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Some Thoughts on Seed Storage

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SOME THOUGHTS ON SEED STORAGE

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During the past 15 years or so, I've written on various aspects of seed storage. In the mid-1970s special and rather detailed attention was given to conditioned or controlled storage of seed. Looking back over these efforts, however, I find that the several aspects of seed storage - including conditioned storage - were not related to each other as they ought to be, and significant aspects of seed storage were neglected. In this article, I hope to overcome deficiences in my previous efforts.

Purpose of Seed Storage

Every seed operation has or should have a purpose. The purpose of seed storage is to maintain the seed in good physical and physiological condition from the time they are harvested until the time they are planted. Seed have to be stored, of course, because there is usually a period of time between harvest and planting. During this period, the seed have to be kept somewhere. While the time interval between harvest and planting is the basic reason for storing seed, there are other considerations, especially in the case of <u>extended storage of seed</u>.

Seed suppliers are not always able to market all the seed they produce during the following planting season. In many cases, the unsold seed are "carried over" in storage for marketing the second planting season after harvest. Problems arise in connection with carryover storage of seed because some kinds, varieties, and lots of seed do not carryover very well.

Seed are also deliberately stored for extended periods so as to eliminate the need to produce the seed every season. Foundation seed units and others have found this to be an economical, efficient procedure for seed of varieties for which there is limited demand. Some kinds of seed are stored for extended periods to improve the percentage and rapidity of germination by providing enough time for a "natural" release from dormancy. For example, seed of some range grass species germinate much better 2 or 3 years after harvest than they do the first planting season after harvest. Some cotton farmers in Texas prefer

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"old" seed because they apparently germinate better at sub-optimal temperatures, i.e., lower temperatures. Breeding lines and germplasm need to be maintained for very extended periods - tens of years - in the seed stage in storage.

Regardless of the specific reasons for storage of seed, the purpose remains the same: maintenance of a satisfactory capacity for germination and emergence. The facilities and procedures used in storage, therefore, have to be directed toward the accomplishment of this purpose.

The Storage Period

Plans and provisions for seed storage are all too often confined to the interval between the completion of conditioning and the beginning of distribution. This "packaged seed" phase is very important in a seed storage program, but it is only one segment of the total period seed are "in storage" (Figure 1). Concentration of the available physical and managerial resources on the packaged seed segment to the neglect of other segments of the storage period often produces disappointing results.

In the broadest sense the storage period for seed begins with attainment of physiological maturity and ends with the resumption of active growth of the embryonic axis, i.e., germination. Seed are considered to be physiologically and morphologically mature when they reach maximum dry weight. At this stage dry-down or dehydration of the seed is well underway. Dry-down continues after physiological maturity until moisture content of the seed and fruit decreases to a level which permits effective and efficient harvest and threshing. This stage can be termed harvest maturity. There usually is an interval of time between physiological maturity and harvest maturity, and this interval represents the first segment of the storage period. Any delays in harvesting the seed after they reach harvest maturity prolongs the first segment of the storage period - often to the detriment of seed quality.

The second segment of the storage period extends from harvest to the beginning of conditioning. Seed in the combine, grain wagon, and bulk storage or drying bins are in storage and their quality is affected by the same factors that affect the quality of seed during the packaged seed segment of the storage period. The third segment of the storage period begins with the onset of conditioning and ends with packaging. The fourth segment of the storage period is the packaged seed phase which has already been mentioned. The packaged seed segment is followed by storage during distribution and marketing, and finally by storage on the farm before and during planting.

The control that a seedsman has over the various segments of the storage period for seed varies from a high degree of control from

SEGMENTS OF THE STORAGE PERIOD FOR SEED

1. Postmaturation - Preharvest Segment - period from physiological maturity to harvest (seed in field).

2. Bulk Seed Segment - period from harvest to packaging (bulk seed in aeration/drying bins, surge bins, etc.).

3. Packaged Seed Segment - period from packaging to distribution (seed in packages in warehouse).

4. Distribution-Marketing Segment - period during distributing and marketing (packaged seed in transit and/or retailer's storehouse).

5. On-Farm Segment - period from purchase to planting of seed (seed in on-farm storage).

Figure 1. Segments of the total storage period for seed.

harvest to distribution, to much less control during the postmaturation-preharvest, distribution-marketing, and on-farm segments. Despite variable degrees of control over the various segments of the storage period, the seedsman's plans for storage must take into consideration all the segments. The things that can be done must be done if the quality of the seed is to be maintained.

Since the main objective of seed storage is maintenance of an acceptable capacity for germination and emergence, it can only be accomplished by reducing the rate of deterioration to the degree required to maintain an acceptable level of quality for the desired period. Since seed storage is basically concerned with control of the rate of deteriorative processes, some understanding of deterioration is essential for planning and implementing a program for successful storage of seed.

Seed Deterioration

Seed are alive. All living systems undergo degenerative changes with time. The rate of degeneration is very much influenced by inheritance, the types and duration of stresses on the living system, and traumatic disturbances of the system. Control of the rate of degenerative processes, therefore, involves minimization of stresses on and traumatic disturbances to the system.

Seed deterioration is progressive. Degenerative changes occur over time which impair function and performance. As mentioned above, the rapidity of deterioration is influenced by several factors including inheritance. In the case of severe traumas such as gross mechanical, heat, or cold injury, or toxification by exposure to certain chemicals, performance potential of a seed can be reduced to zero in a few minutes - even instantaneously. Less severe traumas reduce performance potential to some level above zero, and increase susceptibility of the seed to other stresses during conditioning, packaged seed storage, and in the seed bed.

Deterioration of seed has several characteristics which must be recognized in developing and implementing plans for storage of seed. First, it is an <u>exorable</u> process. Deterioration cannot be prevented. The rate of deterioration, however, can be reduced to the extent that seed can be stored for about as long as most folk want to store them. Secondly, and perhaps more important in practical terms, deterioration is <u>irreversible</u>. The quality of seed is not improved by storage unless dormancy is involved and gradually released during storage. (It should be noted that there are certain lines of evidence which if pursued successfully might make if possible to significantly reverse deteriorative changes. Presently, and practically, however, seed deterioration is still irreversible.)

Seed deterioration is the progressive impairment in function and performance. The direct consequences of deterioration derive from this impairment in function and performance. Aspects of seed performance are progressively reduced cultimating in loss of the germination capacity of the seed. The indirect consequences of deterioration are equally important. As the seed system deteriorates, it becomes more vulnerable to stresses such as sub- or supra-optimal temperatures, reduced oxygen supply resulting from excessive moisture, invasion by seed rotting microorganisms, and mechanical impedance to emergence, or to use a "buzz" term, "vigor" decreases.

Seed Longevity

Reference has been made several times to the influence of heredity on rate of deterioration of seed. Seed of some species are inherently longer-lived than others. Most seedsmen know that soybean seed do not store as well as corn seed or cottonseed. Peanut seed producers think that soybean seed are long-lived! There are also inherent differences in longevity among varieties within a species. Some inbred lines of corn do not store as well as others. Varieties of soybeans and cotton also differ in terms of rate of deterioration. In some cases, perhaps most, differences in storability of varieties within a species can be related to dormancy, which is an inherited characteristic. Dormancy not only delays and distributes germination over time, it also protects the seed during the "delay" period against some of the stresses that accelerate deterioration so that germination capacity can be maintained during "distribution" over time.

Field Deterioration of Seed

Climatic conditions during the postmaturation, preharvest period establish the basic quality of seed, and thus, have an important influence on the storability of seed after harvest. Frequent and prolonged rain, heavy dews, fog, high humidity and warm temperatures contribute to deterioration of seed while they are still on the plant. Seed which have been subjected to such conditions do not store well even though germination might be relatively high after harvest.

Timely harvesting and other steps that can be taken to reduce the field deterioration of seed are as important as the postharvest measures used to maintain seed quality. In a very fundamental sense, the production of high quality seed is the essential first step in successful storage of seed.

Harvesting

Mechanical harvesting is the first exposure of seed to mechanical forces that can cause injury. Damage to seed during harvesting can not only reduce germination almost immediately but also reduce the storage potential of less severely injured seed. The same situation pertains in shelling operations such as the shelling of corn and peanuts. Reduction in the incidence and severity of mechanical damage, therefore, must be given attention in planning for successful storage of seed.

The moisture content of seed at harvest has an important influence on mechanical damage. Generally, seed at a moisture content 13% or higher - up to about 16% - are less susceptible to mechanical damage - especially fracturing of the seed coat, cracking and breaking of the cotyledons, endosperm, and embryonic axis. While seed at moisture contents above 13% are resistant to mechanical forces, problems can develop as the seed are taken from the combine and placed in bulk storage. A relatively high seed moisture content combined with a warm temperature favors deteriorative processes which lead to loss of vigor and ultimately a decrease in germination.

Influence of Seed Moisture

The moisture content of seed is determined or influenced by several independent factors which are operative at different times. During seed development and maturation, growth of the seed in size and weight is accompanied by a decrease in moisture content. Moisture content decreases rather slowly from above 80% a few days after fertilization until the seed attain physiological maturity at moisture contents ranging from 30 to 55%, depending on the species. Therafter, moisture content decreases rather rapidly until the seed are harvested or come under the influence of climatic conditions in the field. If the seed are harvested at relatively high seed moisture contents, e.g., corn and rice, the moisture content is determined by the stage of drydown at the time of harvest. For other kinds of seed which are essentially allowed to complete drydown before harvest, the moisture content at harvest might be determined by the degree of drydown or by re-wetting and re-drydown during inclement weather. Regardless of the factor influencing seed moisture content at harvest, the moisture content of seed at harvest, in bulk storage, and later, has the greatest influence on rate of deterioration of the seed.

The rate of seed respiration is closely related to moisture content and temperature. Seed at 14% moisture and higher respire much more rapidly than seed at 12% or less. Respiration produces heat which can raise the temperature in a mass of seed well above the ambient. If the seed moisture content is 15% or higher, the relative humidity in the seed mass will be well above 75%, which is favorable for growth and reproduction of storage molds. The molds also respire and produce heat which raises the temperature in the seed mass still higher. This heating cycle initiated in even moderately high moisture content seed can cause rapid deterioration and loss of germination. Even when seed moisture content is below 13%, moisture can migrate or be transferred in a bulk storage bin to the extent that some of the seed increase to well above 14% in moisture.

Since seed moisture content is so crucial in terms of retention of seed quality from harvest through marketing, steps must be promptly taken to reduce moisture when it is above 13% and to prevent moisture migration in bulk storage bins.

Importance of Drying and Aeration

Heated air drying, of course, is the usual method of reducing the moisture content of seed harvested at relatively high moisture levels such as corn and rice. In some years, drying of other kinds of seed such as wheat, sorghum, and even soybeans is necessary. Drying should be initiated promptly because any delay in the start-up of drying can be detrimental.

The effectiveness of drying in maintenance of seed quality is largely determined by the rate of drying and the drying temperature. Drying too slowly prolongs the period the seed are at a high moisture content and results in deterioration of the seed. Use of a sufficient flow of air at an appropriate temperature is very important in drying seed. Drying too rapidly, on the other hand, can also be damaging to seed quality, especially when associated with higher-than-safe temperatures.

Heated air drying is often not necessary to reduce seed moisture content a few points, say from 14 to 12%. At such a moisture content drying does not have to be accomplished as rapidly as when the seed are harvested at higher moisture levels. "Natural" air drying with a sufficient air flow rate will usually pull down moisture to the desired level within a few weeks.

Aeration of seed even at relatively low seed moisture contents, i.e., 11 to 13%, is important to remove "field heat" from the seed mass and to further reduce the temperature of the seed mass as ambient temperature decreases during the fall. Proper aeration also evens out temperature in the seed mass and prevents the migration or transfer of moisture in the bulk storage bin.

Drying reduces the field moisture of the seed to a level "safe" for handling, conditioning and storage. Aeration reduces the temperature of the seed mass during bulk storage and prevents the development of wet spots. Problems associated with high seed moisture do not end, however, with the completion of drying and aeration. During aeration and thereafter, seed moisture content comes under the influence of the relative humidity of the atmosphere. Seed moisture content rises during periods of high humidity and decreases during periods of low humidity. Relative humidity and temperature, therefore, become the most important determinants of seed longevity during the packaged seed phase of the storage period.

Hygroscopic Moisture Equilibrium

Seed are hygroscopic, that is, they absorb moisture from the atmosphere or lose moisture to it until the vapor pressures of seed moisture and atmospheric moisture (vapor) reach equilibrium. Since the vapor pressure of atmospheric moisture at a specific temperature and pressure is directly related to the degree of saturation or relative humidity, seed attain specific and characteristic moisture contents when exposed to different levels of relative humidity. The characteristic moisture contents attained by the different kinds of seed under different levels of relative humidity are variously referred to as equilibrium moisture contents of hygroscopic equilibrium values.

The equilibrium moisture content varies among seed kinds (Table 1). In general, the equilibrium moisture content for oil seeds, e.g., soybeans, cotton, peanuts, sunflower, is lower than that of starchy seed, e.g., wheat, corn, sorghum, rice, at the same relative humidity and temperature. This phenomenon can be mostly accounted for by the fact that fats and oils do not mix with water. Thus, in a seed that has an oil content of 50%, the moisture is concentrated in the non-oil portion, or 50% of the seed, while in a seed kind that contains only 10% oil, moisture is distributed throughout 90% of the seed.

Since the hygroscopic equilibrium moisture content of seed varies among seed kinds in relation to chemical composition, it is not possible to specify "safe" moisture contents for seed unless the kinds of seed are known along with the period of storage, ambient temperature and relative humidity. For example, corn seed attain a moisture content just over 13% at a relative humidity of 60% and a temperature down to about 50F. Under the same conditions, soybean seed attain a moisture content of about 10%.

Establishment of hygroscopic moisture equilibrium in seeds is a time-dependent process, that is, it does not occur instantaneously. A period of time is required, the length of which varies with the seed kind, initial moisture content, the <u>average</u> relative humidity, and temperature. Under open or non-conditioned storage, seed moisture content fluctuates with <u>long term</u> changes in relative humidity, and does not rise and fall with the normal diurnal variation in relative humidity from low in mid-afternoon to high in early morning.

The equilibrium established between seed moisture content and atmospheric relative humidity is two-directional. In an open system, seed moisture content is established by the relative humidity, but in a closed or relatively closed system, the relative humidity is established by the moisture content of the seed. A closed system would consist of a container impervious to the passage of atmospheric moisture vapor, while a "relatively" closed system would be something like a bulk storage bin filled with seed, or any large mass of seed.

Table 1. Moisture contents of some field crop seed at equilibrium with various levels of relative humidity (approximately 77F).

Kind	Relative Humidity (%)						
	15	30	45	60	75	90	100
Alfalfa	--	6.4	7.4	8.6	13.0	18.0	--
Barley	6.0	8.4	10.0	12.1	14.4	19.5	26.8
Bermudagrass, Hulled	--	8.1	9.2	10.8	13.6	17.2	--
Clover, Red	--	7.2	8.2	9.2	13.2	18.4	--
Corn, Field	6.4	8.4	10.5	12.9	14.8	19.1	23.8
Corn, Pop	6.8	8.5	9.8	12.2	13.6	18.3	23.0
Fescue, Tall	--	8.4	9.8	11.2	13.3	17.1	--
Flax	4.4	5.6	6.3	7.9	10.0	15.2	21.4
Peanut	2.6	4.2	5.6	7.2	9.8	13.0	--
Rice, Milled	6.8	9.0	10.7	12.6	14.4	18.1	23.6
Rye	7.0	8.7	10.5	12.2	14.8	20.6	26.7
Ryegrass	--	7.5	10.0	11.2	13.8	17.0	--
Sorghum	6.4	8.6	10.5	12.0	15.2	18.8	21.9
Soybeans	4.3	6.5	7.4	9.3	13.1	18.8	--
Sunflower	--	5.1	6.5	8.0	10.0	15.0	--
Wheat:							
Soft Red	6.3	8.6	10.6	11.9	14.6	19.7	25.6
Hard Red	6.4	8.5	10.5	12.5	14.6	19.7	25.0
White	--	8.6	9.9	11.6	15.0	19.7	26.3

If the moisture content of seed in a bulk storage bin, metal container, or thick-walled plastic bag is high, the relative humidity of the air in the space not occupied by seed will be high. If the humidity is above 65-70% storage molds can develop and accelerate the deteriorative processes. High humidities in a mass of seed also provide an ideal environment for the activity and reproduction of storage insects. Maintenance of seed moisture content at such a level that the relative humidity within the pore spaces in the seed mass is below 65% not only reduces the rate of purely physiological deterioration, but eliminates storage molds as a factor in the deterioration process.

The equilibrium moisture contents of seed at the different levels of relative humidity are established at 77F (25C). As temperature increases, the equilibrium moisture content decreases on the order of about 1% moisture for each 20F rise in temperature. As the temperature decreases below 77F, the equilibrium moisture content increases slightly. Deteriorated or low quality seed tend to have a slightly higher equilibrium moisture content than high quality seed.

Storage Conditions

Since seed moisture content and ambient relative humidity are in equilibrium during storage, maintenance of a "safe" moisture content requires an average level of relative humidity in the storage environment no higher than that in equilibrium with the "safe" or desired moisture content. This favorable situation can be achieved in only three ways: (1) location of the storage facility in a region where relative humidity does not rise - on the average - above the critical level; (2) maintenance of the relative humidity at the desired level by packaging seed in moisture vapor proof containers; or (3) dehumidification of the storage room atmosphere to the desired level. The desired level of relative humidity for successful storage of seed depends, of course, on the kind of seed, the duration of the storage period, and the temperature.

With reasonable precautions, good quality seed of the major crops can be successfully stored in most regions in the U.S. from harvest to the following planting season without packaging in moisture vapor proof containers or dehumidification of the storage environment. In the U.S. conditions for storage, i.e., relative humidity and temperature, become progressively more favorable from south to north and from east to west. Conditions along the Gulf Coast from South Texas across Florida are marginal for seed storage even for one season. Throughout the humid tropics, e.g., Central America, rapid deterioration of seed during storage is the major problem in seed production and supply operations.

Preventative Practices

A successful seed storage program requires knowledge of the principles involved, planning, implementation of quality assurance procedures, follow-up actions as necessary, and a quantum of common sense. The principles of storage have been reviewed. Planning must be done within the context of operational scope and style taking into account the principles of storage. Quality assurance procedures can range from the relatively simple to the elaborate, but they must address the operational stages that can influence the maintenance of seed quality so as to provide the needed information on which to based management decisions, i.e., application of that quantum of common sense.

Over the years I've detected a substantial amount of wishful thinking and/or reluctance to face facts among seedsmen - a good bit of it in the seed storage area.

Seedsmen have complained about the 13% maximum moisture content for certification of soybean seed in Mississippi and other states with the result that the standard has been considerably moderated. It is all too widely believed that there's not any real difference between seed at 13% moisture or less and those above 13% - even 14%+. Therefore, it's wasteful to aerate (dry) to reduce moisture content to 13% or less. The difference between 13 and 14% moisture soybean seed - or other kinds of seed - is the 13% seed will maintain viability and vigor about twice as long as those at 14%. Often, it (the lower moisture content) provides the margin of safety for soybean seed that have to be carried in storage until June or even early July before planting. There is no doubt that the extra effort and expense required to reduce the moisture content of seed to the 13% or less level favorable for retention of viability and vigor for 8-10 months will reduce complaints. Whether the reduction in complaints is worth the effort and expense is, of course, a matter for management to judge.

Seedsmen often receive and store marginal or even quite inferior seed rather than diverting them to the grain or alternative market on the gamble that supplies might be short enough to "make" the seed acceptable for marketing. Sometimes the gamble pays off, other times the investment in the seed is simply increased through conditioning, packaging, and storage before the bags are "busted" for delivery of the seed to the elevator. There are, of course, good business reasons to accept and hold a limited amount of marginal quality seed as it becomes well established that supplies of good to high quality seed will be tight. It is a fact that a lot of low quality seed in inventory is marketed at high prices during tight supply situations - the warehouses are "cleaned out". However, seedsmen should bear in mind, especially in these times of litigation, that low quality seed are low quality seed whether the supply is short or long. The risks are about the same. The supply situation is usually not germane in a complaint or civil suit based on poor or no performance of seed.

Some seedsmen exhibit a rather-not-know attitude. They get a minimal germination % from a test made in mid-winter, but do not have the seed retested in the spring because they're fearful germination might have dropped further, thus, confronting them with the decision to market or not market the seed. So, they'd rather not know. But, the times are changing and there's just too many lawyers for such practices to long survive.

The storage operation - in its broadest meaning - is crucial in a seed business. Seed in storage represent the potential return on considerable investments made to purchase the raw seed, condition them, store them until distribution, market them, and manage all these operations. As seed enters the market place - still in storage - they are the product on which judgements will be made by consumers. At the bottom line, it is the seedsman's reputation on the line!

As a minimum, a quality assurance program relating to storage should look into the extent of weathering before harvest, the adequacy of aeration/drying in bulk storage, determine germination and mechanical damage before final acceptance of the seed for conditioning, and then monitor germination every 3-4 months until marketing. Positive action programs to ensure that the seed are harvested in a timely manner so as to minimize weathering, harvested properly so as to minimize mechanical damage, aerated/dried to a desired moisture content, handled and conveyed to minimize damage, and stored in a properly ventilated, clean warehouse substantially improve the chances that the storage operation will be successful.

Sanitation is very important in a successful storage operation. Storage insects thrive in refuse and can ruin seed, especially "carried over" seed, or seed stored during the summer months. Cleanliness of the warehouse is the first step in insect control. Regular clean-ups combined with periodic space sprays with insecticides minimize storage insect problems. All seed entering the warehouse should, of course, be inspected for insects. Infested seed should be diverted to an alternate market or fumigated elsewhere before it enters the warehouse.

Rodents can be enormously destructive to seed in storage. Cleanliness, construction of the warehouse to make it as rodent proof as possible, and employment of a good exterminator are about as much as can be done.

Summary

Successful seed storage does not just happen - it has to be planned for. Application of the principles of storage can insure that the investment made in seed pays off in seed sales and satisfied customers.

CLASSICS FROM SHORT COURSE PROCEEDINGS

Prior to the late 1950s, "literature" on seed conditioning (processing) was essentially non-existent. A Proceedings of the Miss. Short Course for Seedsmen began to be published in 1958 to gather the available literature, and "produce" a literature based on practical experiences. The next two articals on "Seed Deterioration" and "Humidity Control in Seed Storage" are reprinted - with minor revisions - from the 1965 Proceedings.