyst's classification of normal seedlings.

The official seed certifying agencies of North America (AOSCA, 1983) recommend a minimum germination of 80% for certified soybean seed (Table 8-1). This germination level tends to be the accepted standard for the industry, however, some seed company quality control programs have raised the minimum standard to 90%. Many state and federal seed laws prohibit the sale of soybean seed unless it has an acceptable germination and has been tested recently (within the past 26–52 weeks).

8-1.2.3 Cultivar Purity

Testing for soybean cultivar purity in seed laboratories received little attention until the passage of the PVPA in 1970 (PVPA, 1973). Since that

time, the number of cultivars in use has expanded rapidly (Batcha, 1983; Perrin et al., 1983) which has placed more emphasis on cultivar purity as a measure of seed quality. However, contrary to crop purity and germination testing; uniform, standardized procedures are not available to seed analysts for determining cultivar purity. As a general rule, a soybean cultivar cannot be identified by examining only the seed's morphological characteristics in the laboratory. It is possible to conclude that the seed belongs to a certain group of cultivars, but it is seldom possible to identify the exact cultivar. Thus, the methods for evaluating seed for cultivar purity are changing from visual observations of seed and seedling morphology to detailed grow-out tests or the use of biochemical or cytological methods.

The prominent morphological seed identification character for soybean cultivars is hilum color which can range from clear, buff, brown, imperfect black to black. Keys have been developed which classify the hilum color of soybean cultivars (Dorchester, 1945; Payne, 1979); however, there are many cultivars within each color classification. Thus, precise identification of soybean cultivars on this basis is difficult if not impossible. Factors which have been shown to affect the expression of hilum or seed color include: fungal infection (Nittler et al., 1974), the production environment (Taylor and Caviness, 1982), and seed handling (Payne, 1979).

Hypocotyl color is another morphological characteristic that has been used in conjunction with hilum color to classify soybean cultivars. This trait is closely related to flower color with purple hypocotyls occurring in cultivars with purple flowers and green hypocotyls occurring in white-flowered cultivars (Bernard and Weiss, 1973). Payne and Morris (1976) evaluated over 60 soybean cultivars for hypocotyl color and classified them into six pigmentation groups. Payne (1979) cautioned, however, that hypocotyl color could be influenced by the length of the photoperiod and light intensity as well as the nutrient content of the growing medium which could lead to interpretation problems when using this procedure.

Because morphological characteristics of soybean seeds and seedlings are subjective and variable, seed scientists have examined chemical or biochemical parameters to evaluate seeds for cultivar purity. A rather simple chemical taxonomic technique was developed by Buttery and Buzzell (1968) to separate cultivars based on the presence or absence of the perioxidase enzyme in the seed coat. They were able to separate soybean cultivars into two groups, those having high (dark red color) or low (no color) perioxidase activity. Due to its simplicity and speed ($<$ 30 min), this procedure has been adapted by many seed testing laboaratories. Similar to hilum or hypocotyl color, perioxidase activity is limited to placing cultivars in two groups and does not positively identify each cultivar.

A more sophisticated and potentially more valuable laboratory method of cultivar verification is the electrophoretic analysis for proteins and isoenzymes. Early research by Larsen (1967) used this procedure and was able to divide most (but not all) soybean cultivars into two groups based on the presence of either the A or B protein band. More recently, electrophoresis of urease (Buttery and Buzzell, 1971), esterase (Payne and Koszykowski, 1978), and other enzymes (Gorman and Kiang, 1977) have been used in separating soybean cultivars.

A recurring problem, when evaluating the purity of soybean cultivars, is that no single test can accurately distinguish and classify all cultivars. Thus, a combination of morphological and chemical techniques must be used. Wagner and McDonald (1981) used five procedures (hilum color, hypocotyl color, peroxidase activity of seed coat, and two electrophoresis procedures) and were able to separate and identify 15 of the 36 soybean cultivars commonly grown in Ohio. Similarly many large seed companies have now finger-printed all of their own cultivars and others as a part of in-house quality control programs. Even when the most sophisticated laboratory procedures are used, however, not all cultivars can be positively identified. This forces seed companies, seed certification agencies, or regulatory officials into extensive greenhouse and field testing for final verification. Grow-out tests in the greenhouse or field are time consuming, however, and are usually conducted after the seed has been planted and used by many farmers.

The quality standard usually used as a guide for cultivar purity is that required for certified seed production for the foundation, registered, and certified classes (Table 8–1). Many argue, however, that current cultivars are released at an earlier generation than in the past and are not as homozygous as older cultivars. This has caused seed certification agencies to classify those plants that differ morphologically, but are acceptable within a cultivar, as variants and those plants that are unacceptable as off-types (AOSCA, 1983). If the trends for earlier release and greater variability within a cultivar continue, these agencies may also have to increase the minimum levels of contamination allowed in the classes of certified seed.

8–1.2.4 Vigor

During the 1970s, no term related to soybean seed quality has received more attention than *seed vigor*. Coordinated efforts, among seed analysts, seed scientists, and seedsmen have been made to establish certain criteria for identifying and classifying seed vigor. This culminated in 1983 when a comprehensive review entitled *Seed Vigor Testing* was published by the Seed Vigor Testing Committee of the Association of Official Seed Analysts (AOSA, 1983). This publication provided a usable definition of seed vigor; "Seed vigor comprises those properties which determine the potential for rapid, uniform emergence and development of normal seedlings under a wide range of field conditions." Thus, two seed lots having nearly identical standard germination levels may perform quite differently under poor field conditions due to differences in their vigor potential. Seed vigor evaluations have been classified as (i) seedling growth and evaluation tests, (ii) stress tests, and (iii) biochemical tests

(AOSA, 1983). Tests falling into the first category include seedling vigor classification, seedling growth rate, and speed of germination. Stress tests include accelerated aging germination and the cold test, while biochemical tests include tetrazolium chloride, electrical conductivity, respiraton, and other tests of metabolic potential. A survey of all seed testing laboratories in North America indicated that 74% of those laboratories responding were evaluating seed for vigor (TeKrony, 1983). Forty-four commercial and official laboratories were testing soybean seeds for vigor and nearly 40% of these laboratories were conducting over 200 tests yr^{-1}. The most popular vigor tests for soybean seeds were the accelerated aging and cold test, while other tests used included conductivity, tetrazolium, and seedling vigor classification.

The accelerated aging test was originally developed to estimate longevity of seed in storage (Delouche and Baskin, 1973), however, it has also been shown to relate well to stand establishment of soybeans (Byrd and Delouche, 1971; TeKrony and Egli, 1977). This vigor test stresses unimbibed soybean seeds with high temperature (41°C) and relative humidity (100% RH) for short periods (3 to 4 days) prior to testing them for germination under optium conditions specified for the standard germination test (AOSA, 1981). The test is commonly conducted in either a large accelerated aging chamber (for multiple seed samples) or a small single sample aging chamber (AOSA, 1983). The single sample procedure involves placing the seeds (40 to 45 g) in a single layer on a wire mesh screen above water inside a small plastic germination box (McDonald and Phaneendranath, 1978). Many of these boxes can then be placed into an incubator set at the desired temperature and high relative humidity.

The accelerated aging test offers the advantages of being inexpensive, simple, and requiring little additional training of seed analysts. However, much variation in test results has been reported between laboratories (McDonald, 1977; Tao, 1978a, 1980a). Thus, precautions must be taken during aging to reduce variability. Tomes et al. (1981) reported that the interaction between aging temperature, seed moisture, and time during aging had the greatest effect on seed germination. They concluded that variability could be reduced by (i) evaluating seed on a weight (40 to 45 g) rather than number (200 seed) basis, (ii) precisely controlling aging temperatures at 41 °C, and (iii) measuring the initial and final moisture of the seed. Recent national vigor referees have incorporated some of these recommendations and have produced excellent test repeatability (Spain, 1982).

The cold test was originally developed to measure corn seed vigor (Clark, 1953; Svien and Isely, 1955), however, in recent years it has been used to evaluate seed vigor in other crops (McDonald, 1975) including soybeans (Johnson and Wax, 1978). The cold test simulates early spring field conditions by providing a seed environment of high soil moisture, low soil temperature, and microbial activity. Seeds are placed in soil or on kimpak or paper towels lined with soil and incubated at 10°C for a specified period (5 to 7 days). At the end of this stress period, the seeds

are transferred (in the same planting medium) to the favorable temperatures prescribed for the standard germination test (AOSA, 1981) and the normal seedlings that develop are counted.

The greatest difficulty with the cold test is the inability to standardize the soil source from one testing location to another (Delouche, 1976; Burris and Navratil, 1979). This was supported by seed vigor referees which showed significant variability between laboratories when using different soil sources (McDonald, 1977; Tao, 1980a). The use of peat moss or vermiculite inoculated with *Phythium* spp. instead of soil in the cold test has not been successful. Burris and Navratil (1979) compared many cold testing procedures for corn inbreds and reported that the temperature of the cold stress environment was more important than the soil medium. They reported that successful seed vigor evaluations may be possible using a sterile cellulose medium (without soil). Even with the inherent problems of the planting medium, the cold test still is used more than any other vigor test (TeKrony, 1983) with consistent results often occurring within a seed testing laboratory. This provides a convenient in-house test for quality control purposes.

The conductivity test is a measurement of electrolytes leaking from plant tissue. Poor membrane structure is usually associated with deteriorating, low vigor seeds. When these seeds are soaked in water, a greater loss in electrolytes (amino and organic acids) occurs and the conductivity of the soak water increases. The higher the conductivity of the soak water, the lower the seed vigor. The use of the conductivity test to measure the vigor of garden pea (*Pisum sativum* L.) has been established in Europe (Matthews and Bradnock, 1967, 1968). This test has been shown to correlate well with the vigor of soybean seed (Yaklich et al., 1979; McDonald and Wilson, 1979; Tao, 1980a; Loeffler, 1981).

Conductivity is measured by placing 25 to 50 uninjured soybean seed in a beaker containing 75 mL of distilled water. The seed are soaked for 24 h at 20 °C after which the conductivity of the soak water is measured using a dip cell (AOSA, 1983). The conductivity test provides a rapid, nonsubjective and inexpensive measure of seed vigor. It has been shown, however, that initial seed moisture (Pollock et al., 1969), seed size (Tao, 1978b; Loeffler, 1981) chemical seed treatment (Tao, 1980b) and seedborne disease (Loeffler, 1981) can influence conductivity results. Another concern is that, since the conductivity test measures the average conductivity of 25 to 50 seeds, a few low quality seeds may bias test results. A commercial instrument is now available which monitors the electrolyte leakage of individual seed (McDonald and Wilson, 1979, 1980). Conductivity estimated with this instrument was closely related to the conductivity of a composite sample (McDonald and Wilson, 1979; Loeffler, 1981).

Seedling vigor tests are usually conducted under the same environmental conditions as the standard germinaton test; however, seedling growth is measured or evaluated in two different ways; (i) seedling growth rate and (ii) seedling vigor classification. Both procedures offer certain

advantages to seed testing laboratories in that they are inexpensive, require no specialized training or equipment and are relatively rapid. Distinct disadvantages of seedling vigor tests, however, are (i) moisture and temperature of the testing medium must be precisely controlled, (ii) the timing of evaluation is critical and (iii) additional evaluation of seedlings into weak or strong categories is too subjective. For these reasons seedling vigor tests have been difficult to standardize among laboratories (McDonald, 1977; Tao, 1978a).

A seedling vigor classification test has been described (AOSA, 1983) and is used in some laboratories for soybean, field bean, cotton (*Gossypium hirsutum* L.), and peanut (*Arachis hypogaea* L.). This test is an expansion of the standard germination test with the requirement that normal seedlings are further classified as *strong* and *weak*. The test is conducted at a constant temperature of 25 °C and a preliminary count and seedling classification are made 5 days after planting. The strong and weak classification of seedlings separates normal soybean seedlings free of deficiencies from those which have deficiencies. Seedlings which would be classified as weak would have: a primary root missing, one cotyledon missing, partial decay, one primary leaf missing, or are short, spindly and poorly developed.

Another type of seedling vigor test is the first count of a standard germination test which has been classified as a speed of germination test. The number of normal seedlings counted at the first count represents the faster germinating seeds and is a measure of seedling vigor. The first count vigor evaluation for soybean has been conducted at either 4 (Burris et al., 1969) or 3 days (TeKrony and Egli, 1977). TeKrony and Egli (1977) counted only those seedlings that were strong and at least 3.75-cm long at 3 days.

Seedling growth rate is a vigor evaluation based on the growth of seedlings under the same conditions of a standard germination test except that the moisture content of the paper towels is precisely controlled (AOSA, 1983). At the end of the germination period, growth of the normal seedlings is measured either by length or dry weight (excluding the cotyledons). Limitations of this test are (i) it is time consuming to remove and/or measure seedlings, (ii) it is influenced by slight variation in moisture and temperature, and (iii) differential cultivar responses can make accurate test interpretations difficult.

It has been shown that soybean seed lots which have nearly identical and acceptable (>80%) standard germination, may have quite different seed vigor levels. Even though seed vigor tests are not presently standardized among seed-testing laboratories, progress is being made toward reducing variability and some vigor tests are widely used (TeKrony, 1983). Thus, many seed growers and seedsmen routinely test soybean seed for seed vigor and use this information as a valuable in-house tool when monitoring the quality of seed lots. As seed vigor testing procedures become accepted and standardized soybean seed may eventually be labeled for vigor and the information related directly to farmers at the time of purchase. Caution must be exercised, however, as misconceptions or misunderstandings of seed vigor could seriously delay final acceptance of this important concept.

8– 1.2.5 Seed-borne Pathogens

A large number of fungi, bacteria, and viruses may attack soybean seed prior to harvest and reduce the quality of the seed (Neergaard, 1977; Sinclair, 1982). Even though seed infection can cause serious reductions in seed germination and vigor, little attempt has been made to identify or report the presence of seed-borne pathogens in seed testing laboratories in the USA. Much greater progress has been made toward developing quantitative laboratory testing procedures for seed-borne diseases in seed testing laboratories in Europe. This has resulted in the publication of procedures for seed health testing by the International Seed Testing Association in the official Rules for Seed Testing (ISTA, 1976) and in a handbook for Seed Health Testing (ISTA, 1959). A comprehensive review of seed-borne pathogens and seed health testing procedures has been published by Neergaard (1977).

Even though some soybean seed-borne pathogens can be detected by visual examination of dry seed, the most commonly used procedure is incubation of seeds on agar plates, ordinary germination blotters or cellulose pads. The symptoms of both the purple seed stain disease caused by the fungus *Cercospora kikuchii* (Mats and Tomoy) and soybean mosaic virus can be detected by direct inspection of dry soybean seed. Seeds that are severely infected with *Phomopsis* spp. can be detected visually by their chalky, shriveled appearance. Positive identification of these and other fungi is usually made, however, after several days of incubation on agar or blotter media (Kmetz et al., 1974; McGee et al., 1980; Shortt et al., 1981; TeKrony et al., 1984). Using the agar method, seeds are usually surface sterilized in sodium hypochlorite and plated on acidified (pH 4.5) potato dextrose agar. The plates are held under fluorescent light at room temperature (22 °C) for 10 to 14 days before fungal identification can be made based on colony morphology. An experienced analyst, familiar with the colony characteristics of *Phomopsis* spp. and other fungi, can identify and count colonies macroscopically by examining both sides of the plates.

The blotter method combines the identification procedures commonly used by plant pathologists with the procedures used by seed analysts for the germination test. The seeds are placed on moistened blotters (Neergaard, 1977) or cellulose pads (Shortt et al., 1981) in petri dishes, plastic boxes, or other suitable containers and incubated in fluorescent light for 7 days. The seeds or germinated seedlings are examined either macroscopically or with a stereomicroscope for the presence of the pathogen and the extent of disease. The blotter method offers an advantage to routine seed testing laboratories since most of the equipment needed for conducting the test is readily available. The agar method requires that the seed analyst train for a period of time with a pathologist experienced

in the use of this method. Similar training is necessary for the detection and identification of fungi for both methods.

8–2 RELATIONSHIP OF SEED QUALITY TO PERFORMANCE

The quality of planting seed is determined to provide information on its potential performance in the field (seedling emergence and/or yield) or its ability to maintain quality during storage. The ability of seed quality parameters to accurately predict performance is hampered by a number of factors, including the many causes of variation in seed quality and the wide range in environmental conditions that may be encountered during seed storage or when the seed is planted.

8–2.1 Storability

The production of a soybean crop requires that the planting seed must be stored (at a minimum) from the time of harvest in the fall until the spring planting season. During storage, quality can remain at the initial level or decline to a level that may make the seed unacceptable for planting purposes. It is well known that seed moisture and temperature are primary determinants of quality changes during storage (Toole and Toole, 1946; Holman and Carter, 1952; McNeal, 1966). However, the deterioration of seed during storage is also related to the quality (germination and/or vigor) of the seeds placed into storage (Egli et al., 1979; Burris, 1980; Ellis et al., 1982).

Byrd and Delouche (1971) reported that, as seeds deteriorate during storage, their performance potential and vigor decline before there is any loss in viability (standard germination). This suggests that the standard germination of a seed lot placed in storage may not be a good indicator of its storage potential because it may not accurately indicate the degree of seed deterioration. Egli et al. (1979) found little relationship (r=0.23) between the initial standard germination of 12 seed lots and germination after 9 months of storage at 135 g kg^{-1} of moisture and ambient temperatures. Similar results were reported by Baskin and Vieira (1980).

Byrd and Delouche (1971) reported that several stress tests (accelerated aging, cold test, and germination after immersion in 75 °C water for 70 s) that measure seed vigor were more closely associated with the longevity of soybean seed in storage than the standard germination test. This association has been supported by a number of studies (Delouche and Baskin, 1973; Egli et al., 1979; Baskin and Viera, 1980; Burris, 1980). Wien and Kueneman (1981) found that the accelerated aging test (40 °C, 100% RH, 72 h), did not accurately predict seed emergence after 39 weeks in storage; however, a modified accelerated aging test (35 to 40 °C and 75% RH for 6 weeks) was a better predictor of deterioration during storage. Egli et al. (1979) reported that the correlation between standard germination of 12 lots of soybean seed after 39 weeks storage at 135 g kg^{-1} of moisture and ambient temperatures and the initial accelerated aging germination (40 °C, 100% RH, 72 h) was r = 0.69. The initial accelerated aging germination was also closely associated with the accelerated aging germination after 26 weeks in storage. They concluded that the accelerated aging test was an excellent predictor of storability.

In some cases, it has been reported that the germination of soybean seed may increase during storage (TeKrony et al., 1982). This has been shown to occur in seed lots that initially have relatively high levels of infection by the pod and stem blight fungi (*Phomopsis* spp.). Germination is closely related to the level of pod and stem blight fungal infection (TeKrony et al., 1984) and, as the fungus dies during storage, the standard germination of the seed increases (TeKrony et al., 1982).

Mechanical damage is another factor that may influence seed deterioration during storage. White et al. (1976) reported that the physical damage caused by drying at high air temperatures resulted in a more rapid decline in germination during storage. Paulsen et al. (1981b) reported that mechanical damage that occurred during harvesting did not have a significant effect on the rate of deterioration during storage. This difference in results may be related to the different levels or types of physical injury imposed in the two studies. It is not yet clear whether mechanical damage can affect the storability of soybean seeds without reducing the initial standard germination or vigor level of the seed.

Several reports (Burris, 1980; Wien and Kueneman, 1981; Minor and Paschal, 1982; Ellis et al., 1982) have suggested that there are genotypic differences in the storability of soybean seed. Wien and Kueneman (1981) screened lines from Indonesia, the International Institute of Tropical Agriculture, and the USA for storability and found that several small seeded lines (80–100 mg seed^{-1}) from Indonesia maintained higher levels of germination in storage than other lines. Minor and Paschal (1982) screened 235 genotypes of potential tropical and subtropical adaptation and found a number of genotypes with potentially superior storability. They indicated that longer storage half-lives tended to be associated with higher initial germination, higher levels of hard seed, small seed, and earlier maturity. Egli et al. (1979) compared the storability of three seed lots from each of four cultivars adapted in Kentucky and concluded that the initial quality of the seed (viability and vigor) was the main determinate of seed storability and that there was no direct cultivar effect on storability per se. Starzing et al. (1982) evaluated black-and-yellow seed from a bulk F_4 population derived from the cross of black-and-yellow seeded parents and found that the germination of the yellow seed declined faster in storage than the black seed. They attributed this difference to lack of fungal growth on the black seeds, although the amount and kind of fungal growth was not determined. Since initial quality levels are frequently confounded with genotypes, it is difficult to determine if there are true genotypic differences in the ability of seed to resist deterioration and loss of quality during storage.

8–2.2 Field Emergence

Many attempts have been made to relate standard germination to field emergence (seedling emergence under field conditions) with widely varying results. Some workers have reported a close association between standard germination and field emergence (Sherf, 1953; Athow and Caldwell, 1956) while other studies have shown that standard germination consistently overestimates field emergence (Edje and Burris, 1971; TeKrony and Egli, 1977; Johnson and Wax, 1978; Yaklich and Kulik, 1979). This diversity of results has been partially explained by variation in field conditions, with standard germination providing accurate predictions of field emergence only under near ideal field conditions. Unfavorable seedbed conditions reduce field emergence and reduce the association between standard germination and field emergence (TeKrony and Egli, 1977; Johnson and Wax, 1978). Delouche (1974) concluded that the standard germination test is an insensitive and misleading measure of seed quality because it focuses primarily on the final consequences of deterioration and does not adequately take into account the very substantial loss in performance potential that can and does occur before germination capacity is lost.

The definition of seed vigor (AOSA, 1983) suggests that measures of seed vigor should provide a better relationship to field emergence than standard germination. This concept has been evaluated in a number of experiments with the general conclusion that estimates of seed vigor relate better to field emergence than standard germination (Edje and Burris, 1971; TeKrony and Egli, 1977; Johnson and Wax, 1978; Yaklich and Kulik, 1979; Clark et al., 1980). However, it was not possible to identify a single vigor test that consistently predicted field performance in all conditions. TeKrony and Egli (1977) reported that the 4-day germination was better than accelerated aging in predicting field emergence in years with adverse field conditions. Yaklich and Kulik (1979) and Kulik and Yaklich (1982) found that the accelerated aging germination, tetrazolium-viable seeds, and the cold test were the most consistent of the many tests they evaluated. Johnson and Wax (1978) obtained consistent results with the cold test but not with the accelerated aging test.

Johnson and Wax (1978) suggested that it may not be possible to develop a single test or array of tests that will predict field emergence for all field conditions to which the seed might be exposed. Several workers have suggested that a combination of vigor tests may relate better to a wide range in field conditions. TeKrony and Egli (1977) converted the results of laboratory tests to a vigor index and related combinations of these vigor indices to field emergence. The combined indices were better than a single index, but the relationship to field emergence was still variable across environments. Luedders and Burris (1979), Yaklich and Kulik (1979) and Loeffler (1981) used the results of various vigor tests to develop multiple regression equations to predict field emergence; however, the predictive ability of the equations was no better than the individual tests.

High-quality seed (high standard germination and high vigor) can be expected to produce better field emergence in a wide range of seed bed conditions than seed of marginal or low quality. However, it has not been possible to accurately predict field emergence under all seed bed conditions from the results of individual measures of quality or from combinations of tests. Soybean yields are relatively insensitive to plant population over a wide range of populations (Tanner and Hume, 1978), thus precise stands are not needed to maximize yield. Consequently, some reduction in field emergence below that predicted by laboratory tests can be tolerated without a significant effect on yield. Most recommended planting rates are higher than the populations required for maximum yield to compensate for possible reductions in emergence.

8–2.3 Yield

Seed quality can influence yield in two ways; indirectly by influencing emergence and final stand or directly through its influence on plant vigor. If inadequate plant populations are obtained as a result of the use of low-quality planting seed, yields will be reduced (Edje and Burris, 1971; Johnson and Wax, 1978). However, when seed lots that varied in quality were compared at populations adequate for maximum yield, there was no relationship between seed quality and yield (Edje and Burris, 1971; Egli and TeKrony, 1979; Kulik and Yaklich, 1982). These results suggest that the primary advantage for the use of high-quality (high germination and vigor) planting seed is to increase the probability of obtaining satisfactory plant populations under a wide range of field conditions.

There are, however, a number of indirect indications that seed quality may have a direct effect on yield, beyond the attaining of adequate plant populations. Some investigators have reported that seed size is positively correlated with yield (Fontes and Ohlrogge, 1972; Burris et al., 1973; Smith and Camper, 1975), while others show no relationship between the two variables (Singh et al., 1972; Johnson and Leudders, 1974). The seed quality of the various seed size classes used in these experiments was usually not reported, however, Burris et al. (1971, 1973) reported that large seed produced more vigorous seedlings than small seed. Fehr and Probst (1971) reported that the source (area of production) of planting seed significantly influenced yield although the differences were not large. Torrie (1958) found that yield from seed that had been stored for several years was lower than the yield from seed that had been stored for only 1 yr. Plants from seed that had suffered imbibitional injury at low temperatures (Hobbs and Obendorf, 1972) or plants that were the last to emerge (Pinthus and Kimel, 1979) showed reduced vigor and yield; however, the plants were grown at lower than normal populations which may give an advantage to more vigorous plants.

A consideration of the available data suggests that in normal production systems, there is little direct yield advantage to be expected from the use of high-quality planting seed. However, considering the cost of replanting or potential yield losses because of stand failure, the use of high-quality planting seeds is clearly justified.

8–3 FACTORS INFLUENCING SEED QUALITY

8–3.1 Environmental

Soybean seed quality is highly variable across locations and years indicating that environmental conditions during seed production have a significant effect on seed quality. Environmental conditions can influence seed quality during seed development, during the desiccation period (physiological maturity to harvest maturity) or after harvest maturity when the seed is essentially in storage in the pod in the field.

The effects of the environment during seed development and maturation have been demonstrated by a number of workers. Green et al. (1965) reported that seed produced from later dates of planting which reached maturity after hot, dry weather had ended generally exhibited higher germination and field emergence than seed which matured during hot, dry weather. Harris et al. (1965) reported similar results. TeKrony et al. (1980b) attributed lower initial germination and vigor at harvest maturity of one cultivar to high temperatures during the period from physiological maturity to harvest maturity.

Seed quality of earlier maturing cultivars at a given location is generally lower than that of later-maturing cultivars (Smith et al., 1961; Green et al., 1965; Mondragon and Potts, 1974; Ross, 1975; Grau and Oplinger, 1981; TeKrony et al., 1984). Delayed planting, especially of early maturing cultivars, has been shown to result in improved seed quality (Green et al., 1965; Nicholson and Sinclair, 1973; TeKrony et al., 1984). TeKrony et al. (1984) evaluated six cultivars of varying maturity in three planting dates for 4 yrs and found a positive linear relationship between the date of harvest maturity and standard germination and seed vigor (accelerated aging germination and speed of germination). They also reported a linear decline in seed infection by *Phomopsis* spp. as harvest maturity was delayed and the variation in standard germination was closely associated with levels of seed infection by *Phomopsis* spp. They concluded that the lower levels of standard germination associated with the early dates of harvest maturity were primarily a result of the high levels of *Phomopsis* spp. seed infection. Seed vigor was not as closely associated with *Phomopsis* spp. seed infection, suggesting that the environment was acting directly on the seed in terms of influencing seed vigor.

A number of workers have shown that seed quality deteriorates when the seed remains in the field after harvest maturity (Mondragon and Potts, 1974; Wilcox et al., 1974; Ellis and Sinclair, 1976; Alexander et al., 1978; TeKrony et al., 1980b). Early maturing cultivars have been shown to be affected more by delayed harvest than late-maturing cultivars (Wilcox et al., 1974). High temperatures, RHs, and precipitaton have been shown to enhance field deterioration (Wilcox et al., 1974; Alexander et al., 1978; TeKrony et al., 1980b). Moore (1971) attributed much of the decline in quality to physical damage to the seed as a result of alternate wetting and drying, although this relationship was not supported by TeKrony et al. (1980b). Mondragon and Potts (1974) concluded that deterioration was related to the rate and range in fluctuations in temperature and RH in the plant canopy rather than the absolute levels. Potts et al. (1978) investigated field deterioration using a soybean strain exhibiting high levels of hardseededness. They found that germination remained high longer during field exposure after maturity and this was associated with less fluctuation in seed moisture.

The declines in germination when seeds remain in the field after harvest maturity have also been associated with increases in the levels of seed infection by *Phomopsis* spp. and other fungi (Wilcox et al., 1974; Ross, 1975; Ellis and Sinclair, 1976; Alexander et al., 1978). The increase in *Phomopsis* spp. seed infection during field weathering was reduced by the use of the foliar fungicide benomyl (Ross, 1975; Ellis and Sinclair, 1976).

TeKrony et al. (1980b) found that after harvest maturity declines in seed vigor (accelerated aging germination) occurred before declines in standard germination. They suggested that seed vigor was more sensitive to field deterioration than seed viability. The loss in seed vigor was accelerated by warm, moist conditions leading to the suggestion that the deterioration was similar to that experienced during storage (TeKrony et al., 1980b).

Environmental conditions during seed development, the desiccation period, and after harvest maturity can influence the quality of harvested seed. The widely varying levels of seed quality encountered as a result of environmental effects suggest that the quality level of a seed lot should be measured as soon as possible after harvest to determine its potential for use as planting seed.

8–3.2 Genetic

Environmental conditions during seed development, maturation, and exposure of the seed on the plant in the field before harvest are an important determinant of seed quality. Thus, any evaluation of genetic differences in seed quality must consider environmental effects. Although there are a number of reports in the literature of cultivar differences in seed quality (Ross, 1975; Paschal and Ellis, 1978) it is not always clear whether the differences are due to differences in specific plant characteristics or a result of variation in environmental conditions at some time in the seed development process.

Cultivars that differ in maturity may show consistent differences in seed quality across years; but, the differences may be due to variations in environmental conditions during seed development and/or seed maturation. Altering planting dates so that the cultivars of different maturities mature at the same time has shown that environmental conditions are, in many cases, more important than other plant characteristics in determining seed quality (TeKrony et al., 1984).

Green and co-workers (Green and Pinnell, 1968a, 1968b; Green et al., 1971) evaluated progeny from crosses of three genotypes from Japan that exhibited high levels of seed quality with two adapted cultivars and reported narrow-sense heritabilities of 3 to 29% for field emergence and 2 to 60% for standard germination. They concluded that it should be possible to improve seed quality through plant breeding and that the most efficient method for evaluating segregating populations was by using a general visual rating of seed quality and a laboratory germination test in which normal seedlings were counted early in the test (Green et al., 1971). Singh et al. (1978) evaluated field emergence in the F_3 and F_4 generations of a diallel cross of six genotypes and also concluded that seed quality could be improved by hybridization and selection. TeKrony et al. (1984) found consistent differences in quality between two genotypes (OX-303 and 'Beeson') of similar maturity and concluded that the two genotypes differed in plant characteristics that were important in determining seed quality.

A number of seed characters that have been related to seed quality or performance have also been shown to be under genetic control. These characters may be useful to plant breeders attempting to improve soybean seed quality. Wide variations in seed size exist in the soybean germplasm (Hartwig, 1973). Paschal and Ellis (1978) and Singh (1976), when evaluating lines for potential tropical adaptation, reported that small seed were associated with higher seed quality. TeKrony et al. (1984) reported that a small seeded genotype (OX-303) was consistently of higher quality than Beeson even though they both matured at approximately the same time. However, no physiological basis for the relationship between seed size and quality has been suggested.

Potts et al. (1978) demonstrated that seeds from a line showing a high level of hardseededness were more resistant to field weathering. The small-seeded genotype that TeKrony et al. (1984) showed to exhibit higher-quality levels also showed higher than normal levels of hardseededness which may have contributed to its high-quality levels. Kilen and Hartwig (1978) suggested that the permeable-impermeable response of soybean seeds may be controlled by as few as three major genes.

Starzing et al. (1982) reported that black seeds from segregating plants of a cross of black-and-yellow seeded lines showed slower deterioration during storage at 100% RH than yellow seeds because of lower levels of fungal infection. The usefulness of this character may be limited, however, by the requirement of the soybean industry for yellow seed.

Caviness and Simpson (1974) reported genotypic differences in seed-coat thickness, but no relationship between seed-coat thickness and visual ratings of seed quality. Seed-coat thickness was not associated with seed size in their studies.

Reductions in seed quality have been related to fluctuations in seed moisture content in the pod (Moore, 1971). Yaklich and Cregan (1981) measured the movement of moisture into seed in mature pods of a number of cultivars from Maturity Groups II through VI and reported significant genotype differences. However, the relationship of this character to weathering of seed in the field has not been investigated.

8–3.3 Mechanical

The soybean seed is poorly designed to resist mechanical damage. The embryo is surrounded by a thin seed coat and the radicle-hypocotyl axis lies against the basal margins of the cotyledons. The position of the radicle-hypocotyl axis combined with the thin seed coat make the seed especially vulnerable to injury from mechanical abuse (Delouche, 1974; TeKrony et al., 1980a). Mechanical injury to the seed can occur at any time during harvesting, drying, and conditioning of the seed (Delouche, 1974). Mechanical damage to an individual seed can include the formation of cracks or breaks in the seed coat, cracks in the cotyledons, injury or breakage of the hypocotyl-radicle axis, and complete breakage of the seed to the point where it would no longer be classified as part of the pure seed fraction (Delouche, 1974; Rojanasaroj et al., 1976).

The amount of mechanical damage to the seed is inversely related to the seed moisture level (Green et al., 1966; Newberg et al., 1980; Paulsen et al., 1981a; Singh and Singh, 1981; Prakobboon, 1982). The optimum moisture level for harvesting or handling seed is between approximately 120 and 140 g kg^{-1}. Physical damage increases significantly as the moisture decreases below 120 g kg^{-1}. Although visible physical damage tends to decrease as the moisture level increases above 140 g kg^{-1}, the seed at the higher moisture level may be damaged internally and the germination reduced (Green et al., 1966). Large seeds tend to be more susceptible to mechanical damage than small seeds (Paulsen, 1978; Paulsen et al., 1981a) and seeds that have been exposed to weathering in the field or that have been dried at high temperatures are more susceptible to mechanical damage (Green et al., 1966; Rojanasaroj et al., 1976).

The effect of mechanical damage on seed viability and potential seed performance will depend upon both the amount and type of damage. In general, as the amount of mechanical damage increases, the standard germination decreases, usually as a result of an increase in the proportion of the seeds producing abnormal seedlings (Green et al., 1966; Stanway, 1974, 1978; Luedders and Burris, 1979; Paulsen et al., 1981a; Prakobboon, 1982). Mechanical damage also reduces field emergence (Green et al., 1966; Stanway, 1974, 1978; Luedders and Burris, 1979; Wall et al.,

1983) although Luedders and Burris (1979) concluded that the amount or severity of mechanical damage was not reliably related to field emergence. Wall et al. (1983) found that treatment of mechanically damaged seeds with fungicides did not improve field emergence and Paulsen et al. (1981a) reported that the use of damaged planting seeds did not influence yield if adequate stands were obtained.

Several tests have been developed to measure mechanical damage. The indoxyl acetate test (Paulsen and Nave, 1979) has been used to detect seed-coat cracks, scratches, abrasions, or other small imperfections in the seed coat. The sodium hypochlorite soak test is a rapid test that detects breaks in the seed coat that allow rapid imbibition by the cotyledons (Luedders and Burris, 1979; Paulsen, 1980). The tetrazolium test is also useful to detect mechanical damage to the cotyledons and the hypocotyl-radicle axis (Moore, 1972).

8–3.4 Seed-borne Diseases

Soybean seeds may be infected by a large number of fungi, bacteria, and viruses (Sinclair, 1975, 1982). Infection of the seed by pathogens may reduce seed quality by altering the appearance of the seed, reducing germination or the ability of the seed to produce a healthy vigorous seedling, or transmitting the pathogen to the next generation of plants. Thus, it is obvious that high-quality seed should be free of pathogens.

More than 30 fungi are listed as being seed borne in soybean (Sinclair, 1975). McGee et al. (1980), using a large number of seed lots produced in Iowa, identified nine genera of fungi as seed borne. Ellis et al. (1979) isolated 35 genera of fungi from seed of cultivars from Maturity Groups VIII, IX, and X grown in Puerto Rico. McGee et al. (1980) reported that only *Fusarium* and *Phomopsis* spp. reduced laboratory germination and only *Phomopsis* spp. reduced field emergence. Ellis et al. (1979), however, found that 19 of the 35 genera they isolated significantly reduced germination.

Phomopsis seed decay caused by *Phomopsis sojae* (Lehman) and *Diaporthe phaseolorum* (Cke and Ell) Scc. var. *sojae* (Lehman) Wehn is generally recognized as a major cause of low seed quality in the USA (Sinclair, 1975, 1982). Although *P. sojae*, *D. phaseolorum* var. *sojae* and *D. phaseolorum* var. *caulivora*, Athow and Caldwell are all associated with seed decay, *Phomopsis* spp. are the most common (Kmetz et al., 1978). All three organisms were isolated from symptomless young plants (Kmetz et al., 1978); however seed infection takes place near maturation (Hepperly and Sinclair, 1980). Germination of seed is reduced in direct proportion to the level of infection (Kmetz et al., 1978; McGee et al., 1980; Kulik and Schoen, 1981; TeKrony et al., 1984). Infected seeds may be shriveled, elongated, cracked, and appear white and chalky or they may show no visual symptoms (Sinclair, 1982). Estimation of infection levels from visual symptoms does not give an accurate estimate of actual seed infection levels (Jeffers et al., 1982b).

Levels of seed infection are increased when soybean residues are present from a previous crop to provide a source of inoculum (Kmetz et al., 1979) and when warm, wet conditions prevail during seed development and maturation, although moisture appears to be more important than temperature (Spilker et al., 1981; TeKrony et al., 1983). Infection can also increase rapidly if the seeds are allowed to remain in the field after harvest maturity (Wilcox et al., 1974; Ellis and Sinclair, 1976). Although germination and field emergence of infected seeds are severely reduced, there is no evidence of higher levels of seed infection on plants produced from infected seed (McGee et al., 1980). Foliar fungicides have been shown to be effective in controlling *Phomopsis* seed decay (Ellis et al., 1974; Jeffers et al., 1982b) and Wall et al. (1983) reported increased field emergence following fungicidal seed treatment of *Phomopsis*-infected seed.

Purple seed stain, caused by *Cercospora kikuchii* (T. Matsu and Tomoyasu) Gardener, occurs in all areas of soybean production (Sinclair, 1982). The purple discoloration of the seed results in a seed lot that is not visually appealing; however, it is not clear whether the fungus reduces germination or field emergence. Murakishi (1951) and Wilcox and Abney (1973) reported reductions in germination and field emergence of purple-stained seed. Hepperly and Sinclair (1981) reported a significant correlation ($r = 0.19$) between the level of purple seed stain and germination for a number of seed lots from Illinois but no significant relationship ($r = 0.12$) in seed lots produced in Puerto Rico. Lehman (1950) and Sherwin and Kreithow (1952) reported no effect of purple seed stain on germination. Several workers have reported an inverse relationship between levels of seed infection by *C. kikuchii* and *Phomopsis* spp. (Roy and Abney, 1977; McGee et al., 1980; Hepperly and Sinclair, 1981) which resulted in an increase in germination as the infection levels by *C. kikuchii* increased because of the decline in *Phomopsis* spp. (Roy and Abney, 1977). Perhaps this antagonistic relationship obscured the relationship between purple seed stain and germination in the past.

There are many other fungi that infect soybean seed, for example *Peronospora manshurica* (Naum.) Syd. or *Colletotrichum dematium* (Pers. ex Fr.) Grove var. *truncatum* (Schw.) Arx, and may reduce germination (Sinclair, 1975, 1982); however their occurrence may be sporadic and they are not usually considered major determinants of seed quality.

A number of bacteria and viruses have been reported to be seed borne in soybean (Sinclair, 1982). Seeds from plants infected with the soybean mosaic virus may be mottled and many exhibit reduced germination (Quiniones et al., 1971; Sinclair, 1982). The soybean mosaic virus is seed transmitted which suggests that virus-free seed would be more desirable for planting purposes (Dunleavy, 1973).

A more complete discussion of seed- borne diseases affecting soybeans can be obtained in the *Compendium of Soybean Diseases* (Sinclair, 1982).

8–3.5 Insects

There are many insects that attack soybean and may cause reductions in yield (Turnipseed and Kogan, 1976); however, only the stink bug complex has a direct significant effect on seed quality. The three most common members of the stink bug complex are the green stink bug [*Acrosternum hilae* (Say)], the southern green stink bug [*Nezara viridula* (L.)], and the brown stink bug [*Euschistus servus* (Say)] (Todd, 1976). Both nymphs and adults feed on soybean by puncturing plant tissues and extracting the juices and, although they may attack all parts of the plant, they prefer young tender growth and fruiting structures (Todd, 1976). Seeds damaged at an immature stage may be shriveled and greatly reduced in size, whereas seed damaged later in development may show only a puncture mark surrounded by a discolored area (Todd, 1976).

Germination and field emergence of injured seeds are reduced in direct proportion to the degree of injury (Daugherty et al., 1964; Todd and Turnipseed, 1974; Yeargan, 1977). Jensen and Newsom (1972) reported that the effect of the injury depended on the location of the puncture. If the puncture was on the hypocotyl-radicle axis, the seed would probably not germinate; however, if the puncture was located in the cotyledons, the seed would probably germinate but may show reduced vigor. Thomas et al. (1974) reported the largest amount of injury when plants were exposed to stink bugs beginning with pod set. There was, however, no effect on germination when exposure was started when the pods were turning yellow. Jenson and Newson (1972) pointed out that most seeds exhibiting moderate to heavy stink bug damage, and low germination, would probably be removed during seed conditioning.

Kilpatrick and Hartwig (1955) reported similar levels of fungal infection in seeds with and without stink bug injury suggesting that the puncture wounds did not facilitate fungal invasion. Stink bugs are able to transmit the causal organism of the yeast spot disease (*Nematospora coryli* Pegl.) (Daugherty, 1967) which may affect seed quality (Sinclair, 1975, 1982).

8–4 PRODUCING AND MAINTAINING HIGH-QUALITY SEED

8–4.1 Cultural Practices

The cultural practices used by seed producers are generally similar to those used in the production of commercial soybean. A major goal of the seed producer is to maximize yield; however, because of the specialized use of the seed crop, there are a number of cultural practices that have a direct influence on seed quality.

Rotating soybean with other crops is generally recommended to prevent build up of certain diseases and to aid in weed control (chapter 9 in this book; Pendleton and Hartwig, 1973; Tanner and Hume, 1978).

In seed production, rotations are frequently used to help maintain genetic purity by eliminating the possibility of cultivar contamination by volunteer soybean plants from the previous years crop. Levels of inoculum are an important determinant of the level of seed infection by *Phomopsis* spp. (Kmetz et al., 1978). Thus, the chances of having high levels of seed infection are greater if soybean residue is present from a previous crop compared with growing soybean in a rotation (Kmetz et al., 1979). Tillage practices that result in incorporation of the soybean residue have resulted in lower levels of seed infection by *Phomopsis* spp. than minimum tillage systems that leave large amounts of residue on the surface (Grau and Oplinger, 1981).

Cultural practices can also be manipulated to create less favorable environmental conditions for infection of seed by *Phomopsis* spp. Seed infection by *Phomopsis* spp. is enhanced by warm, wet conditions during seed development (Spikler et al., 1981; TeKrony et al., 1983). Delaying planting of early maturing cultivars or growing cultivars on the northern edge of their zone of adaptation (causing them to mature relatively late), results in generally cooler and drier and conditions during seed development and maturation and can significantly reduce seed infection by *Phomopsis* spp. (Grau and Oplinger, 1981; TeKrony et al., 1984). Trends for improved germination and vigor were reported by TeKrony et al. (1984) when the planting of early maturing cultivars was delayed. In some areas, planting early maturing cultivars in a double-cropped system after wheat (*Triticum aestivum* L.) has become a common practice to improve seed quality; however, the seed producer must be willing to accept the yield reduction usually associated with this practice (Egli, 1976).

The occurrence of gray moldy seed caused by infection of the seed by *Phomopsis* spp. and *D. phaseolorum* (Cke and Ell.) Sacc. var. *sojae* (Lehman) Wehn has been decreased by K fertilization (Crittenden and Svec, 1974). Jeffers et al. (1982a) reported that K fertilization decreased the incidence of moldy seed, increased germination in some cases, but had essentially no effect on the level of seed infection by *Phomopsis* spp. or *D. phaseolorum*. They also reported that fertilizer rates in excess of those required for maximum yield had little influence on germination or moldy seed.

A number of fungicides are available to control fungal leaf diseases on soybean and these fungicides have been shown to reduce levels of *Phomopsis* spp. seed infection and improve seed quality (Ellis et al., 1974; Jeffers et al., 1982b) in addition to increasing yields in some environments (Ross, 1975; Backman et al., 1979). To reduce the level of *Phomopsis* spp. seed infection, the fungicide must be applied before there is visual evidence of the presence of the disease. Thus, several point systems have been developed, including field history, cultivar maturity, planting date, and environmental conditions to provide a guide on when to use foliar fungicides to improve seed quality (Stuckey et al., 1981; Sinclair, 1982).

Weed-free soybean fields are the goal of all soybean producers; however, freedom from weeds or other crop species is particularly important

for seed production. If these contaminants are present in the seed when harvested, it will create additional problems during seed conditioning and, in extreme cases, may make it impossible to condition the seed to the point where it can be marketed. Thus, field selection is one of the most important decisions a seed producer makes to reduce contamination from weeds, other crops, and potentially detrimental seed-borne diseases.

8–4.2 Harvesting

Threshing and conveying operations during harvest consist of dynamic events which often involve large momentum exchanges during collisions of seeds with machine components and other seeds (Bartsch et al., 1979). Paulsen et al. (1981a) stated that the common cause of damage in all grain-handling studies is the particle velocity immediately before impact and the rigidity of the surface against which the impact occurs. Several impact devices have been designed to evaluate the effect of impact velocity on soybean seed quality (Cain and Holmes, 1977; Bartsch et al., 1979; Paulson et al., 1981a). Paulsen et al. (1981a) reported that the percentage of splits and fine material increased as the impact velocity increased and as the seed moisture decreased from 170 to 80 g kg^{-1}. The seed that had low percentages of splits after impact also had high standard germination. Bartsch et al. (1979) reported that detectable levels of mechanical damage were observed at impact velocities as low as 5 m s^{-1} although significant increases in damage levels did not occur until impact velocities increased from 10 to 15 m s^{-1}. Thus, it was concluded that a reduction in the cylinder speed of a combine from 15 to 10 m s^{-1} peripheral velocity would result in a significant reduction in harvest damage. They also concluded that soybean seed harvesting and conditioning should be completed at the highest practical seed moisture content. Significant reductions in impact damage occurred as the moisture content increased from 80 to 180 g kg^{-1}. Analysis of temperature effects indicates that cold weather handling can also be expected to reduce seed quality (Burris, 1979b).

Bartsch et al. (1979) found that seed impacted near the radicle had the largest reduction in tetrazolium vigor index and that seed orientation was highly significant in influencing impact damage. However, seed orientation would appear to be impossible to control or even predict during harvesting or conditioning operations.

Cain and Holmes (1977) evaluated the impact damage to soybean seed as the result of a single high speed collision with a steel plate and concluded that impact damage is dependent on both seed moisture content and the velocity of impact. A single impact produced extensive external injury in relatively dry (107 g kg^{-1}) seed. Seeds at approximately 190 g kg^{-1} of moisture sustained the least impact damage. Seeds impacted at higher moisture levels (253, 302, and 353 g kg^{-1}) did not exhibit extensive external injury, but showed increased respiration rates and decreased germination after impact in comparison to control samples at the same moisture levels.

It is apparent that one method to improve the quality of soybean seed is to reduce the number and level of physical impacts imposed on the seed during harvesting, handling, and conditioning operations. The moisture content at which these operations are performed will also have a significant effect on the resulting impact damage. While it is not possible to totally eliminate impact damage to soybean seed, it is possible to reduce such damage by following management practices which reduce the level of impacts and their overall effect on seed quality.

Equipment used for combining soybean seed fields must achieve a high-harvesting efficiency and meet the same operational requirements as equipment used for commercial grain production. However, in addition, equipment selection, operational procedures, and management decisions must also consider final seed quality. Nave (1977, 1979) has reviewed the present status of soybean-harvesting equipment and those innovations which have been introduced to reduce header losses. A seed producer must be concerned with maintaining threshing and separating efficiency while avoiding undue impact damage to the seed. Efforts to reduce threshing damage while increasing capacity have resulted in the development of rotary threshing equipment (Nave, 1979). Rotary combines have one or more longitudinal rotors to replace the conventional cylinder and straw walkers for threshing and separating grain from crop material. Because the material is apparently subjected to less impact with the rotor, the harvested seed sustain much less breakage than with the conventional rasp-bar cylinder (DePauw et al., 1977).

Newberg et al. (1980) evaluated the damage to soybean caused by rotary and conventional threshing mechanisms. Three different combines (a single-rotor machine, a double-rotor machine, and a conventional rasp-bar cylinder machine) were tested under field conditions at four peripheral velocities. For the cultivar tested ('Amsoy 71'), the percentage of splits were significantly higher for the conventional cylinder than for either the single or double-rotor threshing mechanisms at similar peripheral speeds. For all three threshing mechanisms, the percentage of splits increased as peripheral threshing speed increased; however, the increase in splits was less with the rotary threshing mechanisms than the conventional cylinder. Threshing and separation losses with the rotary combines were significantly higher at the slowest rotor speeds relative to those at the higher speeds. Increasing concave clearance generally decreased the percentage of splits for all three combines; however, the effect was less than that caused by changes in cylinder or rotor speed. Newberg et al. (1980) also found a significant increase in the percentage of splits caused by the elevating mechanism used to move the soybean from the clean-grain auger to the grain tank in all three combines. This indicates that improvements in the design of the augers and elevators used to convey soybean into combine grain tanks are needed; especially for harvesting soybean for seed.

The viability and vigor of soybean seeds tend to decline in the field after reaching physiological maturity especially under adverse weather conditions. Thus, soybean seed should be harvested as soon as possible after they reach a practical harvest moisture content (usually 150 g kg^{-1} or less). If the harvest moisture content of the soybean is too low (below 120 g kg^{-1}), unacceptable levels of physical damage can be expected. Rotary combines tend to produce less physical damage to soybean during harvest; however, conventional combines can do a satisfactory job if properly adjusted. Adjustment of cylinder speed and concave clearances does not appear to be as critical for rotary-type combines. In either type, the cylinder speed should be high enough to achieve complete threshing and separation but not so high as to increase seed impact damage. Combine settings often need to be readjusted as harvest conditions change with time of day or with varying field environmental conditions.

8–4.3 Drying

As discussed above maximum seed quality is obtained when soybean seed is harvested as soon as possible after field drying to a suitable harvest moisture content (150 g kg^{-1}). Often, some drying will be required after harvest to maintain seed viability during storage. Drying temperatures, air flow rates, and drying times all need to be controlled within certain limits to maintain maximum seed quality. Improper drying conditions can reduce seed germination and physically damage the seed and decrease its quality. Prior to 1970, little research on soybean drying was reported in the literature. In 1945 and 1946, Holman and Carter (1952) conducted a limited numer of drying studies as a part of their work on soybean storage. They found that drying was best accomplished using forced-natural air in mild weather or forced-heated air when ambient temperatures were low and/or RHs high. For natural air drying they recommended that air temperatures should be above 16 °C and the RH below 75%. Matthes et al. (1974) found a definite correlation between drying time and seed germination in the upper levels of their batch dryer. They recommended minimum air flow rates of 9.9 to 13.2 m^3 $min\text{-}t^{-1}$ to maintain seed germination for the moisture contents (227 to 280 g kg^{-1}) and drying conditions (of 42 to 55% RH) tested. Rodda (1974) stated that natural air drying at air flow rates of 2.2 to 3.3 m^3 $min\text{-}t^{-1}$ was adequate for drying soybean seed harvested at moisture contents up to 160 g kg^{-1}.

Walker and Barre (1972) observed considerable cracking of the seed coat in soybean dried at high temperatures and/or low RH. There were significant differences between cultivars when the RH of the drying air was 40% or more. There was little effect of temperature on germination up to and including 54 °C; above that, however, there was a drastic reduction in germination. Similar results were reported by White et al. (1980) although they found that the incidence of seed-coat cracks did not approach zero until the drying air RH was 50% or higher. Data from these experiments was used to develop a thin-layer drying model (White et al., 1981) to describe the effect of initial moisture content, drying air temperature, and RH on the drying rate of fully exposed soybean seeds. Ting et al. (1980) studied the development of seed-coat cracks as a function of depth when soybeans were dried in a batch-type dryer and found that distance from the air inlet was the most significant factor affecting the development of seed-coat cracks. The further any location was from the air inlet, the lower the drying damage. Drying conditions were found to affect the magnitude of the seed-coat damage gradient existing in the soybeans after drying had been completed.

Pfost (1975) reported that crackage increased with an increase in drying air temperature, initial moisture content, and drying rate and decreased with an increase in final seed moisture and drying air RH. Drying air temperatures of 54 °C and lower had little or no effect on germination; however, germination was sharply reduced by 66°C air temperatures. Soybean seed at high initial moisture contents suffered greater losses of germination than those at low moisture contents from equal exposure to 66°C drying air.

In an effort to improve the quality of soybean seeds dried with heated air, Sabbah et al. (1977) investigated the use of a reversed-direction airflow procedure with a laboratory batch dryer. This procedure involved periodically changing the direction of the air flow through the drying bed according to a given set of drying conditions. This approach resulted in considerable improvement in soybean seed quality, however practical application would require some modification in the design of conventional batch-in-bin drying systems. Villa et al. (1978) used simulation techniques and developed mathematical models for predicting the drying process and the loss of soybean seed germination. Good agreement between experimental and simulated results was obtained for a limited range of drying conditions. Results showed that relatively high air flow rates are required for drying in hot and humid areas because of the adverse effect of temperature on germination. Air flow requirements for drying soybean seed in bins were found to be about one and a half times higher than those for drying soybean for the commercial grain market.

Ghaly and Sutherland (1983) reported that soybeans of 140 to 180 g kg^{-1} initial moisture can be dried for 4 h, using temperatures of 40 to 55 °C, without significantly reducing germination. An air temperature of 80 °C killed all the seed at the three moisture levels tested (140, 160, and 180 g kg^{-1}) as did 70 °C at 160 and 180 g kg^{-1} of moisture. It was clear that the soybean seeds became more sensitive to heat damage as the initial moisture increased from 140 to 180 g kg^{-1}. Maximum safe drying temperatures reported for soybean seed at 140, 160, and 180 g kg^{-1} of moisture were 65, 60, and 55°C, respectively. Heating soybean seeds to 60°C at a fixed seed moisture was found to increase the susceptibility to heat damage.

In drying soybean seeds, the objective is to reduce the moisture content of the seed to the desired level without undue loss of seed viability and vigor and without inflicting physical damage on the seed which could

significantly reduce their quality and storability. To limit seed-coat cracks in the dried seed, the RH of the drying air should be above 40% (Walker and Barrer, 1972; White et al., 1980). The maximum RH must be sufficiently low (65% or lower) to dry the seed to the desired moisture.

When drying soybean seeds and most cereal grains, a maximum drying air temperature of 43 °C is generally recommended (Hall, 1980). Nellist (1980), however, pointed out that a range of recommended drying temperatures are being used in various countries and some recommendations are based on somewhat sparse experimental evidence. Several investigations (Walker and Barre, 1972; Pfost, 1975; Ghaly and Sutherland, 1983) have shown that under certain conditions drying air temperatures can exceed 43 °C without any obvious damage to soybean seed germination. Apparently, safe drying temperatures are affected by both soybean seed moisture and the time of exposure to the drying air. If one wishes to limit physical damage to soybean seed by controlling the RH of the drying air, then the question of a safe maximum drying air temperature is usually of little consequence. Limitations on temperature increases for humidity control will keep the drying air temperatures well below the generally recommended 43 °C maximum.

Natural air drying can be used to dry soybean seeds with moisture contents of 160 g kg^{-1} or less if the air temperature is above 10°C and the RH below 70%. Air flow rates of 2 to 3 m^3 $min\text{-}t^{-1}$ are required. If the RH is higher, a few degrees of supplemental heat will be required. For seed between 160 and 190 g kg^{-1} moisture, air flow rates of 5 to 6 m^3 $min\text{-}t^{-1}$ should be used with supplemental heat added as necessary to keep the drying air RH in the 55 to 65% range. For soybean seed moistures above 200 g kg^{-1}, Matthes et al. (1974) suggested supplemental heat to control the RH at 40 to 50% with air flow rates of 10 to 12 m^3 $min\text{-}t^{-1}$. At this air flow rate, soybean depths should be limited to 1.2 m or less.

Soybean seeds can be dried with any type of commerical grain dryer provided RH and temperature restrictions are observed. However, drying equipment which utilizes recirculators or stirring devices are not recommended because of potential seed damge. Because of the temperature and humidity restrictions on drying air, most soybean seeds will be dried with batch-in-bin or in-storage type drying systems (for a description of various drying systems see Hall [1980] and Justice and Bass [1978]). When the drying air RH is below 60%, the seeds can potentially dry below 100 g kg^{-1} of moisture which can increase damage in subsequent handling operations. Overdrying can be compensated for in batch-in-bin systems by blending the overdried seed with the underdried portion of the batch when emptying the bin. This is not possible with in-storage types of drying systems so the operator must limit overdrying in the bin by keeping the RH of the drying air above 55%.

8–4.4 Storage

Soybean seed must be properly stored in order to maintain an acceptable level of germination and vigor until needed for planting. Storage

periods may vary from as little as 6 months, if the seeds are to be planted the next season, up to 20 months or longer if the seeds are to be carried over for one or more seasons. Longevity of seed in storage is influenced by the quality of the seed going into storage, seed moisture content, and storage temperature (Delouche, 1974; Justice and Bass, 1978; Egli et al., 1979; Burris, 1980).

The quality of soybean seed entering storage can be reduced by: adverse weather conditions prior to harvest; damage from pathogens, insects, and other pests; mechanical damage caused by harvesting and handling operations; and seed injury resulting from necessary drying operations. Seed deterioration from these causes should be minimized insofar as possible to increase potential seed longevity in storage.

Irrespective of initial seed quality, temperature and seed moisture are the two most important factors affecting seed deterioration in storage. Because seeds are hygroscopic, they will exchange moisture with the surrounding air until the vapor pressure of the seed and that of the air reach a state of equilibrium. If the seed comes to equilibrium with air maintained at a relatively constant moisture level, then its moisture content is referred to as the equilibrium moisture content (EMC) of that seed corresponding to the existing air conditions. On the other hand, if the seed are surrounded by a limited amount of air (such as occurs in the interstitial spaces among seeds in a storage bin) then the air will come to moisture equilibrium with the seed without any significant change in the seed moisture. The RH of the air in this situation is referred to as the equilibrium relative humidity (ERH) corresponding to the existing seed moisture at the prevailing temperature. All equilibrium moisture properties are a function of seed temperature.

Equilibrium moisture properties are specific for each type of seed and are important in developing storage recommendations and in the management of seed drying systems. The EMC values for soybean seed as measured by Alam and Shove (1973) and tabulated in the *ASAE Yearbook* (ASAE, 1983) are presented in Table 8–2. The values presented are for desorption (drying) conditions where the seed moisture decreases to reach equilibrium with the stated air conditions. For adsorption conditions, where the seed gains moisture to achieve equilibrium, equilibrium

Table 8–2. Equilibrium moisture content of soybeans under desorption conditions.†

Temperature	Relative humidity, %								
	10	20	30	40	50	60	70	80	90
°C	g kg^{-1}								
5	52	63	69	77	86	104	129	169	224
15	43	57	65	72	81	101	124	161	219
25	38	53	61	69	78	97	121	158	213
35	35	48	57	64	76	93	117	154	206
45	29	40	50	60	71	87	111	149	—

†All moisture contents are presented on a wet basis as grams of water per kilogram of seed weight.

moisture contents would be slightly lower than those presented. This means that the values from this table should predict the lowest moisture to which soybean seeds can be dried when using air of a specified temperature and RH; however, under adsorption conditions the expected seed moisture levels would be lower than those shown in Table 8–2.

Equilibrium moisture properties are useful in analyzing drying and storage systems. For example, soybean seed can be dried to a moisture content of 97 g kg^{-1} when using 25°C drying air having a RH of 60%. Seeds at a moisture content of 158 g kg^{-1} stored at 25°C will produce a RH of 80% in the air contained within the seed mass. This type of information can be used to predict the growth of microorganisms in the stored seed and the potential for seed deterioration. Most storage fungi cannot grow and reproduce on seeds in equilibrium with a RH $< 65\%$ (Christensen and Kaufmann, 1969). As indicated in Table 8–2, this corresponds to a 109 g kg^{-1} seed moisture at 25 °C. Activity of storage insects can also be expected to drop at RHs below 50% (Delouche, 1974).

Temperature and moisture conditions are known to affect physiological, biochemical, and genetic changes in seeds during storage (Roos, 1980). Microbial activity is also closely related to these parameters (Christensen and Kaufmann, 1969). Most studies related to seed storage do not separate the influence of the above processes on seed deterioration; instead, they relate reductions in seed quality to the storage environment and storage time.

Ramstad and Geddes (1942) reported a close relationship between grade, chemical changes, germination changes, and the moisture of stored soybean seed. When soybean with seed moistures varying from 138 to 169 g kg^{-1} were stored for 15 weeks at room temperature and at 37.8 °C, none of the seed were viable. However, seed samples stored at the same moisture for the same length of time at approximately 2 °C retained a high degree of viability. After 18 months storage at 2 °C, germination levels of 85, 84, 78, and 42% were reported for samples at 138, 149, 158, and 189 g kg^{-1} moisture, respectively. They concluded that maintenance of high-germination soybean seeds required storage at a low moisture and a low temperature.

Toole and Toole (1946) studied the effect of temperature and seed moisture on soybean seed viability of two cultivars stored for periods of 10 yrs. Seeds with approximately 180 g kg^{-1} of moisture were dead in 1 to 3 months at 30 °C, in 22 to 39 weeks at 20 °C, and in 2 yrs at 10 °C. The seeds maintained high viability for 2 to 3 yrs at 2 °C, but were dead in 6 yrs. Nearly complete germination was obtained after 6 yrs at −10 °C. At a more typical storage moisture content of approximately 135 g kg^{-1} the seeds were dead after 22 weeks storage at 30 °C and after 2 yrs at 20 °C. High viability was maintained for 3 yrs at 10 °C and 10 yrs at 2 °C while little change in germination occurred after 10 yrs at −10 °C. At 80 to 90 g kg^{-1} moisture, the rate of seed deterioration was less at all storage temperatures with no change in germination over a 10-yr period at 10, 2, and −10 °C. Hukill (1963) used the data from Toole and Toole

(1946) to develop an "age index" to show the relationship between moisture, temperature, time, and germination for soybeans. His results, however, could not account for variation in the viability of the seed when placed in storage.

Burris (1980) stored seeds of six soybeans cultivars for 3 yrs at seed moisture levels of 80, 100, 120, and 140 g kg^{-1} and storage temperatures of −1, 10, 15, and 27 °C. The rate of seed deterioration in storage increased with increasing temperature and seed moisture for all cultivars. Burris (1980) used the combined data from all cultivars and developed constants for seed storage prediction equations initially proposed by Roberts (1960). These equations were based on the assumption that the frequency of individual deaths with time in a seed population stored under constant conditions could be described by a normal distribution. With the appropriate constants, these equations can be used to predict the percentage viability of a seed lot after any given period under any combination of temperature and seed moisture normally encountered. Roberts (1972) showed that such equations could be applied to a wide range of seed species as well as to a particular seed lot. A major disadvantage, however, was that they did not take into account variations in potential longevity between seed lots resulting from differences in genotype or differences in seed quality caused by prestorage treatments or conditions.

Ellis and Roberts (1980) improved the viability prediction equations (Roberts, 1960) to take into account variations in initial seed quality within a given species and to more accurately consider the influence of a wider range of storage environments. Constants for the improved equations were shown to be essentially the same for soybean seed lots of both high and low vigor levels. Three equations were employed by Ellis and Roberts (1980) to predict seed viability. They first described the seed survival curve in terms of the viability, ν (probit percentage viability) to be expected after a given storage period, p.

$$\nu = K_i - p/\sigma \qquad [1]$$

where K_i is a constant for the seed lot in question and σ is the standard deviation of the cumulative frequency distribution of seed deaths for the specified storage conditions. Differences between seed lots should not affect the value of σ and are accounted for by differences in the value of K_i.

The storage environment has no effect on K_i, but it affects σ according to the following equation:

$$\log \sigma = K_E - C_W \log m - C_H t - C_Q t^2 \qquad [2]$$

where m = percent seed moisture content on a wet basis, t = storage temperature in °C, and K_E, C_W, C_H, and C_Q are constants whose values are common for all seed lots of a given species.

Equations [1] and [2] can be combined to give

$$\nu = K_i - p/10^{K_E - C_W \log m - C_H t - C_Q t^2}. \qquad [3]$$

This equation describes the probit percentage viability to be expected for

any seed lot after any time when stored at various temperatures and seed moisture. Ellis et al. (1982) summarized four essential features of seed physiology characterized by the above viability equations.

1. Although the survival of different seed lots, or cultivars within a seed species, may differ when stored under identical conditions, the seed survival curves are symmetrical sigmoids which can be described by negative cumulative normal distributions which, in a given species, have the same standard deviation in any given combination of temperature and seed moisture.
2. The relative difference between seed lots is maintained in all storage environments because the relative effect on longevity from altering either temperature or seed moisture is the same for all lots.
3. There is a negative logarithmic relationship between seed longevity and seed moisture.
4. Seed longevity increases slightly less than exponentially with a decrease in temperature so that the rate of loss in viability per 10 °C rise in temperature increases with temperature.

The K_i in the above viability equations is specific for each seed lot and is a measure of initial seed quality (Ellis and Roberts, 1980). Its value is dependent on genotype, the prestorage environment and their interaction. The K_i must be estimated before the viability equations can be applied. This may be accomplished by conducting a germination test at the start of the storage period, or more accurately by carrying out an initial rapid-aging test, in which a sample of seed is rapidly deteriorated under a constant adverse environment (Ellis and Roberts, 1980).

The survival of soybean seed in sealed storage has been investigated by Ellis et al. (1982). Various combinations of storage temperature (from −20 to 70 °C) and seed moisture (ranging from 50 to 250 g kg^{-1}), were studied for four different soybean cultivars. Viability constants for the above equations (with p expressed in days) were derived from the data as follows:

$K_E = 7.748$,
$C_W = 3.979$,
$C_H = 0.053$, and
$C_Q = 0.000228$.

This work confirmed the applicability of the viability equations in predicting the storage life of soybean seed under known environmental conditions. All soybean cultivars responded in the same fashion to storage temperature and moisture. The relative initial difference between seed lots in absolute longevity was maintained in all storage environments because the relative effect on longevity from altering either temperature or moisture was the same for all lots (Ellis et al., 1982). The value of K_i for a given seed lot is indicative of its quality and potential storage life. For known storage seed moistures and temperatures, seed with a high value of K_i will have higher viability and vigor after a predetermined storage period. This agrees with the recommendation of Burris (1980) that seeds of high moisture and average vigor be marketed first and that seeds of low moisture and high vigor be selected if necessary for carrying over to the next planting season.

The viability of soybean seed after storage for specified periods of time at given levels of moisture and temperature can be predicted using the viability equations of Ellis and Roberts (1980) along with the viability constants presented by Ellis et al. (1982) provided an accurate estimate of K_i, the initial viability constant, has been established. Without such an estimate, only generalized storage recommendations can be made.

Misra (1981) indicates that soybean seed at 120 g kg^{-1} of moisture should be stored for no longer than 9 months. This is generally accepted for the storage of seed until the next planting season although the actual level of seed deterioration will depend on initial seed quality and storage temperature. Delouche (1974) recommends that soybean seed be rapidly and properly conditioned to 100 to 120 g kg^{-1} of moisture after harvest for storage until the following spring. He recommended 100 g kg^{-1} of moisture content or less for carryover seed storage and air conditioning to reduce a summer storage temperatures. For longer-term storage soybean seed moistures of 80 g kg^{-1} would be advantageous (Burris, 1980); however, significant mechanical damage can be expected when handling and conditioning soybean seed at this moisture. In tropical areas, high temperatures and humidities make storage more difficult. Rodda and Ravalo (1978) stored soybean seed at 25 °C and found that only low moisture seed (65 g kg^{-1}) stored in sealed containers maintained adequate germination levels for 9 months.

Seeds stored in bulk should be preconditioned prior to storage, if possible, and aerated as necessary to maintain seed quality. Aeration reduces temperature gradients in storage and, thereby, reduces convective air currents which can cause moisture migration. Aeration systems need to provide at least 0.11 m^3 of air min^{-1} t^{-1} of seed. In the fall, the seed needs to be cooled as necessary to keep the average seed temperature within approximately 3 °C of the average monthly temperature until the seed temperature reaches 2 to 4 °C. It is not a good practice to freeze seed if it can be prevented since it will require a longer period to warm up and condensation can be a problem if frozen seed is moved or aerated during periods of high humidity. In the spring, the aeration system should be used to warm the seed to 10 to 12 °C but no higher in order to avoid unnecessary seed deterioration. A detailed description and analysis of aeration systems can be found in the literature (Burrell, 1974; Midwest Plan Service, 1980; Loewer et al., 1979).

8–4.5 Seed Conditioning

Seed conditioning is the final step that converts soybean seed into the finished product, high-quality seed for planting purposes. Depending upon the crop maturity and seed moisture at harvest, the final product may be overthreshed resulting in split seeds and seed fragments or under-

threshed resulting in pods, stem portions, and other materials in the grain. In either case, the grain as it leaves the combine is not fit for planting and seed conditioning is necessary before the seed is sold to the farmer. Thus, there are several reasons for conditioning soybean seed to upgrade the quality. These include the following:

1. Remove other crop and weed seed.
2. Remove damaged, immature, and diseased soybean seed.
3. Remove foreign material (pods, stems, soil peds, and insects).
4. Apply seed protectants.
5. Improve seed lot appearance.
6. Maintain or improve seed germinability.

Several excellent reviews have been published which discuss the conditioning machines available for soybean seeds (Harmond et al., 1968; Vaughan et al., 1968; Greg et al., 1970; ISTA, 1977). The operator of a seed-conditioning plant must be able to exploit the differences between the physical characteristics of the soybean seed and the other components of the seed lot. A knowledge of the capabilities and the limitations of all equipment is important for successful seed conditioning. It is the intent of this section to briefly review the flow of soybean seed through a typical seed-conditioning plant and discuss the following steps:

(i) preconditioning, (ii) basic seed cleaning, (iii) seed separation and grading, and (iv) seed treatment.

The basic diagram that is commonly used for flow of seed through a seed-conditioning plant is shown in Fig. 8–1. Nearly all soybean seed is received at a conditioning plant in bulk and may be preconditioned over a scalper or aspirator prior to storage or basic seed cleaning. Seeds are most commonly conveyed from bulk storage bins to a receiving pit where they are elevated to a distribution point before being passed by gravity to the basic seed cleaner or other seed-cleaning machines (Fig. 8–2). Depending upon the design of the seed-conditioning plant (vertical or horizontal), the seeds may be elevated from one to several times and dropped from various heights into holding bins prior to cleaning, treating, and final bagging operations (Fig. 8–1).

8–4.5.1 Preconditioning

Prior to basic seed cleaning, a precleaning examintion of the rough seed is essential and preconditioning of the seed is often beneficial. As rough seed is received from the combine, but prior to storage, a seed sample should be taken and tested immediately to determine seed moisture. Seed that is too low (< 100 g kg^{-1}) in moisture or of extremely low quality (high percentage of splits or contaminants) may be unfit for seed purposes and should be rejected. If the seed moisture is too high (> 150 g kg^{-1}) it may have to be dried before bulk storage. Seeds that are high in moisture will often contain considerable trash and green material (pods, stems, etc.) which, if removed during preconditioning, may lower the seed moisture enough to allow storage without additional drying.

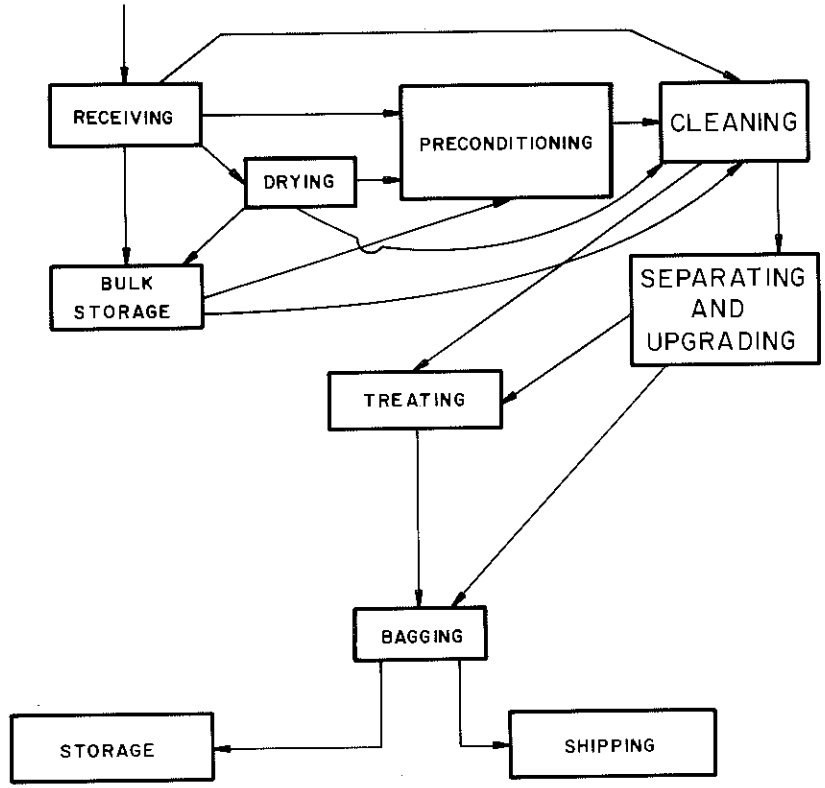


Fig. 8–1. Basic flow diagram of operations in seed conditioning.

A scalper is the most commonly used preconditioning machine. Many types of scalpers are available; however, the simplest types are the single-flat vibrating screen or a rotating reel screen, which allow the soybean seed to pass through and the rough, larger material to be scalped off. The maximum benefits from scalping rough seed are achieved during receiving (Fig. 8–1) before conveying the seed into drying or aeration bins. By removing trash from the seed lot at this time, it reduces the resistance of the seed to air flow, increases the rate of drying, and aids in the control of storage molds and insects. It also increases the efficiency and effectiveness of basic seed cleaning equipment and improves the chances for separation of crop and weed contaminants.

Prior to basic seed cleaning, a seed sample should be taken and examined for purity, by a visual examination or a complete purity test. This precleaning examination is conducted to determine the kinds and quantities of contaminants that need to be removed to achieve the desired purity. The use of hand screens will provide information on seed size and assist the operator in selecting screens to use in basic cleaning. Failure to conduct a precleaning examination (or to conduct it accurately) is often a primary reason for substandard seed quality and costly recleaning.

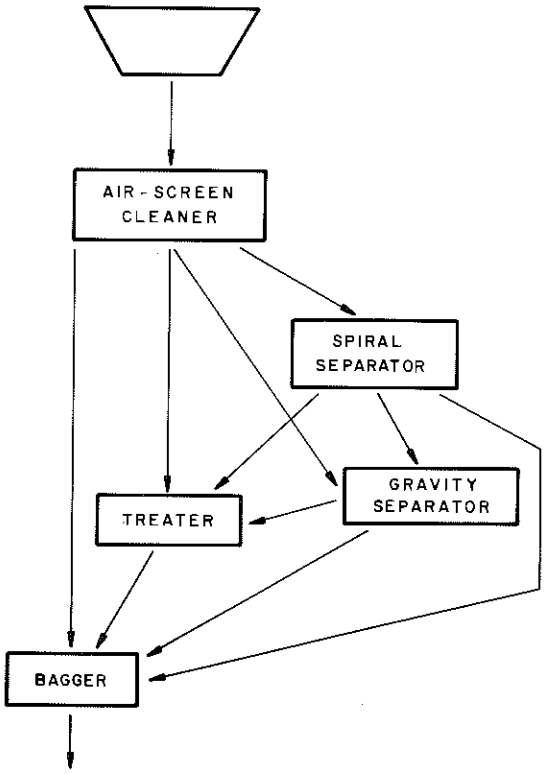


Fig. 8–2. Common sequence of machines used to condition soybean seed.

8–4.5.2 Basic Seed Cleaning

The basic machine used in seed-conditioning plants for soybean and most other crop seed is the air screen cleaner. Most modern soybean seed-conditioning plants will have air screen cleaners that range from two air separations and four screens (Fig. 8–3A) to multifan machines with up to eight screens. The air screen machine exploits the differences in seed size, shape, and density of the seed lot. The machine uses three cleaning elements: (i) aspiration, in which light material is removed from the seed mass, (ii) scalping, in which the good soybean seeds are dropped through screen openings, but larger material is carried over the screen and removed, and (iii) grading, in which the good soybean seeds ride over the screen openings, while smaller particles fall through. A flow diagram of seed through an air screen machine is shown in Fig. 8–3A with two air separations (at the seed entry and discharge) and two scalping screens (1 and 3) and two grading screens (2 and 4). The size of seed in each soybean seed lot will vary depending upon the environmental conditions during production and the cultivar being conditioned. A typical selection of screen sizes that may be used for each of the four screens when cleaning soybean has been recommended by the manufacturers of

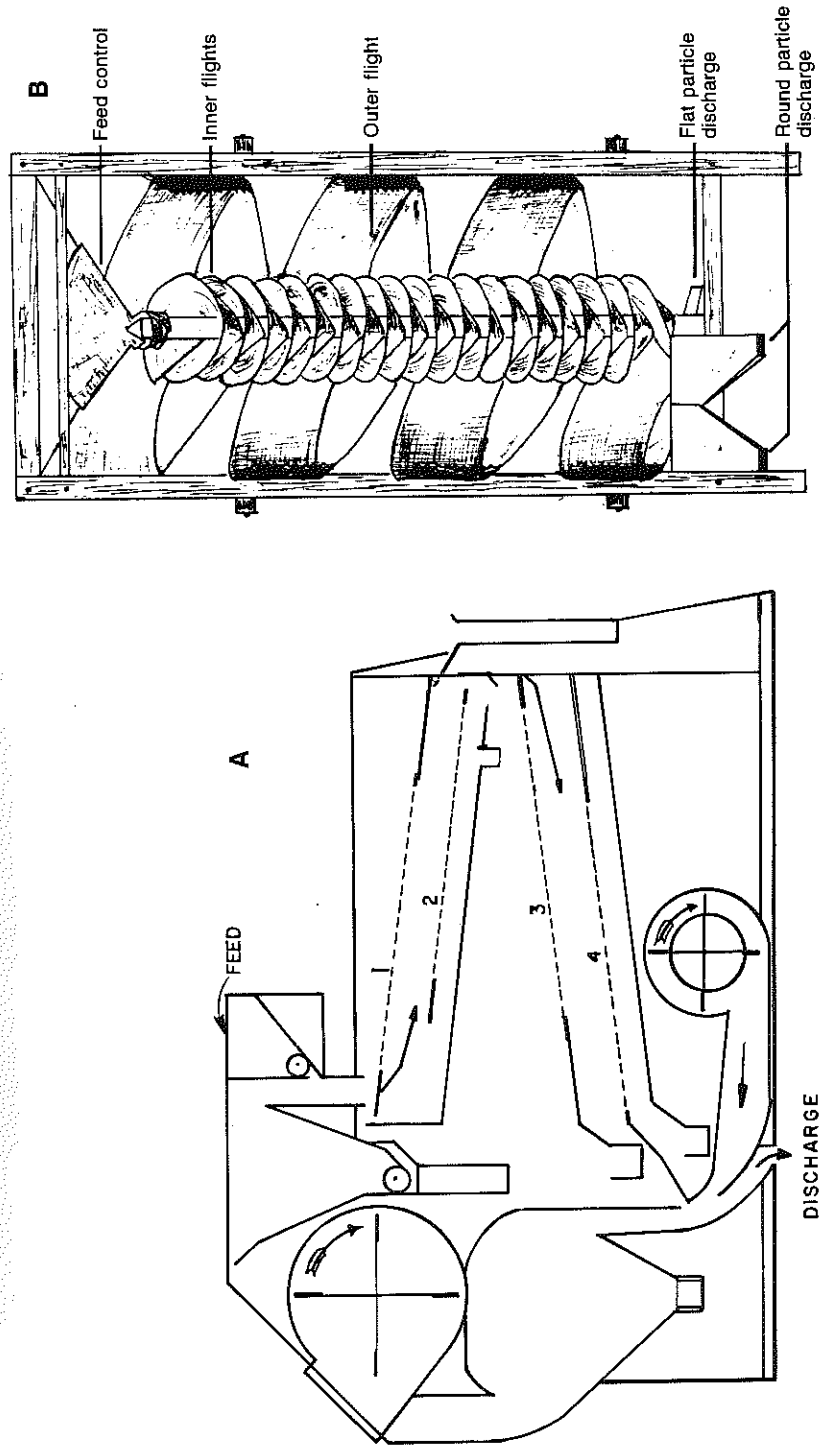
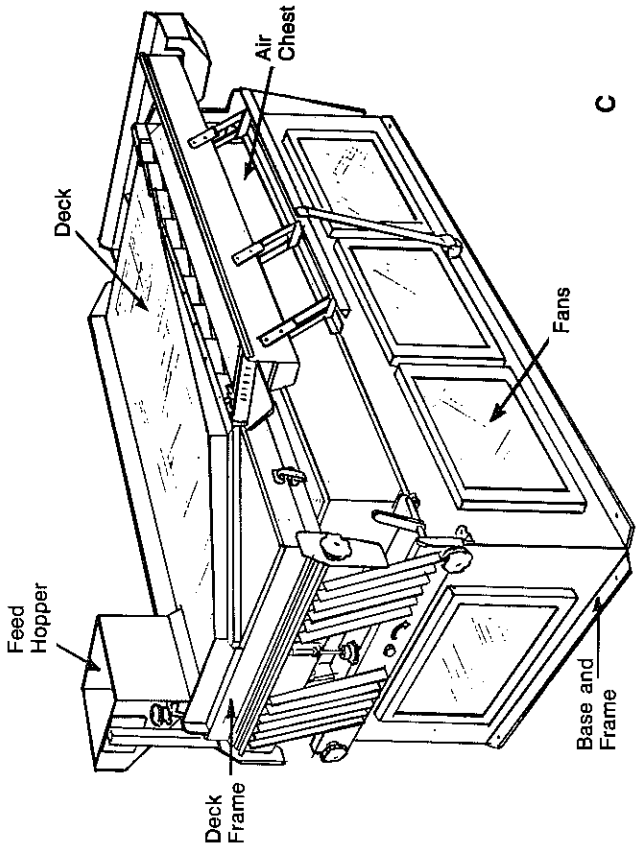


Fig. 8–3. Soybean seed conditioning machines; (A) cross section of a four-screen air-screen cleaner, (B) cutaway view of a spiral separator, and (C) diagram of a specific gravity separator. Drawings are the courtesy of Seed Technology Lab., Mississippi State University.



C

Fig. 8–3. Continued.

air screen machines and has been reviewed by Potts and Vaughan (1977) and Henderson and Vaughan (1980).

The precision of an air screen cleaner is determined by the purity level desired and the quality of rough seed received following harvest. In some cases, the operator of a seed-conditioning plant cannot afford the time and seed loss involved in cleaning all soybean seed lots to the highest purity level. Unfortunately, the most frequent cause of poor soybean seed cleaning on an air screen machine is the tendency to operate the machine at an excessive rate. Thus, many seed lots remain average in quality and do not reach the purity levels desired. The air screen cleaner is an excellent machine, however, which (if properly operated) can clean many seed lots to the desired purity level. When additional uniformity is needed it may be necessary to use more specialized seed separation equipment.

8–4.5.3 Seed Separation and Grading

In recent years, an increasing number of seed conditioning plants are cleaning soybean seeds over specialized equipment to improve both the quality and appearance of the seed. The two machines that are commonly used are: (i) spiral separators, and (ii) specific gravity separators (Fig. 8–3B, and 8–3C). Both offer much more precision in separation, however, all seed must initially be cleaned over the air screen machine.

A spiral separator consists of from one to several sheet metal flights spirally wound around a central vertical tube or axis (Fig. 8–3B). The seed lot is fed into the top and flows down the spiral so that the rounder and heavier soybean seeds tend to flow faster and in a wider arc of travel than the smaller immature or flattened soybean seeds or other contaminants. The seed separation is made according to the shape, density, and degree of roundness of the seed components. Weed seeds which can be separated from soybean seeds using a spiral separator include purple moonflower, common morningglory, common cocklebur, and giant ragweed (Potts and Vaughan, 1977). The spiral can also be used to remove those remaining broken soybean seeds (splits), corn seeds, misshapen or immature soybean seeds, and soil peds in soybean cyst nematode infected areas. Spirals are not effective, however, in separating soybean seeds from cowpea and balloonvine seed, or other soybean seeds having cracked seed coats.

Since a spiral separator has no moving parts, it is relatively inexpensive and easy to operate. Rate of seed flow into the separator is the only adjustment that is necessary; however, recently the addition of flight dams (small wooden or rubber strips) attached to the inner flight of the spiral has improved the separation of weed seed from soybean seed. Equipment companies manufacture spirals which are enclosed to reduce the noise level and have adjustable flight dams on each spiral unit. These companies also offer spirals in multiple units to increase capacity and allow the seed to flow continuously from various air screen machines.

The specific gravity separator is one of the most sophisticated machines in a seed-conditioning plant. The principle of separation for this machine is primarily air stratification on a flat deck (table) and vibrational conveying (Fig. 8–3C). Seed are separated by differences in seed density, size, and surface texture. For many years, little success was achieved using specific gravity separators on soybean seeds; however, with additional research and operator experience the machine has gained acceptance as a finishing machine. It has been particularly successful in removing soil peds from soybean seeds (Lasqueves et al., 1979), which is important in production areas which have the soybean cyst nematode. For this reason, they recommended the addition of a gravity table to the air screen, spiral separator line when conditioning soybean seed. It has also been used to separate de-spined common cocklebur seed from soybean seed; however, less success has been realized in separating machanically damaged and diseased soybean seeds from sound soybean seeds.

In summary, the primary purpose of seed conditioning is to upgrade the quality of soybean seed; however, precautionary measures must be taken during conditioning to prevent the quality from being lowered. Previous sections have discussed the susceptibility of soybean seeds to mechanical injury during seed-handling operations. The seed moisture, seed temperature, rigidity of the surface at which impact occurs, and the type of conveying and seed cleaning equipment can all influence the amount of physical breakage that occurs during conditioning (Bartsch et al., 1979; Burris, 1979a; Hoffman and McDonald, 1981; Paulson et al., 1981a). Delouche (1974) reported that seed cracking and splitting increased sharply as moisture decreased below 125 g kg^{-1}, while seed bruising injury may occur at seed moistures above 140 g kg^{-1}. Increases in mechanical damage and reductions in seed quality have also been reported when seeds are dropped or impacted at low temperatures (Bartsch et al., 1979; Burris, 1979b). Thus, seed conditioning and handling during freezing temperatures is not recommended.

Investigations have been conducted to determine where seed injury occurred as the seed flowed through a seed conditioning plant (Hoffman and McDonald, 1981; Misra, 1982). Mechanical injuries incurred at each step were dependent upon seed moisture but tended to be cumulative. The initial seed elevation from the receiving pit to a bin over the air screen machine created the greatest mechanical injury and reduction in seed quality. For most seed lots, however, the quality improved as the seed was cleaned and mechanically damaged seed were removed. It is important to remember that seed conditioning is only one step in the production of high-quality soybean seed. The seed producer can do many things during production, harvesting, drying, and bulk storage to improve the cleanliness and condition of combine-run seed. Close cooperation between the producer and conditioner will reduce seed conditioning costs and assure higher quality of all seed lots.

8-4.5.4 Seed Treatment

The quality of soybean seeds prior to conditioning is dependent on many environmental and management factors that may occur during production, harvesting, drying, and storage. It has been shown that treating diseased seeds with a fungicide can improve germination and emergence (Athow and Caldwell, 1956; Ellis et al., 1975). A fungicide can also protect the seed from some pathogenic soil microorganisms. This is especially important when seeds are planted in cold, wet soils or other field conditions that are not favorable for seed germination and growth.

A recent survey estimated that 48% of the soybean seeds planted in the USA in 1981 were treated with a fungicide (MacFarlane, 1980). Only 11% was commercially treated, however, while the remainder (37%) was treated in the hopper or planter box by farmers just before planting. Commercial seed treatment was most prevalent in the midwestern states (Indiana, Illinois, and Ohio) while planter box treatment occured most often in southern states (Arkansas, Mississippi, and Louisiana).

Fungicides for seed treatment have been formulated into four basic types; liquids, flowables (concentrated or ready-to-use), wettable powders, and dusts. These fungicides can all be applied commercially by seed conditioners using seed treaters designed to apply accurately measured quantities of fungicide to a given weight or volume of soybean seeds. Seed treatment chemicals are usually formulated for a specific type of application (i.e., dust, liquid). Attempts to apply a slurry formulation as a dust or planter box treatment is not recommended and could be hazardous. To perform accurately, a commercial seed treater must be adjusted correctly and given continuous maintenance.

Seed treatment machinery is classified in many ways, however, McFarlane and Hairston (1984, personal communication) have provided the following simplified outlines.

1. Wet-type treaters utilize the slurry, mist, and spray principles and employ the weight of the seed to operate a seed dump and chemical measuring system.

Slurry treaters utilize fluid formulations that are usually kept in a uniform suspension by continuous agitation to be applied as a slurry. Slurry formulations may be purchased in a ready-to-use liquid or flowable forms or may be prepared by mixing wettable powders or emulsifiable concentrates (flowable) with water. After the chemical is applied, the seeds and chemical are conveyed through a coating chamber (auger or revolving drum), spreading an even coat of chemical on each seed and allowing the moisture to evaporate. Slurry treaters provide accurate and thorough seed coverage, but have the disadvantage of requiring continuous agitation (especially on older models) and may produce considerable dust if wettable powders are used.

Mist or spray-type treaters do not require agitation and utilize true liquids or flowable materials of low viscosity. The chemical is fed directly into the treater and is applied directly to the seed as an atomized mist

or with nonplugging nozzles as a spray after which the treated seeds move through a coating chamber. These treaters are recommended when small amounts of chemical must be applied to a relatively large quantity of seed. They require less space and provide excellent seed coverage with no dust problem.

2. Dry dust-type treaters are used for dry, powder formulations and are usually used for seeds that are fragile such as soybeans. Measured amounts of powdered chemical are continuously applied to the seeds using a vibrating feeder and the seeds and chemical are blended together in a coating chamber (auger-type or revolving drum). If the auger-type mixer is used, the element inside the chamber is a nylon brush for gentle movement of seeds through the chamber. Dust treaters are easy to clean and operate as no moisture is added to the seed during treatment. Dust-type treaters do not distribute the chemical as uniformly as a wet-type treater, however, and require controlled ventilation because of excessive dust in the working area.

Regardless which treater is used, the seed must move through a coating chamber of some sort before it is conveyed to a bin for final bagging. Because soybean seeds are rather fragile, a drum-type coater is better to use than the auger-type or film coater with rods. If an auger-type chamber is used, it should be kept three-fourths full of treated seeds to prevent the seeds from "banging" against each other and the chamber walls which can cause mechanical damage.

While most mechanized seed treatment is done by seed conditioners, smaller scale, less expensive equipment is available for on-the-farm treating. This equipment ranges from simple augers into which a metered supply of fungicide is pumped to small units that are similar to commercial treaters. The primary concern with on-the-farm systems is adequate supervision and adjustment to insure complete seed coverage. No matter what formulation or method of fungicide application is used, to be effective, thorough coverage of the seed is essential. Regardless of the method of seed treatment, it is important to follow good health and sanitary precautions and to apply fungicides only at labelled concentrations.

For planter box seed treatment, a measured amount of fungicide is mixed together with a predetermined weight or volume of seed in a planter box or outside container. It is absolutely essential to thoroughly mix the fungicide (usually a dust formulation) with the seed immediately before planting. Even though planter box seed treatment is inexpensive and widely used for soybean seeds (MacFarlane, 1980) it is the least effective and most nonuniform method of seed treatment.

MacFarlane (1980) reported that 95% of the plant pathology specialists at universities in major soybean producing states recommend soybean seed treatment at least in some situations. Yet only an estimated 11% of the soybean seeds planted in 1981 were commercially treated. The primary reason for not treating soybean seed is that treated seed not sold for seed purposes cannot be sold as grain. Secondly, in most production areas soybean seeds (treated or untreated) cannot be carried over into the next planting season. Thus, if the seed is treated with a fungicide, it must be used for planting purposes or destroyed.

8–5 SEED MULTIPLICATION

The development of superior soybean cultivars by plant breeders has been a major factor in the continued use and expansion of this crop. It takes many years to develop a cultivar and when it is released only a small amount of breeders (stock) seed is available. Thus, the seed multiplication program provides the critical seed increase link betwen the plant breeders who develop new soybean cultivars and the farmers who use them. It is essential that seed multiplication programs; (i) insure high levels of cultivar purity, (ii) increase seed supplies rapidly, and (iii) maintain high levels of seed quality.

For publicly developed soybean cultivars released by state agricultural experiment stations and the USDA, seed certification programs have provided an unbiased system of seed increase for many years. Seed certification agencies are available in each state and internationally to provide uniform procedures for field and laboratory inspection to insure genetic identity and purity for each cultivar produced. Seed companies have developed similar in-house multiplication programs for privately developed cultivars which are often increased with assistance from state seed certification programs. The seed multiplication program for both publicly and privately developed cultivars must be organized in an efficient, yet accurate manner to allow for rapid increase and distribution of seed. This usually means that several agencies or departments must be coordinated to work as an intermediate between the plant breeder and farmer.

8–5.1 Cultivar Release

Regardless of the developing agency, a procedure must be available for evaluating potential cultivars and recommending their release. Policy statements have been developed by state agriculture experiment stations and the USDA governing the development, release, and multiplication of publicly developed cultivars (ESCOP, 1972). Similar statements are available in seed companies. When a plant breeder has an experimental breeding line for which release is recommended, appropriate information on identifying characteristics, descriptive information, area of adaptation, agronomic performance, and other specific use information must be submitted to a review committee or board. The Experiment Station Committee on Organization and Policy (ESCOP, 1972) stated that a cultivar should not be released unless it is distinctly superior to existing cultivars in one or more characteristics or it is superior in overall performance in areas where adapted and is at least satisfactory in other major requirements. Due to university and company release policies as well as intense

competition, most private and public soybean cultivars meet this criteria before release. A single major production hazard which a new cultivar can overcome, e.g., resistance to phytophthora root rot, may become an overriding consideration in releasing a cultivar.

The cultivar is given a permanent name, which is acceptable to all participating agencies and preferably one short word, although seed companies may use brand names and numerical designations. In most cases, a newly released cultivar is registered with the Crop Science Society of America and a seed sample submitted to the National Seed Storage Laboratory in Fort Collins, CO. A procedure is usually outlined at this time for the increase, maintenance, and distribution of breeder, foundation, and certified seed.

In some countries, tests and trials of new cultivars are organized on a national level by an authoritative body. Such testing may be voluntary or compulsory, but is usually conducted over a period of 2 to 3 yrs. After extensive testing for agronomic performance and crop quality, the cultivar may be recommended and/or registered for farmer use. Usually the decision to release the cultivar in that country is closely aligned to its performance in these tests and its recommendation (or registration) by the authoritative testing agency.

8–5.2 Plant Variety Protection

The PVPA became law in the USA in 1970 with the following purpose—"To encourage the development of novel cultivars of sexually reproduced plants and to make them available to the public, providing protection to those who breed, develop, or discover them, and thereby promoting progress in agriculture in the public interest" (PVPA, 1973). The Act provided protection to new cultivars of sexually reproduced crops such as soybeans that are novel; that is, they are distinct, uniform, and stable compared to existing cultivars. Performance testing was not a requirement for acceptance and all participation and application for protection was voluntary. If protection was granted the protection period was for 18 yrs and it was the owner's responsibility to protect the cultivar. The owner could specify, however, that the protected cultivar be sold by cultivar name only as a class of certified seed under Title V of the Federal Seed Act (USDA, 1975).

Before 1970, soybean cultivar development was done primarily by state agricultural experiment stations and the USDA. A recent chronicle of plant variety protection (Batcha, 1983) indicated that only six seed companies had soybean cultivar development programs in 1970 with six plant breeders employed by these companies. By 1983, 28 seed companies had cultivar development programs that employed 60 plant breeders. During the period from 1971 through 1982, plant variety protection certificates were issued for 247 soybean cultivars which was more than for any other crop. The impact of these privately developed cultivars on the American farmer was emphasized in a recent survey of 15 soybean producing states (which accounted for 88% of the acreage harvested) which showed that over 20% of the acreage was planted to privately developed cultivars in 1983 (Anonymous, 1983) compared to approximately 4% 5 yrs earlier. For the first time, all cultivars developed by one company ranked second nationally to the leading single cv. 'Williams,' and accounted for nearly 9% of the total acreage. Thus, plant variety protection has provided the incentive for private seed companies to invest in plant breeding programs and cultivar development. As these plant-breeding programs continue to exand, the trend for increased use of privately developed cultivars will continue.

8–5.3 Eligibility of Soybean Cultivars

To be eligible for seed certification, Plant Variety Protection, or marketing under state and federal seed laws a cultivar must be properly named and described. Guidelines have been developed for classifying plant populations, which include a definition of a cultivar that has been accepted by several public and private agencies.[1] The term *cultivar* is considered an exact equivalent of variety and means a subdivision of a kind which is distinct, uniform, and stable; distinct in the sense that the cultivar can be differentiated by one or more identifiable, morphological, physiological, or other characteristics from all other cultivars of public knowledge; uniform in the sense that variations in essential and distinctive characteristics are describable; and stable in the sense that the cultivar will remain unchanged to a reasonable degree of reliability in its essential and distinctive characteristics and its uniformity when reproduced.

Seed certification agencies are aided in determining the eligibility of newly released soybean cultivars by local and national cultivar (variety) review boards. The National Soybean Variety Review Board was established by the Association of Official Seed Certifying Agencies (AOSCA) of North America in 1973 and consists of six members representing the American Seed Trade Association, AOSCA, Crop Science Society of America, National Council of Commercial Plant Breeders, USDA and USDA-ARS. The function of this board is to review and evaluate information provided by plant breeders of public and privately developed cultivars on the acceptability of these cultivars for seed certification. The board carefully evaluates the descriptive information and performance data provided to determine that the cultivar will remain distinct, uniform, and stable when increased through seed certification programs. If a soybean cultivar is accepted by the national review board most state certification agencies will accept it in that state.

8–5.4 Seed Increase Programs

The primary responsibility of a seed increase program is to multiply seed of a cultivar in such a way as to maintain high levels of genetic

[1] Committee to develop guidelines for classifying cultivated plant populations, 1977.

purity. To accomplish this, minimum standards must be set for field inspection during production and seed purity following harvest by an official seed certifying agency. This agency may be a governmental department or agency, an association of seed growers, or a seed company.

Seed certification is a quality control program whereby seed and propagating materials of improved cultivars is maintained at a high level of genetic purity and made available to the public. Certified seed in the USA is produced by outstanding farmer-growers following the procedures outlined by the certification agencies in each state and AOSCA (AOSCA, 1983). In Canada, the seed certification program is administered by the Canadian Seed Growers Association. These procedures insure positive identification of stock seed planted, field inspection during the growing season and seed inspections following harvest to assure the genetic identification and purity of each cultivar. In some states and Canada certified seed must also meet minimum quality standards for germination, crop purity, and freedom from certain weeds and diseases as well as genetic purity.

8-5.4.1 Limited Generation System

Inherent in the certification concept is a generation system whereby the pedigree of soybean cultivars is maintained through subsequent seed production. A four-generation scheme has evolved for soybeans and seed of each generation is produced under different quality criteria and identified by a specially colored tag.

1. *Breeder seed* (white tag) is that limited amount of seed produced under the direct supervision of the originating plant breeder or a designated agency. It supplies a source for foundation seed and is not available to the general public.
2. *Foundation seed* (white tag) is the first generation progeny of breeder seed produced under the direct supervision of the foundation seed organization. It is sold directly to certified seed growers and is usually available in limited quantities.
3. *Registered seed* (purple tag) is the progeny of foundation seed and is produced by certified seed growers as another seed increase generation before the production of certified seed. It is not intended as a comercial class of seed. A few states do not recognize the registered class for soybeans and produce certified seed directly from foundation seed.
4. *Certified seed* (blue tag) is the progeny of foundation or registered seed and is produced by certified seed growers. It represents the final seed class in the certification program and is usually available in large quantities for use by commercial farmers.

The Canadian generation system is the same as the USA's except there is a select seed class between the breeder and foundation seed generation.

8-5.4.2 Foundation Seed Production

The success of the limited generation scheme of seed multiplication is largely due to the role of foundation seed organizations. These organizations insure a continuous supply of seed stock from which registered and/or certified seed are produced. The foundation seed organization may consist of a separate project within the agriculture experiment station, a private association of seed growers, or a private seed business. Regardless of the organization, close-working relationships are usually maintained between foundation seed organizations and the originating plant breeder or institution.

Foundation seed organizations receive breeder seed of newly released soybean cultivars and increase them to foundation seed. In succeeding years, breeder seed of the cultivar must be maintained and made available. This is usually done by the foundation seed organization in cooperation with the originating plant breeder or institution. Usually breeder seed is produced in a small portion of a foundation seed field which is carefully inspected and rogued for off-type plants. Less frequently, the releasing institution may grow small lots of breeder seed under the direct supervision of the plant breeder for annual release to the foundation seed organization.

Foundation seed organizations must plan production carefully to anticipate the demand of all soybean cultivars and avoid over production. Foundation seed organizations do not usually have adequate land or facilities to produce the necessary foundation seed. Thus, contract seed production is commonly done with careful selection of seed growers.

8-5.4.3 Certified Seed Production

Seed certification programs provide an unbiased, service-oriented method of maintaining genetic identity of seed on the open market. Certified seed production for the registered and certified classes is conducted by seed growers under procedures outlined by the seed certification agency (AOSCA, 1983). All state agencies have published minimum requirements for land history, field inspection, and seed standards which must be met for each seed lot. Seed certification has become important for publicly developed cultivars of soybeans and many other crops. It is of less importance for privately developed cultivars. Some larger seed companies have established their own seed multiplication programs and completely avoid seed certification while other seed companies utilize seed certification agenices as an unbiased third party to aid in their own quality control programs. Many smaller seed companies and seed cooperatives multiply most of their privately developed soybean cultivars through seed-certification channels.

8-5.4.3.1 Eligibility and Application for Certification—Farmers should be familiar with the soybean seed certification requirements and have adequate equipment and experience with soybean production before attempting certified seed production. An application for certification must be submitted to the seed-certification agency requesting field inspection and certification for all soybean fields. The grower must keep a tag and/or invoice of the class planted (foundation or registered) to document

the seed source. Prior to planting the grower should carefully check the previous cropping history of the seed field to be certain it qualifies for the production of the certified class and cultivar intended.

8–5.4.3.2 Field Inspection and Harvesting—Since contamination from off-type soybean plants (AOSCA, 1983) cannot always be detected in the harvested seed, the field inspection is the most critical step in monitoring the genetic purity of each cultivar. Inspection of soybean seed fields is commonly made at leaf-fall when genetic differences in pubescence color and maturity are most obvious, however, many certification agencies also make an earlier inspection at full bloom. The maximum percentage of off-type soybean plants allowed in the foundation, registered, and certified classes at the time of field inspection is 0.1, 0.2, and 0.5%, respectively (AOSCA, 1983). Important criteria that the field inspector examines for each seed field are: (i) vertification of previous land history, (ii) identification and percentage of off-type soybean plants, (iii) sufficient border between adjoining soybean fields to prevent mechanical mixing at harvest, and (iv) contamination by other crops, weeds, and diseases that may influence the quality of the seed at harvest. Following field inspection each seed field is either accepted, rejected, or rejected subject to reinspection (providing contaminants could be rogued from the field by the grower). Seed growers must take the extra time and patience necessary at harvest to carefully clean all combines, trucks, and storage equipment to prevent mechanical mixtures of certified seed with soybean or other crop seed. Seed lot and cultivar identity is critical during harvesting and storage.

8–5.4.3.3 Conditioning, Sampling and Testing—Most seed certification agencies have an approved list of seed conditioners who have the necessary equipment and experience for cleaning certified seed. Established certified growers and seedsmen have their own facilities for seed conditioning and storage and are on this list, while other seed growers must have their seed conditioned at an approved plant. Extreme care must be taken during conditioning to clean all equipment before each seed lot and cultivar is conditioned. After the seed lot has completed all seed conditioning, a sample must be taken and submitted for seed analysis. Certified seed may be sampled by automatic samplers, but is commonly sampled from bagged or bulk seed by officials designated by the certifying agency.

8–5.4.3.4 Seed Testing and Tagging—Certified seed is either tested in the laboratory of the official agency or in official state laboratories or commercial laboratories that have a registered seed analyst. All certified seed must exceed the minimum genetic requirements for the class inspected before certification is completed (Table 8–1). Some certifying agencies also require that certified seed meet certain requirements for crop purity, germination, and freedom from crop or weed seed.

Certified seed is identified by official tags or labels which state the class of seed (foundation, registered, or certified) and other pertinent

information including the name of the certification agency. Some agencies have a *one-tag system* in which the certification tag serves as a complete labeling tag with all information for certification and analysis (germination, purity, etc.) included. Other agencies have a *two-tag system*, where the analysis tag and certification tag are different and attached separately. Some certification agencies allow approved seed conditioners to *pretag* the certification and analysis tag (one-tag system) on the bag during conditioning, provided the seed is not marketed until testing is completed.

8–5.5 Quality Control Programs

Many seed producers and companies have relied entirely on the state seed certification agency for quality control and the certified blue tag was their assurance that the seeds met the quality standard. Other seed companies and seedsmen have developed their own quality control programs with standards that usually exceed the minimum standards for certified seed (Berkey, 1981). Such programs are concerned with quality at all phases of the seed business from planting through production, harvesting, drying, storage, and conditioning until final seed marketing. They require a commitment from management, an understanding of seed quality by all employees, and commonly designate one employee as the quality control coordinator for the entire program.

A good quality control program is established on the premise that poor soybean seed quality can be prevented. Such a program will usually include the following components:

1. Establishment of minimum acceptable standards for soybean seed quality.
2. Development of an organized system of sampling and evaluating seed quality to be certain these standards are met.
3. Isolation and prevention of seed quality problems.
4. Total commitment from management and all employees.

A seed quality control program should not be limited to a simple germination and purity standard, but should include all the major quality characteristics important for soybean seed. The first step should be the establishment of minimum standards acceptable for all quality characteristics.

Any good seed producer knows that quality is most often gained (or lost)in the production field long before the seed arrives at the seed conditioning plant. Thus, the quality control coordinator will select only the best farmers as contract growers and will monitor fields throughout the production cycle regarding recommended practices for weed, insect, and disease control to insure high seed quality. Seed fields will also be inspected several times throughout the growing season for stage of seed development and contamination from other crops, weeds, or off-type soybean plants.

Systematic sampling and testing of each seed lot is one of the most important factors in a quality control program. The first sample should

be taken at (or before) harvest with additional samples taken at various stages before and after conditioning. The last sample will usually provide the information needed for final labeling purposes. The number of samples taken is determined by the control limits that the quality control coordinator establishes for each seed lot and cultivar. The control limits may be narrow and specify sampling before and after harvesting, conveying, drying and storage, and seed conditioning. Most established quality control programs take fewer samples including a rough seed sample at harvest, one or two samples during storage and/or conditioning and a final sample after conditioning.

The tests conducted on each sample are determined by the time of sampling and previous experience of the seed grower and quality control coordinator. Due to the importance of seed moisture on the mechanical integrity of soybean seed each sample taken should be evaluated for moisture. Quality control charts are estabished for each seed grower, cultivar and seed lot and the results are checked against standards. Quality control can be a powerful management technique which can be used to the advantage of a seed grower or company. It can result in an improvement in seed quality, a reduction in operating costs, and as a competitive tool by the progressive seed grower or company.

8–5.6 Changing Concepts

Farmer demands and attitudes regarding seed needs have changed substantially over the last 20 yrs. They are no longer content to merely buy and plant soybean seed, but instead insist upon improved, named cultivars and high-quality seeds. Such seeds must not only be genetically pure but also of high germination, vigor, and emergence potential when planted under a range of field conditions.

Soybean cultivar development, production and use is dependent upon the coordinated efforts of agricultural experiment stations and the private seed industry. Plant variety protection has not only resulted in greater numbers of cultivars, but increased competition for farmer acceptance and sales. Even though cultivars are no longer recommended by most agricultural experiment stations, the farmers still demand unbiased evaluations of performance before seed purchase. Thus, seed sales are still highly dependent upon cultivar performance, even though release and acceptance in plant variety protection is based on novelty.

For many years, certified seed of primarily publicly released cultivars provided farmers with the assurance that the seed purchased was true-to-type for the cultivar as labeled. Certified seed also provided farmers with a minimum quality standard for crop purity and germination needed to produce an adequate field stand with a minimum of additional weed and disease problems. With the passage of the PVPA in 1970, plant breeders of private seed companies were given the option of protecting their cultivars through seed certification. This has benefited many smaller seed companies who cannot afford the costly procedures of civil court

action, but still want protection for their investment. Certified seed agencies have adjusted their procedures to accommodate the certification of these private varieties while maintaining the confidentiality of the closed pedigrees. Some larger seed companies have argued that the minimum-quality standards for all certified seed prevent them from gaining a competitive edge over other seedsmen by marketing high-quality seed. This has led to the dropping of the quality standards for certified soybean seed in many states and certification for genetic (cultivar) purity only. Only time and farmer satisfaction will determine if this change is to the advantage of the seedsmen or the farmer.

Cultivar blends of soybean seed have been developed by private seed companies in many states and are marketed aggressively in competition with named cultivars. The development and merits of such blends are discussed in chapter 7 in this book. In most states, these blends can be sold by company brand name without disclosing the components of the blend, while in other states and Canada the seed laws require labeling as to kind and cultivar. Thus, all blend components (in excess of 5% of the total crop purity) must be listed on the label. This has been a controversial issue in interstate sales of soybean blends and is hotly contested by seedsmen in some states. With the continued development of privately developed soybean cultivars, the future of soybean blends may depend entirely on performance and farmer acceptance.

8–6 SUMMARY

The production of high-quality seed requires a high level of management which must begin before planting of the seed crop and does not end until the seed is sold to the producer. In many respects, the technical knowledge and management information needed to produce high-quality seed is available as documented in this chapter. However, this does not mean that high-quality seed is always available to the producer. Unfavorable environmental conditions during maturation and/or harvest may lower seed quality to unacceptable levels prior to harvest. Under favorable environmental conditions, seed producers do not always utilize the technology and information available to them. In both cases, the efficiency of the production system is reduced and the seed produced may not be of marketable quality.

Considerable progress has been made in understanding the effect of environmental factors during production and storage on seed quality. Less information is available on the relationships between seed developmental processes and the ultimate germinability and vigor level of the seed and their interaction with the environment. The development of improved cultivars by plant breeders has had a significant impact on the soybean industry; however, there has been less attention given to developing cultivars with improved seed quality. The development of cultivars whose seeds are less susceptible to environmental stress or show slower

rates of deterioration in storage would have a significant impact on the soybean industry.

The techniques used to measure seed quality have shown steady improvement and new techniques have been developed. Sufficient evidence has been published to confirm that soybean seed vigor is a separate, measurable entity of seed quality and progress is being made toward standardizing vigor-testing techniques among seed-testing laboratories. However, it is still difficult to relate the results of laboratory tests to the actual performance of the seed, either in terms of field performance (emergence and stand establishment) or storability. Progress on this problem will help insure the consistent availability of high-quality seeds to soybean producers.

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