Chapter 32

HARVEST AND POST-HARVEST FACTORS AFFECTING THE QUALITY OF COTTON PLANTING SEED AND SEED QUALITY EVALUATION

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INTRODUCTION

A uniform, vigorous stand of cotton is the first major milestone in an economically successful cotton production program. Obtaining such a stand is also among the first of a host of problems that beset the cotton producer. Stand failures or poor stands can result from any one or a combination of factors and their interactions: poor seed bed preparation, low soil temperature, mechanical impedance from crusting, excessive or deficient soil moisture, soil microorganisms and other pests, chemical injury and low quality seed (Delouche, 1969). Low quality seed are probably a major contributing factor in most stand failures, for they are much more susceptible to adverse conditions in the seed bed environment and will usually produce a satisfactory stand only under very favorable conditions. Unfortunately, the quality of cotton planting seed available to producers is relatively low as compared to other crops such as corn, wheat and even soybeans, while conditions at planting time are relatively more adverse.

The quality of cottonseed is affected by an array of factors which can be grouped into two categories: pre-harvest factors and harvest, post-harvest factors (Colwick *et al.*, 1972; Gelmond, 1979; Presley *et al.*, 1967). The pre-harvest factors affecting the quality of cotton seed have been reviewed in Chapters 30 and 31. This paper considers the harvest and post-harvest factors or operations that can affect the quality of cottonseed for planting and the present status of seed quality evaluation and assurance.

The quality of cottonseed can be affected by harvesting procedures and all of the subsequent operations involved in handling, removal of the fiber and preparation of planting seed for marketing. The latter includes: storage of seed cotton before ginning, handling of seed cotton and cottonseed, bulk storage (cottonseed), delinting, conditioning and treatment of the seed, and storage of conditioned, packaged seed before and during distribution and marketing. The major types of damage to cottonseed during harvesting and post-harvest operations are mechanical damage, chemical injury and physiological deterioration resulting from high temperature and seed moisture levels, and their interaction. Mechanical damage and chemical injury, of course, have physiological consequences in terms of the performance of cottonseed as the reproductive units for the crop.

MECHANICAL DAMAGE

The six-layered seed coat of cotton is thick, strong and slightly elastic (Simpson *et al.*, 1940). It provides much greater protection to the embryo than the relatively fragile and brittle seed coverings of other major crops, *e.g.*, corn, soybean, wheat, sorghum. Yet, mechanical damage of cottonseed is a major cause—directly and indirectly—of quality problems.

Mechanical damage to cottonseed probably began with the introduction of the mechanical fiber remover, or gin. While the "early" gins undoubtedly inflicted some injury, mechanical damage to cotton has become a major problem only in relatively recent times. Substantial mechanical abuse and injury of cottonseed is a product of mechanization, and its increasing seriousness has closely paralleled advancements in this sphere (Colwick *et al.*, 1972).

The advent of the mechanical picker introduced another potential source of seed injury. Since the vastly increased efficiency of mechanical harvesting overtaxed the capacity of conventional gins, better, more efficient and higher capacity gins had to be developed. High capacity ginning greatly increased the potential of the gin as a source of injury. Since accelerated operations in the gin yard require high capacity handling and conveying systems, the potential for injury to the seed was further increased.

From another direction, more advanced mechanization of planting and cultural practices, combined with the development of better varieties and higher seed costs, created a rising demand among planters for seed with better flowability characteristics that could be effectively treated and planted more precisely at lower rates per acre. Mechanical delinting or reginning is one method of improving the flowability of cottonseed. It became an accepted practice, and yet another source of injury was added. Acid delinting is an even better method of improving the flowability of cottonseed, and it has become the dominant method of delinting. While acid delinting does not cause mechanical injury *per se*—only incidently in the conveying systems involved—it has complicated quality problems by permitting direct contact of a very reactive chemical with embryonic tissue through breaks in the seed coat.

The incidence of mechanical damage to cottonseed varies among locations, seasons and producers. In a survey of the quality of cottonseed planted in Mississippi in 1964, Helmer (1965b) found that about 70 percent of the lots planted had mechanical damage levels (percent damaged seed) of 5 percent or higher (Table 1).

Table 1. Incidence of mechanical damage in 738 lots of cottonseed planted in Mississippi in 1964 (From Helmer, 1965b).

Mechanically damaged seed (%)	No. of samples	Percent of total
Damage level:		
0-5	233	31
5-10	301	41
10-5	139	19
Over 15	65	9

Table 2. Effect of mechanical picking on the incidence of cracked seed and germination in Carolina Queen cotton (From Colwick *et al.*, 1972)

	Picker treatment[1]			
Year	HP	PDO	S1ST	S2ST
	Percent visibly damaged seed			
1965	0.1	6.3	---	20.8
1967[2]	6.1	12.9	14.4	44.6
1968	0.4	4.1	3.9	7.7
	Percent germination			
1965	94	90	---	87
1967	17	16	18	14
1968	87	87	86	82

[1]HP = hand picked; PDO = doffed on canvas without going through conveying system; S1ST and S2ST = through complete system at fan speeds of 1807 and 2,338 r.p.m., respectively.

[2]Harvesting delayed until February because of inclement weather.

Based on other evidence, Helmer's findings in 1964-65 appear to be rather low. In smaller surveys in 1967 and 1968 (Colwick *et al.*, 1972) damage averaged 14 percent. Reviews of the quality control records of several cottonseed companies indicate that damage levels of 10-15 percent among the lots handled are commonplace, while even higher damage levels are frequent enough to require careful selection of lots for acid delinting and treatment with some systemic insecticides.

HARVESTING

On the basis of their studies of the effects of mechanical harvester damage on the germination and vigor of cottonseed, Douglas *et al.* (1965, 1967) concluded: mechanical harvesters (picker type) of certain designs cause severe damage to cottonseed; harvester damage was reflected in reduced germination and vigor;

seed of some varieties appeared to be less susceptible to harvester damage than others. In studies at Clemson University, Garner and associates (see Colwick *et al.*, 1972) found that several factors affected the percentage of seed coats cracked in mechanical harvesting and that reduced germination was associated with the incidence of cracked seed (Table 2). The percentage of cracked seed increased with an increase in fan speed in the picker. Severe weathering which delayed harvesting in one year decreased the resistance of the seed to picker damage. Apparently, weathering erodes the mechanical strength of the seed coat. Weathered soybeen seed are also more susceptible to mechanical damage (Green *et al.*, 1966).

Harvester damage to cottonseed appears to be more of a problem in arid, irrigated production areas. Miller (1967) reported that pickers cracked 18-25 percent of the seed produced in California under contract for his company before quality control procedures were used to reduce the damage level to 3-5 percent. The main sources of damage in the cotton picker are high picker speeds, doffing, blowing (conveying) and impact of the seed cotton against the top of the basket. High speed movies of doffing revealed two causes of damage at the doffing position (Colwick *et al.*, 1972): pinching of the seed between the spindle and the doffer and tearing off fragments of the seedcoat as a result of competition of adjacent spindles for the same boll. In the same study, fan speed and blade design (radius of curvature) had the greatest influence on seed damage. A fan speed of 2,300 r.p.m. caused two to four times as much damage as a fan speed of 1,800 r.p.m.

Miller emphasized the importance of proper maintenance and adjustment of the picker and close monitoring of individual pickers. Baskin *et al.* (1972) described field modifications that can be made in various makes of pickers to reduce the incidence of seed coat cracking.

GINNING AND MECHANICAL DELINTING

The ginning operation—especially saw ginning—is an important cause of damage to cottonseed. Moore and Shaw (1967) point out that ginning damage to cottonseed was evident on acid delinted seed in 1934 linter content studies at the U.S. Cotton Ginning Research Laboratory, Stoneville, Mississippi. This was in the days when gin saws were mostly 12 inches in diameter and were operated at speeds of only 300 to 400 r.p.m. Damage levels in those times, however, were rather low.

Extensive studies of gin damage to seed in Louisiana and Mississippi were conducted by Watson and Helmer (1964) in 1963. Seed cotton and cottonseed samples were drawn from 30 bales at each of seven gins. Six of the gins utilized high capacity equipment. Moisture content of the seed cotton averaged 11.0 for the 210 bales and exceeded 12 percent (12.3 percent) at only one gin. The incidence of seed damage in the seed wagon, which can be attributed to mechanical harvesting, ranged from 2.7 to 5.9 percent among the gins with an overall average of 4.2 percent. Seed damage was increased by about one percent during seed cotton cleaning, drying and associated conveying up to the feeder. Ginning contributed an additional 5 percent to the total mechanical damage of the seed. Although seed cotton moisture was mostly below 12 percent, Watson and Helmer demonstrated a fairly consistent trend of seed damage increase with increases in seed moisture content (Figure 1). Seed damage also increased as ginning rate increased, while germination—as might be expected—decreased as the percentage of damaged seed increased (Figure 2).

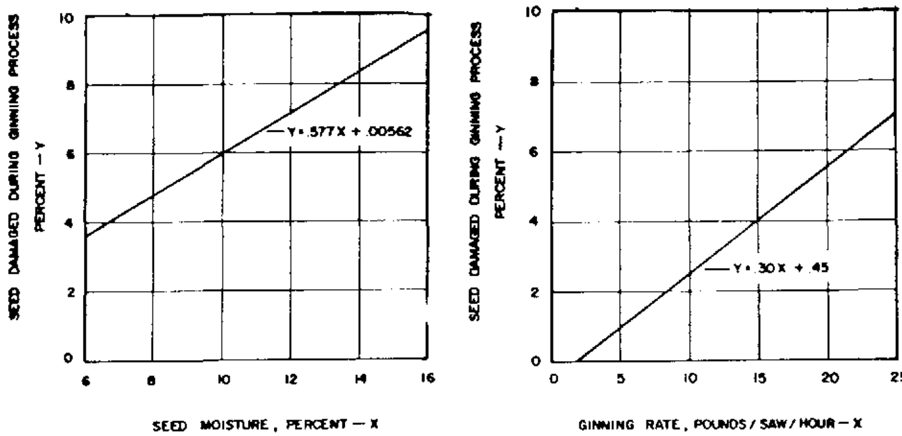

Figure 1. Effects of seed cotton moisture content (left) and ginning rate (right) on mechanical damage to cottonseed (from Watson and Helmer, 1964).

In a similar follow-up study (Moore and Shaw, 1967) in California in 1964, mechanical damage to the cottonseed averaged 10.7 percent. Harvesting (5.0 percent) and ginning/handling (5.7 percent) contributed equally to the total damage. Other, more comprehensive and controlled studies (Moore and Shaw, 1967) at the U.S. Cotton Ginning Research Laboratory, Stoneville, MS, during the period 1964-66 established that: there is considerable variation in the amount of damage inflicted to cottonseed at gin plants; average damage levels of 16-17 percent are not uncommon in a gin-run cottonseed; the spindle-type cotton harvester contributes about 44 percent of the damage, ginning about 44 percent, while about 12 percent is contributed by the drying, overhead cleaning and conveying systems for seed cotton; the action of the gin saw causes a major portion of the seed damage at gin plants; increasing feed rates of seed cotton into the gin stand increases seed damage. The incidence of seed damage also increased as seed moisture decreased, which is in disagreement with earlier results (Watson and Helmer, 1964) and other data from Texas which suggested an opposite relationship between the percentage of damaged seed and seed cotton moisture content.

Mechanical delinting is essentially a reginning operation, except the saws are

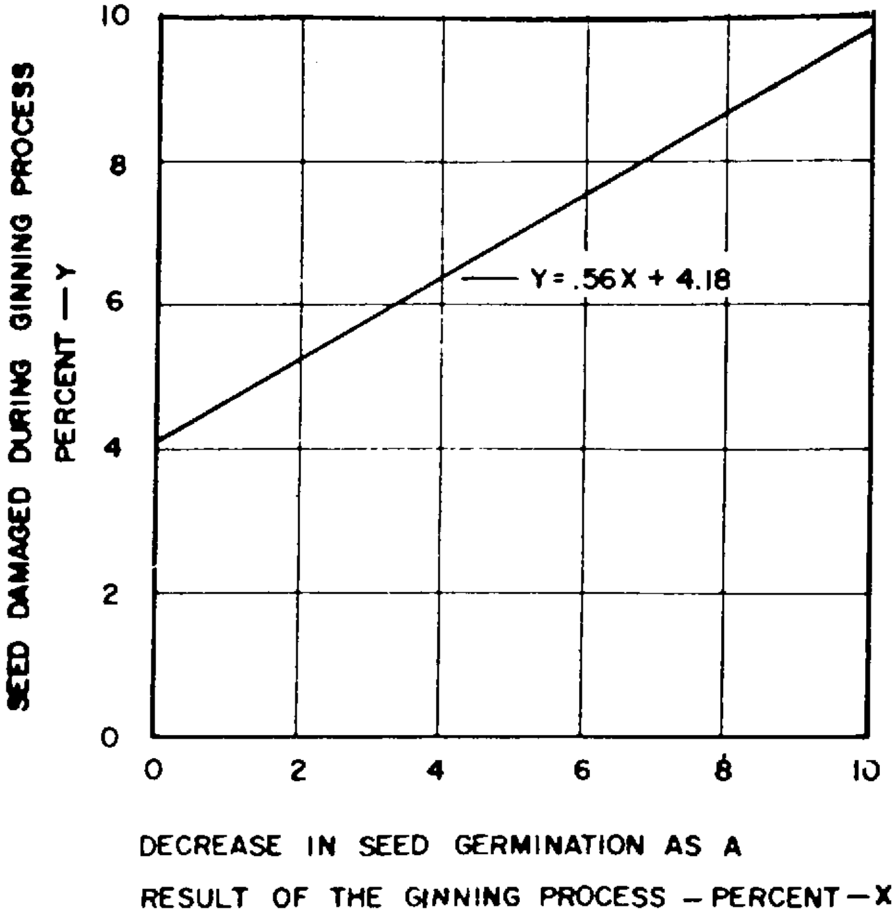

Figure 2. Relationship between seed damage during ginning and reduction in germination percentage (from Watson and Helmer, 1964).

finer and more closely spaced. It reduces the amount of linters on the seed and improves their flowability. Generally, only one cut, i.e., pass through the delinting stands, is made for planting seed. Mechanical delinting always adds a couple of points to the percentage of damaged seed. Close gauging of the ginning saws, incautious delinting and double cut delinting can inflict considerable damage to the seed. The conveying and handling systems in the mechanical delinting plant are other potential sources of seed injury.

Harvester and conveying/handling damage can usually be distinguished from gin saw damage by close visual examination of a sample of acid delinted seed. Typically, seed damaged during harvesting and conveying exhibit cracking or fracturing of the seed coat. Fragments of the seed coat are often missing, exposing the embryo, but the fractured edges are straight. Gin saw-damaged seed, on the other hand, exhibit cuts or deep gashes in the seed coat with enrolling of the cut edges.

HANDLING AND CONVEYING

Seed cotton and cottonseed are handled many times from harvesting through packaging of the seed for marketing. The pneumatic seed cotton handling system in the mechanical harvester is a major source of harvester damage, especially when the seed cotton is conveyed through the fan (Douglas *et al.*, 1967; Miller, 1967). At the gin and seed house, several types of conveyers are used. Pneumatic conveyors are used to handle both seed cotton and cottonseed (Shaw and Franks, 1964; Stedbronsky, 1964). Belt conveyors are often used to transport cottonseed from under the gin stands to a pneumatic line intake, while screw conveyors are used to convey cottonseed, gin trash and some seed cotton (Alberson, 1964). Pneumatic and belt conveyors have the advantage for planting seed of being essentially self-cleaning (Franks and Oglesbee, 1957; Shaw and Franks, 1963); thus, varietal mixing in multi-variety gins is minimized. Screw conveyors have to be thoroughly cleaned to prevent mixtures, but this task can be facilitated by fitting drop bottoms to U-trough types.

In the delinting and conditioning plant, cottonseed are conveyed by pneumatic, screw and belt conveyors, and by belt-buckle elevators. Improperly maintained and operated screw conveyors can cause substantial damage to seed, but the major source of damage in conveying/handling operations is the pneumatic conveyor. Pneumatic conveyors are very damaging to other kinds of seed and are seldom used (Metzer, 1961a).

Miller (1967) reported that under California conditions the most significant source of damage (15-20 percent) at the gin plant was pneumatic conveying of the cottonseed from the seed scale to the seed storage pad. Conveying distance in some cases was as far as 300 feet. Using good quality-assurance procedures, Miller and colleagues were able to reduce seed damage during pneumatic conveying to less than 2 percent. This was accomplished by eliminating all 90 degree elbows, rubberizing long-sweep elbows, reducing air velocity to the minimum that conveyed the seed without plugging, and replacement of 5 inch piping with 6 inch piping. Watson and Helmer (1964) found that the percentage of damaged seed rapidly increased with successive passes through a pneumatic conveying system.

MECHANICAL PROPERTIES OF THE COTTONSEED COAT

Several studies have been made to determine the mechanical properties of the cottonseed coat. Kirk and McLeod (1967) reported that the total energy absorption to rupture of the cottonseed coat was relatively constant at 0.70 in.-lb, although the force (pounds/seed) required to rupture cottonseed and the resulting seed deformation under static loading decreased as seed moisture content increased from 6 to 14 percent. Seed damage from impact velocities increased rapidly above 4000 f.p.m. and was as high as 50 percent at 8000 f.p.m. In contrast to static energy tests, seed moisture content had no effect on seed damage due to impact.

In a more detailed study of the effects of static loading and energy on cottonseed germination, Chang *et al.* (1967, see also Colwick *et al.*, 1972) found that cottonseed were more easily damaged, i.e., reduced in germination, when a static load was applied to the ends of the seed than when an equivalent force was applied to the sides of the seed. The maximum force that could be applied to the sides of high quality cottonseed (97 percent germination) without reducing germination below 80 percent was 26, 25 and 13 pounds/seed for cottonseed at 4, 8 and 12

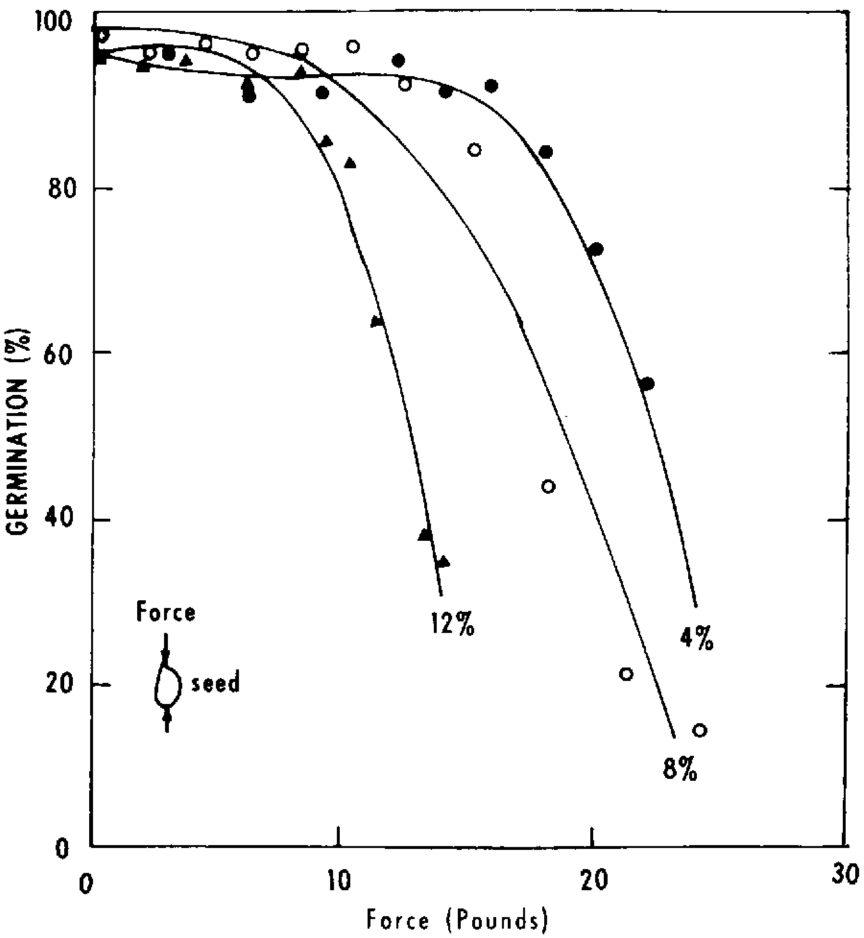

Figure 3. Effect of static loading with seed oriented longitudinally (end-to-end) on germination of cottonseed at 4, 8 and 12 percent moisture content (from Colwick *et al.*, 1972).

percent seed moisture, respectively. When the load was applied to the ends of the seed, the maximum force for maintaining 80 percent germination was 18, 14 and 10 pounds/seed at 4, 8 and 12 percent seed moisture, respectively (Figure 3). In terms of energy absorption, the maximum static energies the high quality seed could withstand without a reduction in germination below 80 percent were 0.34 in.-lb. on the sides and 0.20 in.-lb. on the ends. These levels are lower than the 0.70 in.-lb. reported by Kirk and McLeod (1967). The latter, however, observed only deformation and rupture of the seed coat and did not consider the effect of static energy on germination.

In dynamic impact studies, Clark *et al.* (1969, also Colwick *et al.*, 1972) found that impacts of equivalent force were more damaging to germination on the radicle end of the seed than the chalazal end or sides, which were least damaging.

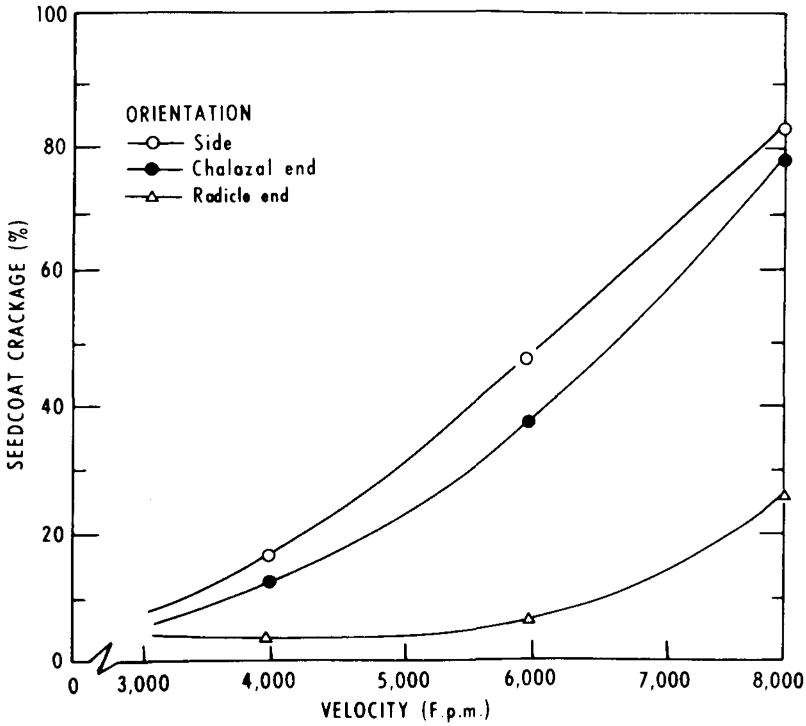

Figure 4. Effect of impact velocity and seed orientation on seed coat crackage of Coker 100 cottonseed over all moisture contents (4 to 12 percent) (from Clark *et al.*, 1969).

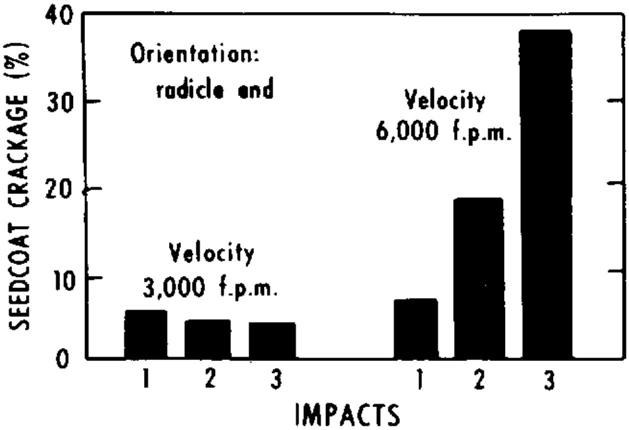

Figure 5. Effect of number of impacts at two impact velocities on seed coat crackage of Stoneville 213 cottonseed at 10 percent moisture content (from Clark *et al.*, 1969).

The seed were most resistant to impacts at seed moisture contents between 9 and 12 percent regardless of seed orientation. At moisture contents within this range, 6500 f.p.m. was the maximum velocity the seed could withstand without reducing germination below 80 percent. Above and below the 9-12 percent seed moisture range, the maximum velocity was about 4500 f.p.m. Although germination was most affected by impacts on the radicle end, impacts on the sides of the seed caused the greatest incidence of crackage of the seed coat (Figure 4). At impact velocities of 3000 f.p.m. successive impacts did not increase damage. However, damage increased rapidly with successive impacts at 6000 f.p.m. (Figure 5). In terms of energy absorption, slowly applied (static) loads were more detrimental to germination than impact forces at levels above 3 in.-oz (Figure 6).

Colwick and associates (1972) studied impact damage in a 90 degree elbow in a pneumatic conveying system and showed that there was very little crackage of the seed below 6000 f.p.m. regardless of stage of weathering of the seed. Cottonseed at 12-13 percent moisture were most resistant to impact damage.

On the basis of the results of the several studies discussed above and other observations, minimal air velocities (4000-5000 f.p.m.) should be used for pneumatic conveying of cottonseed, 90 degree elbows should be replaced with long-sweep turns and conveyor piping should be at least 6 inches in diameter.

The mechanical strength of cottonseed under static loading indicates there is little possibility of damage from high stacking of bulk or packaged seed. Much more fragile kinds of seeds (Associated Seed Growers, Inc., 1942; Huelsen and Brown, 1952) are also not injured by static loads in stacks. The static loading data for cottonseed, therefore, are most applicable to such actions as pinching of the

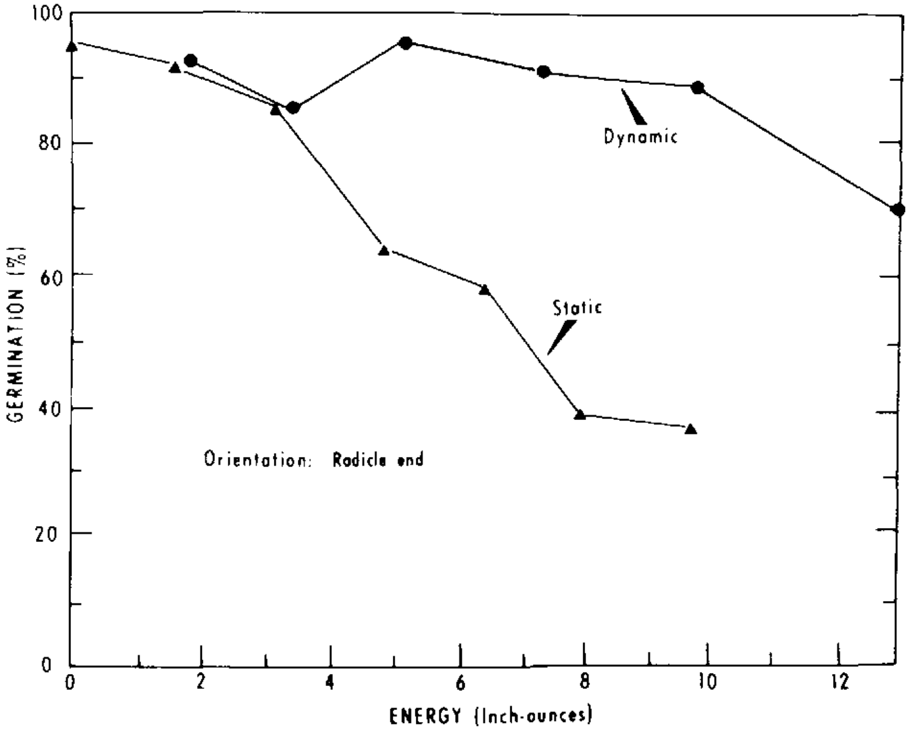

Figure 6. Effects of static and dynamic energy absorption on germination of Stoneville 213 cottonseed at 12 percent moisture content (from Colwick *et al.*, 1972).

seed between spindle and doffer, and transport of seed by screw conveyors. Overall, the mechanical properties of the cottonseed are superior to those of some other kinds of seed (Leonhardt *et al.*, 1961; Perry and Hall, 1965).

CONSEQUENCES OF MECHANICAL DAMAGE

Mechanical damage of seed has direct and indirect effects, both of which can have immediate and latent consequences. Severe damage or damage in a vulnerable area such as the radicle can result in an immediate loss of the capacity to germinate (Associated Seed Growers, Inc., 1942; Atkin, 1957; Keith, 1972; Klein and Harmond, 1966; Toole and Toole, 1951). Less severe injury produces seedling abnormalities (Atkin, 1957; Spreafico, 1965) and reduces storage life, vigor and field emergence potential (Colwick *et al.*, 1972; Koehler, 1957; Wortman and Rinke, 1951). The indirect effects of mechanical damage are often as important as the direct effects. In the soil, damaged seed are more susceptible to seed rotting microorganisms which gain easy entry to necrotic tissue through cuts or fractures in the seed coat (Erwin *et al.*, 1964; Koehler, 1957; Oatout, 1928). Mechanically damaged seed are also more susceptible to processes and materials used in preparation of seed for marketing. In acid delinting of cottonseed, cuts in the seed coat expose the embryo to the acid, causing acid burn (Colwick *et al.*, 1972). Damaged seed are often injured by chemical seed treatments such as the formerly widely used organic mercurials (Roane and Starling, 1958; Sakolnik, 1948) and some of the systemic insecticides applied to cottonseed (Colwick *et al.*, 1972).

Studies at our laboratory in the late 1960's (Colwick *et al.*, 1972) on the effects of mechanical damage on the quality of cottonseed produced the following conclusions: in damaged seed, necrosis is initiated in embryonic tissue beneath cuts and fractures; germination and storability decreases as the incidence and severity of mechanical damage increases: the detrimental effects of acid delinting (conventional wet-acid process) increase as the incidence of mechanical injury increases; treatment of damaged seed with fungicides improves laboratory germi-

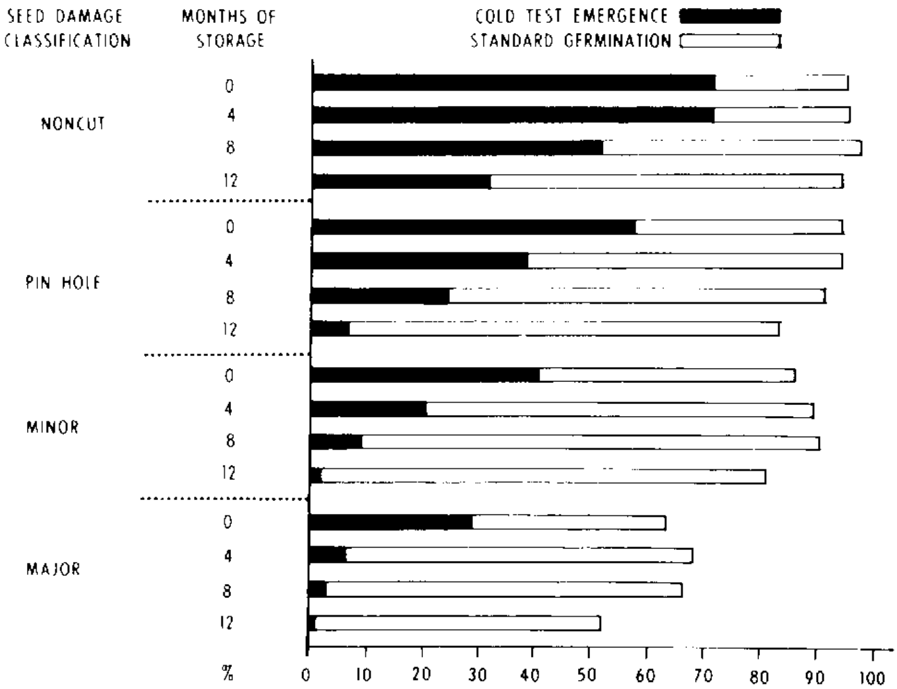

Figure 7. Effects of seed damage level over all treatments on germination percent and cold test emergence percent of cottonseed after 0-12 months warehouse storage (from Colwick *et al.*, 1972).

nation, cold test and field emergence; in commercially processed seed lots, three in four minor-damaged seed, one in three major-damaged seed, and one in five immature seed are capable of germinating; x-ray analysis can be used to rapidly assay gin-run seed for immature and empty seed, but only a small portion of the mechanical damage can be detected.

Typical responses of mechanically damaged seed over several combinations of seed treatments (fungicides and systemic insecticides) in germination and cold tests at intervals during storage are shown in Figure 7. Germination of minor- and major-damaged seed in these tests was higher than indicated in the "conclusions" above. The latter, however, represented the averages for a very large number of commercially processed seed lots.

DELINTING

The linters that remain on cottonseed after ginning become entangled, causing the seed to clump. Since gin-run seeds do not singulate and the flowability is very poor, cleaning, upgrading and accurate metering in planting operations are difficult to impossible. Various methods have been and are used to singulate the seed and improve flowability. Most of the methods involve partial or complete removal of the linters and tags, but a variety of coating procedures have also been tried without much success—technically or economically (Mezynski, 1966; Webber and Boykin, 1907).

Mechanical delinting is the traditional process for improving the flowability of cottonseed. As discussed previously, mechanical delinting is basically reginning with finer and more closely spaced saws to remove a portion of the linters, which have commercial value.

Mechanical delinting improves flowability of the seed, but not sufficiently for the precision conditioning operations required to separate despined cockleburs and immature, low density seed (Bunch *et al.*, 1961; Mezynski, 1966). Plantability is also improved, but precision of metering is less than for smooth, readily flowable seed. The major effect of mechanical delinting on seed quality—other than improvement of flowability—is mechanical damage, which was discussed earlier.

The limitations of mechanical delinting in terms of improvements in flowability led to the development of supplemental or other methods for partial or complete removal of the linters. Flame delinting is used to effect further improvement in the flowability of mechanically delinted seed. Several acid delinting processes are used to remove the linters completely, or more recently, partially.

FLAME DELINTING

In flame delinting (flame "zipping") mechanically delinted seed are dropped through an intense flame to singe or burn off loose linters. Flowability is substantially improved, but again not sufficiently for precision cleaning and conditioning operations. Properly designed and managed flame zippers have little, if any, effect on seed quality. However, since the seed are heated passing through the flame and by the burning linters, rapid "de-sparking" and cool-down of the seed are critical. If these tasks are not accomplished effectively and rapidly, the seed can be severely damaged by heat. I know of several cases where several hundred tons of good quality cottonseed were ruined for planting purposes by flame delinting. In most of the cases, new installations were involved and start-up, check-out testing was inadequate. Modifications were made which eliminated the problem.

ACID DELINTING

Three major types of acid delinting systems are in use (Jones, 1980): wet-acid, gas-acid and dilute wet-acid. The first two systems produce lint-free seed with excellent flowability, while the latter process produces lint-free "black" seed or partially—but uniformly—delinted seed. All of the acid delinting systems can reduce seed quality, if not properly controlled and managed.

Gas-acid Process—The gas-acid delinting process is mostly used in arid areas where moisture content of cottonseed is less than 9 percent and low humidity reduces corrosion of the equipment and facilities. Anhydrous hydrochloric gas is

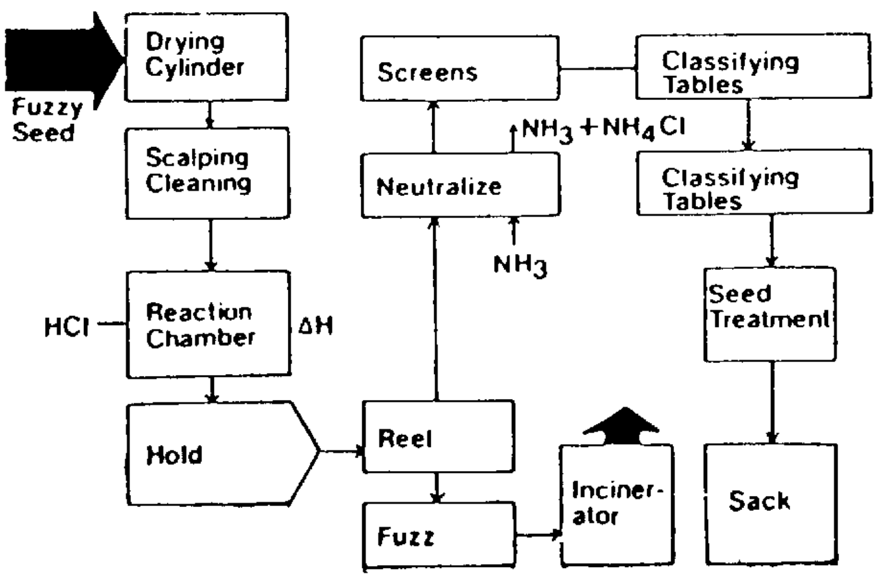

Figure 8. Generalized flow chart for commercial gas-acid delinting of cottonseed (from Jones, 1980).

used to degrade the linters so that they can be removed from the seed by frictional forces (Jones *et al.*, 1974). A generalized scheme of the gas-acid process is shown in Figure 8.

The seed are first dried as needed to reduce moisture content to 5-7 percent, then rough cleaned to remove gross contaminants. A charge of seed is then placed in a rotating reaction chamber where the temperature is raised to 60-70C before injection of the gas-acid at a concentration of 0.5-2.0 percent of seed weight. Reaction time varies from 5 to 20 minutes, depending on the temperature, seed moisture content, concentration of the gas-acid and variety. After exit from the reaction chamber, the seed pass through a reel where frictional forces complete removal of the degraded linters. Neutralization is usually accomplished with ammonia. The lint-free, readily flowable seed can then be cleaned, density graded, treated and packaged as efficiently as other kinds of seed.

The gas-acid delinting process requires fairly sophisticated equipment, close monitoring and stringent control of the various operations for effective delinting without injury to the seed. The major causes of injury to the seed are too high a reaction temperature and gas-acid concentration, too long a reaction time and "over" neutralization with ammonia. Poorly controlled and managed gas-acid delinting can cause a drastic reduction in germination and vigor.

Wet-acid Process—The wet-acid delinting system is favored in humid, rainfed areas of the cotton belt. The process is relatively simple and does not require

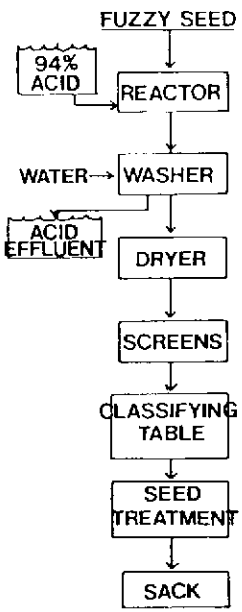

Figure 9. Generalized flow chart for the conventional wet-acid delinting process for cottonseed (from Jones, (1980).

sophisticated equipment (Figure 9). Gin-run seed are fed into a reactor trough or tank and mixed with concentrated sulfuric acid. From the reaction trough the seed are passed through washers where the residual degraded linters and acid are washed off. Since the seed are wet they have to be dried before moving to the cleaning, grading, treating and packaging line.

Seed quality losses in the wet-acid delinting process can occur when reaction time is longer than necessary, seed temperature rises too high during drying, the seed delinted are low in vigor, and the incidence of mechanical damage is above 12-15 percent.

The major problem in wet-acid delinting—apart from the high cost of sulfuric acid—is disposal of the spent acid and wash water. In earlier days the effluent was usually dumped in a stream. This easy solution has been eliminated by environmental concerns and regulations (Sigman, 1973). The alternative solution of collecting the effluent in a sort of sewerage lagoon also poses environmental problems.

Dilute Wet-acid Process—The dilute wet-acid delinting process was developed by Cotton, Inc. (Jones, 1980; Jones and Slater, 1976). The process differs from the conventional wet-acid process as follows (Figure 10): a dilute solution of sulfuric

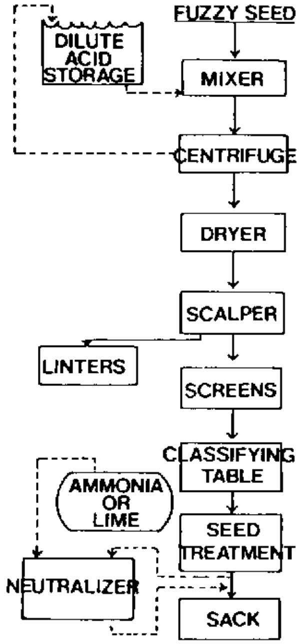

Figure 10. Generalized flow chart for dilute-sulfuric acid delinting of cottonseed (from Jones, 1980).

acid (about 10 percent) is used instead of concentrated sulfuric acid to wet the linters; the wet seed are "dewatered" by centrifugation to about a 10 percent add-on level of the dilute acid; the seed are dried with heated air to evaporate water, thus, increasing the concentration of the acid; the degraded linters are removed by frictional forces in a rotating buffer-drum; neutralization of residual acidity is accomplished by ammonia or adding lime in the seed treatment process. The advantages of the dilute wet-acid delinting process are a great reduction in the quantity of sulfuric acid required because of the much lower quantity used and the recovery of a major portion in dewatering, and elimination of the effluent produced in wet-acid delinting. In addition, the hydrolyzed linters removed during buffing have potential value in ethanol production and as an animal feed additive.

The basic dilute acid delinting process has been modified in several installations. In one case the centrifuge has been eliminated. Most plants produce two kinds of delinted seed: lint free or black seed and partially delinted seed. Partial delinting is accomplished by further reduction of the acid concentration.

The relatively recent introduction of the dilute wet-acid delinting process has not permitted much time for thorough assessment of its potential effects on seed quality. It is claimed that the dilute wet-acid process has little, if any, effect on mechanical properties or permeability of the seed coat. Quality problems that arise appear to be mostly associated with heat damage during the drying cycle.

ACID DELINTED *VS.* MECHANICALLY DELINTED SEED

There has long been controversy about the relative merits of acid delinted and mechanically delinted cottonseed, especially in the humid portions of the cotton belt. Cotton producers concede that acid delinting greatly improves plantability, but many contend that acid delinted seed are more susceptible to environmental stresses in the seedbed, *e.g.*, cold and wet, than mechanically delinted seed. The production of partially delinted seed in the dilute wet-acid process is aimed at a rather large market that continues to discriminate against lint-free seed. The objections to acid delinted seed stated by Gore (1943) still holds in the minds of many farmers: "Our experiences with acid-delinted seed reveal that its high cost . . . and occasional failure to get a stand, more than offset its advantages."

Early interest in acid delinting of cottonseed was related to control of certain diseases. Duggar and Cauthen (1911) reported that the percentage of cotton bolls infected with "boll rot" or anthracnose was reduced from 11.3 to 5.9 percent by "charring" the seed coat with concentrated sulfuric acid before planting. Other workers (Archiblad, 1927; Brown, 1933; Sherbakoff, 1927; Young, 1942) reported on the beneficial effects of acid delinting for the control of various diseases. Chester (1938, 1940, 1941) found that acid delinting and gravity grading of cottonseed practically eliminated "internally-infected" seed and increased the rate of emergence, thus, shortening the period of susceptibility of the seed to *Rhizoctonia*. He believed that the latter response was the reason for the wide-spread acceptance of acid delinted seed in the Southwest, where *Rhizoctonia* is very prevalent. Conversely, he attributed the low level of acceptance of acid delinted, gravity graded seed in humid areas of the cotton belt to the effectiveness of organic mercurial seed treatments in control of the prevalent seedling disease organisms in the area, *Glomerella gossypii* and *Fusarium moniliforme*.

The general experience has been that acid delinted seed do not store as well as gin-run and mechanically delinted seed (Colwick *et al.*, 1972). In terms of the effects of acid delinting on germination and emergence, the initial quality of the seed appears to be the controlling factor. Seed low in vigor and with a high incidence of mechanical damage are more adversely affected by acid delinting than high quality seed (Colwick *et al.*, 1972).

A review of quality control records of several cottonseed companies in the late 1960's revealed that in the Mississippi Delta area emergence percentages of acid delinted seed were slightly lower than those of mechanically delinted seed. Similar results were reported by Minton and Quisenberry (1980). On the other hand, Marani and Amirav (1970) stated that acid delinting improved and accelerated germination and emergence by increasing the permeability of the seed coat, and Garber and Hoover (1973) reported that acid delinted seed produced stands

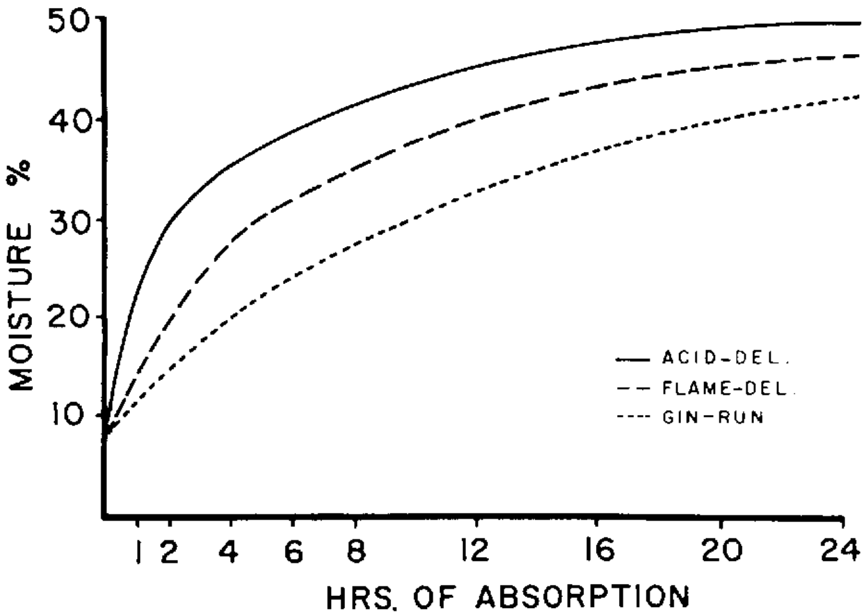

Figure 11. Effect of delinting method on rate of moisture absorption by cottonseed (from Helmer, 1965a).

similar to those produced by mechanically delinted seed, even though 13 percent less seed were planted.

Bourland and Ibrahim (1980) evaluated three methods of acid delinting—dilute acid, concentrated acid, and water-plus acid—in combination with several drying procedures. Delinting and drying methods had no influence on speed of germination and mold growth on the seed at a cool temperature. Acid delinting also increases the exudation of amino acids from hydrolyzed portions of the seed coat (Lewis, 1969b). This apparently has little significance except in tests where free amino acid exudation is used as an assay of quality.

Helmer (1965a) made a detailed comparison of the laboratory and field performance of gin-run, flame delinted and wet-acid delinted sublots taken from the same lot of seed. The acid delinted seed absorbed moisture, germinated and emerged (in the field) more rapidly than flame delinted seed which, in turn, responded more rapidly than gin-run seed. In soil tests involving two soil types, optimum and suboptimal temperatures, and several soil moisture tensions, the acid delinted seed performed better than flame delinted or gin-run seed. Illustrative responses from Helmer's studies are shown in Figure 11 and 12.

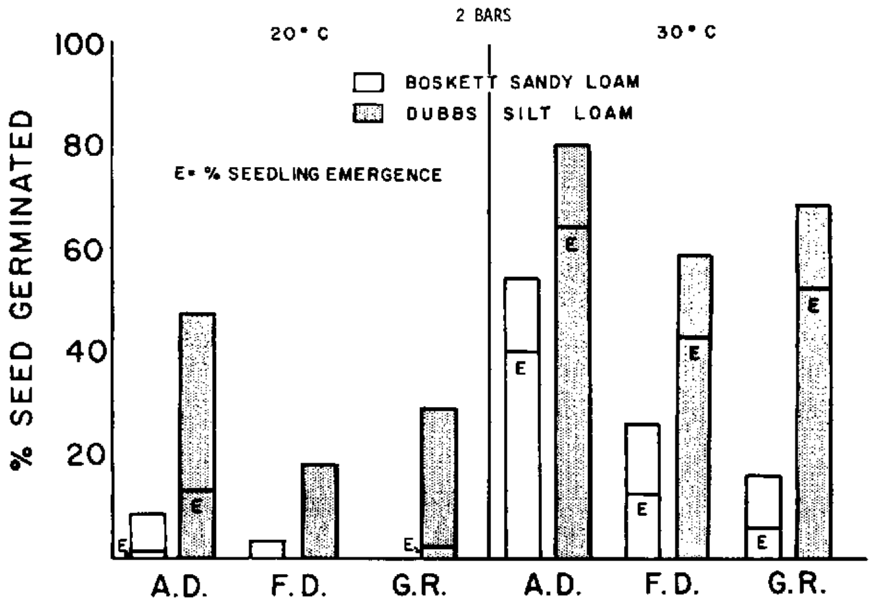

Figure 12. Effects of delinting method on germination and emergence of cottonseed in two soil types at 2 bars moisture tension at 20 and 30C. A.D., F.D. and G.R. refer to acid delinted, flame delinted and gin run seed, respectively (from Helmer, 1965a).

CONDITIONING

Cottonseed are conditioned—cleaned, graded and treated—to the extent possible after delinting to prepare them for marketing. The poor flowability characteristics of mechanically delinted and flame-zipped seed severely constrains the efficiency and effectiveness of cleaning operations and essentially precludes grading.

The concentration of despined cockleburs, which are a troublesome contaminant, can be reduced in mechanically delinted, flamed seed with cylindrical screen length/width separators but usually not enough to meet certification standards for cocklebur contamination (Bunch *et al.*, 1961; Mezynski, 1966). Separation of immature seed, which often constitute a relatively large percentage of the lot by number and are of low quality, is virtually impossible.

Complete removal of the linters by acid delinting transforms cottonseed into singulated, readily flowable "particles", which can then be cleaned and graded with considerable precision. Despined cockleburs can be completely removed with a gravity separator because they are much lower in density than cottonseed. A very high percentage of cockleburs can also be removed with a length grader, because they are generally longer than cottonseed (Mezynski, 1966). Most importantly, however, lint free seed can be density graded with a gravity separator to upgrade germination and vigor.

The close association of seed density and quality in cottonseed has been recognized for many years (Arndt, 1945; Chester, 1938, 1940; MacDonald *et al.*, 1947; Porterfield and Smith, 1956; Webber and Boykin, 1907) and well documented in the last 15-20 years (Bartee and Krieg, 1974; Dave *et al.*, 1971; Ferguson and Turner, 1971; Gregg, 1969; Johnson, 1970; Justus, 1965; Krieg and Bartee, 1975; Minton and Supak, 1980; Peacock *et al.*, 1971; Tupper, 1969; Tupper *et al.*, 1971; Turner and Ferguson, 1972; Wilkes, 1969). The subject is discussed in Chapter 33 and has been extensively reviewed by Tupper (1969) and Tupper *et al.*, (1971) in previous papers. Here I will only briefly summarize the detailed studies made in our laboratory by Gregg (1969) in 1968-69.

Nineteen lots of cottonseed, representing the important varieties in the Mississippi Delta area, were acid delinted (wet-acid process) in a commercial plant and gravity graded into 10 density fractions according to discharge positions from a gravity table separator. Standard bulk density of the density fractions over all lots ranged from 33 lb./bu. to over 47 lb./bu. Standard germination, accelerated aging and cold test responses, and field emergence increased as bulk density of the seed increased up to about 46 lb./bu. (Figure 13), while free fat acidity increased as bulk density decreased (Figure 14). Gregg recommended discard of seed below 42 lb./bu. for an "average" quality product and discard of seed below 44 lb./bu. for premium seed.

Presently, the gravity table is the most practical machine for density separation and upgrading of acid delinted cottonseed. The aspirator, especially the fraction-

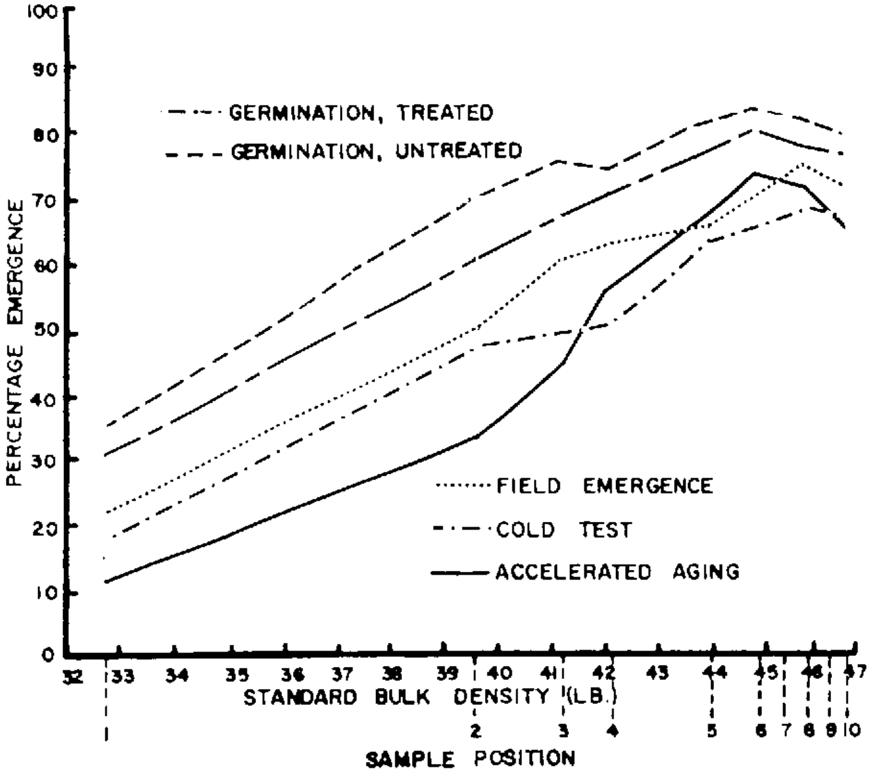

Figure 13. Effects of bulk density (lb./bu.) of acid delinted cottonseed on germination, germination after accelerated aging, cold test and field emergence. Data are averages of 19 seed lots. Sample position refers to 10 equidistant areas along discharge end of an Oliver Model 50 gravity table (from Gregg, 1969).

ating aspirator, does separate the seed on the basis of density but not with the precision of the gravity table (Lai, 1972).

After gravity grading the remaining steps in conditioning are treatment of the seed with fungicides and insecticides and packaging. Seed treatment has a positive effect on performance of the seed, except in cases where there is an adverse reaction to some of the systemic insecticides. Packaging has no effect on the seed quality unless seed moisture content is high and the packages relatively impervious to diffusion of water vapor.

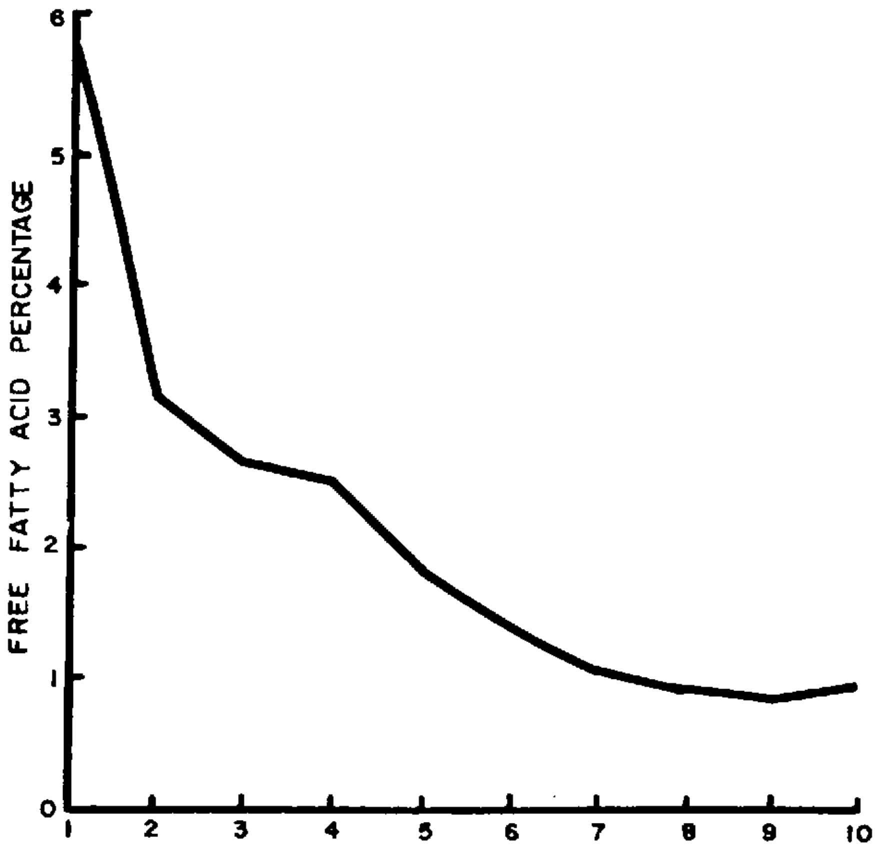

Figure 14. Relationship of free fatty acids in cottonseed (avg. of 19 seed lots) to sample position along discharge end of an Oliver Model 50 gravity table. Bulk density ranged from 33 lb./bu at sample position 1 to 47 lb./bu. at sample position 10 (from Gregg, 1969).

STORAGE

The total storage period for cottonseed encompasses three distinct phases. The first phase is seed cotton storage from harvest to ginning. It is a critical phase because cotton is harvested under a variety of conditions, and the period of storage can be rather long. Deterioration of the seed cotton is relatively high due to heating in the mass of seed cotton. Sorenson (1973) and Colwick *et al.* (1972)

determined the following "safe" storage periods for seed cotton at various moisture contents packed at densities of 7-12 lb./cu. ft:

Seed cotton moisture (%)	Safe storage period (days)
8-10	30
10-12	20
12-14	10
14-15	3

The introduction of the module and other devices for field storage of seed cotton before ginning added another dimension to the problem of seed deterioration. Drastic reductions in seed quality have been reported.

After ginning, the gin-run cottonseed are conveyed or transported to a seed house for storage in bulk until they are delinted and conditioned. Considerable reduction in quality can occur in the huge piles of cottonseed when seed moisture content is too high and/or the seed are not adequately aerated to even out moisture and reduce the temperature in the seed mass. In the Mississippi Delta area, cottonseed companies summarily divert cottonseed at 12 percent moisture or higher to the oil mill. It is too difficult and expensive to dry the seed under the prevailing humid conditions. Seed quality problems associated with storage of seed cotton and bulk cottonseed are discussed in Chapter 33.

Good quality conditioned, packaged cottonseed store surprisingly well—much better than other kinds of oil seeds. Simpson (1935b) found that sea-island and upland cottonseed deteriorated rapidly after two years in "ordinary storage" at James Island, South Carolina. Seed at 8 percent moisture stored in tin containers to prevent reabsorption of moisture showed little deterioration after 4.5 years, while seed at 13.7 percent moisture were all dead in nine months. In subsequent studies, Simpson (1946) demonstrated the great influence of climatic conditions on longevity of cottonseed. He produced a single lot of seed at Jackson, Tennessee, subdivided the lot for various treatments (gin-run, gin-run treated with 2 percent "Ceresan", acid delinted, and acid delinted treated with 2 percent "Ceresan") and shipped samples from each sublot for storage at seven locations ranging from Jackson, Tennessee to Baton Rouge, Louisiana. Germination trends over all treatments for the seven-year storage period are shown in Figure 15. Storage life was shortest—as might be expected—at Baton Rouge, the warmest and most humid location. Acid delinted seed stored about as well as gin-run seed at all locations. Germination of Ceresan-treated seed was higher than untreated seed for the various storage periods, but Simpson properly attributed this response to the control of fungi during germination rather than to any effect of the chemical on rate of deterioration during storage. In the same paper, Simpson reported on the germination of samples of cottonseed stored in unsealed containers at Saca-

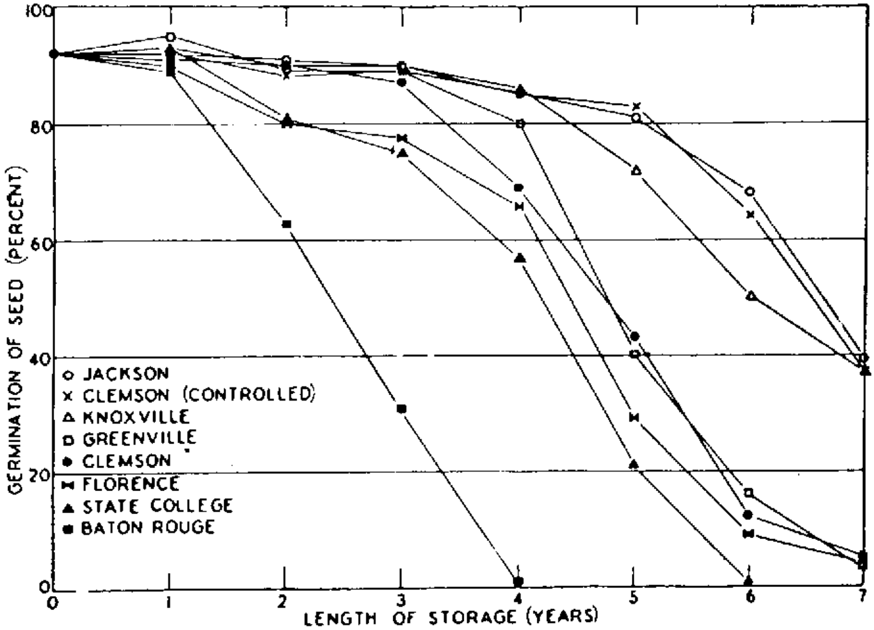

Figure 15. Germination percentages of cottonseed after periods of warehouse storage at eight locations (from Simpson, 1948).

tion, Arizona, for 6 to 35 years. The oldest sample that contained germinable seed (6 percent) had been in storage for 25 years. Many samples 15-20 years old germinated above 40 percent—a few above 80 percent. Stewart and Duncan (1976) brought the latter study up to date in 1976. Seed stored in Sacaton, Arizona, from the year of production ranging from 1925 to 1938 until 1945 under open conditions, then at Knoxville, Tennessee in sealed containers at 21C from 1945 to 1957, and finally at near 0C from 1957 to 1974, were evaluated for germination in 1974. The oldest viable seed lots were produced in 1929 and had a maximum germination of 68 percent in 1974 (after 45 years). Cottonseed at College Station, Texas in a sealed container at 10C germinated 92 percent after 16 years, while seed stored at room temperature in sealed glass and paper envelopes germinated 66 and 8 percent, respectively, after 6 years (Table 3). In California, 17 samples of seed with average germination of 84 percent were stored for 10 years at Shafter in a metal warehouse (Towers and Harrison, 1949). Average germination after 10 years was 15 percent.

The general experience of seed companies is that good quality cottonseed maintains germination for 18-24 months with some reduction in vigor. In some cases, storage for 2-3 years appears to improve field performance under stress conditions (Taylor and Lankford, 1972).

Table 3. Germination percent of cottonseed stored under different conditions at College Station, TX, for periods up to 20 years (From Bockholt *et al.*, 1969).

Condition	Years					
	0	4	6	11	16	20
10C-sealed	92	96	80	86	92	41
Rm. temp.						
Sealed glass	92	95	66	0		
Paper env.	91	88	8			

SEED QUALITY

The quality of a lot of planting seed is determined—and established—by several factors and/or characteristics: the varietal and physical purity of the lot; the physical condition, germinability and vigor of the seed; the types and incidence of seedborne microorganisms; and the types and uniformity of applied seed treatments. In cotton, varietal purity can be assured through careful and systematic varietal maintenance, seed multiplication and production practices, and by well established quality assurance procedures such as field and facility inspections, one variety seed farms, gins and storehouses. The several types of delinting procedures in use are adequate for conditioning gin-run seed into a readily flowable, singulated product which can be cleaned, density graded, uniformly treated and planted with considerable precision. Cleaning equipment and density separators are available to remove physical impurities and contaminants, and most immature, rotten and other low density seed. Modern seed treaters can apply one, two or more fungicides and insecticides simultaneously or in sequence at controlled dosages just before packaging for storage and marketing.

Considering the array of quality assurance procedures, processing technology and facilities presently available for the production and conditioning of cottonseed there is little reason for quality problems related to varietal and physical purity, contaminants, physical condition of the seed, and—to a lesser degree—seedborne microorganisms. Problems that do arise in these areas can usually be attributed to lapses in quality control, poor management and/or inadequate facilities and can be resolved by appropriate corrective actions. The one problem which continues to elude a satisfactory resolution relates to the germination, vigor and stand producing potential of the seed. Indeed, much of the technology used to produce, harvest and condition the large quantities of cottonseed needed for planting in an efficient manner, and which has made possible the resolution of other quality problems, has aggravated the germination/vigor problem as discussed in previous sections.

The causes of cottonseed germination and vigor problems are well known: indeterminate habit of the plant; preharvest climatic conditions; mechanization of harvest and post-harvest operations; priority attention to lint rather than seed. Improvements in the germination and stand producing performance of cottonseed have been and are being made, but most cotton producers do not perceive these as sufficient for their needs. Judging from the voluminous literature on germination, vigor, stand establishment and related problems in cotton, many cotton researchers share the perception of cotton producers that further improvements are necessary.

"Getting a Stand" was the second of 20 areas considered in the Blueprint of Cotton Research developed by the National Cotton Council of America in the early 1960's. Tharp (1961) pointed out that, "The problems connected with 'getting a stand' spread across all phases of cotton production" . . . and, "present a challenge to research workers in all production disciplines—from the geneticist, who can improve the inherent quality of planting seed, to the agricultural engineer, who can preserve the quality during the harvesting and ginning operation." Seed quality improvement was highlighted as one of the broad opportunities for research. Specifically, Tharp felt that research was needed to: develop better methods for evaluating seed quality; improve properties of the seedcoat; identify genetic sources of "quality" for incorporation into commercial varieties; elucidate the biological/biochemical bases and mechanism of vigor, cold tolerance and resistance to seedling diseases; prevent or reduce field deterioration of the seed; and identify and develop chemical means for "preserving" vigor. Tharp's view have been echoed in later reviews and discussions of the cottonseed quality situation (Delouche and Baskin, 1970; Niles, 1967; Noggle, 1971; Presley *et al.*, 1967, Scott, 1979; Wilkes, 1970), and his strategy is reflected in the work of many researchers.

The economic consequences of low germination and vigor of cottonseed lots are difficult to assess because the quality of the seed planted is only one of the factors that affect stand establishment. Tharp (1961) estimated the annual loss attributable to "stand" problems at $150 million in the early 1960's. More recently, Parvin *et al.* (1978) discussed the direct and indirect benefits that can be realized with high quality cotton planting seed. They pointed out, however, that redirection of breeding efforts to improve seed quality at the expense of lint yield and quality would not be a satisfactory solution.

EVALUATION OF SEED QUALITY

Adequate methods for evaluating the physical purity of cottonseed lots have been developed and are in use. Quality assurance procedures in the production field, gin and conditioning plant are generally satisfactory in terms of maintaining varietal purity, although there is need for more research and developmental work on methods for identifying varieties in the seed and seedling stage. The major problems in evaluation of cottonseed quality are in the areas of germination, vigor and timeliness.

Germination.—Germination of cottonseed is determined by the standard germination test (Association of Official Seed Analysts, 1983). Four replicates of 100 seed each are planted on moist paper towels, blotters or in sand and incubated at an alternating 20-30C or 30C temperature. A first or preliminary count is made after 4-5 days and a final count after 12 (20-30C) or 8 days (30C). The Rules for Seed Testing (Association of Official Seed Analysts, 1981) state that samples which do not respond to the usual method should be placed in a closed container with water and shaken until the lint is thoroughly wet, after which the excess moisture is blotted off. The latter recommendation is based on a suggestion by Toole and Drummond (1924). Test results are expressed as a germination percentage, which is further defined as the percentage of normal seedlings that develop during the test period. Criteria—mostly morphological—for normal seedlings are specified in the Rules.

Despite long-term use and periodic refinement, the standard germination test for cottonseed presents problems to seed analysts and seedsmen. Different laboratories frequently obtain widely varying results on seed from the same lot or portions of the same sample. Excessive variation in germination test results, even within the same laboratory, is also rather commonplace, with the result that much retesting is required. Seedsmen confronted with widely differing test results from different laboratories or the same laboratory have a rather shaky basis for labelling of seed lots.

Difficulties in germination testing of cottonseed have long been noted. Toole and Drummond (1924) reported that seed above 10 percent moisture content appeared to "mold" badly during testing, while seed at 5-6 percent moisture often exhibited some hardseededness which interfered with germination testing. They felt that conditions contributing to rapid germination produced the best and most consistent results.

Weir (1959) and Stanway (1960, 1962) compared the germination of many samples of cottonseed at 20-30C and 30C temperatures and concluded that while final germination percentages were not different at the two temperatures, germination was "completed" 2-5 days sooner at the higher, constant temperature. Arndt (1954a) and Bohorquez (1977) also reported that the optimal germination temperature for cottonseed is in the range of 30 to 33C. Stanway recommended that 30C be accepted as an alternate temperature for germination testing of cottonseed. Her recommendation was adopted in the mid-1960's.

McWilliams (1961) found that interpretation of germination test results could be made when the radicle was one-half inch in length with essentially the same results as evaluation at later stages of seedling development. Test results tended to be more consistent because mold problems, which complicate interpretation, were avoided. Powell and Morgan (1973) developed a germination test system—the TAMU rapid germination test for cottonseed—which generally produced higher results than the standard germination test.

Excessive variation in germination test results of cottonseed—as well as other kinds of seed—is caused by many factors ranging from improper sampling to analyst fatigue. Better training and periodic workshops for analysts from cotton-belt laboratories would substantially improve the uniformity and reliability of germination test results for cottonseed. Additional research is also needed to determine the effects of substrate moisture content on germination of cottonseed. Although the Rules for Testing Seed give little attention to substrate moisture relations, observations indicate that excessive moisture can cause wide differences in test results.

Quick Tests.—During receiving and bulk storage operations, cottonseed producers often have to make almost immediate judgments of quality and important decisions based on these judgments. Methods are available for rapidly determining moisture content, contaminants and even mechanical damage. However, germination, which at this stage is of crucial importance, cannot be determined in less than 4 to 5 days. It is not surprising, therefore, that cotton seedsmen are extremely interested in any type of "quick test" for estimating germination percentage. One cottonseed company uses a "cutting" test. The seed are sampled and 50 to 100 seed are placed in a holder which permits rapid longitudinal bisection of the seed. The cut embryos are visually rated for "fullness" and color and an estimate of germination is made. The test takes about 15 minutes. On the average, the estimates are surprisingly close to germination percentage as determined by the standard test.

The tetrazolium test for seed viability is widely used in the cottonseed industry (Baskin *et al.*, 1972; Metzer, 1961). Experienced analysts can obtain reliable estimates of germination in 8 to 16 hours. The tetrazolium test is described and discussed in Chapter 33.

More recently there has been considerable interest in quick tests for viability based on the electrical conductivity of pre-conditioned seed or seed exudates (Anderson *et al.*, 1964; Bondie *et al.*, 1978; Brashears *et al.*, 1979; Hopper, 1981). This approach, in turn, is based on the work of Presley (1958), among others, which demonstrated a relationship between "protoplast" permeability and seed quality. The electrical conductivity or current flow methods are reasonably accurate in identifying very high or low quality seed but are often quite unreliable in predicting germination of seed in the medium quality range. McDaniel (1977) described a somewhat different method for estimating germination of cottonseed based on exudation of materials. Seed were soaked in water at 65-70C for one and one-half hours and the leachates "read" with a refractometer. Readings below 0.2 were considered indicative of good seed, while readings above 0.6 were considered indicative of poor quality seed.

Free fatty acids content is extensively used as a rough index of the quality of cotton planting seed. In the late 1940's, Hoffpauir *et al.* (1947, 1950) found that germination percentage decreased as the percentage of free fatty acids increased. Individual seed with over 1 percent free fatty acids (3 percent in extracted oil) did not germinate. They recommended that cottonseed saved for planting purposes have a free fatty acids content of less than 1 percent. Lewis (1969a), on the other hand, contended that the concentration of specific fatty acids was a more relevant parameter of quality than total free fatty acids. In any event, free fatty acids can only be used as a very rough index of quality. A few badly deterioriated seed in a sample can produce an alarmingly high free fatty acids concentration although the rest of the seed germinate vigorously. Conversely, a seed lot can germinate poorly—or not at all—even though free fat acidity is below 0.5 percent.

Vigor.—The deficiencies of the standard germination test as the measure of the physiological quality or stand producing potential of seed have long been recognized (Association of Official Seed Analysts, 1976; Delouche and Caldwell, 1960). The reasons for the deficiencies of the test have been discussed in detail by Delouche and associates (Delouche, 1969; Delouche and Baskin, 1970a, 1973b; Delouche and Caldwell, 1960). Basically, the deficiencies of the standard germination test derive from two sources: first, the dominant philosophy of germination testing has been, and is, optimization of results; secondly, the test methodology—including interpretation criteria—do not adequately take into account the progressive nature of seed deterioration.

Field conditions are seldom optimal for germination, emergence and seedling growth. The weaker seed that produce normal seedlings in the laboratory frequently succumb to stresses in the seed bed with the result that field emergence usually differs markedly from laboratory germination. This situation would not be too bad, if every lot of seed of the same variety and equivalent germination performed the same—albeit more poorly—under similar field conditions. A relatively simple calibration scale could be constructed to relate germinability to emergence for various types and degrees of environmental stress in the seed bed. Seed lots of the same variety and equivalent germination, however, often perform (emerge) quite differently when planted at the same time and under the same conditions in the field. These differential responses of seed lots to less than optimal conditions reflect different degreees of deterioration—or vigor—among the lots. Interpretation of the germination test focuses on loss of the capacity to germinate, which is the final practical consequence of seed deterioration. The lesser consequences of deterioration, which reduce rate of germination and seedling growth and the seed system's resistance to environmental stresses in the seed bed, are virtually ignored.

The deficiencies of the germination test are strikingly evident in the data presented in Table 4. Samples from 50 commercial lots of cottonseed labelled 80 percent germination were collected in the spring of 1967. The seed were tested for germination and 34 samples with actual germination between 80 and 85 percent were selected for field emergence tests in mid-April and mid-May. In the mid-April planting, emergence percentage (actually 18-day seedling survival) ranged from 80+ percent to less than 40 percent. Twenty samples emerged 60 percent or higher, while 14 samples emerged below 60 percent—5 below 40 percent. Emergence percentages in the mid-May plantings were higher, but five samples still emerged below 60 percent. Farmers who purchased the low emergence lots were surely disappointed and most likely blamed the poor stands or stand failures on the weather.

Table 4. Field emergence of 34 lots of cottonseed with germination percentages from 80-85 percent. Emergence tests made at Mississippi State University, Mississippi in 1967.

	No. lots with emergence percentage of:					
Date	80+	70-79	60-69	50-59	40-49	40-
Mid-April	1	8	11	6	3	5
Mid-May	6	10	13	2	2	1

Seed vigor, which has been a much researched and somewhat controversial areas for the past 20 years (Bridges, 1962; Delouche, 1976; Delouche and Baskin, 1973; Grabe, 1976), is a sort of reverse expression of deterioration. In a physiological sense—but not necessarily a genetic sense—seed vigor is highest when deterioration is minimal and decreases as deterioration progresses. In 1978 the Vigor Test Subcommittee of the Association of Official Seed Analysts (1978) defined vigor as follows: "Seed vigor comprises those seed properties which determine the potential for rapid, uniform emergence and development of normal seedlings under a wide range of field conditions."

Seed vigor is generally considered especially important in field emergence and stand establishment (Baskin, 1979; Bird and Reyes, 1968; Bishnoi and Delouche, 1980; Delouche, 1976; Delouche and Caldwell, 1960; Grabe, 1976). However, several investigators (Bishnoi, 1971; Delouche, 1969; Johnson, 1970; Peacock and Hawkins, 1970; Rajanna, 1972) presented evidence that the quality, i.e., vigor, of cottonseed planted can also affect plant growth, development and yield. Peacock and Hawkins (1970), for example, found that seed source affected lint yield in two varieties of cotton even though good stands were produced by the seed from different sources. The differences in yield must have been related to differences in vigor. In a study of the emergence and lint yield of cotton from seed produced under plant bug infestations, Hanny *et al.* (1975) observed that seed from different harvest dates produced significantly different yields which could not be related to stand and suggested that, "there are some yet unrecognized areas of planting seed quality where seed technologists and plant physiologists might study cotton yields."

A variety of vigor tests for cottonseed have been developed. Mahdi *et al.* (1971) modified the well known soil cold test for corn seed for use on cottonseed. Seed were planted in moist sterile sand and incubated at 6C for 4 days, followed by 4 days at 30C, after which the percentage of normal seedlings was determined. The test was capable of differentiating among seed lots but probably confounded vigor with susceptibility to chilling injury during the early stages of germination (Buxton *et al.*, 1976a; Christiansen, 1964, 1967; Cole and Christiansen, 1975). Another variation of the soil cold test is used by several laboratories (Bishnoi and Delouche, 1980). The seed are incubated for 3 to 5 days at 13C in soil at 60 percent moisture saturation followed by 4 days at 30C, after which the percentage of normal emerged seedlings is determined.

Christiansen (1961) developed a method for measuring epigeous seedling growth rate (in cotton) based on the rate of transfer of cotyledonary dry weight to the axial parts of the seedling. He advocated use of the method for selection for genetic vigor and as a bioassy for evaluation of the effects of certain treatments. The dry weight transfer test, however, has not been very effective in identifying lots with high emergence potential (Buxton *et al.*, 1977b).

The electrical conductivity of exudates or leachates from cottonseed has been used to assess vigor as well as to predict or estimate germination (Bishnoi and Delouche, 1980; Halloin, 1975b; Hopper, 1981; Presley, 1958). Results have been mixed. The tetrazolium test discussed previously as a quick test for viability is also used to evaluate vigor (Association of Official Seed Analysts, 1976; Baskin, 1979; Delouche and Baskin, 1970). It is a very powerful and reliable test in the hands of an experienced quality assurance specialist (see Chapter 33).

The most widely used vigor tests for cottonseed are the tetrazolium test and the cool germination test, i.e., Texas Cool Test (Association of Official Seed Analysts, 1976; Baskin, 1979; Rejanna, 1972; Wiles, 1960). The cool germination test is similar to the standard germination test except that a temperature of 18C is used rather than 20-30C or 30C, and the percentage of normal seedlings 1½ inches or longer (hypocotyl and radicle) is determined after 6 to 7 days, respectively, for acid delinted and mechanically delinted seed. The tetrazolium and cool germination tests were selected for refinement and standardization by the Association of Official Seed Analysts (1976, 1983).

Other methods developed, used or advocated for evaluating cottonseed vigor are based on seedling vigor classification criteria (Association of Official Seed Analysts, 1976, 1983), rate of seed respiration (Bishnoi, 1971), rate of germinative responses following accelerated aging (Baskin, 1979; Bishnoi and Delouche, 1980; Bollenbacher *et al.*, 1963; Delouche and Baskin, 1973) and germinative responses following rapid release of a vacuum pulled over immersed seed (Bridges, 1962; Metzer, 1961b).

Vigor tests are not and cannot be designed to predict field emergence, because the environmental conditions and stresses in the seed bed cannot be predicted. But, they are extremely useful in identifying high quality seed lots which have a high potential for successful stand establishment under a wide range of field conditions, or low quality lots which should not be used for planting. Vigor tests are also very efficient in establishing the relative quality of seed lots received, in inventory and marketed. They are most effectively used to supplement the quality information obtained from germination and other quality tests.

DORMANCY

When planted under conditions favorable for germination, dormancy is manifested as the complete failure of the seed to germinate, a slow rate of germination or as an increased specificity of the conditions required for germination. At least two mechanisms of dormancy appear to be involved.

Simpson (1935a) noted that seed from freshly opened bolls (1-5 days) of several upland varieties remained ungerminated and sound after 28 days in a germinator. Seed harvested from bolls opened longer than 5 days germinated better but at a much slower rate as compared to seed from storage. Drying and storage of freshly harvested seed for about one month practically eliminated the dormant conditions. Hsi and Reeder (1953) also found that dormancy was most intense in seed extracted from freshly opened bolls and dissipated 21 to 30 days after boll opening. The intensity of dormancy also appears to increase as date of boll opening increases (Christidis, 1955).

In some lots of cottonseed, dormancy persists for much longer than a few weeks after harvest. Seed analysts frequently encounter seed dormancy problems during the heavy testing season from January to April. Generally, the problem—dormancy—can be eliminated by drying the seed at 40C for a few days before testing or by germinating them at 30C rather than 20-30C. Taylor and Lankford (1972; see also Reynolds, 1968) reported a type of "secondary" dormancy which persisted for 3 years and which was manifested as an increased sensitivity of the seed to low germination temperatures and salinity.

The type of dormancy discussed above is not caused by impermeability of the seed coat to water. The seeds readily absorb water. Rather, this type of dormancy appears to be related to inhibition of germination by abscisic acid (ABA) (Davis and Addicott, 1972; Halloin, 1976a). ABA content in the developing boll and seed increases rapidly from 30 to 40 days after anthesis, then declines in the seed but continues to increase in the carpel wall until boll opening (David and Addicott, 1972; Guinn, Chapter 12). Helmer and Adbel-Al (1965) found that dormancy in Deltapine 15 cottonseed was most intense (0 percent germination) 40 days after anthesis (DPA) and was rapidly released during boll opening a few days later. Since excised embryos germinate in the later stages (Berkey, 1974; Dure, 1975), ABA is probably concentrated in the seed coat. Although Trelease *et al.* (Chapter 29) suggested that the postulated mechanism of ABA inhibition of germination should be revised, they felt that the concept that ABA prevents vivipary should be preserved.

that dormancy was most intense about 48 DPA—the boll cracking stage. Some seed harvested at 28, 30 and 32 DPA germinated when planted fresh but rotted within a few days when dried before testing for germination. Injecting distilled water in developing bolls 34 DPA stimulated germination of seed harvested 40 DPA. Injections of gibberellin and kinetin singly and in combinations were not any more effective than distilled water. Seed from bolls detached from the plant 30 DPA and "cultured" for 10 days in White's solution germinated above 88 percent as compared to 0 percent for seed from 40-day bolls. Seed extracted from 40-day bolls germinated 50 percent in atmospheres of 60 or 100 percent oxygen, as compared to 0 percent in a normal atmosphere. Removal of the seed coat or excision of a portion of the seed coat at the chalazal end promoted prompt and complete germination. In a very tedious experiment, Berkey removed the various layers of the seed coat by abrasion. Germination was dramatically increased when the inner pigment layer was disrupted. On the basis of this and other responses, he concluded that dormancy in cottonseed was at least partially conditioned by a restriction imposed on oxygen absorption by the hydrated inner pigment layer of the seed coat.

Another type of mechanism of dormancy in cotton is water impermeability of the seed coat, or hardseededness (Christiansen and Moore, 1959). Hardseededness has been reduced to a very low level in modern cotton varieties by conscious or unconscious selection. It is much more prevalent in the primitive strains and in the relatives of cotton such as okra and weedy malvaceous species. Lee (1975) reported that hardseededness in cotton was caused by two genes whose concerted action determined the level or degree of water impermeability of the seed coat in interaction with environmental conditions during seed development and maturation. Halloin (1976b), for example, found that oxidative processes during ripening are necessary for development of seed coat impermeability. Exclusion of oxygen during this state increased permeability and prevented "cementing" together of the various layers of seed coat. Hardseededness can be overcome by time, mechanical and acid scarification, hot water treatment and electrical treatments (Stone *et al.*, 1973). The potential benefits of dormancy in terms of resistance to field weathering and adverse storage conditions are discussed in the next section.

IMPROVING SEED QUALITY

Several approaches for improving the quality of cottonseed are available. Better management based on a rigorous quality assurance program can greatly reduce seed quality losses sustained during the various operations, as previously discussed. Positive programs, designed to take full advantage of the quality upgrading capability of density separators and to identify and market premium quality seed lots, would be well accepted by farmers, even with substantially higher seed prices. The information/technology bases are sufficiently developed for full exploitation of these avenues for improving the quality of cottonseed available to cotton producers.

Other approaches for improving cottonseed quality are in the idea or beginning stages and considerable research and developmental work will be required to advance them even to the pilot-scale evaluation stage. Two approaches, which have good potential and are receiving considerable attention, are enhancement of quality (and performance) through conditioning treatments and procedures and genetic improvements in the physical and physiological characteristics of the seed.

The work of Christiansen (1964, 1967, 1969) and others (Buxton *et al.*, 1976a; Cole and Christiansen, 1975) on chilling injury to cottonseed during imbibition and the early phases of germination have pinpointed periods of sensitivity to low temperatures and identified several desensitization treatments. Since low seed bed temperatures are often associated with stand failures, efforts have been made to improve germination and emergence of cottonseed at cool temperatures through various conditioning or desensitizing treatments. Seed imbibed at 30-31C for several hours followed by drying, or seed elevated in moisture content to 14 percent or higher in a humid atmosphere, are very resistant to low temperature injury under laboratory conditions (Christiansen, 1969; Christiansen and Thomas, 1971; Cole and Wheeler, 1974; Cole and Christiansen, 1975; Fowler, 1979). Responses in field tests, however, have been negative or variable (Buxton *et al.*, 1977a; Fowler, 1979; Krzyzanowski, 1980; Wanjura and Minton, 1974). Similarly, pre-conditioning treatments with various phytohormones such as gibberellin and kinetin have not usually been beneficial under field conditions (Buxton *et al.*, 1977a; Shannon and Francois, 1977).

Although pre-plant hydration and other pre-conditioning treatments have not produced consistently beneficial results under field conditions, the approach appears to be worthy of additional exploration. Controlled hydration or osmotic priming, as reported by Heydecker *et al.* (1973, 1975) for "invigorating" seed, are especially interesting approaches. The permeation or infusion techniques utilizing organic solvent systems to inplace phytoactive chemicals in seed also need further evaluation for cotton (Halloin, 1977; Khan *et al.*, 1976).

Singh and Singh (1972) reported that pre-planting soak treatments of *G. aboreum* seed with succinic acid (0.01 percent) increased stand, plant growth and yield. Calcium treatment of field deteriorated cottonseed produced seedlings that were healthier and more vigorous than those from untreated seed. More recently, McDaniel and Taylor (1979) found that treatment of Pima cottonseed with buffered adenosine monophosphate improved germination and emergence. The benefits of the AMP treatment was greatest under disease or cold stress conditions. Gas plasma (glow discharge) radiation of cottonseed increased rate of germination and early seedling growth in the laboratory but not in the field (Webb *et al.*, 1964, 1966). The effects of radiation treatments are probably attributable to an increase in permeability of the seed coat to water.

There are substantial opportunities for improvement of inherent characteristics or properties of cottonseed associated with improved quality or which contribute to maintenance of improved quality during the pre-harvest and post-harvest periods. Although much of the work has been directed at improving the processing of cottonseed (Kohel, 1978a), some efforts are underway to improve the planting quality as well. There is genetic variability in cotton for tolerance to low temperature during germination (Buxton and Sprengler, 1976) which might be related to isocitratase activity (Scholl, 1974, 1976).

El-Zik and Bird (1969) reported that final seedling stand was inherited and that improvements in this important characteristic through breeding appeared to be possible (see Chapter 35). In a somewhat different connection, Bird *et al.* (1979) used resistance of the seedcoat to molds and a reduced rate of germination at 13C as key traits for selection for multi-adversity resistance to stresses in the seedbed.

Christiansen and Moore (1959) pointed out the potential of hardseededness in cotton for maintenance of seed quality. Followup work (Christiansen and Justus, 1963; Christiansen *et al.*, 1960) demonstrated that hardseededness was especially effective in reducing field deterioration of the seed. One cultivar (LA 901) of cotton with a high degree of hardseededness has been released. The demonstrated benefits of hardseededness in maintenance of seed quality have stimulated similar effort for other kinds of seed (Potts, 1978; Potts *et al.*, 1975). McDaniel (1979) suggested that selection for a thicker palisade layer in the seed coat of cotton might increase its mechanical strength, thus, decreasing some types of mechanical damage.

Much more effort is needed to identify seed and seedling traits associated with superior quality and performance. In this connection, the continuing efforts and progress (Wanjura and Buxton, 1971, 1972) in simulation of cotton germination and emergence should be helpful.

SUMMARY

The quality of cotton planting seed can be affected by harvesting procedures and all the subsequent operations involved in handling, removal of the fiber and linters, and preparation of the seed for marketing. Reductions in seed quality during the various operations are usually associated with mechanical damage, chemical injury, or physiological deterioration resulting from high temperature and moisture levels, and their interactions. These losses in quality can be minimized by proper selection and adjustment of equipment, better design of facilities, improvements in operational management and a rigorous quality assurance program. On the positive side, the close association of seed quality with seed density offers an opportunity for substantial upgrading of quality by removal of low density seed.

The germination test has serious deficiencies as a measure of the planting value of cottonseed. The refinement and standardization of one or more of the vigor tests used for cottonseed would permit more effective identification and marketing of high quality seed lots.

Improvements in the quality and performance of cottonseed can be achieved through various conditioning treatments prior to sowing and selection in breeding programs for traits associated with superior quality and performance.