Physical Properties Related to Seed Viability.

AID-W-607

631.521 Mississippi State Univ. Seed Technology
M436b Laboratory.
Physical Properties Related to Seed
Viability. . 3. Kenneth Matthes, et al.
Feb. 1968.
21 p.
Bibliography: p. 20-21.
Proj. 931-11-130-203.
AID-W-607.

1. Seed industry. 2. Separators (Machines). 3. Agricultural machinery. I. Matthes, R. Kenneth. II. Contract. III. Title.

JOURNAL NO. 1609
FEBRUARY, 1968

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PN-ABS-071

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For Presentation at the 1968 Annual Meeting
Southeast Region Amer. Soc. of Agri. Engr.
Kentucky Hotel
Louisville, Kentucky
February 5 - 7, 1968

Journal No. 1609

Mississippi Experiment Station
State College, Mississippi

INTRODUCTION

Many factors affect the performance and productivity of crops. Farmers have control over some of the factors while others, such as temperature and rainfall are not yet susceptible to control. Of those factors over which a farmer has some control, the quality of the seed to be planted is the most important. Seed of low viability and low vigor perform poorly even under ideal planting conditions, while seed of high viability and high vigor can perform well even under relatively unfavorable conditions.

Individual seeds in a lot deteriorate at various rates. At any one time a lot may be a mixture of completely dead seed, highly vigorous seed, and all gradations between these two extremes. Once the proportion of non-germinable to germinable seed reaches the point where the lot does not meet acceptable marketing or legal standards for germination the seedsman usually has three alternatives: (a) the lot can be removed from inventory and discarded; (b) it can be directed to feed or oil markets--provided the seed are suitable; or (c) it can be salvaged by blending with another lot (or lots) of higher quality. Suppose, however, that the seedsman could remove the nonviable and nonvigorous seed or even a portion of them. This would permit upgrading and standardization of quality, and assure the farmer of a consistent supply of uniformly high quality seed.

Since individual seeds differ in viability and vigor, it is reasonable to assume that they also differ in one or more physical properties which are indicative of the seed's viability and vigor. If a physical property such as size, density, color or electrical property is closely correlated with viability and vigor, then this property could be utilized to effect separation of the deteriorated seed and raise the quality of the entire lot.

This paper attempts to summarize the work that has been done on the relations of certain physical properties to seed viability and to point out potentially fruitful lines of work on other properties that might also be indicative of seed viability.

PREVIOUS WORK

Information and data on methodology for separating seeds on bases of viability and vigor are limited. Current practices used in a limited way in the seed industry are mostly based on experience, and results are not consistent. It is known that gravity separators upgrade germination and vigor of some lots under certain conditions. The situation is very similar in respect to aspiration and pneumatic separations.

Bleached seed in certain varieties of lima beans are removed from the vigorous, green seed by color sorting techniques (14). Vaughan (12) reported that seed size, color, and specific gravity of clover seed were closely associated with viability. Moore (10) has shown that the magnetic separator can be used to upgrade lots of the seed by removal of the cracked or broken seeds.

Dexter (7) determined that live and dead corn seed differ in electrical characteristics and suggested that they might be separated on a basis of these differences. Holaday (9) has recently shown that heat damage in artificially dried corn could be determined by a combination of electrical measurement of the surface d.c. resistance and the electrical capacitance of the kernel.

In 1935 Burr and Northrup (2) proposed a working hypothesis to the effect that the electrical signs to be found everywhere among living things indicate the existance of an underlying electrodynamic field whose characteristic forces impose patterns on the protoplasm.

In 1943 Burr (3) made a study of the electrical patterns in several pure line and hybrid strains of sweet corn. The corn seed used were from strains which have been under study for some time. These strains differed considerably in genetic constitution and in the degree of hybrid vigor shown in crosses between them.

The technique employed was developed by Burr in earlier work which consisted of determining the difference of potential between opposite ends of the longitudinal axis of the kernel. The point of attachment of the kernel to the cob was invariably positive and the opposite end negative. Contact with the system was made by silver-silver chloride electrodes and measurements made with a microvoltmeter and gavanometer. After more than 2000 measurements it was determined that there was a close relationship between the genetic constitution and the electrical pattern.

No less interesting than the electrical correlates of the pure strains was the relationship between the potential differences and hybrid vigor. The electrical studies showed a significant relationship between the potential difference and the degree of hybrid vigor; a relatively high potential difference indicated a high degree of hybrid vigor as manifested in the fields, while a lower difference indicated a lower degree of vigor.

In 1946, Nelson and Burr (11) attempted to correlate differences of potential across corn deed with viability. They hypothesized that each living corn seed is a physio-chemical system with an inherent electrical potantial which is presumably the sum of the E.M.F.'s of each individual cell, and as such the degree of magnitude of this force might be expected to show correlations with growthprocesses which are being initiated.

When e.m.f. measurements were taken on the long axis, it was found that the micropylar end was nearly always negative to the germ end of the seed. Further, if an electrode was placed at the micropylar end, and the other electrode was shifted about the surface end of the seed, it was found that there was a regular pattern of equipotential lines over the surface (Fig. 1).

Recently Delouche (5) showed that crimson clover could be separated as to viability by using differences in density, color, and behavior in an electrostatic separator.

The seed were separated in a Model B. South Dakota seed blower with three different air rates. This separation resulted in four fractions of increasing in particle weights: (a) seed lifted at a blower setting of 60; (b) seed lifted at 70; (c) seed lifted at 80; and (d) the remainder. These four fractions and the unblown control fraction were then tested for germination. The results are shown in Table 1.

Germination percentages increased as blower settings (or seed density) increased. The remainder of highest density fraction germinated from 6 to 15 percent higher than the unblown or checked sample or 24 to 54 higher than seed of the lowest density. The highest density fraction constituted from 46 to 64 percent of the total sample. Thus, germination was increased by 6 to 15 percent with seed losses of 36 to 54 percent. These results agree substantially with those reported by Vaughan (12) who found that on the average the lightest fraction resulting from a series of blowing in a South Dakota seed blower germinated 30 percent less than the heavier fraction. Although the South Dakota seed blower is not a processing machine, its operating principle is similar to that employed in several types of regular processing equipment.

In this same study Delouche separated crimson clover as to color using a Sortex (Model G 414 Mark 5 F.), commercial size, electric color sorting machine. In this machine, the seed are fed from a vibrating hopper onto an endless V-belt and are discharged from the belt and free fall through a viewing box. As the seed pass in single file through the viewing box, they are viewed from four sides. The sorter can be adjusted to accept on the basis of reflectivity of light seed of a certain color or shade and to reject seed which differ in these characteristics by means of a directed blast of compressed air. Separation is thus accomplished by alteration of the trajectory of the falling seed.

In the first run the sensitivity was set high in the range of 5.6 to 6.5 so that during the run through the sorter only very light colored seed would be rejected. This fraction was designated "1st pass reject". The seed accepted during the 1st pass were rerun at a slightly lower sensitivity and separated again into rejects and accepts. The three fractions increased in color from light to dark as follows: (a) lightest in color

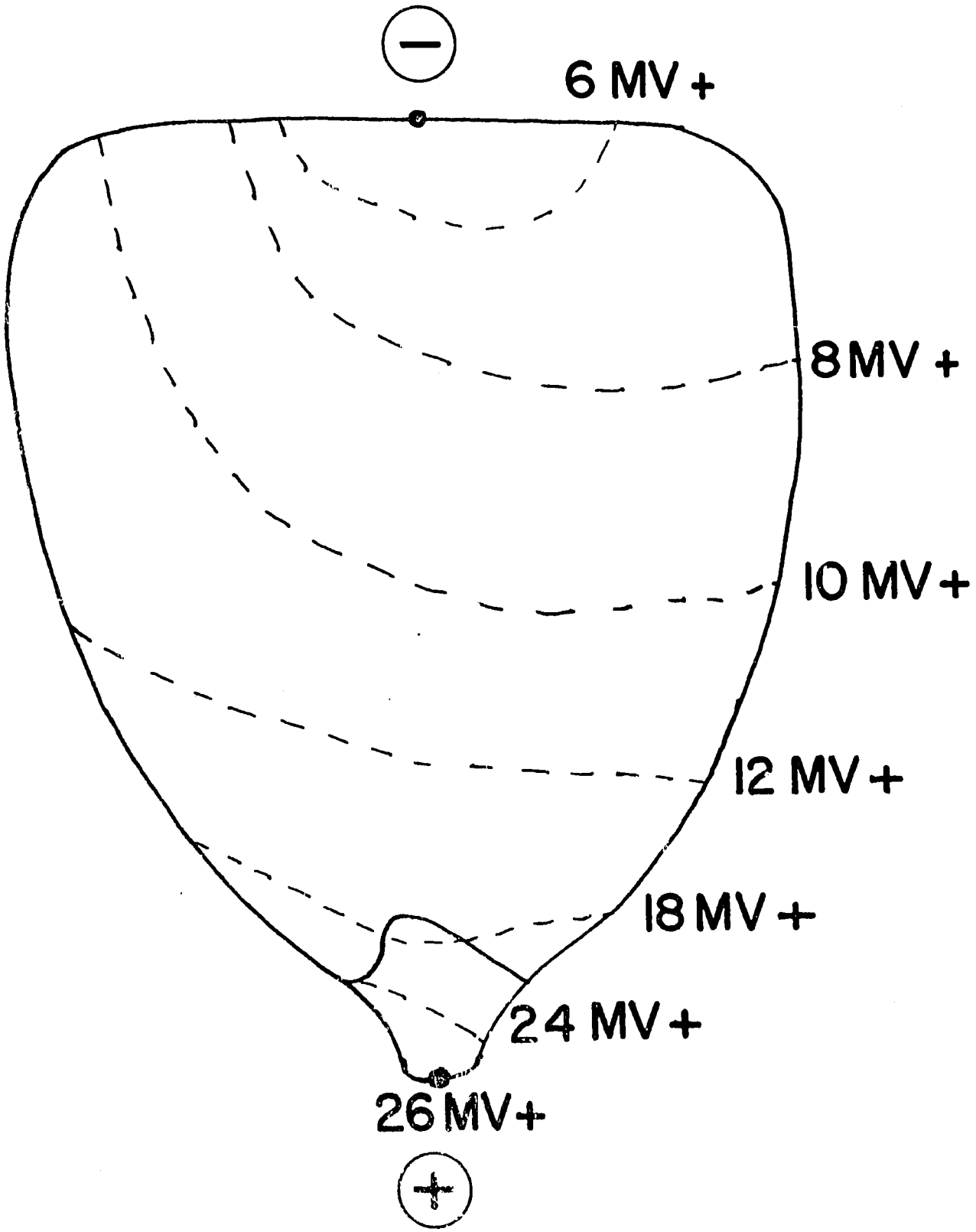

Figure 1. Equipotential lines on the surface of a corn seed.

(1st pass rejects), (b) intermediate (2nd pass rejects), (c) darkest (2nd pass accepts).

TABLE 1. Viability of separates from five lots of crimson clover seed obtained from three blowing levels in a South Dekota seed blower.

Lot No.	Original	S. D. Blower Setting 60	70	80	remainder
C10					
% Germ.	80	54	68	77	88
% Seed		(5)	(14)	(18)	(63)
C11					
% Germ.	72	54	68	72	78
% Seed		(8)	(17)	(25)	(50)
C12					
% Germ.	76	56	67	79	84
% Seed		(10)	(19)	(25)	(46)
C13					
% Germ.	82	38	66	75	92
% Seed		(7)	(11)	(18)	(64)
C14					
% Germ.	68	36	61	64	83
% Seed		(12)	(12)	(20)	(56)

Germination test of the three fractions resulting from two passes through the color sorter and an unsorted control were made. The results are shown in Table 2.

The separates lightest in color (1st pass rejects) germinated 8 to 23 percent higher than the unsorted sample. The separates darkest in color (2nd pass accepts) germinated 22 to 44 percent less than the unsorted sample, while the separates intermediate in color had germination percentages somewhat intermediate between the two extremes. Color sorting therefore increased germination over the control by 8 to 23 percent at the expense of seed losses ranging from 24 to 42 percent.

Color sorting seed the size of crimson clover is a slow process. The color sorter, however, does work untiringly. A battery of sorters could separate a considerable volume of seed in a 24 hour period. The

bases for the separation is sound. It has been shown that naturally light colored seed of clover and alfalfa darken with age. Vaughan (12) visually separated dark brown seed from lots of crimson, white and red clover. He found that the germination percentages of the dark brown seed were as much as 50 percent less than those of the light colored seed. West and Harris (13) reported essentially the same results on color separations in alfalfa, crimson, and white clover seed. They also found that the water extracts from dark alfalfa seed inhibited germination of yellow seed and reduced root growth of the seedlings.

TABLE 2. Viability of separates from five lots of crimson clover seed obtained after two passes through an electronic color sorter.

		Color Sorter		
		1st Pass	2nd Pass	
Lot No.	Original	Rejects	Rejects	Accepts
C10				
% Germ.	80	90	70	38
% Seed		(76)	(17)	(7)
C11				
% Germ.	72	90	72	46
% Seed		(60)	(18)	(22)
C12				
% Germ.	76	88	72	50
% Seed		(58)	(28)	(14)
C13				
% Germ.	82	90	72	60
% Seed		(70)	(22)	(8)
C14				
% Germ.	68	91	45	24
% Seed		(60)	(24)	(16)

Boyd (1) induced color differences in four lots of corn seed - two white and two yellow seeded - which had been mechanically damaged by passing the seed through a Crippen Model S scarifier. Following the mechanical treatment, samples of each lot were briefly soaked in a 0.1 percent solution of fast green to stain damaged areas on the seed. The effectiveness of a Selexso 10 Electric Color Sorter in separating the mechanically damaged, stained seed from undamaged, unstained seed

seed was then evaluated. The results of the separation are presented in Table 3.

Standard germination percentage of the acceptable (undamaged) seed was 1 to 6 percent higher than that of the composite and 8 to 21 percent higher than that of the rejected seed. The effectiveness of color sorting for removal of damaged seed was even more evident when cold test germination results were considered. The accept fraction had a cold test germination of 5 to 8 percent higher than the reject fraction. These data indicated that color sorting of pre-mechanically damaged seed upgraded both standard and cold test germination percentage. Treatment of the seed with a red staining fungicide did not appear to impair the effectiveness of the separation.

Boyd (1) also induced color differences in soybean seed with cracked seed coats by immersing the seed in a solution of incoxyl acetate, removing immediately to an electric dryer in which ammonia fumes were introduced into the intake air stream. This treatment resulted in a blue-indigo stain on the damaged areas of the seed.

After drying, the seeds were processed on the Selexso 10 Electric Color Sorter to remove the stained seed. Results presented in Table 4 indicate that a satisfactory "accept" product was obtained. Germination percentages of the original and stained seed before sorting indicate a reduction in germination of 12 percent. This reduction was cuused by the staining and drying processes. The damage, however, appeared to be more attributable to seed coats sloughing off from wetting and drying, than any toxic effect of the idoxyl acetate. After electric color sorting the "accepts" germinated 98 percent and the rejects germinated 36 percent.

Boyd (1) using the color sorter raised the quality of a lot of Lee soybean seeds by removing the green colored seed and a lot of moderately weathered cowpea seed by removing the severely damaged seed.

Delouche (5) used an electrostatic separation for the final separation of crimson clover seed. Taking advantage of differences in permeability, a difference in moisture content of viable and nonviable seed was induced by placing the seed in a single layer in contact with a moist paper or cloth surface for 10 minutes. After pre-conditioning, the seed were passed three times through a combination discharging, non-discharging electrical field. The seed were divided into four classifications: (a) seed lifted at 28,000 volts, (b) seed lifted at 30,000 volts, (c) seed lifted at 32,000 volts, and (d) seed not lifted at 32,000 volts.

Germination percentages of seed from the various separates and a control sample are given in Table 5. The third pass pinned seed (poorest conductors) in every case had the highest germination percentage. Compared to the control, seed from this separate germinated 10 to 18 percent

TABLE 3. Standard and cold test germination percentages of four lots of damaged corn seed separated into a damaged fraction (rejects) and undamaged fraction (accepts) with a Selexso 10 Electric Color Sorter.

Sample No.	Sample (% of)		Standard Germination (%)			Cold Test Germination (%)		
	Accepts	Rejects	Composite	Accepts	Rejects	Composite	Accepts	Rejects
White untreated	90.6	9.4	92	96	85	81	86	64
White treated	81.5	19.5	88	93	72	72	80	51
Yellow untreated	82.4	17.6	91	97	83	78	84	58
Yellow treated	84.7	15.3	94	95	90	79	82	60

TABLE 4. Results of standard germination tests on soybeans stained with indoxyl acetate and separated into damaged (rejects) and undamaged fractions (accepts) with a Selexso 10 Electric Color Sorter.

Sample	Germination %
Original before staining	94
Original after staining	82
Accepts	98
Rejects	36

TABLE 5. Viability of separates from five lots of crimson clover seed obtained after three passes through an electrostatic separator.

		Electrostatic Separator			
		1st Pass	2nd Pass	3rd Pass	
Lot. No.	Original	Lifted	Lifted	Lifted	Pinned
C10					
% Germ.	80	64	60	74	90
% Seed		(7)	(12)	(14)	(67)
C11					
% Germ.	72	56	68	67	88
% Seed		(23)	(23)	(17)	(37)
C12					
% Germ.	76	52	63	74	90
% Seed		(13)	(13)	(26)	(48)
C13					
% Germ.	82	60	72	79	92
% Seed		(14)	(11)	(22)	(53)
C14					
% Germ.	68	56	52	68	86
% Seed		(25)	(20)	(18)	(37)

higher with seed losses ranging from 33 to 63 percent. Differences in germination between the poorest conductors (3rd pass pinned) and the best conductors (1st pass lifted) ranged from 26 to 38 percent. These results indicated that non-viable seed could be concentrated by use of an electrostatic separator.

FURTHER TESTS USING ELECTROSTATIC SEPARATION

Based on Delouche's results it was felt that the electrostatic separator has considerable potential as a practical, economical technique for upgrading germination of seed in the size range of crimson clover; therefore, further studies were run in this area.

Original plans were to run alfalfa seed, cottonseed and soybeans through the separator and determine the effectiveness of separation in terms of percent germination and moisture content. The distance of fall for the cottonseed and soybeans, however, was insufficient to obtain any significant separation; thus, tests were run on only alfalfa seed. The electrostatic separator has recently been modified to allow a sufficient trajectory for the cottonseed and soybeans.

The Principle of the Electrostatic Separations

Essentially the electrostatic separator operated on the basic principle that unlike electrical charges are attracted to each other. The seed are fed onto a grounded rotor into an electrical field set up by a highly charged large diameter electrode, a fine wire electrode or a combination of both electrodes. The mechanical arrangement of the two electrodes is given in Figure 2.

The attraction of seed with an induced charge toward an electrode of the opposite charge is referred to as the "lifting effect" as in Figure 3. By use of this lifting effect seed which have a tendency to become charged with one or another definite polarity may be separated from each other even though their relative conductivity may be similar. This type of separation is sensitive to humidity and small temperature changes. The current flow from the electrode to the grounded rotor is in the range of 0-20 microamps per five feet of rotor length.

When the seed receive a spray discharge of electricity causing some of them to momentarily retain the charge and to be pinned to the grounded rotor, the phenomenon is known as the "pinning effect" and is illustrated in Figure 4. As an example, if a mixture of seed of various susceptibilities to surface charge is fed onto the spinning rotor and sprayed with high voltage discharge, the seed of relatively poor conductivity will assume a charge easily and be attracted to and pinned to the rotor. Seed

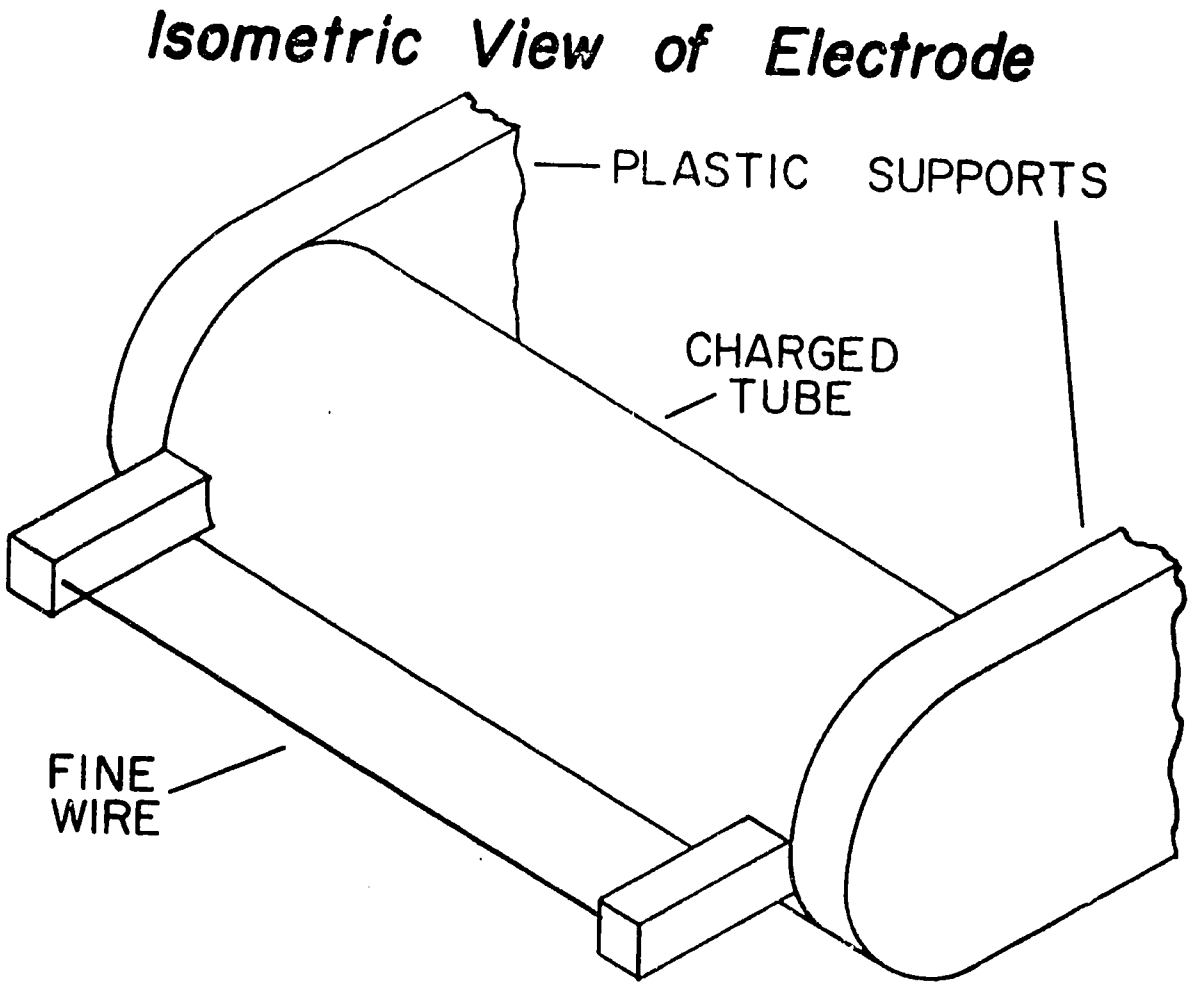

Figure 2. The electrode assembly of the electrostatic separator.

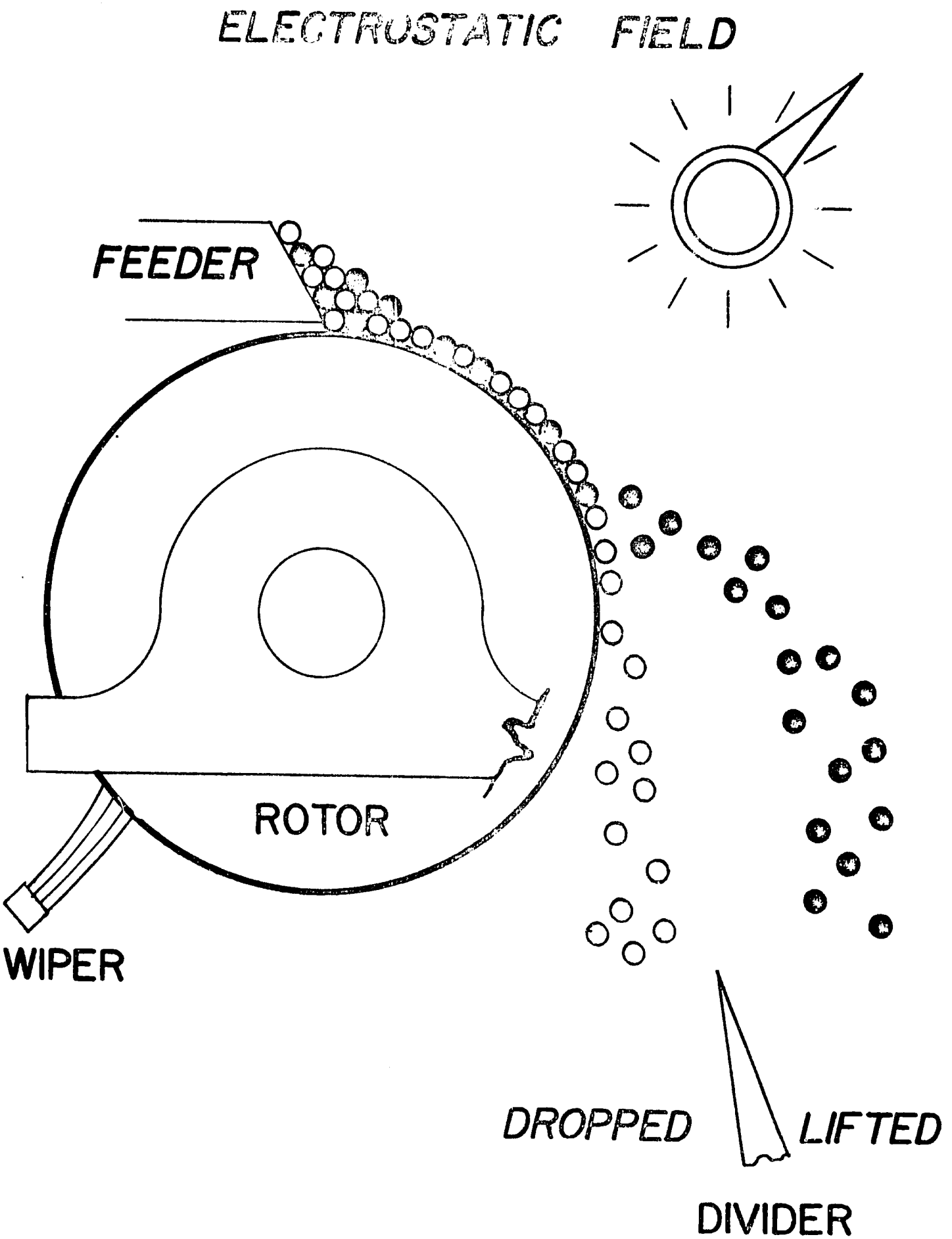

Figure 3. The electrostatic separator producing an electrostatic field and causing a "lifting effect" on the seed.

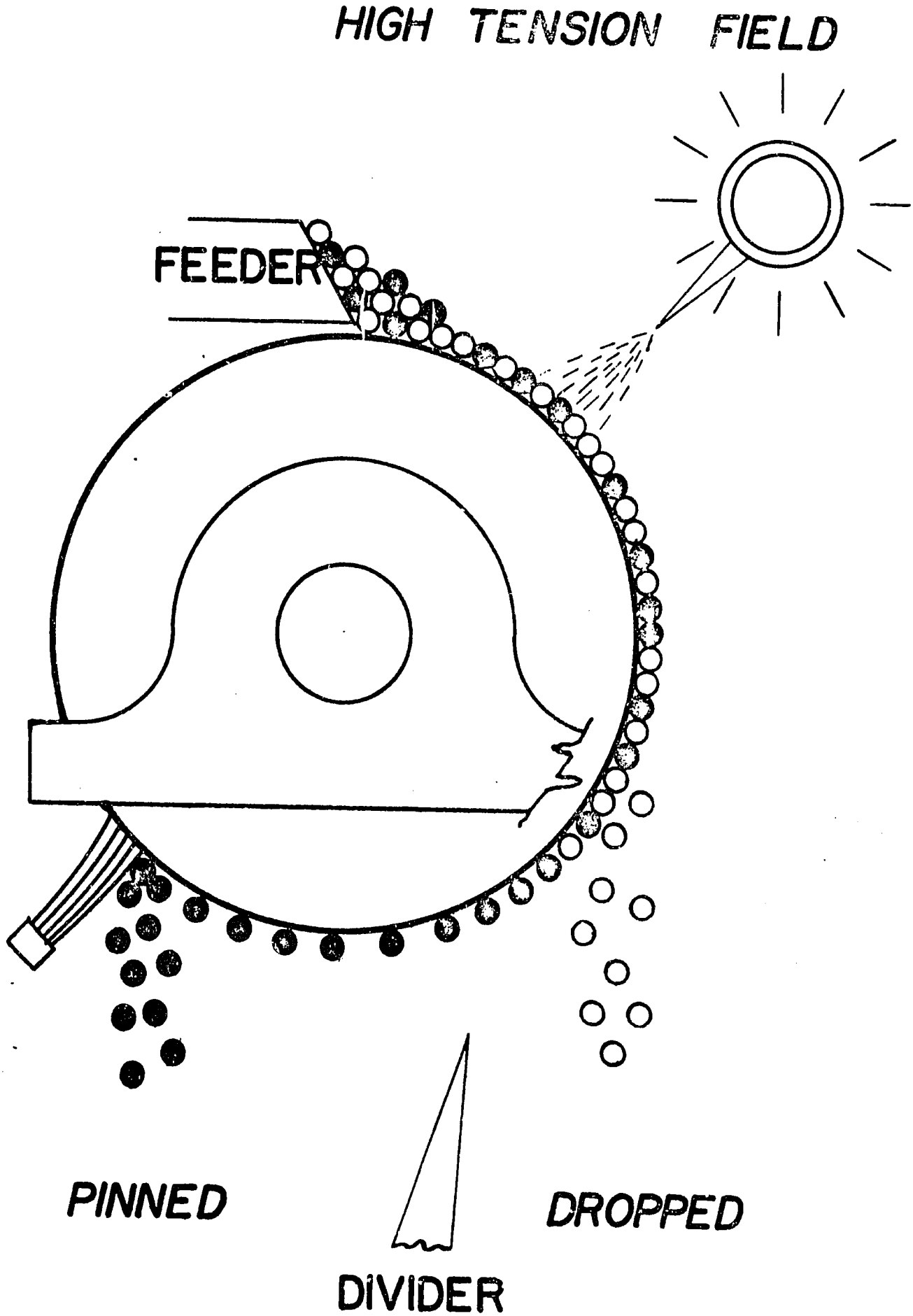

Figure 4. The electrostatic separator producing a high tension field and causing a "pinned effect" on the seed.

of relatively high conductivity will not assume a charge easily and what little they do receive will readily leak off to the grounded rotor. These particles of higher conductivity therefore, when leaving the rotor, will follow a flight path approximately the same as if there were no charging effect at all.

Electrostatic separation makes use of the pinning effect to a very high degree and in some cases may combine both a strong pinning effect with some lifting effects. Figure 5 illustrates the relative position of the two electrodes which causes a combination pinning and lifting effect. The current flow from the wire electrode in this position is 0.25 to 1 miliamp per 5 ft. of rotor.

Experimental Procedure

Prior to all separation tests the alfalfa seed were stored in rooms of constant temperature and relative humidity. From a given batch of seed approximately 100 gms. was removed for the control and approximately 400 gms. was removed to be run through the electrostatic separator. From the control sample approximately 60 gms. was used for a moisture determination, using the standard oven method, and 200 seed were used for a standard germination test. The remaining 4000 gms. were run through a precision divider resulting in two identical samples. Each sample was run through the separator which divided the seed into three groups (pinned, dropped, and lifted). The moisture content and standard percent germination was determined for each group. In some cases the number of seed in the pinned category was insufficient to make these determinations. When the moisture content and the percent germination were completed on the two identical samples, the results from each of the three separates were averaged for the two samples.

Results

The results of seven tests are given in Table 6. You will note that in all seven tests the percent germination increases from "lifted" to "dropped" to "pinned" categories. In all but two tests the percent germination in the "pinned" and "dropped" categories were substantially increased over that in the "lifted" category for over 50% of the total seed in each test.

The results of separating the seed as to moisture content were not entirely consistant. However, in all but two tests the moisture content of the seed in the "lifted" category or seed with the lowest percent germination had a higher moisture content than those in the other two categories. This agrees with the hypothesis stated by Delouche that the poorer quality seed have a higher permeability, and the seed would thus

COMBINATION FIELD

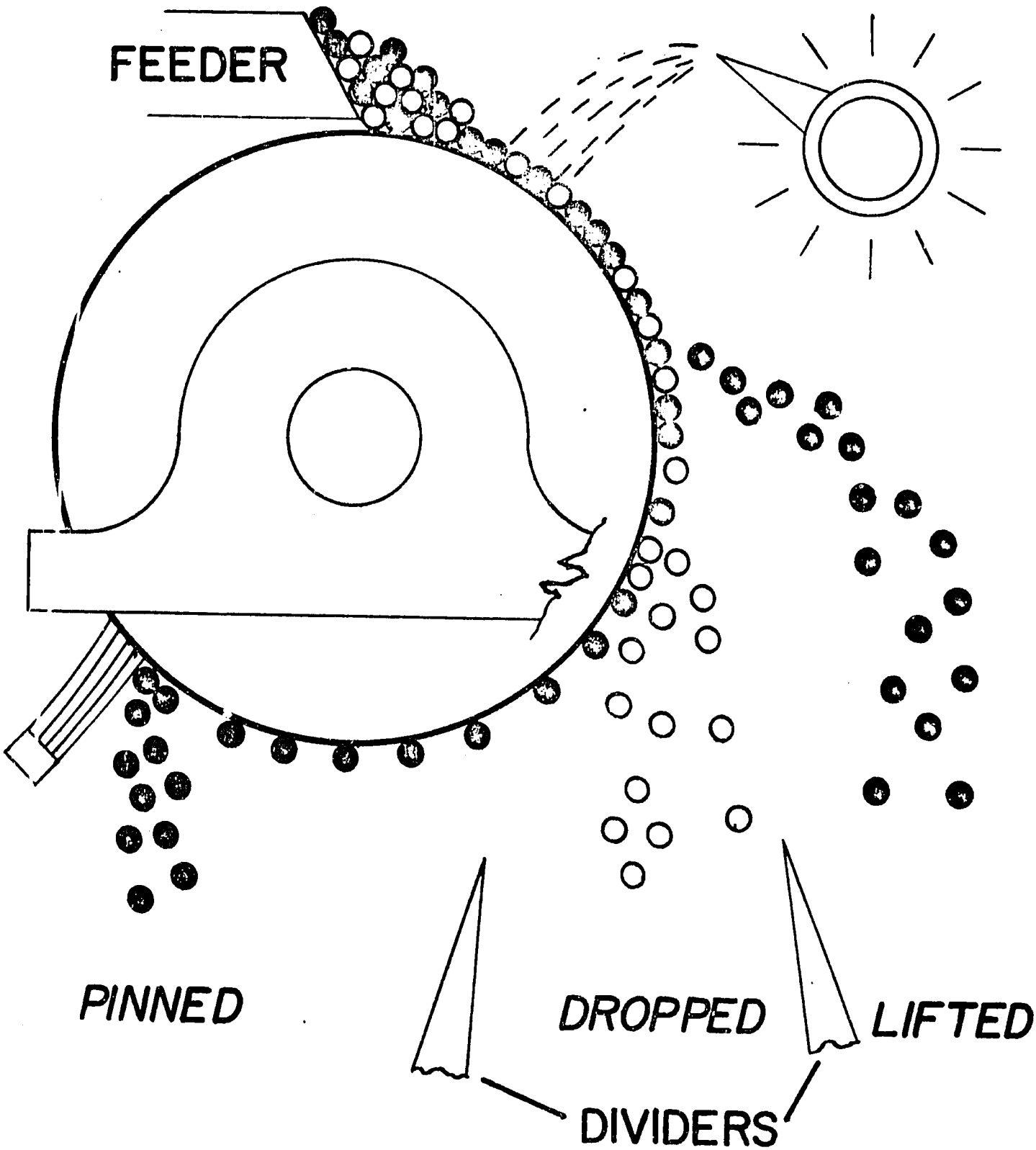

Figure 5. The electrostatic separator producing a combination filed and causing a combined "pinned and lifting effect" on the seed.

absorb a greater amount of moisture when stored under high humidity conditions such as these.

TABLE 6. Viability of separates from seven lots of alfalfa seed obtained from pinned, dropped and lifted categories in electrostatic tests.

Test No.	Voltage	Control	Electrostatic Category Pinned	Dropped	Lifted
1	30,000				
	% Germ	58.5	74.0	62.2	55.8
	% Moisture	8.02	8.08	8.51	8.35
	% Seed		(54.71)	(33.67)	(11.62)
2	40,000				
	% Germ	64.5		76.0	64.0
	% Moisture	7.93		7.58	7.77
	% Seed		(0)	(44.21)	(55.79)
3	30,000				
	% Germ	66.0		67.3	54.3
	% Moisture	9.40		8.96	9.72
	% Seed		(0.80)	(90.6)	(8.6)
4	30,000				
	% Germ	66.0		72.3	60.0
	% Moisture	9.40		9.63	9.52
	% Seed		(1.06)	(91.10)	(7.84)
5	30,000				
	% Germ	66.0		73.8	50.0
	% Moisture	9.40		9.46	9.56
	% Seed		(1.30)	(93.5)	(5.20)
6	30,000				
	% Germ	78.0	83.8	80.0	67.5
	% Moisture	6.94	6.58	6.44	6.65
	% Seed		(17.02)	(35.49)	(47.49)
7	30,000				
	% Germ	81.5			
	% Moisture	8.90			
	% Seed		(3.43)	(79.44)	(16.73)

It was noted that in some cases the control was higher in moisture than the separated seed and in other cases the control was lower in moisture. An explanation is that the tests were not run under controlled humidity conditions and seed lost or gained moisture depending on whether the humidity was lower or higher than the equilibrium moisture content of the seed.

At this point we should stress that the reliability of the moisture content determinations is low when compared to the germination tests. To determine the percent hermination, 200 seed from each of the two identical runs were tested for germination. Statistically, we have 400 seed which individually will either germinate or not germinate; thus, the average percent germination is highly reliable. On the other hand, we have no method of determining the moisture content of individual seed, but are required to determine it on a sample of seed. Therefore, the final average moisture content was derived from duplicate samples from the two identical runs or a total of four tests which could not be considered very reliable.

One interesting observation is that the total percent germination of seed exposed to the electrical field obtained by summing the products of the percent germination and percent of seed in each category, was higher in most cases than that of the control. The total germination of the exposed seed and the control seed as given in table 7 for 7 tests using alfalfa seed show that in 4 out of 5 tests using seed below 70 percent germination the overall germination was substantially raised by running the seed through the electrostatic separator one time.

This suggests that the germination of lower quality alfalfa seed might possibly be increased by exposure to a discharging high voltage electrical field.

TABLE 7. Total germination of separated seed in seven electrostatic tests using alfalfa.

Test	Control	Separated Seed
1	58.5	67.9
2	64.5	69.3
3	66.0	65.6
4	66.0	70.5
5	66.0	71.6
6	78.0	74.7
7	81.5	78.6

Harmond (8) exposed samples of various legume and grass seed to voltages up to 25,000 volts and found that there were no statistical differences in the percent germination before and after exposure; however, he did not give the original percent germination of the seed tested.

RECOMMENDATIONS FOR FURTHER STUDY

Electrical properties appear to be closely related to the physiological status and balance of living components of seed, and thus, possibly good indications of a seed's viability and vigor. The problem is to determine which properties are the most reliable indicators and why. The "why" is the difficult part in most cases, and for this reason is often omitted. If we can answer "why" we can generalize our solution to other types of seed and altogether new and effective techniques of upgrading seed.

Further study using the electrostatic separator is warranted. More basic knowledge of the electrical properties of seed, such as resistance, capacitance and dielectric properties should furnish the answer to why the seed behave in a particular manner under the influence of a given electrical field. With these answers we will be in a better position to develop effective separation techniques based in differences in electrical properties of seed.

Burr's work on the existance of an electrical potential across a seed is of utmost interest. This work should be verified for other types of seed, and if the results are as successful, many new avenues to the separation of live and dead seed will be opened.

Any future studies should include not only percent germination, but also vigor and moisture content. Delouche (5) points out the importance of knowing the response of a lot of seed to the stress conditions it will face in the field, and this only shows up in vigor tests. We are well aware of the effect of moisture content and moisture distribution on electrical properties of hygroscopic material; therefore, any differences in electrical properties of seed may well be differences in the moisture distribution. This moisture distribution among and within an individual seed may be the key to a seed's viability and vigor.

SUMMARY

Several physical properties are related to seed vigor and viability. These properties can be utilized to effect separation between viable and non-viable seed, thus raising the quality of the remaining

seed. The properties which have been most successfully used to upgrade seed lots are size, density, color and electrical conductivity, and other properties which have the potential for being used for this purpose are the electrical potential differences within an individual seed and the electrical capacitance of individual seeds.

Some physical property differences have been induced in viable and non-viable seed by preconditioning such as electrical conductivity in clover seed by moistening the seed and color in soybean seed and corn seed by soaking the seed in a coloring agent.

The major obstacle in the utilization of physical properties for raising the quality of seed is the development of methods and instrumentation for making successful separations between viable and non-viable seed.

REFERENCES

1. Boyd, A. H., Jr. Potential applications of electric color sorting techniques in seed technology. Thesis (M.S.), Mississippi State University, State College, Miss.

2. Burr, H.S., and F.S.C. Northrop. The electro-dynamic theory of life. Quart. Rev. Biol. 10:322-333. 1935.

3. Burr, H.S. Electrical correlates of pure and hybrid strains of sweet corn. Proc. Nat. Acad. Sci. 29:163-166. 1943.

4. Carpco Research and Engineering, Inc. High tension separation. Carpco Bulletin No. HTB-103. 1955.

5. Delouche, J. C. A preliminary study of methods of separating crimson clover seed on basis of viability. Journal Paper No. 1313 of the Miss. Agri. Expr. Sta. 1965.

6. Delouche, J. C. Stamina, strength, health . . . they add up to vigor. Cotton. 3:7-8. Dec. 1967.

7. Dexter, S. T. Separation of living and dead corn (Zea mays) kernels without germination. Agron. Jour. 57:95-96. 1965.

8. Harmond, J. E., L. M. Klein, and N. R. Brandenbury. Seed cleaning and handling. U. S. Dept. Agri. Handbook No. 179. 1961.

9. Holaday, Charles E. An electronic method for the measurement of heat-damage in artificially dried corn. Cereal Chemistry. 41: 533-542. 1964.

10. Moore, C. E. Magnetic separation of seed. Thesis (M.S.), Miss. State University, State College, Miss. 1958.

11. Nelson, O. E., and H. S. Burr. Growth correlates of electromotive forces in maize seeds. Proc. Nat. Acad. Sci. 32:73-84. 1946.

12. Vaughan, C. E. Physical and physiological properties of seed associated with viability. Thesis (M.S.), Miss. State University, State College, Miss. 1962.

13. West, S. H., and H. C. Harris. Seed coat colors associated with physiological changes in alfalfa and crimson clover and white clover. Crop Sci. 3:190-193. 1963.

14. Wester, R. C., and H. Jorgensen. Relation of chlorophyll fading from cotyledons to germination and vigor of some green-seeded lima beans. Seed World. 78(5):8. 1956.