ISN=2400; P134/08172
AID-W-607
PN-ABJ056

631.521 Mississippi State Univ. Seed Technology
B789a Laboratory.
~~INV 26~~
~~ISN=2400~~
~~loc=P134/08172~~
Potential Applications of Electric Color Sorting Techniques in Seed Technology.
A. H. Boyd, et al. Dec. 1968.
34 p.
Bibliography: p. 32-34.
Paper for the 1968 Winter Meeting, American Society of Agricultural Engineers, Chicago, Dec. 10-13, 1968.
Proj. 931-11-130-203. AID-W-607.
1.Separators(Machines).2.S[illegible]d industry.3.Agricultural machinery.I.Boyd, A.H.II. Contract.III.Title.IV. Sorting Techniques in Seed Technology.

PAPER NO. 68-808

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PN-ABJ056
73240

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Abstract

Electric color sorting techniques were applied to separation problems in three areas of seed processing: research, upgrading physiological quality of seed, and purification of seed stocks. Procedures used were generally effective in making the desired separations. Separation efficiency, however, varied with the problem and was in some cases so low as to limit application to special situations.

For presentation at the 1968 Winter Meeting
AMERICAN SOCIETY OF AGRICULTURAL ENGINEERS
Sherman House
Chicago, Illinois
December 10-13, 1968

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POTENTIAL APPLICATIONS OF ELECTRIC COLOR SORTING TECHNIQUES IN SEED TECHNOLOGY [1]

by

A. H. Boyd, Jr., G. Burns Welch, and James C. Delouche

INTRODUCTION

It is the function and responsibility of the seed industry to supply farmers with seed of high quality in sufficient quantity and at a reasonable price. State and Federal Laws establish certain minimum quality standards for seeds offered for sale. To meet these requirements and the much more stringent demands of the farmers themselves, the seedsman uses a variety of machines and methods to remove undesirable material from seed lots. Undesirable material may consist of weed seeds, other crop seeds, off-size seed, inert matter, and immature, damaged, or deteriorated seed. Contaminats and other undesirable material are separated from good seed on the basis of differences between undesirable material and seed in several properties or characteristics: size, shape, surface texture and density. Frequently, separations effected on the basis of these characteristics with conventional equipment are unsatisfactory and the seedsman must either try to find a market for low quality seed or turn to more sophisticated types of processing and separating equipment such as electric color sorters.

Electric color sorters were used to sort beans in Michigan as early as the 1930's. The first machines used were actually slower than hand sorting and their use was only justified on the basis of accuracy. Later developments in electronics and refinements in the sorters increased capacity and resulted in a lower cost per machine unit. From the early machines, several models of electric color sorters have evolved that are now widely used in sorting such diverse products as coffee, peanuts, vitamin pills, pearls, and processed and whole vegetables and fruits.

The objective of the present study was to explore possible applications of electric sorting machines in seed processing with emphasis on separations difficult or impossible to effect with conventional equipment.

1/. Journal No. 34 of the Mississippi Agricultural Experiment Station, Mississippi State University, State College, Mississippi.

REVIEW OF LITERATURE

Although color is one of the principal quality factors used in grading agricultural products, there is relatively little information available on the instrumentation and methodology used for sorting and grading for color. This relative scarcity of information can be largely attributed to the fact that the instrumentation and equipment for color sorting and grading were developed by private companies that generally do not publish information on the technical aspects of their developments.

Colorimetric principles and procedures for sorting agricultural products came into wide use in the 1950's to eliminate or minimize errors in grading foods such as rice (13), meats (26), sweet potatoes (1), tomatoes (24), and eggs (20). In 1940 Pittman (19) constructed a simple device to aid in the analysis of soils for phosphorus by measuring the amount of light transmitted through a flask of soil solution with a photographic light meter. Powers et al. (21) developed a color sorter for lemons in 1953. Commercial color sorting machines were installed on a large scale to grade beans in Michigan in 1953 (17). Wet product color sorters have recently been introduced into the cherry processing industry (18). Continued development and refinement of the electronic and mechanical technology of color sorting have increased capacity and stability of the machines to the point that it has become economically sound to color sort some vegetable and agronomic seeds (3,11,15).

Electric sorting machines are available for sorting materials on the basis of differences in their brightness and/or color. Through use of appropriate light sources and corresponding photo cells these machines can operate in regions of the electromagnetic spectrum outside the range of the human eye (15). Since the human eye is not equally sensitive to all colors even within the visible spectrum (9), there are many possiblities for separations not discernible to the human eye.

There are few references in the literature concerning the actual or potential application of color sorting techniques to seed and grain. Vaughan (28) and others (6,7) showed that there was a correlation between seed color and viability in clover seeds. Delouche (5) demonstrated that crimson clover seeds could be separated into fractions of high, medium and low germination with a color sorter even though the capacity was very low with such small seeds. Wester and Jorgensen (29) reported that lima beans with bleached cotyledons were much less vigorous than those in the same lot with natural green cotyledons. They suggested the use of color sorters to remove the bleached, low vigor seeds. Mezynski (16) reported the sucessful separation of delinted cottonseed from despined cockleburs with electric color sorters.

French, Thompson and Kingsolver (8) described a method of staining cracks in legume seeds using an indoxyl acetate solution to wet the seeds and ammonia fumes to develop a stain. Damaged areas of the seeds turn a blue-indigo on exposure to the ammonia fumes. Worthman and Renke (30) found that mechanically damaged seed corn did not perform as well in the cold test as did non-damaged seeds. However, they made no suggestion for separating the damaged from the undamaged seeds.

The poultry feed industry's interest in an economical source of xanthophyll is evident from Hastings (11) report on the use of pigments in rations. Ratcliff, Day, Grogan, and Hill (23) demonstrated that experimental strains of high xanthophyll yellow corn could furnish enough xanthophyll for good pigmentation of the birds. The current emphasis on low fiber, high energy rations restricts the use of alfalfa meal as a xanthophyll source and commercial xanthophyll concentrates are expensive.

METHODS AND MATERIALS

The methods used in these studies were an essential component of the results since the studies were undertaken to explore possible applications of electric color sorting in seed processing. It is recognized that different methods might have been used to accomplish the same objectives. Indeed, rapid advances in the technology of color sorting necessitates rather frequent changes in methodology.

Electric Color Sorters

The electric color sorting machines used were a Selexso 10 manufactured by Mandrel Industries, Electric Sorting Machines Division, Houston, Texas, and a Sortex G414 manufactured in England and distributed in the United States by Sortex of North America, Lowell, Michigan. Since the two machines differ in cost and capacity, it was not an objective of this study to compare the two but rather to gain knowledge and experience in possible uses of both machines for processing seed. Detailed operational procedures for each machine are contained in technical manuals available from the manufacturers (14,25). Schematic diagrams of the essential features and components of each machine are shown in Figures 1 and 2. The two machines are hereafter referred to as Sorter S (Sortex G414) and Sorter M (Mandrel Selexso 10).

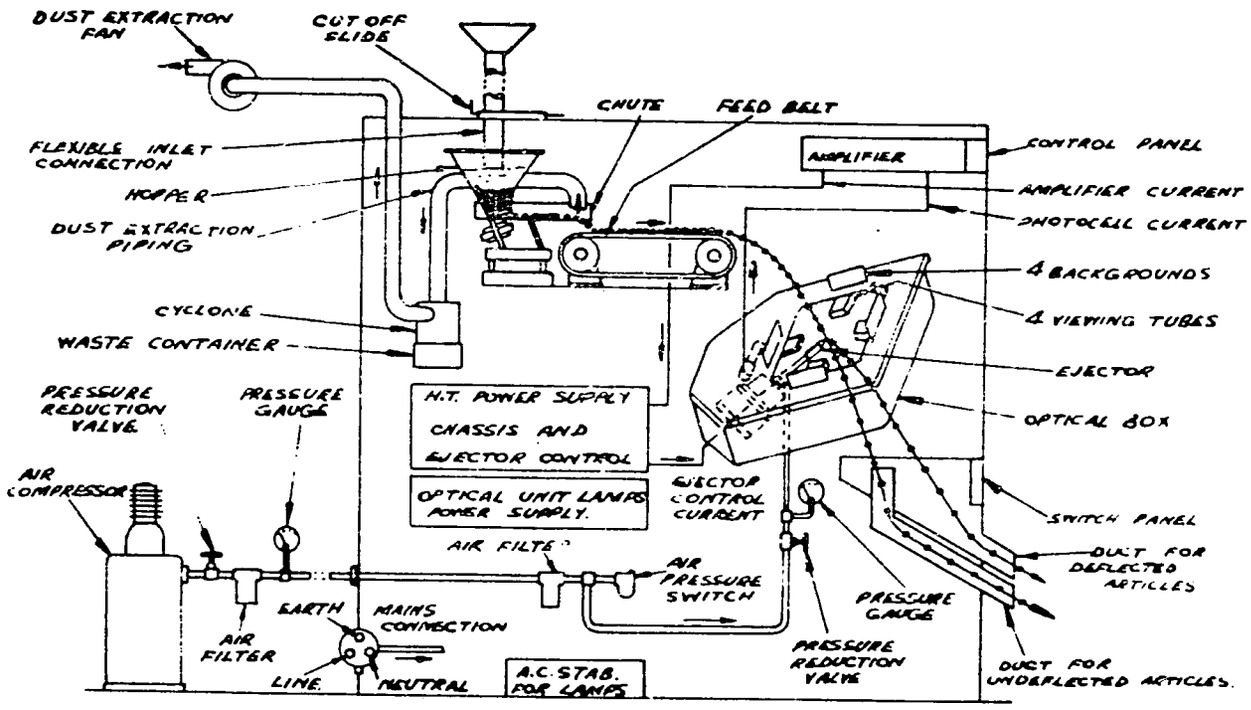
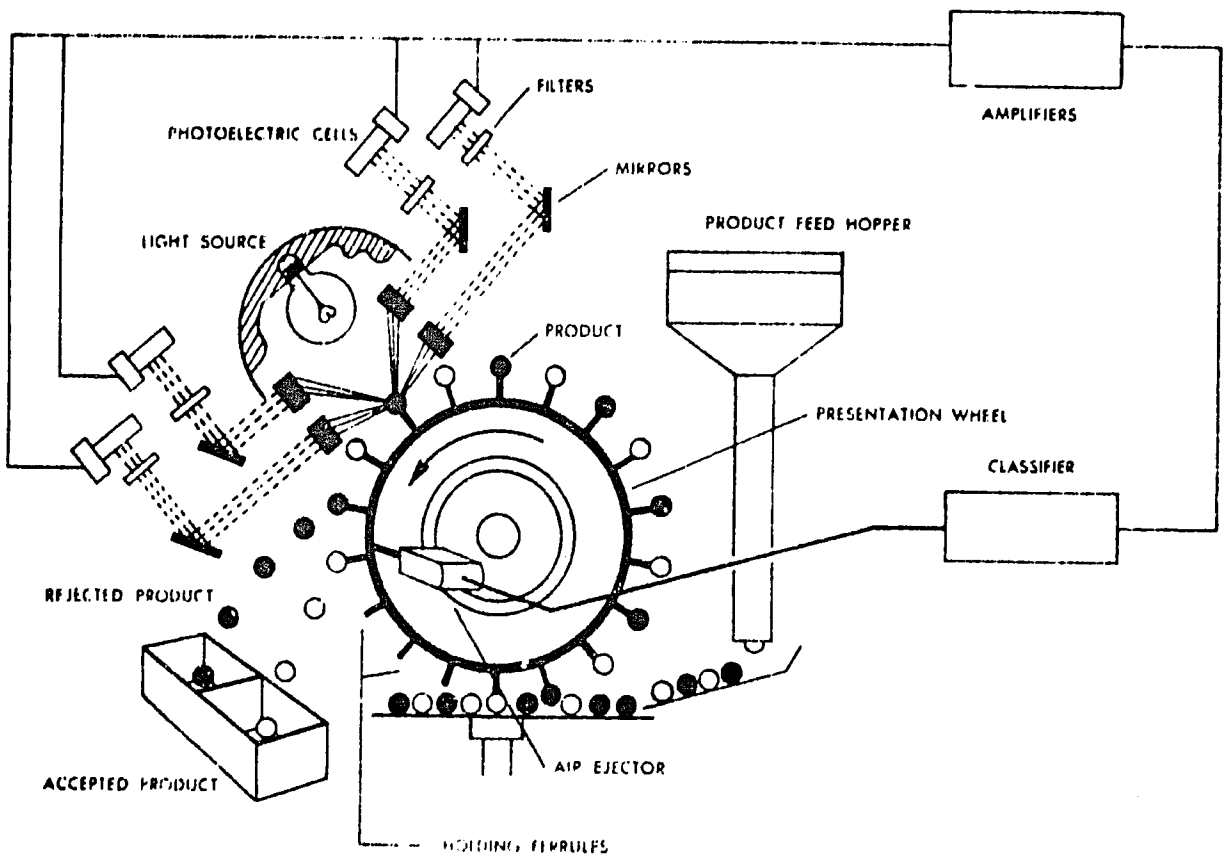


Figure 2. Schematic diagram of the mechanical system for the Sortex G. 414 and G. 415 machines



Flow Diagram
of ESM machine

Separation of Corn Seed On Basis of Xanthophyll Content

Samples of corn seed were obtained from the USDA corn project at Mississippi State University. The seed were from the F_3 generation and varied in color from white to orange-yellow. Sorter M was used because the electrical signal from the photoelectric cell is converted into a trace of light on the face of the cathode ray tube, thus, providing a visual basis for comparison of color values. A carbon black flag was used as the O percent reference and a magnesium carbonate flag as the 100 percent reference.

A color analysis of the seed lots was made to determine which filter with its corresponding phototube could detect the least differences in color among the seed. One blue-green filter and one red filter were selected. The blue sensing combination was used first to separate each sample into seven fractions according to degree of brightness. The first fraction consisted of those seed 10 percent or less as bright as the magnesium carbonate reference, and was the darkest and yellowest of the fractions. The next five fractions increased in brightness in 5 percent increments up to 35 percent of $MgCO_3$. The seventh fraction consiste of those seed at least 75 percent as bright as the reference $MgCO_3$.

In the second stage of the separation, four of the darkest yellow fractions (relative brightness from 11 to 35 percent) were again classified by the red sensing combination into two shades of color each: over 80 percent reflectivity and 70 to 80 percent reflectivity, as compared to 0 percent for carbon black.

Since it had already been established that seed of progressively darker shades of yellow have correspondingly higher xanthophyll contents (23) the samples analysed were selected to determine if the almost imperceptible differences in color detected by the color sorter were related to different concentrations of xanthophyll and carotene. All analyses for xanthophyll and carotene were made by the United States Department of Agriculture, Northern Utilization Research and Development Division, Peoria, Illinois.

Purification of Breeders and Foundation Seed Stocks

Off-type seed from Dawn rice

Breeders seed of the Dawn variety of rice were obtained from the Delta Branch Experiment Station, Stoneville, Mississippi. Dawn rice seed is typically gold colored, however, a straw colored off-type occurred at the rate of about 10 per pound. Samples of breeders seed of Dawn rice

were sorted with both Sorter S and Sorter M to determine if a satisfactory separation were possible and practical.

Off-types from sorghum varieties

One of the problems for producers of hybrid sorghum seed is the appearance of off-color outcrosses in their breeding lines. These may appear both as light colored seed in dark seed varieties and dark colored seed in light seeded varieties. The Sorter S and Sorter M were both used to separate off-types from white and brown seeded varieties of sorghum. Seed of Rio sorghum, a brown seeded variety, which was contaminated with 100 seed per pound of a white seeded off-type, and of Sart sorghum, a white seeded variety, which had been contaminated with 100 brown off-type seed per pound, were used in the study.

Weed seed from arrowleaf clover

A seed lot of Meechee arrowleaf clover, a newly released variety, was obtained from Foundation Seed Stocks at Mississippi State University. This lot failed to meet minimum standards for foundation seed because of an excess of weed seed (dock and Panicum spp.). Dock seed were removed with a roll mill but Panicum spp. seed in the lot could not be removed by conventional equipment. Since the arrowleaf clover varied from dark brown to yellow and the Panicum seed were a shiny white, color sorting appeared to be possible. Sorter S was used because the grooved belt conveyor could handle the small seed. No modification of the machine was necessary except taping a part of the feeder gate to prevent overfeeding and installing a conveyor belt with a more nearly V-shape trough.

Removal of cockleburs from cottonseed

Cocklebur contamination of cottonseed is a serious problem to seed producers. Farmers strongly object to the presence of cockleburs in the seed they purchase, and seed certification regulations either prohibit cockleburs in certified seed or limit rate of occurence to one bur per two pounds.

Cottonseed become contaminated with cockleburs during harvest. During ginning and mechanical delinting, the spines of the cockleburs are removed. The resulting despined cockleburs are similar in size to the cottonseed in all dimensions except length, and in other properties

except density and color. Density or length separations are not possible because the linters remaining on the cottonseed prevent the free flow of individual seeds required for effective use of gravity tables or length graders.

Four 22 pound lots of mechanically delinted cottonseed contaminated with despined cockle burs at the rate of 50 per lot were processe with both Sorter S and Sorter M. The adjustments and setting used for each sorter are given in the Results section.

Upgrading Seed Viability

Damaged corn seed

Two lots each of white and yellow corn were obtained from reserve stocks of the Seed Technology Laboratory. One lot each of white and yellow corn had been processed but not treated. The other two lots of white and yellow corn were both processed and treated with a material that imparted a reddish tint to the seed. All four lots had a high germination percentage (above 90 percent).

Seed damage was induced to approximate severe mechanical damage from shelling or combining by processing the seeds through a Crippen Scarifier Model S. Small fragments of seed were removed with a Mandrel pneumatic separator leaving only whole or nearly whole seed. Color differences between the damaged seed and the undamaged seed were developed by treatment with a solution of fast green. The seed were immersed in a 0.1 percent solution of fast green stain, immediately removed, washed with tap water, and dried with an electric dryer. The fast green dye stained the cracks and exposed starchy endosperm green. Standard germination tests were made before and after application of the stain to determine if it had any effect on germination.

Each lot was separated with Sorter M to remove the green stained, mechanically injured seed. Standard germination tests and cold tests were made on the composite sample of the seed before and after they were subjected to mechanical damage treatment, and on the separates obtained by color sorting. Standard germination tests were made according to the "Rules for Testing Seeds" (2) and all cold tests were made by the Hoppe method (12).

Mechanically damaged soybeans

A lot of Lee soybeans that had been damaged during harvest

by excessive threshing cylinder speed was obtained from Foundation Seed Stocks, Mississippi State University. Some of the damage such as cracked seed coats and cracked cotyledons was had to detect visually and there was not enough color difference for sorting without pretreatment to develop a color difference between damaged and undamaged seed. The seed were immersed in a 0.1 percent indoxyl acetate solution, removed immediately and dried in an electric dryer. A ball of cotton soaked in household ammonia was placed at the air intake of the dryer to develop a blue-indigo color around damaged parts of the seed. This was an adaptation of the laboratory method for determining the amount of mechanical damage in legumes as reported by French, Thompson, and Kingsolver (8). It was found that seed coats stayed on better if the seed were immersed in the solution a minimum length of time as opposed to the one minute period specified in the laboratory method.

After staining, the seed were separated with Sorter M. Standard germination tests were made on the original sample, the dyed sample, and the accepts and rejects after sorting.

Separation of "green" seed from soybeans

Lots of Lee soybeans were obtained that contained approximately [illegible] to [illegible] percent seed with greenish cotyledons. Cotyledons of the Lee variety are normally light yellow. The "green" soybeans were - with the exception of color - essentially the same size and shape as the other beans in the lots. A separation was effected on the Selexso 10 machine and germination tests made on composite samples and each of the separates to determine the association of cotyledon color with viability.

Weathered cowpea seed

Two lots of cowpea seed were used in this study. One lot consisted of Bunch Purple Hull, a white seeded variety, which was moderately weathered. The weather damage in this lot was caused by the pods having been in contact with moist soil. The other lot was a brown crowder, Mississippi Silver, which was more uniformly and severly damaged due to prolonged exposure in the field to high humidity and frequent showers. Both lots failed to meet minimum standards for germination of foundation seed (80 percent).

The seed were color sorted by Sorter M, and standard germination tests were made on the composite samples and the separates to determine if germination percentage was upgraded by sorting.

Deteriorated clover and alfalfa seed

Seed of crimson clover and alfalfa darken in color as they age and deteriorate. Thus, seed color is associated with viability - the darker the seeds the lower the viability.

Five samples of crimson clover seed and four samples of alfalfa seed of approximately 2 pounds each were obtained from the Mississippi State Seed Testing Laboratory files. Each sample had been taken from a different lot of seed. The samples were separated into three fractions with Sorter S: light colored seed, medium dark colored seed, and dark colored seed. After separation germination tests of each fraction were made and compared with that of the original sample. The percentages of seed in each category for each lot were also calculated.

RESULTS AND DISCUSSION

Separation of Corn Seed on Basis of Xanthophyll Content

This study was undertaken to determine if electric color sorting could provide a more rapid and repeatable method for sorting breeding material on the basis of color differences and if these differences were reflected in xanthophyll content.

A graphic illustration of the color analysis data of the F_3 breeding matherial is shown in Figure 3. Filters number 5450 (blue-green), and 3386 (red) were selected as having the capability of most sensitive discrimination among the various colors. It should also be noted that the maximum transmission of light through the selected filters roughly corresponds to the maximum and minimum absorption curves of the xanthophylls (24). The color analysis was used as the basis for adjustment and set-up of the color sorter for separation.

Two series of separations were made. In the first series the sample was separated into seven fractions according to reflectivity under a blue-green sensitive set-up. The results of analyses for xanthophyll and carotene content are given in Table 1. Xanthophyll content generally decreased as percentage reflectivity increased with the exception of separate No. 25. The probable reason for this divergent response will be considered later. There was very little difference in carotene content except in the case of separate 27, the brightest and lightest fraction.

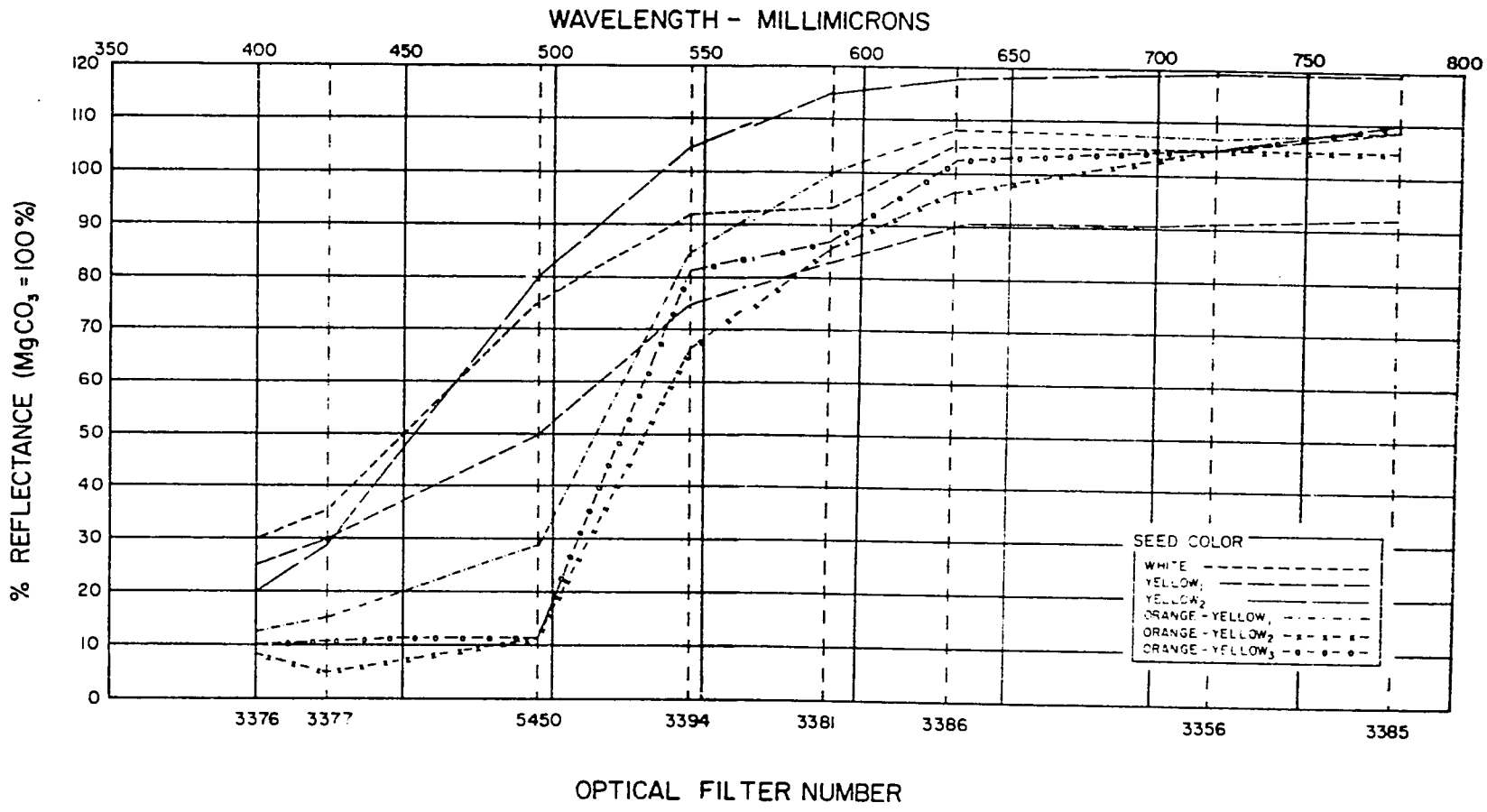

WAVELENGTH - MILLIMICRONS
350
400
450
500
550
600
650
700
750
800
% REFLECTANCE ($MgCO_3$ = 100%)
120
110
100
90
80
70
60
50
40
30
20
10
0
3376
3377
5450
3394
3381
3386
3356
3385
OPTICAL FILTER NUMBER
SEED COLOR
WHITE
YELLOW1
YELLOW2
ORANGE - YELLOW1
ORANGE - YELLOW2
ORANGE - YELLOW3

Table 1. Xanthophyll and carotene content of F_3 corn seed separates sorted with an electric color sorter using a blue-green sensitive set up.

Reflectivity	Separate No.	Carotene PPM	Xanthophyll PPM
Carbon Black = 0%			
0 - 10%	21	---	----
11 - 15%	22	3.9	25.8
16 - 20%	23	3.0	19.5
21 - 25%	24	3.9	15.7
26 - 30%	25	---	----
31 - 35%	26	3.9	18.0
Over 75%	27	1.3	3.1
Mg CO_3 = 100%			

Adjustment and setup of Sorter M:

Filter No. 5450 (Blue Green)

Phototube No. 16442

Separates No. 22, 23, 24, and 26 were further separated with a red sensitive set-up. Those portions of each separate with reflectivity values of over 80 percent and from 70-79 percent were separated and analyzed for xanthophyll and carotene content. Results are given in Table 2.

The most intense orange-yellow (brightest) seed in separates 22 and 23 tended to be higher in xanthophyll than the other separate and the composite. This trend did not hold true for the remainder of the separates. The brightest fraction of separate 24 had a very low xanthophyll content but twice as much carotene as the composite. The medium yellow color of this separate was apparently more related to carotene content than to xanthophyll content. The brightest portions of separate 26 were lower in xanthophyll content than the composite.

These results indicate that electric color sorting is an effective and efficient method for identifying and separating seed high in carotene content. Use of electric color sorting at the proper stage in plant breeding should greatly accelerate development of high xanthophyll and carotene lines of corn.

The principle limitations in separating corn for color variation are related to the shape of the seed and a natural color variation from top to bottom of the kernel. Preliminary studies including photographs taken with an electronic flash indicated that the best results were obtained when operating the machine near full capacity as the seed tended to be always held in a vertical rather than random position on the ferrules if the feed was very slow.

Purification of Breeders and Foundation Seed

Off-type seed from rice

Three lots of breeders Dawn rice seed ranging in size from 5 to 1800 pounds were used in this study. The 5-pound lot had 242 off-type straw colored seed per pound, while the 20 and 1800 pound lots had 13 and 19 off-type seed per pound, respectively. Both color sorting machines were used. Since both machines were equally effective in making the separation only the results of the separation made by Sorter M are given along with, adjustments and set-ups of each machine in Table 3.

Off-type rice seed were completely removed by both machines with a maximum seed loss of only 2.2 percent of the lot. Although the

Table 2. Xanthophyll and carotene contents of the brightest fractions of selected color separates of F_3 corn seed sorted with a red sensitive set-up.

Separate No.	Reflectivity	Carotene PPM	Xanthophyll PPM
	Carbon Black = 0%		
22	Composite	3.9	25.8
22.1	Over 80%	3.6	26.0
22.2	70 - 80%	4.6	23.4
23	Composite	3.0	19.5
23.1	Over 80%	2.9	21.3
23.2	70 - 80%	4.5	19.8
24	Composite	3.9	15.7
24.1	Over 80%	7.7	9.3
24.2	70 - 80%	5.0	17.4
26	Composite	3.9	18.0
26.1	Over 80%	3.9	15.7
26.2	70 - 80%	3.9	15.1
27		1.3	3.1
	100% = $MgCO_3$		

Adjustment and setup for Sorter M:

Optical filter 3386 (Orange Red)

Phototube 16443

Table 3. Results of separation of off-type seed from Dawn rice by electric color sorting.

Lot	Quantity lbs./lot	Off-types No./lb.	Accepts Off-types No./lb.	Accepts % of Lot	Rejects % of Lot
1	5	242	0	97.8	2.2
2	20	13	0	99.1	0.9
3	1800	19	0	98.8	1.2

Adjustments and Setup

Sorter S

Channel	Backround	Filter(s)
C1 - C2	BR5 - 50%	Green and red
L3 - L4	BR5 - 50%	Blue

Sensitivity 5 1/2 Capacity 20/lbs./hr.

Sorter M

Horizontal optical filter 3386 100 % reference 5574 (white)

Vertical Optical filter 5450 0 % reference 8631 (black)

Background 3420 Capacity 80/ lbs./hr.

capacity of both machines was very low compared to other types of processing equipment, it was adequate to handle the relatively small lots of breeders' seed involved.

Off-type seed from sorghum

Two lots of sorghum seed were used: Sart sorghum, a white seeded variety, contaminated with off-type brown seed, and Rio sorghum, a brown seeded variety, contaminated with off-type white seed. In each case the off-types occured at the rate of 100 per pound.

The effectiveness of both machines in making the separations was evaluated. Since both machines were effective in accomplishing the separation only the results obtained with Sorter S are given in Table 4.

Weed seed from arrowleaf clover

Color Sorter S was used to remove weed seed (Panicum spp.) from two lots of foundation Meechee arowleaf clover. The adjustments for the color sorter and results of the separation are given in Table 5.

Weed seed content of the two lots was reduced from an unacceptable 0.45 per cent concentration to an acceptable 0.01 per cent concentration. After separation the two lots were combined and certified as foundation seed.

Separations involving the removal of off-type seed and contaminants the size of rice, sorghum, and arrowleaf clover with an electric color sorter are necessarily of low capacity since each seed must be viewed individually, and capacity is closely related to the number of seed per pound. The rate of separation of arrowleaf clover seed which are very small (about 500,000 per pound) was extremely low (3/4 pounds per hour). The manufacturer of the Sortex G414 sorter does not recommend the use of the machine for separations of this type for economic reasons. From a commercial standpoint this position is valid. However, when one is dealing with breeders and foundation seed, purely business considerations are secondary. Even though breeders and foundation seed are sold for a given price, one must consider the costs of development of the variety plus the potential benefit to farmers in the area for which the variety was developed. For example, only three decisions were possible with the lots of Meechee arrowleaf clover: (1) reject the seed making it necessary to wait another year for effective release of the variety; (2) release inferior uncertified seed stocks; or (3) remove the excess weed seed in any way possible. Under such conditions the many hours of operation of the color sorter are [illegible] justified.

Table 4. Results of separation of off-type seed from Sart and Rio sorghum with electric color sorters.

Lot	Quantity lbs.	Off-type No./lb.	Accepts: Off-type No./pound	Accepts: % of Lot	Rejects: % of Lot
Sart Sorghum with off-types	10	100	0	99.2	0.8
Rio Sorghum with off - types	10	100	0	98.9	1.1

Adjustments and Setup

Sorter S

Sart: channels - D1, D2, D3, D4; backgrounds - A,20%; filter - blue; sensitivity - 5 1/2; capacity - 20/lbs./hr.

Rio: channels - L1, L2, L3, L4; backgrounds - Br6, 30%; filter - blue; sensitivity - 5 1/2; capacity - 20/lbs./hr.

Sorter M

	Sart	Rio
Horizontal optical filter	3386	3386
Vertical optical filter	5450	5450
100% reference (white)	5574	5574
0% reference (black)	8631	8631
Background	63%	6033
Capacity	80/lbs./hr.	80/lbs./hr.

Table 5. Adjustments and setup of Sorter S for removal of *Panicum* spp. seed from arrowleaf clover and results of the separation.

Lot	Lot Size	Original % Panicum spp.	Accepts % Panicum spp.	Rejects % of Lot
1	2 lb.	0.45	.01	5.2
2	300 lb.	0.40	.01	9.5

Sorter S

Channels	Background	Filter
L1, L2, L3, L4	CR 4 50%	Blue

Sensitivity 6 3/4

Capacity 1/2 to 3/4 lbs. / hr.

In the same manner, a commercial seedsman can materially reduce his rogueing expenses and enhance the quality of his product by sorting his stock seed before releasing it to contractors or seed production farms.

Cockleburs from cottonseed

Four lots of mechanically delinted cottonseed contaminated with despined cockleburs at the rate of 60 burs per lot (2.73/lb.) were processed with each sorter. The results of the separation are given in Table 6.

Both sorters (Sorter S and Sorter M) were effective in separation of the despined cockleburs from cockleburs. Ninety to 100 percent of the burs were removed reducing the concentration from an initial 2.73 burs/ lb. to less than .2 burs/lb., which is well below the 0.5 bur/lb. limitation for certified cottonseed. In only one case, however, were all the burs removed ,thus, illustrating the difficulty of absolute separation. The efficiency of separation was quite high for both machines and losses were very low. These results corroborate the work of Mezynski (16), who reported that electric color sorting was the most effective procedure - of many evaluated by him - for effecting a separation of despined cockleburs from mechanically delinted cottonseed.

Upgrading Seed Quality

Damaged corn seed

Four lots of corn seed - two white seeded and two yellow seeded - were mechanically damaged by passing the seed through a Crippen Model S scarifier. After mechanical treatment, 5-pound 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 Sorter M in separating the mechanically damaged, stained seed from undamaged, unstained seed was then evaluated. Adjustment and set-up of the machine and results of the separation are presented in Table 7.

Standard germination percentage of the acceptable (undamaged) seed was 1 to 6 percent higher than that of the composite and 5 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 22 to 29% higher than the reject fraction. These

Table 6. Separation of despined cockleburs from mechanically delinted cottonseed by electric color sorting.

Lot No.	Lot Wgt. (lbs.)	Initial burs/lot	Burs Removed	Seed Loss (%)
		Sorter S		
102	22	60	55	4.75
103	22	60	57	1.50
104	22	60	58	4.25
105	22	60	59	0.70

Adjustment and Setup

Channels	Background	Filters	Sensitivity
C1, C2	BR7	Blue & red	5 1/2
L 3, L 4	BR7	Blue	5 1/2

Capacity: 140 lbs./hr.

		Sorter M		
102	22	60	56	3.75
103	22	60	60	1.90
104	22	60	59	0.90
105	22	60	56	1.80

Adjustments and Setup

Horizonal optical filter	- 3357	100% reference - 55%
Vertical optical filter	- 3376	0% reference - 8631
Background	- 6033	Capacity 350 lbs./hr.

Table 7. Standard and cold test germination percentages of four lots of damaged corn seed separated into a damaged fraction (rejects) and undamaged fraction (accepts) with Sorter M.

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

Sorter M

Horizontal optical filter	3386 + 24439	Vertical optical filter		5450
100% reference	5574 (White)	0% reference	(Black)	8631
Horizontal phototube	17020	Vertical phototube		16442
Backgrounds				
Samples 10 and 11	Special (Locates 105:75)			
Samples 12 and 13	Special (Locates 70:25)			

data indicated that color sorting after pretreatment of the seed with fast green was effective in removing mechanically damaged seed, and upgrading 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.

Mechanically damaged soybeans

A lot of Lee soybeans was obtained from Foundation Seed Stocks at Mississippi State University. These seed had been damaged at harvest by excessive threshing cylinder speed. Normal processing procedures could not remove the seed with cracked seed coats, broken cotyledons and fractures extending into the cotyledons. Also, there was not enough color difference in the damaged areas for detection with electric color sorters. To induce a color difference the seed were immersed in a solution of indoxyl acetate, removed immediately to an electric dryer where ammonia fumes introduced into the intake air stream of the dryer developed a blue-indigo stain on the damaged areas of the seed.

After drying, the seed were processed on Sorter M to remove the stained seed. Results presented in Table 8 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 caused 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 indoxyl acetate. After electric color sorting the "accepts" germinated 98 percent and the rejects germinated 36 percent.

Green seed from Lee soybean seed

Four lots of Lee soybeans that contained 18 to 36 percent green colored seed was obtained from the Seed Technology Laboratory at Mississippi State University. Seed of Lee are normally buff colored but in some seasons some of the seed of Lee and other varieties retain a green color in the cotyledons. It is not known what prevents the cotyledons of these seed from changing to the normal light yellow color during maturation.

The green seed were separated using Sorter M and germination tests were made to determine if there was any difference in the quality of the green and normal colored seed (Table 9). The normal buff colored seed germinated 22 to 32 percent higher than the green seed. These results indicated that there is a pronounced difference in germinability of the buff colored and green seed, and that a color sorter can separate them and upgrade germination.

Table 8. Results of standard germination tests on soybeans stained with indoxyl acetate and separated into damaged (rejects) and undamaged fractions (accepts) with Sorter M.

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

Sorter M

Adjustments and Setup

Horizontal optical filter	3408 - C
Vertical optical filter	3394 + 24439
100 % reference	5645 (White)
0% reference	8630 (Black)
Background	51%

Table 9. Results of germination tests on the composite and each color separate of samples of soybeans containing both buff and green seed.

Sample	Germination %		
	Composite	Buff	Green
A	84	93	66
B	66	84	52
C	78	86	64
D	70	88	56

Sorter M

Adjustments and Setup

Horizontal optical filter	660 mu
Vertical optical filter	3394
100% reference	5574 (White)
0% reference	8630 (Black)
Background	47%

Weathered cowpea seed

Two lots of cowpeas were obtained from Foundation Seed Stocks, Mississippi State University. One lot, Bunch Purple Hull, a white seeded variety had been moderately weathered, while the other lot, Mississippi Silver, was more uniformly damaged by frequent showers and humid weather at harvest time. Both lots failed to meet minimum germination standards for foundation seed (80 percent).

Weather damaged seed were removed from both lots and germination tests run on each separate (Table 10). The germination of the Bunch Purple Hull lot was increased from 68 to 84 percent with a loss of 34 percent of the lot, and qualified as foundation seed. Germination of the Mississippi Silver lot was increased only 6 percent with a loss of 28 percent of the lot. Thus, it did not meet standards even after shorting. The electric color sorter performed well where there was a visible difference due to weathering. However, when weathering was severe and uniform, effective separation was not possible.

Deteriorated clover and alfalfa seed

Lots of crimson clover and alfalfa seed were separated into three fractions in two passes through Sorter S. In the first pass, the lightest colored seed (light) were rejected. The accept fraction was further divided in the second pass into rejects (tan seed) and accepts (brown seed). The germination percentages and percentages of seed in each separate are given in Table 11.

Germination of crimson clover seed was increased by 8 to 18% over the composite at the expense of seed losses of 24 to 42 percent. The light colored seed separates germinated 30 to 67% higher than the brown seed separates. Color sorting alfalfa seed increased germination by 11 to 20 percent over the composite at the expense of seed losses of 26 to 49 percent. The light colored seed separates germinated 21 to 67 percent higher than the brown colored seed separates.

Table 10. Results of electric color separation of two lots of weathered cowpea seed on germination percentage.

	Original	Accepts		Rejects
	% Germ.	% of Sample	% Germ.	% Germ.
Bunch Purple Hull	68	66	84	37
Mississippi Silver	62	72	68	42

Adjustments and Setup (Sorter M)

Horizontal optical filter	3403	100% reference	5574
Vertical optical filter	3376	0% reference	8631
Background	3424		

GENERAL DISCUSSION

Electric color sorters have potential application in three areas of seed processing: research, upgrading seed quality, and purification of seed stocks. The research area provides an almost unlimited opportunity for workers who wish to study physiological aspects of seed quality related to color or various other phenomena associated with radiation in or near the visible spectrum. Although there are many references available in the literature concerning the significance of seed color, few previous attempts have been made to obtain large quantities of color sorted seed for field plantings except by hand sorting. Classification of very small color differences by visual examination is possible for only a few minutes at a time because of eye fatigue.

Photoelectric cells, which are the basic units of electric sorting machines, are sensitive to certain wave lengths of radiation depending on the materials used in construction of the phototubes. Filters positioned between the seed being viewed and the phototube make the cell more selective in its sensitivity. By determining the color values through color analysis of the seed lot under study and selection of proper filters, it is possible to study specific seed quality problems on a larger scale than has been practical.

In the second area, upgrading seed quality, the value of each

Table 11. Germination percentage of separates of five lots of crimson clover seed and four lots of alfalfa seed obtained in two passes through Sorter S.

Lot No.		Seed Color			
		Composite	Light	Tan	Brown
		Crimson Clover			
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)	(3)
C14	% Germ.	68	91	45	24
	% Seed		(60)	(24)	(16)
		Alfalfa			
AXX	% Germ.	72	92	72	25
	% Seed		(51)	(32)	(17)
4666	% Germ.	82	96	80	52
	% Seed		(54)	(27)	(9)
1715	% Germ.	84	95	88	74
	% Seed		(74)	(16)	(10)
78	% Germ.	77	90	80	53
	% Seed		(60)	(26)	(14)

class or kind of seed being processed must be considered by each seedsman to determine the practicality of using electric color sorting.

The removal of mechanically damaged seed from seed lots was demonstrated to be possible. In some cases, such as removal of "bald heads" from peanuts, the separation can be accomplished without any pre-conditioning or staining process. In such cases - and when the value of the seed is sufficiently great - some commercial seedsmen are already using electric sorting machines. It is more difficult to separate seed in which there is little color difference between mechanically damaged and undamaged seed. Some means must be used to induce a color difference so that damaged seed can be detected by the photocells of color sorters. The staining agents used in this study, while effective, leave much to be desired from a practical standpoint. The fast green dye used to stain damaged areas of corn seed did give satisfactory results. However, to accomplish staining, it was necessary to immerse the seed in a solution of the dye, immediately rinse in running water to prevent excessive coloring, and then dry the seed. Although inconvient and tedious to apply, the fast green stain did not have any adverse effect on germinability of the seed. This was not true in the case of the stain used for soybeans. The indoxyl acetate treatment caused many of the seed coats to slough off with a resulting decrease in germination percentage. The indoxyl acetate stain did color the damaged soybeans sufficiently to allow removal with the electric sorter.

Exploitation of the idea on the separation of mechanically damaged seed from undamaged seed developed here will require more suitable and practical methods for accentuating color differences of damaged area. Suitable treatments with a gas or aerosal would be most practical.

Separation of severely weather damaged seed from less deteriorated seed with the electric color sorter was evaluated. The variable results, however, indicate that the electric sorting machines are no panacea for upgrading weather damaged seed lots.

The results obtained by color sorting alfalfa and crimson clover seed revealed a striking relationship between seed color and viability. Darkening of seed color was associated with deterioration of the seed. Color sorting effectively upgraded germination by concentrating the lightest and darkest colored seeds into separate fractions.

In the third area, processing to purify breeders and foundation seed stocks, it is easier to justify use of electric color sorting techniques on a much wider range of seed kinds since the benefits of purification of stock seed will be evident even in succeeding generations.

Rice was successfully sorted to remove off-types and at the same time to separate weed seed that remained after conventional processing. While it would require many color sorters in processing plants throughout the rice growing area to sort all the seed of a given variety, it is believed that purification of relatively small lots of breeders or foundation seed would result in much less rogueing, higher quality seed stocks, and more rapid progress toward elimination of off-type seed in the variety.

It was also demonstrated that a good separation could be made of white off-type seed from a brown seeded variety of sorghum or brown off-type seed from a white seeded variety. In the hybrid sorghum seed producing areas this technique could be of immense value because of the presence and effect of stray pollen even in the most isolated fields.

Color sorting effectively separated despined cockleburs from mechanically delinted cottonseed. Indeed it was the most effective procedure of many evaluated (but not reported here) in an extensive investigation on means for effecting the separation. The capacity of the separation appears to be in the economical range for the more valuable foundation and registered cottonseed.

The potential of electric color separation of very small seed was explored in the removal of Panicum spp. from a lot of a new variety of arrowleaf clover. While processing the lot of seed required a comparatively long time and was not considered within the real capability of the machine, purity was brought up to requirements for foundation seed. Since this was the only lot of seed of this new variety available for further multiplication, the value of these seed can not be calculated and any effort necessary to prevent delayed release was considered justified.

The use of electric color sorting to separate corn seed into various shades of yellow was evaluated. Results indicate that the color sorters can be a valuable tool to plant breeders who are developing high xanthophyll lines of corn. High xanthophyll corn will materially reduce feed costs in the poultry industry since synthetic sources of xanthophyll are expensive. This pigment is a necessary

ingredient in poultry feed to impart a creamy skin color to dressed poultry and a pleasing yolk color to eggs. High xanthophyll corn also has a better competitive position in the export market.

By implication the results achieved here suggest the possibility of effecting separations of seed with electric color sorters on the basis of other physiological or chemical properties such as lysine content or specific quality factors demanded by the food processing industry.

SUMMARY AND CONCLUSIONS

The purpose of these studies was to explore several possible applications of electric color sorting techniques in the area of seed processing and seed research.

Two lots of F3 corn seed with a wide variation in color from white to deep orange-yellow were separated into several shades of orange-yellow with an electric color sorter. Analyses for carotene and xanthophyll were run on selected samples to determine the effectiveness of the color sorter in separating the seed on the basis of xanthophyll content. A blue-green sensitive photoelectric combination was used first to separate the seed with the lowest reflectivity values for that range of color. The darkest separates were further processed by a red-orange sensitive photoelectric setup and the fractions with reflectivity values of over 80 percent, and 70 to 80 percent relative to magnesium carbonate (white) were separated. Results indicated a close relationship between the more intense shades of orange-yellow and xanthophyll content and the medium shades of yellow and carotene content.

The effectiveness of electric color sorters in purifying breeders and foundation seed stocks was evaluated on seed lots of rice, sorghum, cotton, and arrowleaf clover. Straw colored off-type rice seed were removed from Dawn, a gold colored variety of rice. Both color sorters used did a satisfactory job of separating the off-type seed. White off-type sorghum seed were completely removed from a lot of Rio, a brown seeded variety, and brown off-type sorghum seed were removed from a lot of Sart, a white seeded variety. A lot of Meechee arrowleaf clover containing an excessive amount of weed seed (Panicum spp.) was processed with the Sortex G414 color sorter and even though the capacity was low and the separation not considered within the real capacity of the machine, sufficient weed seed were removed from the lot to meet standards for foundation seed. Despined cocklebur were effectively removed from mechanically delinted cottonseed.

Several lots of seed were processed to explore uses of electric color sorters in upgrading seed quality. Four lots of corn seed were treated with fast green stain to color damaged areas of the seed so that the color sorters could detect the damaged seed and remove them. Results of the separation, germination and cold tests indicated that the color sorter did remove the damaged, stained seed. In all cases the undamaged separate performed better in germination and cold tests than either the damaged separate or composite sample. The fast green staining treatment did not have any adverse effect on germination.

A lot of mechanically damaged Lee soybeans was treated with an indoxyl acetate solution to stain the damaged areas of the seed. Subsequent color separation to improve germination was effective but the staining process caused an additional 12 percent processing loss due to seed coats sloughing off and staining of the cotyledons of seed which would otherwise have germinated.

Physiologically "off-type" seed of Lee soybean with green cotyledons were successfully separated from normal colored seed with yellow cotyledons by the electric color sorter. Germination percentage of the buff colored seed separates were much higher than that of either the composite or the green seed separates. It is not known what causes the green seeded condition in some soybean varieties but it is evident that the green seed are physiologically inferior in quality.

The upgrading of germination in cowpeas with electric color sorters was attempted with variable results. One lot of weather damaged Bunch Purple Hull cowpeas was separated with a subsequent 18 percent increase in germination of the "accept" portion. Another lot of Mississippi Sliver, which was more uniformly damaged, was separated with only a 6 percent rise in germination that was insufficient to meet minimum standards.

Seed lots of alfalfa and crimson clover seed were upgraded in germination by separating out the dark colored, deteriorated seed with a color sorter.

The electric color sorters can be a valuable tool for research and commercial processing. They are extremely versatile and accurate when operated properly. Their principle disadvantages are high cost, low capacity, and the need for some specialized training for operators.

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