I have chosen this particular title for my discussion to emphasize the objective we should strive for as seedsmen. We are interested in providing as high a quality product as possible in terms of vigor and stand potential, rather than just distributing seed that meets some particular germination standard. As we are all aware from past experience, germination percentages are inadequate for indicating vigor of particular lots of seed, and we may well anticipate the time when germination standards are supplemented by some measurement of vigor to aid consumers in their selection of seed.

Our consumers, to an ever-increasing degree, will expect and demand higher quality seed as a means of insuring stands over a wider range of conditions. With advances in all phases of agriculture, it is imperative that we in the seed industry keep pace by utilizing the available knowledge in providing a high quality product for our consumers.

Taking as our objective the production and distribution of seeds with maximum vigor, let us review those factors which influence seed quality and the procedures we must follow to maintain this quality in our product until the seed is ultimately used by the consumer.

The retention of vigor in any particular seed crop depends on the environment under which it is produced, the method of handling during harvest and processing, and the environmental conditions to which it is subjected during the storage period. Seeds of different species, as well as varieties within a species, will vary both in initial vigor and rate of decline, but the same general practices for preserving maximum vigor apply to all field seeds.

---

1/ Dr. Rogers is Director of Agronomic Crops; breeders and growers of vegetable and field seeds, Asgrow Texas Company, San Antonio, Texas.
A seed crop attains its highest quality at the time of full maturity, when the seed reaches maximum dry weight and the principal process thereafter is loss of moisture. From this point of full maturity, the vigor of the seed crop can only decline, and it is our objective to slow this decline as much as possible. The extent of our success will determine the quality of our product. Every step taken in harvesting, processing and storage will have some effect on reduction of quality, and it behooves us to use the best, practical procedures in preserving vigor.

Moisture content of the seed from the time of full maturity must receive primary attention, and practices followed should be directed toward lowering the moisture content to a level where decline of vigor is minimized. Harvest at full maturity is impractical for most crops because of the high moisture content, although some, such as corn, can be harvested essentially at this stage and artificially dried.

Since most crops must dry down to safe harvesting moisture in the field so that harvesting machinery will not damage the seed, weather conditions in the area of production are important in determining decline in quality while the seed is still in the field. Excessive humidity during the period from full maturity to harvest is especially damaging and, in some cases, can result in complete deterioration before the seed can even be harvested. Because of this, production areas should be chosen where favorable weather conditions may be anticipated prior to and during the harvest period. Dessicants and defoliants may also be used to hasten field drying and permit earlier harvest.

Extreme care should be exercised in harvesting and processing to minimize mechanical damage to the seed. In crops such as corn, sorghum and soybeans, results indicate that physical damage is minimized if they are threshed and processed at moisture contents of 14 to 16%. In other words, the seed must be allowed to attain relative dryness in the field, but not to the point of safe storage. Handling at moisture contents of 18 to 20% causes damage because of excessive
moisture, while cracking and breaking become severe at lower moisture contents of 10 to 12 %. Apparently, this intermediate moisture content of 14 to 16 % reduces damage by rendering the seed coat and other parts of the seed more flexible.

A partial reversal in procedure will be required to permit harvesting and processing at this optimum moisture level of 14 to 16 %. Under standard procedures, seed crops are allowed to dry in the field until the seeds are at a safe storage level, or the crop is harvested at an unsafe moisture level and dried before processing. If seed remain at the optimum level for processing, 14 to 16 %, vigor will decline rapidly, while if they are dried immediately after harvest considerable physical injury will result at processing. The more desirable approach, from the standpoint of quality, is to harvest and process as received at the 14 to 16 % level, followed by immediate drying to the 10 to 12 % range. Such a procedure would probably require modifications in most plants to permit processing to keep up with receiving, but higher quality would be insured by processing at the optimum moisture level while still reducing the seed moisture to a safe storage level soon after the seed is brought in from the field. For field crops, a drying temperature of 100° F is recommended for seed moisture between 10 and 18 %. With moisture levels above 18 %, 90° F should be used, while on seed below 10 % a temperature of 110° F is safe.

Seed quality may also be affected by pathogenic organisms or noxious insects. Appropriate seed treatments are available for controlling both diseases and insects, however, and damage can usually be avoided with adequate control measures. Field treatment is sometimes essential, as well as treatment of stored seed with both fungicides and insecticides. When proven recommendations are followed, these treatments are unlikely to reduce vigor and in many instances will increase the possibility of better stands.

These practices discussed so far relate to the preservation of vigor prior to the point of seed storage. It is obvious, however, that any success in maintaining
vigor in stored seed will depend to a great extent on its condition at time of storage, and optimum practices during production, harvesting and processing are required to insure a minimum decline in vigor up to the time of storage. We should, therefore, make every effort to follow those practices that will maintain maximum quality during all steps prior to storage.

Before discussing the various precautions and procedures which must be considered in seed storage, let us review briefly the basic concept of a seed and the primary factors which influence seed aging.

Seeds are living organisms, subject to the aging process, even though they are in an essentially dormant state. The rate at which seeds age depends primarily on the process of respiration. Since moisture content and temperature are the two primary factors affecting respiration rate, relative humidity and temperature under which seed are stored determine the speed of the aging process. Moisture content of seed in storage is directly related to relative humidity, since seed of each species reaches an equilibrium with the surrounding atmosphere. Data shown in Table 1 give the moisture content of different field seeds at various relative humidities. As may be readily seen, the moisture content rises noticeably with each 15% increase in relative humidity.

Ample evidence from previous research shows that the higher the relative humidity and, therefore, the related moisture content of the seed, the greater the rate of decline. As a general rule, for each drop of one percent in seed moisture, the period of time before a serious drop in vigor occurs will be doubled. When considered on the basis of relative humidity, each 5% reduction at the higher levels, ranging from 60 to 80%, will approximately double the period before serious deterioration. At lower levels, from 30 to 50%, a 10% reduction in relative humidity will be required to double this period preceding decline. It should be noted that this effect of reducing moisture content of the seed is cumulative, and while reduction from 12 to 11% will double the period before substantial loss of vigor, reduction
from 12 to 10% will increase it by four times. Information of this type, on the effect of seed moisture, stresses the value of any reduction we may accomplish in relative humidities during storage.

Table 1. Absorbed moisture content of field seed in equilibrium with air of various relative humidities at room temperature (approximately 77° F).

<table>
<thead>
<tr>
<th>Relative humidity per cent</th>
<th>15</th>
<th>30</th>
<th>45</th>
<th>60</th>
<th>75</th>
<th>90</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barley</td>
<td>6.0</td>
<td>8.4</td>
<td>10.0</td>
<td>12.1</td>
<td>14.4</td>
<td>19.5</td>
<td>26.8</td>
</tr>
<tr>
<td>Corn</td>
<td>6.6</td>
<td>8.4</td>
<td>10.4</td>
<td>12.9</td>
<td>14.7</td>
<td>18.9</td>
<td>24.6</td>
</tr>
<tr>
<td>Cotton</td>
<td>-</td>
<td>-</td>
<td>7.3</td>
<td>9.1</td>
<td>11.3</td>
<td>19.6</td>
<td>-</td>
</tr>
<tr>
<td>Flaxseed</td>
<td>4.4</td>
<td>5.6</td>
<td>6.3</td>
<td>7.9</td>
<td>10.0</td>
<td>15.2</td>
<td>21.4</td>
</tr>
<tr>
<td>Oats</td>
<td>5.7</td>
<td>8.0</td>
<td>9.6</td>
<td>11.8</td>
<td>13.8</td>
<td>18.5</td>
<td>24.1</td>
</tr>
<tr>
<td>Peanut</td>
<td>2.6</td>
<td>4.2</td>
<td>5.6</td>
<td>7.2</td>
<td>9.8</td>
<td>13.0</td>
<td>-</td>
</tr>
<tr>
<td>Rice, Milled</td>
<td>6.8</td>
<td>9.0</td>
<td>10.7</td>
<td>12.6</td>
<td>14.4</td>
<td>18.1</td>
<td>23.6</td>
</tr>
<tr>
<td>Sorghum</td>
<td>6.4</td>
<td>8.6</td>
<td>10.5</td>
<td>12.0</td>
<td>15.2</td>
<td>18.8</td>
<td>21.9</td>
</tr>
<tr>
<td>Soybeans</td>
<td>4.3</td>
<td>6.5</td>
<td>7.4</td>
<td>9.3</td>
<td>13.1</td>
<td>18.8</td>
<td>-</td>
</tr>
<tr>
<td>Wheat, Hard Red Winter</td>
<td>6.4</td>
<td>8.5</td>
<td>10.5</td>
<td>12.5</td>
<td>14.6</td>
<td>19.7</td>
<td>25.0</td>
</tr>
<tr>
<td>Wheat, Soft Red Winter</td>
<td>6.3</td>
<td>8.6</td>
<td>10.6</td>
<td>11.9</td>
<td>14.6</td>
<td>19.7</td>
<td>25.6</td>
</tr>
</tbody>
</table>

It has also been determined that the higher the temperature at which seed are stored, the more rapid will be the aging process. A general guide for temperature effect is that the period before serious decline in quality will be doubled with each drop of 10° F in temperature.

Since both moisture content and temperature are important factors affecting seed quality, storage conditions with low relative humidities and low temperatures are essential for preservation of maximum vigor.

In dealing with field seeds, where volumes are large and relative unit value low, it is much easier to outline effective storage conditions for preserving
vigor than to develop practical procedures permitting their adoption. Nevertheless, by clearly defining our objective to preserve maximum vigor prior to use by the consumer, we can adjust our procedures in the direction of attaining such a goal.

The exact procedure followed by any individual or firm will depend on their particular situation. Location of the main storage warehouse and period of time before the seed are used will be the major factors determining any approach to the storage problem.

Firms located in cool, dry areas may require no artificial protection whatsoever, since the natural conditions will protect the seed adequately until shipped to another region. In other locations, where conditions are less favorable, varying degrees of protection in storage will be required to maintain seed quality.

The desirability of seed warehouses, as measured by relative humidity and temperature, should be carefully considered in evaluating storage conditions. Environmental conditions at various locations may be important factors in determining location of production centers and warehouses.

Storage conditions are generally considered safe where percent relative humidity plus the temperature in degrees F do not exceed 100. For purposes of illustration, and as a rough evaluation of storage conditions at various locations, let me cite the totals for relative humidity and temperature at several locations in Texas. Such figures have been obtained by totaling the mean relative humidity and mean temperature for a location and, while fluctuation in these two measurements during the year is no doubt important, some general index is provided as a basis for evaluating these locations for seed storage.

At College Station, Texas the total is 150, at San Antonio 133, at Lubbock 121 and at Amarillo 110. Continual improvement in storage conditions is noted as the locations move to the West and North. Field seed could ordinarily be stored safely under natural conditions at Amarillo for a considerable period of time, while at College Station, under natural conditions, deterioration would be quite rapid
after the first year.

Time of storage before use by the consumer will be an important factor in determining any seedsmen's solution of the storage problem. There again, location will be a big factor in deciding how long it is practical to retain seed in storage for distribution to consumers. Firms located under more favorable natural conditions might plan for longer storage periods than those under less favorable conditions. In any case, the period of time for which seed are to be kept for commercial distribution should be determined, to provide a basis for developing storage which will insure seed of good vigor for this chosen period of time. As an example, storage conditions have been developed for certain vegetable seed which insure retention of vigor and viability for at least 3 years at 85°F.

As a general approach for field seeds, particularly in areas where natural conditions are not too favorable, a practical procedure might be to use seed for no longer than the second year after production. In most instances seed would then be stored for a maximum period of 18 to 20 months, and through only one entire summer. Under certain conditions new seed might be required annually. Production and distribution of most varieties in such that more than a 2-year's supply would seldom be produced, so that all seed from a particular year would be distributed either the first or second year after production. In fact, more than 75% of most varieties would usually be distributed the first year after production.

Seed moisture at time of storage is an important factor to consider with all field crops, and a general recommendation would be in the range of 10 to 12%. As previously indicated, this moisture content should be attained as rapidly as possible after harvest, in accord with practices that will not otherwise damage the seed. The exact safe moisture level will again depend on the species or variety, condition of the seed crop, storage environment and the required period of safe storage.

The importance of seed moisture, relative humidity and temperature
emphasize a few precautions to be observed by all seedsmen. Moisture samples of each seed lot should be taken as a basis for all operations - harvesting, processing, drying and storage. In particular, moisture content should be checked before any seed is put into storage. Moisture content and temperature of seed in bulk storage must be carefully checked. Relative humidity and temperature records should be obtained throughout the year in the warehouse, to provide accurate information on the conditions under which the seed is stored. Records of this type should serve as a guide in storage and distribution practices.

With these general thoughts in mind, let us consider some of the possible storage alternatives which will enable us to provide high vigor seed to our consumers.

Seed vigor can frequently be retained during initial storage periods by keeping the seed in bulk containers where there is little, if any, change in moisture content. Bins or boxes may be used for this purpose, and the major precaution is to be sure that moisture contents are at a safe level at time of storage. In crops such as sorghum, corn, soybeans or cotton 11% or less would be highly desirable.

Aeration is sometimes an effective supplement to bin storage, since it may be used, under appropriate weather conditions, for either drying or cooling. Aerated bins may actually represent improvements over some present situations, where drying or cooling of seed after receiving depend on gradual adjustment to existing relative humidities and temperatures. Such bins have definite limitations for removing moisture, however, as the rate of removal is slow and they are dependent on weather conditions for successful operation. Atmospheric relative humidities and temperatures limit the possibilities for drying and cooling, although heated air may sometime be used to speed up the drying process. Drying and cooling may also be hastened by operating fans during periods of low relative humidity and temperature and stopping operation when humidities or temperatures are undeniably high.
With crops such as cotton, where the seed is quite bulky, aerated bins have been effectively used for cooling. Texas Agricultural Experiment Station results show that cotton seed temperatures can be lowered from 85°F in September to below 60°F by November. No drop in germination was reported for a 7-month period after storage, if the seed were 12% or below at the beginning of storage. Aeration was not effective in maintaining germination or preventing an increase in free fatty acid content when seed were high in moisture and fat acidity at the time of storage.

Aerated bins are also used for storage of sorghum and corn immediately after harvest, and under certain conditions have merit, depending on the moisture content of the grain and atmospheric temperatures. For example, sorghum seed harvested on the High Plains of Texas in October, when temperatures are not excessively high, can be handled reasonably well with aerated bins. Such bins in South Texas will ordinarily not be as effective in preserving quality, because sorghum seed is harvested during July or August when temperatures are high.

In any case, a more certain drying procedure, than the use of aerated bins alone, will usually be required to reduce the rate of seed decline. Such bins should usually be considered as a holding operation, and not as the primary means of reducing seed moisture to a safe level. Once high quality seed has been reduced to a safe moisture level, 11% or below, and storage temperatures range from 60 to 70°F during most of the year, seed stored in bins may be expected to retain good vigor into the second season.

Storage rooms with rigid control of relative humidity and temperature offer a method of keeping seed from year to year. Cotton, corn and sorghum, with respective moisture contents of 6.2, 9.5 and 7.6%, have been successfully stored at College Station, Texas at 50°F for 22 years. Cotton is still germinating at 89%, corn at 58% and sorghum at 95%. Similar samples stored at room temperature (75 - 80°F) retained some viability for periods of 7 to 11 years.
because of its higher moisture content, deteriorated much more rapidly than either cotton or sorghum. Of the latter two, sorghum maintained the highest viability.

The control of humidity and temperature in storage rooms is not ordinarily practical for large volumes of field seed. It is used effectively for foundation seed stock storage, where seed may be retained for several years and the quantities are relatively low. Carry-over seed may sometimes be satisfactorily stored during the summer months in refrigerated warehouses, if the relative humidity is kept at a level of 50 to 60%. Such a procedure is expensive, but may sometimes be practical where carry-over volumes are small and cold storage is convenient and economical. At least such a system is practiced in some of the southern states where carry-over seed under normal conditions is subjected to several months of high temperatures.

The methods so far discussed pertain to the preservation of seed quality in places of somewhat permanent storage - bins, boxes, warehouses or controlled storage rooms. Seed vigor can be retained in such storage either through location in a favorable environment, or by artificial control of seed moisture and/or temperature. Once seed is moved from permanent storage, into normal trade channels, such controls are no longer operative.

The problem then becomes how to control one or more of the factors influencing decline in vigor after seed leaves the place of permanent storage. Since effective temperature control is impossible after seed is released for distribution, recent efforts to preserve seed quality have been directed toward the development of individual containers which provide complete or partial control of moisture content.

Hermetically sealed tin cans, which provide a complete barrier to movement of moisture vapor, are being used successfully for vegetable seeds such as tomato, onion, cucumber and pepper. Such containers are possible for crops with a high unit value and relatively low volume.
Extreme care must be practiced in the use of sealed containers for storing any kind of seed. The seed must be dried to a sufficiently low level, as determined by previous experiments, to insure no serious decline in vigor during the period of storage. As a general rule, crops may be safely stored in sealed containers if they are reduced to a moisture content in equilibrium with relative humidities of 15 to 20%. This equilibrium will be reached between 4 and 8%, the exact moisture content depending upon the particular species. For example, corn and sorghum approximate 8% at these relative humidities, while cotton and soybeans, which are high in oil, are around 6%.

Research and experience with sealed containers for vegetable seed has proved that properly conditioned seed can be safely stored, with no appreciable loss of vigor, for periods of 3 years at a temperature of 85°F. Since moisture content is controlled, and temperatures in areas of use are seldom above 85°F for any long period of time, seed in sealed containers can be distributed through normal trade channels with the assurance of the product retaining high quality for at least 3 years after initial storage. Let me emphasize again that success of such a procedure is dependent on proper moisture content at storage and a complete moisture seal by the container. In fact, experimental results have definitely shown that seed stored in a sealed container, at an excessive moisture level, deteriorates more rapidly than if stored where no moisture barrier existed.

The reduction of seed moisture to a safe level, 4 to 8%, and its subsequent control through the use of sealed containers, as practiced with vegetable seeds, has proved a successful method for preserving seed vigor. By controlling moisture content with the packaging container, the initial moisture level can be retained regardless of the environmental conditions of the area into which the seed is shipped for distribution. The method also provides for adequate seed vigor over the entire period of time during which the seed will ordinarily be offered to consumers.

Sealed, moisture-proof tin cans have proved effective for certain small-
seeded vegetable crops, but other types of containers are required for field seeds with large volume and low unit value. The general principle, of controlling moisture content by the use of special containers, may also be applied to field seeds. Recent efforts, therefore, have been directed toward the development of practical, moisture-resistant containers for field seeds.

A number of different moisture-resistant bags are now available and, although they differ in materials and construction, all are designed to protect against transfer of moisture vapor. These moisture-resistant bags usually have several plies of paper, supplemented with such materials as aluminum foil, polyethylene or asphalt to serve as moisture barriers. The degree of moisture resistance varies, depending on the kind and quantity of the material and construction of the bag.

Foil laminated bags, which are an inner ply laminated with polyethylene and foil, have proved quite effective in reducing moisture transfer, as have also 3-ply multiwalls with 4 mil poly liners. Multiwalls with 3 and 1 mil poly liners, as might be expected, have proved less effective than those with heavier liners. Bags with asphalt or polyethylene coated paper barrier sheets are also used to protect vigor of some of the lower-priced, less moisture sensitive seeds. Heat seals and valve sleeves are other devices now in use to provide greater moisture resistance to bags which may be used for field seed.

A number of different moisture-resistant type bags are now in use, but additional information is needed to determine the extent of their effectiveness in preserving seed quality. Certainly the rate of moisture transfer can be greatly reduced, with the exact rate depending on the environmental conditions and particular type of bag. Such bags are beneficial when inhibiting a rise in moisture content of the stored seed, but they can be detrimental by slowing down moisture loss when atmospheric relative humidities are conducive to a reduction in moisture content.

Sudan grass and alfalfa stored in multiwall, foil laminated poly coated bags
at 100°F and 90% relative humidity maintained good germination for 90 days, while seed in multiwalls with 4 and 3 mil poly liners showed a noticeable decline. Seed stored in more porous type bags under the same conditions lost their germinating power in 30 to 60 days.

Experiments conducted with onion seed stored at 75°F and 55% relative humidity, using 5 and 10 mil polyethylene bags, showed that good viability was retained for 32 weeks. A moderate decline in viability occurred over a 32-week period when the seed were stored at 75°F and 95% relative humidity. Onion seed in the same type bags, stored at 104°F and either 55% or 95% relative humidity, declined rapidly within 4 to 8 weeks. At the higher temperature, seed deteriorated rapidly because of the much faster change in moisture content of the seed.

These results indicate that moisture-resistant bags, while they slow down moisture transfer, do not eliminate it completely. They cannot, therefore, be utilized with the same degree of safety as can a completely moisture-proof container. With proper usage, however, they do provide opportunities for improving seed quality.

The major precaution, which must be followed in the use of moisture-resistant bags, is to avoid packaging seed with too high an initial moisture content. On the basis of present knowledge, field seed should be dried to at least 11% before placing them in any type of moisture-resistant bag. Excessive deterioration can definitely be expected if such crops as corn and sorghum are packed at 12 to 14% moisture and subjected to temperatures of 70 to 80°F for any appreciable period of time. Seed stored at such moisture levels would decline slower under most conditions if stored in porous bags. With adequate drying before packing, however, seed stored in moisture-resistant bags should maintain better vigor.

In addition to adequate drying before packing, attention must be given to the moisture gain which can occur in these moisture-resistant bags over a long
period of time. If storage conditions are such that moisture content gradually rises above 12 %, care should be exercised in distribution of this seed. Should such a situation prevail, the effect would be the same as if the seed had been packed at too high an initial moisture content.

When moisture content of seed in moisture-resistant bags is in the 12 % range, caution should be observed in subjecting the seed to high temperatures for more than a few weeks. In some areas during the summer, when temperatures are high and relative humidities comparatively low, 50 to 70 % moisture-resistant feature might tend to keep moisture in rather than out. Under such conditions, where moisture-resistant bags inhibit loss of moisture, the rate of seed decline is increased. In any particular situation, these moisture-resistant bags are only more effective when they maintain a lower moisture content than would occur if seed are in equilibrium with the atmospheric relative humidity.

Under normal operating practices, where carry-over seed from various areas is returned to the warehouse for storage, a careful check should be made on moisture content and the period of time the seed has been exposed to high temperatures. Moisture levels of around 11 %, and certainly no more than 12 %, should be maintained to minimize seed decline during the summer months when temperatures are highest.

Moisture-resistant containers, when used properly, are definitely effective in preserving vigor of field seed. The major precaution in using them is to avoid excessive moisture content of the seed by adequate drying before packing and prevention of any undue moisture gain over long periods of storage. Where initial moisture contents are 11 % or below, and little if any gain occurs during storage, it should be possible to preserve reasonable vigor in field seed for an 18 to 20 - month period under most conditions ordinarily encountered by seedsmen.
Summary

Preservation of vigor in field seed, till the time of use by the consumer, should be one of our main objectives as seedsmen. Production under a favorable environment, harvesting and processing at optimum moisture levels for each crop, rapid drying to safe moisture levels of 10 to 12%, storage under low relative humidity and temperature conditions, and the proper use of moisture-resistant containers are all practices which should enable us to attain that goal.

Definite progress has been made in recent years in the improvement of seed quality in our field crops. In particular, progress has been possible in crops such as hybrid corn and hybrid sorghum where new seed is required each year and the unit value is relatively high. I think these crops afford us an example of what we may anticipate for other field crops in the future. The benefits derived from high quality, vigorous planting seed are continually becoming more evident, and consumers will increasingly demand seed of all crops that will insure stands over a wider range of conditions. As planting seed is produced more and more for that specific purpose, rather than being obtained as a by-product of the farm crop itself, we may expect distinct improvement in seed quality of all of our field crops.

Selected References


