The six-layered seed coat of cotton is thick, strong and slightly elastic (152). 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 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 (51).

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 (51).

The advent of the mechanical picker introduced another potential source of seed injury. Since the vastly increased seed handled per picker had it been developed, high capacity ginning greatly increased the potential of the gin as a source of injury. Since accelerated operations in the gin yard required 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 efficiently treated and planted more rapidly at lower rates per acre. Mechanical delinting or removing 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 a more 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, it can only incidently be 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 (60) found that about 70% of the lots planted had mechanical damage levels (% damaged seed) of 5% or higher (Table 1). Based on other evidence, Helmer's findings in 1964-65 appear to be rather low. In smaller surveys in 1967 and 1968 (51) damage averaged 1%. Reviews of quality control records from several companies indicate that damage levels of 10-15% 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. (59, 60) 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 harvest damage than others. In studies at Clemson University, Garner and associates (see Colwick et al., 51) found that several factors affected the percentage of cracked seed coats 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 soybean seed are also more susceptible to mechanical damage (72).

Harvester damage to cottonseed appears to be more of a problem in arid, irrigated production areas. Miller (70) reported that pickers cracked 18-25% 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%. The main sources of damage in the cotton picker are high pickers speeds, deflowing, blowing (conveying), and impact of the seed cotton against the top of the basket. High speed moves of the seed through the picker, the deflowing position (51); pinching of the seed between the spindle and the deflopper and tearing off fragments of the seed coat as a result of competition of adjacent seed packs, for the same relief of seed coat damage to seed coat cracking. Mechanical and chemical damage (51, 60) described field modifications that can be made in various makes of pickers to reduce the incidence of seed coat cracking.

Ginning and Mechanical Delinting

It is not surprising that the ginning operation - especially saw ginning caused damage to cottonseed. Moore and Shaw (123) point out that ginning damage to cottonseed was evident on acid
Experiments of gin damage to seed in Louisiana and Mississippi were conducted by Watson and Helmer (174) 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 while one gin had older, lower capacity equipment. Moisture content of the gin run cotton was 1-10% and operated at speeds of only 300 to 400 r.p.m. Damage levels in those times, however, were rather low.

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).

In a similar follow-up study (123) in California in 1964, mechanical damage to the cottonseed averaged 10.7%. Harvesting (5.0%) and ginning/handling (5.7%) contributed equally to the damage. Other studies of comprehensive and controlled studies (123) 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% are not uncommon in gin-run cottonseed. The spindle-type cotton gin caused about 44% of the damage, ginning about 44%, while about 12% is contributed by the drying, overhead cleaning and conveying systems for seed cotton. The action of the gin caused the greatest damage to the seed at gin plants; increasing seed rates of seed cotton into the gin stand increases seed damage. The incident of seed damage also increased as seed moisture decreased, which is in disagreement with earlier results (174) 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 beginning operation except that the saws are finer and more closely spaced. It reduces the amount of lint on the seed and improves their flowability. Generally, only one cut, i.e., pass through the delinting stands, is made for linted seed. Mechanical delinting always adds a couple of points to the percentage of damaged seed. Close gauging of the gin saws, incalculous 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.

Harvesting 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 evidence of tearing or tearing 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 ginning process of gin harvesters are especially damaging to seed when the seed cotton is conveyed through the fan (60, 120). Air and seed house, several types of conveyors are used. Pneumatic conveyors are used to handle both seed cotton and cottonseed (146, 157). 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 (1). Pneumatic and belt conveyors have the advantage of being self-cleaning (67, 145); thus, variational 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-, bucket-, and belt-bucket elevators. Improperly maintained and operated screw conveyors can cause substantial damage to the seed, but the major source of damage in conveying/handling operations to cottonseed is pneumatic conveyors are very damaging to other kinds of seed and are seldom used (116).

Miller (120) reported that under California conditions, the most significant source of damage (15-20%) 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 ft. Using good quality assurance procedures, Miller and colleagues were able to reduce seed damage during pneumatic conveying to less than 2%. This was accomplished by eliminating all 90° elbows, rubberizing long-sweep elbows, reducing air velocity to a minimum that conveyed the seed withoutplugging, and replacing 5 in. piping with 6 in. piping. Watson and colleagues showed 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 Morgan (77) reported that the maximum impact on the cottonseed coat was relatively constant at 0.70 in.-lb., although the force (pounds/seed) required to rupture cottonseed and the resulting seeds germination decreased as seed moisture content increased from 6 to 14%. Seed damage from impact velocities increased rapidly above 4000 f.p.m. and was as high as 50% 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. (34. see also Colwick et al., 51) 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 the load was applied to the sides of the seed. The maximum force that could be applied to the sides of high quality cottonseed (97) without reduction in germination below 80% was 26, 25, and 13 pounds/seed for cottonseed at 4, 8, and 12% seed moisture, respectively. When the load was applied to the ends of the seed, the maximum force for maintaining 80% germination was 18, 14, and 10 pounds/seed at 4, 8, and 12% seed moisture, respectively (Figure 3). In terms of energy absorption, the maximum static energies the high-quality seed stood without reduction in germination below 80% were 0.35 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 Morgan (77) for cottonseed. With the internal 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. (48, also Colwick et al., 51) 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. The least seed most susceptible to impacts at seed moisture contents between 9 and 12% regardless of seed orientation. At moisture contents within this range, 100 f.p.m. was the maximum velocity the seed could withstand without reducing germination below 80%. Above and below the 9-12% seed moisture range, the maximum velocity was about 4,500 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).

Garnier and associates (51) studied impact damage in a 90° elbow in a pneumatic conveying system and showed that there was very little damage to the seed below 6000 f.p.m. regardless of stage of weathering of the seed. Cottonseed at 12-13% 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 in. 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 (6, 88) 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 seed between spindle and doctor, and impact by screw conveyors. Overall, the mechanical properties of the cottonseed are superior to those of some other kinds of seed (106, 130).

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 (6, 9, 94, 98, 164). Less severe injury causes abnormal seedling abnormalities (9, 154) and reduces storage life, vigor and field emergence potential (51, 99, 182). The indirect effects of mechanical damage are often as important as the direct effects. Damaged seed are more susceptible to seed rotting microorganisms in the soil which gain easy entry to necrotic tissue through cuts or fractures in the seed coat (64, 95, 126). Mechanically damaged seed are also more susceptible to processes and materials used in the preparation of seed for marketing. In acid delinting of cottonseed, cuts in the seed coat expose the embryo to the acid causing acid burn (51) and then lead to the chemical seed treatments such as the formerly widely used organic mercurials (139, 140) and some of the systemic insecticides applied to cottonseed (51).

Studies at our laboratory in the late 1960s (51) on the effects of mechanical damage on the quality of cottonseed produced the following conclusions: in damaged seed necrosis is initiated in embriotic 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) increases as the incidence of mechanical injury increases; treatment of damaged seed with fungicides improved laboratorv germination and test 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-radiographs should be made to 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 interval temperatures and 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 lint that remain on cottonseed after ginning become entangled causing the seed to clump. Since the lint-free, readily flowable seed can be cleaned, density graded, treated and packaged as efficiently as other kinds of seed.

Mechanical delinting is the traditional process for improving the flowability of cottonseed. As discussed previously, mechanically delinted seed is basically beginning 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 despinned cockleburs and immature, low density seed (28, 119). Plantability as improved but precision of metering is less than for smooth, ready 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 improvement on flowability led 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 (28). 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 delining. 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 - (90): 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 gas-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% and low humidity reduces corrosion of the equipment and facilities. Anhydrous hydrochloric gas is used to degrade the linters so that they can be removed from the seed by frictional forces (91). 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%, then rough cleaned to remove gross contaminants. A charge of seed is then placed in a charging hopper. The charging temperature is raised to 140-160°F before injection of the gas-acid at a concentration of 0.5-2.0% of seed weight. Reaction time varies from 5 to 20 minutes, depending on the temperature, feed stock composition of 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 the 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 delining system has been favored in humid, rainfed areas of the cotton belt. The process involves little expense and does not require 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%.

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 streams. This practice has been considerably reduced by more effective methods of neutralization of residual acidity, e.g., with ammonia. The alternative solution of collecting the effluent in a sort of seawage lagoon also poses environmental problems.

**Dilute Acid Process:** The dilute acid delinting process was developed by Cotton, Inc. (90, 92). The process differs from the conventional wet-acid process as follows (Figure 10): a dilute solution of sulfuric acid (about 10%) is used instead of concentrated sulfuric acid to wet the linters; the wet seed are "dewatered" by heat, with no further reduction in the acid concentration of the seed. 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 good reduction in the quantity of sulfuric acid required because of the much lower quantity used and the recovery of a major portion in blowwater and elimination of the effluent produced in wet-acid delinting. In addition, the hydroyzed linters removed during buffing have potential value in ethanol production and as an animal feed additive.

The basic dilute acid delining 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 humid areas 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 humid, cold, wet, and high, 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 (70) in 1943, still hold 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. In 1941, Duggar and Cauthen (61) reported that the percentage of cotton bolls infected with "boll rot" or anthracnose was reduced from 11.3 to 5.9% by "charring" the seed coat with concentrated sulfuric acid before planting. Others workers (3, 27, 147, 183) have reported on the beneficial effects of acid delinting for the control of various diseases. Chester (35, 36, 37) found that acid delinting greatly reduced the incidence of mechanical damage in the 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 widespread 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 mercurl seed treatments in control of the prevalent seedling disease organisms in the area, Gliocera psossypii and Fusarium moniliforme.

The general experience has been that acid delinted seed do not store as well as gin-run and mechanically delinted seed. The mechanical damage done by acid delinting on germination and emergence, the initial quality of the seed delinted appears to be the controlling factor. Seed low in vigor and with a high incidence of mechanical damage are more drastically affected by acid delinting than high quality seed (51).

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 have been reported by Minton and Quisenberry (121). On the other hand Marani and Amirav (111) stated that acid delinting improved and accelerated germination and emergence by increasing the permeability of the seed coat, and Garber and Hoover (68) reported that acid delinted seed produced stands similar to those produced by mechanically delinted seed. Even though 13% less seed were planted. Bourland and Ibrahim (24) evaluated three methods of acid delinting - dilute acid, concentrated acid, and water-plus acid - in a combination involving two soil types, optimum and suboptimal temperatures, and several soil moisture tensions, the acid delinted seed produced better than flame delinted and ginned seed. The results from Helmer's studies are shown in Figures 11 and 12.

**Conditioning**

Cottonseed are conditioned - cleaned, graded and treated - to the extent possible after delinting to prepare them for marketing. The poor flowability characteristics of acid-delinted 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, ginned seed by cylindrical screen length/width separators but usually not enough to meet...
certification standards for cocklebur contamination (28, 119). 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. Despinned cocklebur can be completely removed with a gravity separator because they are much lower in density than cottonseed. A very high percentage of cocklebur can also be removed with a length grader because they are generally longer than cottonseed (119). Most importantly, 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 (5, 35, 36, 109, 111, 175) and well documented in the last 15-20 years (10, 52, 65, 73, 89, 93, 101, 122, 129, 167, 168, 170, 180). The subject is discussed by Tupper and Kunze (169) in a separate paper for this symposium and has been extensively reviewed by Tupper (167) and Tupper et al. (168) in previous papers. Here I will only briefly summarize the detailed studies made in our laboratory by Gregg (73) in 1968-69.

Kinetin lots of cottonseed representing the important varieties in the Mississippi Delta area were acid delinted with wet-acid processes and then density separated. Seed gravity graded into 10 density fractions according to discharge position from a gravity table separator. Standard bulk density of the density fractions over all lots ranged from 13 lb./bu. to 47 lb./bu. (Figure 13). 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 quality seed.

Presently, the gravity table is the most practical machine for density separation and upgrading of acid delinted cottonseed. The aspirator, especially the fractionating aspirator, does separate the seed on the basis of density but not with the precision of the gravity table (103).

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 processed in cases where there is an adverse reaction to some of the systemic insecticides. Packaging has no effect on seed quality unless seed moisture content is high and the packages relatively impervious to diffusion of water vapor.

Storage

The total storage period for cottonseed encompasses three distinct phases. The first phase is seed cotton harvested at 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. Considerable deterioration of the seed can occur during the moisture content of the seed cotton is relatively high and heating occurs in the mass of seed cotton. Sorensen et al. (see Colwick, 51) determined the following "safe" storage periods for seed cotton at various moisture contents packed at densities of 7-12 lb./cu. ft.

<table>
<thead>
<tr>
<th>Seed Cotton Moisture (%)</th>
<th>Safe Storage Period (Days)</th>
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<tr>
<td>8-10</td>
<td>30</td>
</tr>
<tr>
<td>10-12</td>
<td>20</td>
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<td>12-14</td>
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<td>14-15</td>
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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 the 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 manage seed until December at temperatures at least 12°F 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 by Baskin (12) in a separate paper for this symposium.

Good quality conditioned, packaged cottonseed store exceedingly well - much better than other kinds of oil seeds. Simpson (150) found that sea-island and upland cottonseed deteriorated rapidly after 2 years in "ordinary storage" at James Island, S. C. Seed at 8% moisture stored for 2 years in airtight containers and stored for 25 years. Many samples germinated about 4% after 25 years. The oldest sample that contained germinable seed (6%) had been in storage for 25 years. Many samples 15-20 years old germinated above 40% - a few above 80%. Stewart and Duncan (159) brought the latter study up to date in 1976. Seed stored in Sacaton, AZ from the year of production ranging from 1925 to 1938 until 1945 under open conditions, then at Knoxville, TN in sealed containers at 21°C from 1945 to 1950, and near 0°C from 1957 to 1974, were evaluated for germination in 1974. The oldest viable seed lots were planted in 1932 and had a maximum germination of 68% in 1974 (after 45 years). Cottonseed stored at College Station, TX in a sealed container at 10°C germinated 92% after 16 years, while seed stored at room temperature in glass and paper envelopes germinated 66% and 8%, respectively, after 9 years (20, Table 3). In California, 17% samples of seed with average germination of 84% were stored for 10 years at Shafter in a metal warehouse (165). Average germination after 10 years was 15%.

The general experience of seed companies is that good quality cottonseed deterioration 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 (161).

Seed Quality

The quality of a lot of planting seed is determined by a number of factors and 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 and uniformity of the 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 and uniform procedures such as field and facility inspections, one variety seed farms, gins, and storerooms. The several steps of delinting procedures in use that are adequate for conditioning gin-run seed in a readily flowable, singulated product which can be cleaned, density graded, uniformly treated, and planted with consider-
able 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 to cottonseed 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 lapse in quality control, poor management, and/or inadequate facilities. The latter two problems are well known: indeterminate habit of the cotton plant, which interferes with the best and most consistent results.

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 the cotton grower which has made possible the large quantities of cottonseed needed for planting in an efficient manner, and which has made possible the resolution of other problems which has accompanied the germination/vigor problem as discussed in previous sections of this paper.

"Getting a Stand" was the second of 20 areas considered in the 1961 report of the Research and Development Committee (RDC) of the National Cotton Council of America in the early 1960s. Tharp (162) pointed out that, "the problems connected with "getting a stand" spread across all phases of cotton production" and, "a serious challenge to the research workers in all the 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 biochemical/biological mechanisms involved in cold tolerance, and resistance to seeding diseases; prevent or reduce field deterioration of the seed; and to identify and develop chemical means for "preserving" vigor. Tharp's views have been echoed in later reviews and discussions of the cottonseed quality situation (58, 124, 136, 143, 181), 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 is one of the factors that affect stand establishment. Tharp (162) estimated the annual loss attributable to "stand" problems at $150 million in the early 1960s. More recently, Parvin et al. (127) 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 field and quality stages 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, ginning, 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 (8). 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 days and a final count after 12 (20-30C) or 8 days (30C). The Rules for Seed Testing (8) state that samples which do not respond to the usual method should be placed in a controlled environment that is thoroughly wet, after which the excess moisture is blotted off. The latter recommendation is based on a suggestion by Toole and Drummond (163) in 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 tests results even at the laboratories that are rather commonplace with the result that retesting is required. Seedsmen confronted with widely differing test results from different laboratories or the same laboratory have a rather shaky basis for labeling of seed lots.

Difficulties in germination testing of cottonseed have long been noted. Toole and Drummond (163) reported that seed below 10% moisture content appeared to "mold" badly during testing, while seed at 5-6% moisture often exhibited some hardseedness which interfered with germination testing. They felt that conditions contributing to rapid germination produced the best and most consistent results.

Weir (178) and Stanway (155, 156) compared the germination of many samples of cottonseed at 20-30C and 30C temperatures and concluded that while final germination percent was not different at the two temperatures, germination was "completed" 2-5 days sooner at the higher, constant temperature. Arndt (4) and Bohorquez (21) have also reported that the optimal germination temperature for cottonseed is in the range 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 1960s.

McWilliams (115) 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 (134) 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 cottombelt laboratories would improve the uniformity and reliability of germination test results for cottonseed. Additional research is also needed to determine the effect of substrate moisture conditions 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 immediate judgments of seed quality and im-
portant decisions based on these judgments. Methods are available for rapidly determining moisture content, contaminants, and even mechanical damage. However, seed vigor, which 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 that will respond to natural conditions. 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 seedlings. The seedlings are 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 (13, 117). Experienced analysts can obtain reliable estimates of germination in 8 to 16 hrs. The tetrazolium test is described and discussed by Baskin (13) in a separate paper of this symposium.

More recently there has been considerable interest in quick tests for viability based on the electrical conductivity of pre-conditioned seed or seed exudates (2, 23, 25, 86). This approach is based on the work of Presley (135), among others, which demonstrated a relationship between "protoplast" permeability and seed quality. The electrical conductivity or current flow methods are apparently identifying very high or low quality seed, but are often quite unreliable in predicting germination of seed in the medium quality range. McDaniel (112) described a somewhat different method for estimating germination of cottonseed based on exudation of materials. Seed were soaked in water at 150-160°F 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 1940s, Hoffpaur et al. (84, 85) found that germination percentage decreased as the percentage of free fatty acids increased. Individual seed with over 1% free fatty acids (3% in extracted oil) did not germinate. They recommended that cottonseed saved for planting purposes have a free fatty acids content of less than 1%. On the other hand, it was found that the concentration of specific fatty acids was a more reliable parameter of quality than total free fatty acids. In any event, free fatty acids are only a very rough index of quality. A few badly deteriorated seed in a sample may produce an alarmingly high free fatty acids concentration although the rest of the seed germinate vigorously - or not at all - even though free fatty acid concentration is below 0.5%.

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 (7). The reasons for the deficiencies of the test have been discussed in detail by Schenck and associates (54, 56, 57, 58). Basically, the deficiencies of the standard germination test derive from the sources of error present in the philosophy of germination testing has been and is dependent on test procedures and conditions as to maximize result. 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 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 is not to say that the test is 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 similar 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 differences reflect different degrees of deterioration - or vigor - among the lots. Interpretation of the germination test focuses on loss of the capacity to germinate. The lesser consequences of deterioration 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 in Table 1. Samples from 50 commercial lots of cottonseed labeled 80% germination were collected in the spring of 1967. The seed were tested for germination and 34 samples with actual germination between 70 and 100% 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% to less than 40%. Twenty seven samples emerged below 60% or higher, while 14 samples emerged below 60% or 5% below. Emergence percentages in the mid-May plantings were higher but 5 samples still emerged below 60%. Farmers who purchased the low emergence lots were surely disappointed and most likely blamed the poor stand or failures on the weather.

Seed vigor which has been a much researched and somewhat controversial area for the past 20 years (26, 55, 58, 71) 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. Two years ago the Vigor Test Subcommittee of the Association of Official Seed Analysts 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 to be especially important in field emergence and stand establishment (116, 19, 79, 55, 58, 71). However, several investigators (18, 54, 89, 128, 137) have presented evidence that the quality, i.e., vigor, of cottonseed planted can also affect plant growth, development and yield. Peacock and Hawkins (128), for example, found that seed source affected lint yield in 10 varieties of cotton even though yields 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 field conditions, Mahdi et al. (78) 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. (110) modified the well known soil cold test for corn seed for use on cottonseed. Seeds were planted in sand and incubated at 60 C for 4 days, followed by 4 days at 30 C, after which the percentage of normal seedlings was determined. The test differed from others among the test procedures and conditions so as to maximize result. Secondly, the test methodology - including interpretation criteria - do not adequately take into account the progressive nature of seed deterioration.

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The electrical conductivity of oxudates or leachates from cottonseed has been used to assess vigor as well as to predict or estimate germination (19, 74, 86, 135). Results have been mixed. The tetratium test discussed previously as a quick test for viability is also used to evaluate vigor (7, 11, 13, 56). It is a very powerful and reliable test in the hands of an experienced quality assurance specialist.

The most widely used vigor tests for cottonseed are the tetratium test and the cool germination test, i.e., Texas Cool Test (7, 11, 13, 179). 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 1/4 in. or longer (hypocotyl and radicle) is determined after 12 days, respectively, for acid delimited and mechanically delimited seed. The tetratium and cool germination tests were selected for refinement and standardization by the Association of Official Seed Analysts in 1974 (7).

Substantial progress has been made in refining and standardizing the tests and detailed test procedures will be published in 1982.

Other methods which have been developed, used, or advocated for evaluating cottonseed vigor are based on seedling vigor classification criteria (7), rate of seed respiratory responses following accelerated aging (11, 19, 22, 57), and germinative responses following rapid release of a vacuum pulled over immersed seed (26, 117).

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

Dormancy in cottonseed is manifested as the complete failure of seed to germinate when planted under conditions favorable for germination, i.e., 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.

In 1935, Simpson (149) noted that seed from freshly opened bolls (1-5 days) of several upland varieties remained ungerminated and persisted 21 to 36 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 storing in dry, fresh, ungerminated seed for months practically eliminated the dormant condition. Sai and Reeder (87) also found that dormancy was most intense in seed extracted from freshly opened bolls and dissipated 21 to 36 days after boll opening. The intensity of dormancy also appears to increase as date of boll opening increases (47).

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 germinating them at 30C rather than 20-30C. Taylor and Lankford (161) suggested that a type of "secondary" dormancy which persisted for 1 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, i.e., the seed coat prevents water seeds readily absorb water. Rather, this type of dormancy appears to be related to inhibition of germination by abscisic acid (ABA) (53, 75). 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 (53, 158). Helmer and Abdel-Al (81) found that dormancy in Deltapine 15 cottonseed was most intense (0% germination) 40 days after anthesis (dpa) and was expressed as early as 10 days after boll opening a few days later. Since excised embryos germinate in the later stages (15, 62), ABA is probably concentrated in the seedcoat. Although Trellese et al. (164) suggested that the post-germination mechanism of ABA inhibition of germination should be revised, they felt that the concept that ABA prevents vivaipry should be preserved.

In his studies of seed dormancy in Deltapine 16 cotton, Berkey (15) found that dormancy was most intense about 48 dpa - the boll cracking stage. Some seed remained ungerminated for 10 weeks after 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 combination were not any more effective than distilled water. Seed from bolls detached from the plant 30 dpa and "cul­
tured" for 10 days in White's solution germinated above 88% as compared to 0% for seed from 40 day bolls. Seed extracted from 40 day bolls germinated 50% in atmospheres of 60 or 100% oxygen as compared to 0% 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. Dormancy 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 or mechanism of dormancy in cotton is water impermeability of the seed coat or hardseededness (45). Hardseededness has been reduced to a very low level in most 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 malicious species. Lee (104) 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. For example, found that oxidative processes during ripening are necessary for development of seed coat impermeability. Exclusively of oxygen during this state increased permeability and prevented "cementing" together of the various layers of the seed coat. Hardseededness can be overcome by time, mechanical and acid treatments and other treatments (160). 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. The programs designed to take full advantage of the quality upgrading capacity of density separators and to identify and eliminate quality defects should 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 the idea of rigorous 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 and associates (39, 40, 43) and others (17, 50) on chilling injury to cottonseed during imbition 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 poor seedlings, efforts have been made to improve germination and emergence of cottonseed at cool temperatures through various conditioning or desensitizing treatments. Seed imbibed at 10-31°C for several hours for delayed by delayed germination and emergence, and response to temperature reductions in seed quality. Follow-up work (42, 46) demonstrated that hardseededness has been reduced at the expense of increased rate of germination and early seedling growth in the laboratory but not in the field (176, 177). Similar results were obtained in field conditions (39, 144).

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 prizing as reported by Baskin et al. (82, 83) for “invigorating” seed are especially interesting approaches. The permeation or diffusion techniques utilizing organic solvent systems to inplane phytoactive chemicals in seed also need to be further evaluated for cotton (77, 95).

Singh and Singh (153) reported that pre-planting soak treatments of G. aboreum seed with succinic acid (0.01%) increased stand, plant growth, and yield. Calcium treatment of field deteriorated cottonseed produced seedling's that were healthier and more vigorous than those from untreated seed. More recently, McDaniel and Taylor (114) found that treatment of Pima cottonseed with buffered adenosine monophosphate improved germination and emergence. The benefits of the AMP treatment were greatest under disease or cold stress conditions. Gas plasma (glow discharge) radiatation of cottonseed increased rate of germination and early seedling growth in the laboratory but not in the field (176, 177). The effects of the radiation treatments can probably be attributed 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 seed of cottonseed (100), some efforts are underway to improve the planting quality as well. There is genetic variability in cotton for tolerance to low temperature during germination (135) which might be related to isocitrate activity (141, 142).

El-Zik and Bird (63) reported that final seedling stand was inherited and that improvements in this important characteristic through breeding appeared to be possible. In a somewhat different connection, Bird et al. (17) have used resistance of the seed to mold and a reduced rate of germination at 13°C as key traits for selection for multi-adversity resistance including resistance to stresses in the seedbed.

In 1959 Christiansen and Moore (45) pointed out the potential of hardseededness in cotton for maintenance of seed quality. Follow-up work (42, 46) demonstrated that hardseededness was associated with increased rate of germination and reduced field deterioration of the seed. One variety or strain (L. 901) of cotton with a high degree of hardseededness has been released. The demonstrated benefits of hardseededness have stimulated similar efforts for other kinds of seed (112, 133). McDaniel (113) suggested that selection for a thicker palisade layer in the seed coat of cotton seed might provide a mechanism 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 (171, 172) in simulation of cotton germination and emergence should be helpful.

Summary

The quality of cotton planting seed can be affected by handling 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 seed moisture levels, and their interactions. These losses in quality can be minimized by proper selection and placement 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.

Literature Cited


Table 1. Incidence of mechanical damage in 738 lots of cottonseed planted in Mississippi in 1965. From Helmer (80).

<table>
<thead>
<tr>
<th>Mechanically Damaged Seed (%)</th>
<th>No. of Samples</th>
<th>% of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Damage Level</td>
<td>--------------</td>
<td>------------</td>
</tr>
<tr>
<td>0-5%</td>
<td>233</td>
<td>31</td>
</tr>
<tr>
<td>5-10%</td>
<td>101</td>
<td>41</td>
</tr>
<tr>
<td>10-15%</td>
<td>139</td>
<td>19</td>
</tr>
<tr>
<td>Over 15%</td>
<td>65</td>
<td>9</td>
</tr>
</tbody>
</table>

Table 2. Effect of mechanical picking on the incidence of cracked seed and germination in Carolina Queen cotton. From Colwick et al. (51).

<table>
<thead>
<tr>
<th>Year</th>
<th>HP</th>
<th>Picker Treatment</th>
<th>% Visibly Damaged Seed</th>
<th>% Germination</th>
</tr>
</thead>
<tbody>
<tr>
<td>1965</td>
<td>0.1</td>
<td>FDO</td>
<td>6.3</td>
<td>20.8</td>
</tr>
<tr>
<td>1967</td>
<td>0.4</td>
<td>S1ST</td>
<td>4.1</td>
<td>7.7</td>
</tr>
<tr>
<td>1968</td>
<td>0.4</td>
<td>S2ST</td>
<td>3.9</td>
<td>7.7</td>
</tr>
</tbody>
</table>

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 2330 r.p.m., respectively.

2/ Harvesting delayed until February because of inclement weather.

Table 3. Germination % of cottonseed stored under different conditions at College Station, TX, for periods up to 20 yrs. From Bockhold et al. (20).

<table>
<thead>
<tr>
<th>Condition</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>100-Sealed</td>
<td>4</td>
</tr>
<tr>
<td>Pen. Temp.</td>
<td>5</td>
</tr>
<tr>
<td>Sealed Glass</td>
<td>6</td>
</tr>
<tr>
<td>Paper Env.</td>
<td>8</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Date</th>
<th>No. Lots with Emergence % of</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mid-April</td>
<td>80+ 79-79 69-69 50-59 40-49 40-</td>
</tr>
<tr>
<td>Mid-May</td>
<td>6</td>
</tr>
</tbody>
</table>


Figure 1. Effects of seed cotton moisture content (left) and ginning rate (right) on mechanical damage to cottonseed. From Watson and Helmer (174).

Figure 2. Relationship between seed damage during ginning and reduction in germination percentage. From Watson and Helmer (174).

Figure 3. Effect of static loading with seed oriented longitudinally (end-to-end) on germination of cottonseed at 4, 8, and 12% moisture content. From Colwick et al. (51).

Figure 4. Effect of impact velocity and seed orientation on seed coat crackage of Coker 100 cottonseed over all moisture contents (4 to 12%). From Clark et al. (48).
Figure 5. Effect of number of impacts at two impact velocities on seed coat crackage of Stoneville 213 cottonseed at 10% moisture content. From Clark et al. (48).

Figure 6. Effects of static and dynamic energy absorption on germination of Stoneville 213 cottonseed at 12% moisture content. From Colwick et al. (51).

Figure 7. Effects of seed damage level over all treatments on germination and cold test emergence % of cottonseed after 0 - 12 months warehouse storage. From Colwick et al. (51).

Figure 8. Generalized flow chart for commercial gas-acid delinting of cottonseed. From Jones (90).

Figure 9. Generalized flow chart for the conventional wet-acid delinting process for cottonseed. From Jones (90).
Figure 10. Generalized flow chart for dilute-sulfuric acid delinting of cottonseed. From Jones (90).

Figure 11. Effect of delinting method on rate of moisture absorption by cottonseed. From Helmer (79).

Figure 12. Effects of delinting method on germination and emergence of cottonseed in two soil types at 2 bars moisture tension at 20 and 30°C. A.D., F.D., and G.R. refer to acid delinted, flame delinted and gin run seed, respectively. From Helmer (79).

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 (73).
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 (73).

Table 2. Linear correlations of fiber and yarn properties in the American Pima breeding nurseries at Phoenix, AZ, 1959 and 1979.

<table>
<thead>
<tr>
<th>Property</th>
<th>50% span fiber length</th>
<th>Uniformity ratio</th>
<th>T1 fiber tenacity</th>
<th>E2 fiber elongation</th>
<th>Micronaire</th>
<th>Yarn tenacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5% span fiber length 1959</td>
<td>0.89***</td>
<td>-0.26*</td>
<td>0.39***</td>
<td>-0.41**</td>
<td>-0.41**</td>
<td>0.31**</td>
</tr>
<tr>
<td>2.5% fiber length 1979</td>
<td>0.49**b</td>
<td>-0.17*</td>
<td>0.07a</td>
<td>-0.15a</td>
<td>-0.21**</td>
<td>0.12</td>
</tr>
<tr>
<td>50% span fiber length 1959</td>
<td>0.17</td>
<td>0.42**</td>
<td>-0.30**</td>
<td>-0.32**</td>
<td>0.44**</td>
<td>0.28</td>
</tr>
<tr>
<td>50% fiber length 1979</td>
<td>0.76**b</td>
<td>0.27**</td>
<td>-0.09</td>
<td>-0.01a</td>
<td>0.25**</td>
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<tr>
<td>Uniformity ratio, UR 1959</td>
<td>0.15</td>
<td>0.24*</td>
<td>0.18</td>
<td></td>
<td>0.16</td>
<td>0.22</td>
</tr>
<tr>
<td>1979</td>
<td>0.25**</td>
<td>0.03</td>
<td>0.15</td>
<td></td>
<td>0.21**</td>
<td></td>
</tr>
<tr>
<td>T1 fiber tenacity 1959</td>
<td>-0.24*</td>
<td>-0.23*</td>
<td>0.67**</td>
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<td>0.67**</td>
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</tr>
<tr>
<td>1979</td>
<td>-0.34**</td>
<td>0.00</td>
<td>0.29**b</td>
<td></td>
<td>0.29**</td>
<td></td>
</tr>
<tr>
<td>E2 fiber elongation 1959</td>
<td>0.32**</td>
<td>-0.17</td>
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<tr>
<td>1979</td>
<td>0.15</td>
<td>-0.09</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Micronaire 1959</td>
<td>-0.42**</td>
<td>-0.12a</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1979</td>
<td>-0.50**</td>
<td>-0.12a</td>
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</tr>
</tbody>
</table>

*, ** Significant within given year at the 0.05 and 0.01 levels of probability, respectively.

a, b Significant difference between years at the 0.05 and 0.01 levels of probability, respectively.

Table 3. Relative contributions of fiber properties for predicting yarn tenacity in 1959 and 1979.

<table>
<thead>
<tr>
<th>Property</th>
<th>R²</th>
<th>Increase in R²</th>
<th>Property</th>
<th>R²</th>
<th>Increase in R²</th>
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<td>T1 fiber tenacity</td>
<td>0.0446</td>
<td>0.0445</td>
<td>T1 fiber tenacity</td>
<td>0.0837</td>
<td>0.0837</td>
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<tr>
<td>Micronaire</td>
<td>0.6176</td>
<td>0.0733</td>
<td>Micronaire</td>
<td>0.1271</td>
<td>0.0194</td>
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<td>Uniformity ratio</td>
<td>0.6527</td>
<td>0.0349</td>
<td>Uniformity ratio</td>
<td>0.1290</td>
<td>0.0039</td>
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<tr>
<td>50% span fiber length 1959</td>
<td>0.5588</td>
<td>0.0062</td>
<td>50% span fiber length 1979</td>
<td>0.1137</td>
<td>0.0300</td>
</tr>
<tr>
<td>2.5% span fiber length 1959</td>
<td>0.5870</td>
<td>0.0281</td>
<td>2.5% span fiber length 1979</td>
<td>0.1407</td>
<td>0.0117</td>
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<tr>
<td>E2 fiber elongation</td>
<td>0.5873</td>
<td>0.0003</td>
<td>E2 fiber elongation</td>
<td>0.1409</td>
<td>0.0002</td>
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