Color Sorting of Coated *Brassica* Seeds by Fluorescent Sinapine Leakage to Improve Germination

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Abstract. Color sorting was performed to upgrade seed quality by removal of fluorescent coated seeds. The fluorescent coating was attributed to sinapine leakage from nonviable seeds. Nine seedlots, three seedlots each of cabbage (*Brassica oleracea* L. Capitata group), broccoli, and cauliflower (*B. oleracea* L. Botrytis group) were custom coated. Seed samples were pretreated before coating with or without 1.0% NaOCl for 10 minutes to enhance leakage. All samples revealed a percentage of seeds with fluorescence. The light emission from selected fluorescent and nonfluorescent coated seeds was quantified by fiber-optic spectrophotometry. Fluorescence was expressed from 400 to 560 nm, with peak emission being from 430 to 450 nm. These data confirmed our visual interpretation of blue-green fluorescence. The ratio of light emission from fluorescent compared to nonfluorescent coated seeds ranged from 4.5 to 7.0 for all samples and averaged 5.7. An ultraviolet (UV) color sorter was employed to separate fluorescent (reject) from nonfluorescent (accept) coated seeds. The percentage of nonfluorescent coated seeds (averaged over seedlot and NaOCl pretreatment) before and after sorting was 89.5% and 95.9%, respectively. Therefore, color sorting was able to remove a high percentage of fluorescent coated seeds with an average loss (rejection of nonfluorescent coated seeds) of 6%. An increase in the percent germination was recorded in eight of the nine seedlots following color sorting, and the greatest improvement was obtained with seedlots of medium quality. Germination of three medium quality lots was increased by 10 to 15 percentage points. The average increase in germination with or without NaOCl pretreatment was 8.2 and 5.5 percentage points, respectively. In conclusion, the germination of *Brassica* seedlots could be improved by separating (removing) fluorescent from nonfluorescent coated seeds. UV color sorting technology was employed to demonstrate that seed conditioning could be conducted on a commercial basis to upgrade seed quality.

Seed quality is composed of several components, including the percent germination, purity, vigor, and pathological condition of a seedlot (Copeland and McDonald, 1985). Our discussion will focus on the percent germination of seedlots and its importance on seedling establishment. The maximum potential for seedling emergence is governed by the percent germination, as a seedlot with 80% germination can not be expected to have >80% seedling emergence. The goal is to increase the percent germination of a seedlot and, thereby, increase seedling establishment potential.

Seed conditioning has been conducted to remove contaminants from seeds including weed seeds, other crop seeds, and inert matter (Brandenburg, 1977; Brandenburg and Park, 1977). Seed conditioning has also been employed to grade seeds by physical traits such as length, width, or thickness (Harmond et al., 1968). The ability to upgrade the germination of seedlots based on physical characteristics alone appears to be limited. The concept of combin-

ing seed conditioning by physical characteristics with physiological characteristics associated with seed viability could provide the opportunity to upgrade seedlot germination.

Physiological seed treatments or seed priming have been employed to enhance the rate of germination (Bradford, 1986; Taylor and Harman, 1990). Seeds were first hydrated under controlled environmental conditions followed by dehydration. Seeds treated in such a manner may be coated, if desired, stored, and eventually sown. An additional advantage of these treatments was that seeds attain a high moisture content and, therefore, become physiologically active. During this period, physiological differences between viable and nonviable seeds may be expressed.

Phenolic or aromatic choline esters have been found in seeds of the Brassicaceae, and the predominant phenolic choline ester was sinapine (3, 5-dimethoxy -4- hydroxycinnamoylcholine) (Bouchereau et al., 1991; Clausen et al., 1985). Sinapine has been shown to leak preferentially from nonviable *Brassica* seeds after imbibition (Taylor et al., 1988). This compound is fluorescent and is yellow at high pH (210). Sinapine leakage was found to be a better predictor of seed viability than electrolyte leakage and has been developed as a rapid seed viability test (Hill et al., 1988).

A novel coating system has been developed to exploit sinapine leakage and upgrade seedlot quality in the Brassicaceae (Taylor et al., 1990). Seeds were first hydrated, which would result in leakage from nonviable seeds, and then were coated with an adsorbent consisting of cellulose with sand. The coated seeds are then dried, examined under UV light, and manually sorted into two fractions:

Abbreviation: PMT, photomultiplier tubes.

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Fig. 1. A photograph of coated *Brassica* seeds illustrating a portion with fluorescent coatings.

fluorescent and nonfluorescent. Three horticultural *Brassicas*, one agronomic *Brassica*, and one flower species were studied with this upgrading system (Taylor et al., 1991). Sowing the nonfluorescent seeds resulted in a greater percent normal seedlings than sowing noncoated seeds in all seedlots. The fluorescent fractions contained a high percentage of dead seeds and seeds that produced abnormal seedlings.

Commercial scale application of this technology requires a rapid technique to separate the fluorescent from the nonfluorescent seeds. Color sorters have been employed to separate seeds based on differences in color or light/dark characteristics (Brandenburg and Park, 1977). Color sorters singulate seed and detect the light reflectance on a single seed basis. Seeds were rejected by an electrically operated air valve, while good (accept) seeds pass through the equipment (Cabrera and Diaz, 1991).

The objective of this project was to study color sorting of fluorescent coated *Brassica* seeds. Research was performed on nine seedlots; three seedlots each of cabbage, broccoli, and cauliflower. The fluorescent emission spectrum was characterized, and color sorter efficacy was determined. Upgrading of seed quality was determined by the standard germination test of nonsorted and sorted nonfluorescent fractions.

Materials and Methods

Seedlots, NaOCl pretreatment, and coating. Three crop seeds were studied: cabbage, broccoli, and cauliflower. Three seedlots of each crop were obtained from commercial vendors: cabbage 'Brunswick', 'Copenhagen Market', and 'Ruby Ball'; broccoli 'Medium Late 423', 'Premium Crop', and 'Shogun'; and cauliflower 'Blue Diamond', 'Dok Elgon', and cauliflower 'Starbrite Y'.

A sample from each seedlot was pretreated with 1.0% NaOCl for 10 min, and other samples were not pretreated before coating. The purpose of the NaOCl pretreatment was to enhance the sinapine leakage rate (Taylor et al., 1993). Nonpretreated and NaOCl pretreated seeds of each seedlot were coated by Seed Systems (Gilroy, Calif.), and the coating formulation was based on earlier developments at Geneva (Taylor et al., 1990). A sample of coated seeds was illuminated with UV light and photographed.

Fluorescence emission. The purpose of this study was to quantify the fluorescence emission from coated seeds using fiber-optic spectrophotometry (Berlage et al., 1989). A coated sample of each seedlot and treatment was manually separated into two fractions: fluorescent and nonfluorescent. Fifteen coated seeds were placed in a custom-designed sample holder and irradiated with UV light from a 45° angle to the detector. The UV light was produced by a 50 W source with a 365 nm wavelength maximum emission (model 125120, Instrument Technology, Westfield, Mass.). The fluorescence emitted from the seed sample was detected by a UV-VIS 6 to 1 probe attached to a fiber-optic spectrophotometer (model 100, Guided Wave, El Dorado Hills, Calif.). The fiber-optic spectrophotometer had been upgraded to a model 150 and employed silicon and germanium detectors. Three data readings were taken with two dwell cycles in 4 nm increments. The fluorescence spectrum was initially characterized from 350 to 650 nm. The percent transmittance was converted to emission ratio, or the ratio of light emitted from the sample compared to the blank; i.e., 100% T= 1.0 emission ratio and 600% T= 6.0 emission. Based on the spectral distribution, the area under the curve was determined from 400 to 560 nm for all samples, and the derived

Fig. 2. The fluorescence spectrum (light emission) from fluorescent and nonfluorescent coated *Brassica* seeds.

value was unitless. There were four replicate samples per treatment and standard errors were calculated.

Color sorter. An Icore model 5141 UV color sorter (Scancor-Sortex, Union City, Calif.) was employed to separate fluorescent from nonfluorescent coated seeds. The feed rate was adjusted to deliver 40 to 50 seeds per second. The feed rollers were adjusted at a 45° angle to singulate seeds before the detection/rejection section of the unit. Seeds were irradiated by fluorescent tubes within the detection head of the unit. Three 931B photomultiplier tubes (PMT) with a spectral range of 300 to 660 nm were mounted at 120° angle from each other. The color sorter had "or" logic, and if any one PMT detected light, it would reject the seed. No filters were used with the PMTs, and slit size (aperture) was 2.3 mm. Seeds were rejected with an air solenoid operated at 400 kPa with a 4 to 5 msec pulse duration. The light sensitivity of the reject mode was determined empirically and correlated with the fiber-optic spectrophotometer values.

There were four replications of 50 g each per treatment used for each seedlot. A 10-g sample was removed and classified as nonsorted, and the remaining 40 g were sorted with the color sorter. Efficacy of the color sorting operation was verified by visual inspection under UV light. The percent nonfluorescent seeds was determined before and after sorting in the good-accept fraction. The percent nonfluorescent seeds rejected were calculated as the percent loss. Standard errors were calculated for each characteris-

tic of each seedlot and treatment. A standard germination test (AOSA, 1988) was conducted on the nonsorted and sorted nonfluorescent (accept) fractions. An arcsin transformation was performed, and data were analyzed within seedlots as a 2 × 2 factorial in a completely randomized design.

Results

Fluorescence emission. Coated seeds were photographed under UV light and a percentage of them revealed fluorescence (Fig. 1). The fluorescence emission was quantified from selected fluorescent and nonfluorescent coated seeds with a fiber-optic spectrophotometer showing light emission (Fig. 2). The fluorescent coated seeds emission was > 1.0 at wavelengths between 400 to 560 nm. The maximum emission ranged from ca. 430 to 450 nm, and the emission ratio exceeded 5.0 in this region. Emission from the nonfluorescent coated seeds was >1.0 between 410 to 490 nm, but did not exceed an emission ratio of 1.4.

The fluorescence was quantified from the nine seedlots with and without the NaOCl pretreatment (Table 1). The data, which are unitless, provided a relative method to compare the emitted light from selected fluorescent and nonfluorescent seeds. The emission ($\times 10^3$) from fluorescent and nonfluorescent coated seeds differed between treatments and ranged from 41.5 to 90.7 and 7.4 to 18.4, respectively. The average emission ($\times 10^3$) from all fluorescent and

Crop	Cultivar	NaOCl	Light emission ^a		Ratio	Color sorter sensitivity
			Nonfluorescent	Fluorescent		
Cabbage	Brunswick	–	7.4 ± 0.2	41.5 ± 0.7	5.6 ± 0.2	72
		+	10.3 ± 0.2	58.8 ± 3.2	5.7 ± 0.2	67
	Copenhagen Market	–	9.3 ± 0.2	55.7 ± 2.9	6.0 ± 0.4	67
		+	7.6 ± 0.1	45.1 ± 5.1	5.9 ± 0.7	70
	Ruby Ball	–	11.4 ± 0.3	66.9 ± 2.2	5.9 ± 0.3	62
		+	10.2 ± 0.2	60.4 ± 2.4	5.9 ± 0.3	62
Broccoli	Medium Late 423	–	13.4 ± 1.0	79.5 ± 5.1	6.0 ± 0.6	65
		+	12.2 ± 0.1	76.1 ± 4.4	6.3 ± 0.3	65
	Premium Crop	–	18.4 ± 1.0	90.7 ± 3.3	5.0 ± 0.4	50
		+	15.3 ± 0.5	86.3 ± 3.4	5.6 ± 0.2	60
	Shogun	–	14.6 ± 0.7	84.1 ± 4.8	5.8 ± 0.5	57
		+	11.9 ± 0.5	68.7 ± 4.3	5.7 ± 0.1	55
Cauliflower	Dok Elgon	–	9.6 ± 0.4	51.5 ± 2.6	5.4 ± 0.4	65
		+	8.0 ± 0.5	45.7 ± 3.5	5.7 ± 0.4	70
	Starbrite	–	9.5 ± 1.0	65.2 ± 5.0	7.0 ± 0.6	70
		+	11.5 ± 0.3	55.2 ± 2.3	4.8 ± 0.1	75
	Blue Diamond	–	9.6 ± 0.4	43.7 ± 7.3	4.5 ± 0.6	70
		+	9.7 ± 0.4	41.7 ± 1.8	4.9 ± 0.3	70
Mean		–	11.5	64.3	5.7	64
		+	10.7	59.8	5.6	66
Grand mean			11.1	62.0	5.7	65

^aThe units are dimensionless; values have been multiplied by 1000.

Table 2. Percentage of seeds with nonfluorescent coatings before and after color sorting and percent loss.

Crop	Cultivar	NaOCl	Seed (%)		
			Before sorting	After sorting	
			Nonfluorescent	Nonfluorescent	Loss
Cabbage	Brunswick	–	93.5 ± 1.6	96.0 ± 1.0	8.4 ± 0.3
		+	81.3 ± 1.5	90.5 ± 0.6	6.9 ± 0.3
	Copenhagen Market	–	90.8 ± 1.1	91.8 ± 1.0	2.9 ± 0.3
		+	84.8 ± 1.9	89.5 ± 1.4	7.7 ± 0.4
	Ruby Ball	–	87.3 ± 1.1	97.5 ± 0.3	5.6 ± 0.5
		+	85.3 ± 1.1	96.3 ± 1.5	6.3 ± 0.2
Broccoli	Medium Late 423	–	96.0 ± 0.7	99.8 ± 0.3	2.3 ± 0.2
		+	96.3 ± 0.5	98.5 ± 0.5	2.9 ± 0.3
	Premium Crop	–	86.3 ± 2.9	97.8 ± 0.6	3.2 ± 0.6
		+	88.0 ± 2.0	97.8 ± 0.6	8.7 ± 0.7
	Shogun	–	77.5 ± 2.8	95.8 ± 1.1	4.7 ± 0.6
		+	77.5 ± 1.2	92.0 ± 1.8	5.3 ± 0.7
Cauliflower	Dok Elgon	–	90.3 ± 1.8	96.8 ± 1.3	13.0 ± 0.6
		+	90.3 ± 1.1	92.3 ± 1.7	10.2 ± 0.9
	Starbrite Y	–	96.5 ± 1.0	98.5 ± 0.9	3.1 ± 0.2
		+	95.0 ± 1.4	98.5 ± 0.6	7.9 ± 0.4
	Blue Diamond	–	97.8 ± 0.6	98.8 ± 0.3	3.2 ± 0.1
		+	96.8 ± 0.5	97.5 ± 1.2	4.4 ± 0.2
Mean		–	90.7	97.0	5.2
		+	88.4	94.8	6.7
Grand mean			89.5	95.9	5.9

nonfluorescent coated seeds was 62.0 and 11.1, respectively. The NaOCl pretreatment affected emission for certain seedlots, but there was no consistent trend among seedlots. Overall, NaOCl slightly increased light emission from fluorescent and nonfluorescent coated seeds compared to nonpretreated seeds. The ratio of emitted light from fluorescent to nonfluorescent coated seeds ranged from 4.5 to 7.0 and averaged 5.7.

Color sorter. The UV color sorter sensitivity was adjusted on an empirical basis for each treatment. This was accomplished by selecting known fluorescent or nonfluorescent coated seeds, passing them through the sorter singly and adjusting the sensitivity for optimum separation. Therefore, the sensitivity setting may differ among and within seedlots (Table 1). The UV color sorter sensitivity level was negatively correlated with both fluorescent and nonfluorescent values obtained from the fiber-optic spectrophotometer, $r = -0.78^{**}$.

The efficacy of the UV color sorter was verified by visual inspection. All seedlots studied contained a percentage of fluorescent coated seeds that was attributed to sinapine leakage into the coated seeds from poor quality seeds (Taylor et al., 1991). The percent nonfluorescent coated seeds differed among seedlots before sorting and ranged from 77.5 to 97.8 with an overall average of 90 (Table 2). The NaOCl pretreatment decreased the percent nonfluorescent coated seeds only in cabbage 'Brunswick' and 'Copenhagen Market' before sorting. After sorting, the percent

nonfluorescent coated seeds ranged from 89.5 to 99.8, and the NaOCl decreased the percent nonfluorescent coated seeds in three of the nine seedlots (cabbage 'Brunswick', broccoli 'Shogun', and cauliflower 'Dok Elgon'). There was an average increase of six percentage points in nonfluorescent coated seeds due to sorting (89.5 vs. 95.9), that was attributed to removal of fluorescent seeds by the color sorter. Loss was <13% and averaged 6%.

A standard germination test was performed to study the interaction of sorting and NaOCl. The analysis was performed on normal seedlings for each seedlot separately. Sorting the coated seed resulted in a significant improvement in the percent germination in eight of the nine seedlots (Table 3). Only cauliflower 'Dok Elgon' did not show a significant difference due to sorting. The average percent germination of the nine seedlots before sorting was 82. After sorting, the germination with or without NaOCl pretreatment was 90.6% and 87.8%, respectively. A significant improvement in germination was measured in medium quality seedlots. The initial germination was 67.1% for cabbage 'Ruby Ball', 70.3% for broccoli 'Premium Crop', and 74.9% for broccoli 'Shogun' (averaged over NaOCl treatments), compared to 81.8%, 84.4%, and 85.3%, respectively, after sorting. NaOCl resulted in a slight decrease in germination in broccoli 'Medium Late 423', while cabbage 'Ruby Ball' exhibited an improvement of 14 percentage points (averaged over sorting). Overall, NaOCl pretreatment resulted in a three percentage point increase after sorting

Table 3. Percent germination of nonsorted and sorted fluorescent seed coatings.

Crop	Cultivar	NaOCl	Germination (%)		Mean squares and level of significance			
			Nonsorted	Sorted	Sorted	NaOCl	Sorted × NaOCl	Residual
Cabbage	Brunswick	–	78.3	79.3	0.0122**	<0.0001 ^{NS}	0.0075**	0.0006
		+	74.8	82.8				
	Copenhagen Market	–	91.3	95.0	0.0409**	<0.0001 ^{NS}	0.0023 ^{NS}	0.0015
		+	89.8	96.0				
	Ruby Ball	–	59.3	75.8	0.1186**	0.1066**	0.0001 ^{NS}	0.0007
		+	75.0	87.8				
Broccoli	Medium Late 423	–	88.8	93.0	0.0074**	0.0064*	0.0040 ^{NS}	0.0011
		+	88.3	89.0				
	Premium Crop	–	73.0	82.0	0.1174**	<0.0001 ^{NS}	0.0158**	0.0006
		+	67.5	86.8				
	Shogun	–	74.5	84.0	0.0697**	0.0019 ^{NS}	0.0007 ^{NS}	0.0011
		+	75.3	86.5				
Cauliflower	Dok Elgon	–	89.3	91.5	0.0022 ^{NS}	0.140 ^{NS}	0.0007 ^{NS}	0.0034
		+	93.0	93.8				
	Starbrite Y	–	94.3	94.8	0.0264**	0.0009 ^{NS}	0.0200*	0.0022
		+	89.8	96.8				
	Blue Diamond	–	92.3	94.5	0.381**	0.0028 ^{NS}	0.0095*	0.0016
		+	87.8	95.5				
Mean		–	82.3	87.8				
		+	82.4	90.6				
Grand mean			82.4	89.2				

^{NS}, *, ** Nonsignificant or significant at $P = 0.05$ or 0.01 , respectively.

than did nonpretreated seeds. Four seedlots, cabbage 'Brunswick', broccoli 'Premium Crop', and cauliflower 'Starbrite Y' and 'Blue Diamond' revealed a significant interaction with sorting and NaOCl, and the same seedlots also exhibited a highly significant difference due to sorting. The percent of the treatment mean square attributed to the interaction was 38% for cabbage 'Brunswick', 12% for broccoli 'Premium Crop', 42% for cauliflower 'Starbrite Y', and 19% for cauliflower 'Blue Diamond', compared to 62%, 88%, 56%, and 76% for the sorting effect, respectively.

Discussion

The concept of this project was to combine physiological presowing treatments with seed conditioning. Seed coating technology was necessary to bridge these two components into a complete system. Physiological presowing treatments are treatments that involve hydration and dehydration of seeds under controlled environmental conditions for a specified period of time (Taylor and Harman, 1990). One consequence of hydrating seeds is that the nonviable *Brassica* seeds would preferentially leak sinapine into the imbibing medium (Taylor et al., 1988). Sinapine would normally be discarded at the completion of the hydration phase in a conventional physiological seed treatment. However, it could be exploited as a biochemical marker to detect seed viability.

Seed coating or pelleting technologies consist of coating indi-

vidual particles (seeds) in a batch process (Scott, 1989; Taylor and Ham-tan, 1990). Seeds may be coated immediately after hydration without dehydrating them (Kaufman, 1991). An adsorbent material could be used as the filler in the coating to trap sinapine (Taylor et al., 1991). After coating, the coated seeds could be dried to decrease moisture content to facilitate seed handling and prolong storage.

Finally, the compound that leaks must be detected physically. In our system, the sinapine was fluorescent, thereby providing a natural indicator for its presence. Seed conditioning equipment, such as the UV color sorter, could be employed to separate seeds with fluorescent coated seeds from nonfluorescent coated seeds. The UV color sorter would upgrade seed lot quality and demonstrate the commercial feasibility of this system.

The fluorescence expressed on a single seed basis was readily observed with UV illumination (Fig. 1). The fluorescence spectrum revealed light emission from 400 to 560 nm (Fig. 2). This physical description verifies our visual interpretation that the fluorescence was blue-green (Taylor et al., 1988). The fluorescence emission varied with seedlot (Table 1) and may be attributed to differences in leakage rate, sinapine content, and coating characteristics. The ratio of light emitted from selected fluorescent and nonfluorescent coated seeds ranged from 7.0 to 4.5 with an average of 5.7. Therefore, large differences in leakage as determined by light emission was consistently observed among seedlots.

The NaOCl pretreatment was intended to accelerate leakage and, therefore, enhance fluorescence (Taylor et al., 1993). In preliminary studies, the NaOCl pretreatment was shown to accelerate leakage from heat-killed and aged seeds. Therefore, greater fluorescence emission was expected from pretreated seeds. Coated seeds with the NaOCl pretreatment had, on average, less fluorescence emission than nonpretreated seeds (Table 1). This reduction may have been attributed to oxidation of sinapine.

Color sorter efficacy was verified by visual inspection under UV light. It was difficult to classify coated seeds as either fluorescent or nonfluorescent due to several reasons. There was a percentage of coated seeds that exhibited partial or incomplete fluorescence. The light emission from these coated seeds would be less than those selected with uniform fluorescence. The degree of observed fluorescence was a subjective evaluation, and the intensity of fluorescence was determined by the UV light source and proximity of the source to the sample.

An increase in percent nonfluorescent coated seeds was generally obtained after color sorting (Table 2). The color sorter was thus able to remove a significant portion of fluorescent coated seeds. A relatively small percentage loss was encountered with the color sorting operation. The loss averaged 6%, and some loss is customary for any seed conditioning operation. The percent improvement (i.e., increase in nonfluorescent coated seeds) and loss are directly controlled by the sensitivity setting on the color sorter. A higher percentage improvement would be accomplished with a concomitant increase in loss and vice versa. A sample could be passed through the color sorter twice to further decrease the percent fluorescent coated seeds found in the accept side; however, additional loss would be encountered with this additional operation.

The nine seedlots tested provided a range of seed qualities. An increase in the percent germination was recorded in eight of the nine seedlots following color sorting (Table 3). The cauliflower 'Dok Elgon' did not exhibit an improvement, even though a high percentage of seeds were discarded (Tables 2 and 3). This behavior may be attributed to the spotty fluorescence observed on the coatings of this seedlot. The greatest improvement in germination was obtained with seedlots of medium rather than of high quality. The germination of broccoli 'Shogun', 'Premium Crop', and cabbage 'Ruby Ball' increased by 10.4, 14.1, and 14.7 percentage points after sorting, respectively. The average increase in germination without or with NaOCl pretreatment was 5.5 and 8.2 percentage points, respectively. The NaOCl may have independently increased germination (Table 3), enhanced leakage (Taylor et al., 1993), and decreased fluorescence (Table 1). Further study is necessary on this pretreatment.

The system developed to upgrade seed quality in *Brassica* consisted of hydration, coating, drying, detection, and separation (Taylor et al., 1991). Since this system consisted of several phases, the final result of germination enhancement depends on the efficacy of each component. Nonviable seeds must first leak sinapine, and leakage is influenced by hydration conditions and seedlot. The coating must effectively trap sinapine on a single seed basis, and the coating can not be detrimental or toxic to the seeds. The color sorter must be set to discriminate between fluorescent and nonfluorescent coated seeds, and this can be performed empirically. The UV color sorter may make errors in separation: fluorescent coated seeds are not rejected or nonfluorescent-coated seeds are rejected. The upgrading of seedlots by UV color sorter was also

dependent on the degree of fluorescence of the coated seeds. Coated seeds with weak or partial fluorescence may not be rejected.

In conclusion, UV color sorting technology can be effectively employed to upgrade *Brassica* seed quality by exploiting sinapine leakage and seed coating technology. Removal of fluorescent coated seeds by color sorting improved the subsequent percentage germination, and an increase in nonfluorescent coated seeds was correlated with an improvement in germination, $r = 0.71$ ". Benefits obtained from physiological seed treatments on seedling emergence can thus be improved by removal of nonviable seeds on a noninvasive basis.

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