A Procedure for Evaluating Scarification Processes[1]

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ABSTRACT

Seed of some species require scarification to germinate within a specified period of time, but seed injury can occur with incorrect scarification. A method of evaluating the effectiveness of scarification procedures is described. An experimental abrasive scarification technique was developed and tested on seed of six species of crop plants. Seed was subjected to nine combinations of mechanical scarification. An optimum treatment was identified for each species. Different seed types were found to have varying requirements for optimum scarification.

Additional index words: **conditioning, hard seed, germination, damage.**

INTRODUCTION

Hard seeds are those seeds that possess a physical barrier to entry of water. While this condition is advantageous to survival in the seeds' natural surroundings, it is generally considered undesirable in agricultural systems because crop emergence is spread over a long period of time. Families of cultivated crops known to contain hard-seeded species include: Asteraceae (1)*, Convolvulaceae (4), Geraniaceae (1), Lamiaceae (1), Fabaceae (68), Lilaceae (2), Malvaceae (4). Many uncultivated families contain hard-seeded species (Justice and Bass, 1978).

Seed scarification refers to seed conditioning procedures that increase the permeability of the seed coat to allow water to enter the seed more easily. In some cases, scarification is used to reduce the hard seed content of commercial seed lots. In certain areas, vegetable, herb, flower, oil, fiber, and forage legume seeds are scarified to produce more rapid and uniform crop stands, increase crop yields, and reduce volunteers in subsequent crop years. Commercial seed lots are usually scarified by machines that condition by impact and/or abrasion. Small seed lots are sometimes scarified by chemically treating the seed with strong acids or bases.

A great deal of research has been devoted to the study of seed dormancy, hard seed, and seed scarification. McKee et al. (1977) described the mechanism for hard seededness in crownvetch (*Coronilla varia* L.) concluding that the cuticle and first cell layer of the seed coat were primarily responsible for the hard-seed condition in that species. Justice and Bass (1978) state that one possible cause of hard seed in some species is storage in low-humidity environments. They relate the chemical composition and thickness of the seed coat to the speed of water uptake during seed germination.

A number of scarification techniques for different species have been reported. Wild rice (*Zizania aquatica* L.) was scarified by tumbling with crushed granite (Oelke and Albrecht, 1978); crownvetch seed (*Coronilla varia* L.) was pierced to various depths (McKee et al., 1977); and soybean (*Glycine max* L.) was subjected to electro-hydraulic shock (Kaisheva et al., 1980). Shrub seed was treated with superheated steam (Sholokov et al., 1975); Stylo seed (*Stylosanthes* spp.) was subjected to acid, hot water and dry heat, and impact (Grant, 1979); and effects of acid, abrasion, and water immersion on bean seed (*Phaseolus* spp.) were studied (De Mattos, 1970). Cycad seeds (*Zamia* spp.) were hand-cut at various locations by Smith (1978), sweet clover (*Melilotus albus* Desr.) was rubbed by passing the seed through various cleaning and threshing machines (Hammer, 1973), perennial vetch (*Vicia* spp.) seed was placed in a thick cotton sack and pounded by Gonyan (1979), and *Eucalyptus* spp. were punctured with a needle by Banks (1968). Dodder (*Cascuta campestris* Yunkr.) was subjected to an abrasive process (Hutchinsen and Ashton, 1979); *Leucaena glauca* Benth. was abrasion tested for reducing hard seed (Ramdeo 1971); alfalfa seed (*Medicago sativa* L.) was exposed to radio frequency energy (Nelson and Kehr, 1963).

Other seed types studied with regard to hard seed and scarification include *Crotalaria* spp. (Jones, 1971), black gum (*Nyssa sylvatica* Marsh.) (McGill and Whitcomb, 1977), pea (*Pisum* spp.) Marbach and Mayer, 1974), and Cherimoya (*Annona cherimolia* Mill.) Jubes et al., 1975).

The literature dealing with scarification suggests that the typical method of evaluating various scarification processes involves separately presenting percentage values for the change in number of hard seed and the number of seed that show normal germination after scarification as determined

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*Number of species in the family that may contain hard seed.

by standard germination tests. No references were found that combined these values nor the changes in the number of dead seed and seed germinating to form abnormal seedlings. Therefore one objective of this research was to develop a method for evaluating scarification processes by combining values for all four common germination categories (i.e., normal, hard, abnormal, and dead).

Little information was found that dealt with the effect of treating a given species of seed with varying degrees of scarification aggressiveness. A second objective then was established to determine the effect of varying degrees of scarification on seed of different species. As an outgrowth of this, a final objective was to develop a mechanical scarification technique capable of providing varying degrees of controlled aggressiveness.

MATERIALS AND METHODS

Samples of six species with hard-seededness characteristics were acquired from different sources. These included flowering geranium (*Pelargonium* spp.), dichondra (*Dichondra repens* Forst.), morningglory (*Ipomoea* spp.), arrowleaf clover (*Trifolium vesiculosum* Savi), alfalfa (*Medicago sativa* L.), and lupine (*Lupinus* spp.).

Development of the Mechanical Scarification Technique

Initial tests of mechanical methods to reduce hard seed in geranium seed involved subjecting 5-g samples of the seed to impact, abrasion, rubbing, hydraulic and pneumatic pressurization, mechanical crushing, a gas flame, and spot burning. Treated samples were evaluated by standard germination tests. The results of these tests indicated that the abrasion process was most effective in reducing hard seed and raising the percentage of seed exhibiting normal germination. As a result of these early tests, an abrasive scarifier was designed, constructed, and tested using each of the six selected seed types.

The scarifier consisted of a polyvinyl chloride cylinder 155 mm in diameter and 620 mm in length. The tube, with a longitudinal rotor, was mounted on a plywood base that allowed the cylinder to be tilted to a 5-, 10-, or 15-degree slope from horizontal. The interior surface of the cylinder was lined with 60-grit abrasive emery cloth. A 25-mm circular hole was cut in the top surface of the upper end of the cylinder and fitted with a funnel to accept unscarified seed from an electromagnetic vibratory feeder. A 25-mm × 100-mm opening was milled in the bottom surface of the lower end to allow discharge of the scarified seed.

The rotor assembly consisted of a shaft with flexible vinyl sheets. The hexagonal steel shaft was machined on each end to fit a ball bearing. Six flexible vinyl sheets 3-mm thick, 15-mm wide, and extending the length of the cylinder were attached to the sides of the hexagonal shaft. The shaft was driven by a variable-speed DC-motor to provide rotor speeds of 0-800 r/min.

With the scarifier in operation, seed was rubbed against the abrasive lining by the six vinyl sheets rotating with the shaft. The degree of scarification was varied by changing the slope of the cylinder and the rotor speed. Greater slopes reduced the time that seed spent inside the scarifier. Lower speeds reduced the centrifugal force of the vinyl sheets on the seed and also the duration of scarifying action on any one seed during its transit through the cylinder.

Scarification of Six Hardseeded Species

The six selected seed species were tested separately. Each species was subjected to nine combinations of three cylinder slopes (5, 10, and 15 degrees) and three rotor speeds (250, 500, and 750 r/min). Each test condition was duplicated for all species. Two replicates of untreated control lots were also tested for germination.

Observation of the scarifier in operation in preliminary experiments indicated that the degree of scarification was influenced by the feed rate. This agrees with work done by Grant (1979) concerning the effect of feed rate on scarification. For this reason, the feed rate was held at a constant rate of 25 kg/hr and a steady state condition was obtained before taking samples for analysis.

Samples weighing approximately 50 g were collected from the discharge end of the scarifier. Between each test replication, the machine was thoroughly cleaned with compressed air, revolution speed and cylinder slope measured and adjusted to prescribed conditions.

Twenty samples of each species of seed (two replications of nine operating conditions and two replications of an untreated control) were tested for germination according to the rules specified by the Association of Official Seed Analysts (1978). Results of these tests were reported as the number of seed falling into four germination categories; normal germination, hard seed, abnormal germination, and dead seed.

RESULTS AND DISCUSSION

The results of germination tests for each of the nine operating conditions for the six species tested are presented in Table 1. In four of the six species examined (geranium, dichondra, alfalfa, and lupine), normal germination values both lower and higher than the control values were obtained. The reduction in normal germination values after scarification indicated operating conditions that either increased dead and/or abnormally germinating seed or decreased hard and/or normally germinating seed. As expected, these reductions tended to occur at low cylinder slope and/or high rotor speed. Normal germination values increased as a direct result of operating conditions that reduced hard seed and caused little or no change in dead and abnormally germinating seed. In these four species, the greatest increase in normal germination occurred at less aggressive operating conditions.

In tests of the remaining two species (morningglory and arrowleaf clover), all operating conditions significantly increased normal seed germination. For arrowleaf clover even the most aggressive condition (5° slope and 750 r/min) left an average of 5.5% hard seed while in morningglory a complete reduction of hard seed content resulted from this treatment. In both species, no significant increase in the number of dead and abnormally germinating seed occured at any of the combinations of operating conditions.

Table 1. Mean germination percentages for scarified seed.

Machine setting		Germination category			
Slope	Rotor speed	Normally germinating seed	Hard seed	Abnormally germinating seed	Dead seed
(°)	(r/min)	-----%			
Geranium					
Control (no scarification)		31.0	64.5	0.5	4.0
5	250	33.5	60.0	1.5	5.0
5	500	89.0	4.5	2.5	4.0
5	750	87.0	0.0	9.5	3.0
10	250	36.0	59.0	0.5	3.0
10	500	86.0	8.5	2.0	3.5
10	750	95.5	0.5	1.0	3.0
15	250	41.0	54.0	1.5	3.5
15	500	89.5	3.0	0.5	7.0
15	750	88.0	3.0	4.0	5.0
Alfalfa					
Control (no scarification)		70.5	14.0	12.0	3.5
5	250	74.0	7.0	16.0	3.5
5	500	71.0	9.5	15.5	4.0
5	750	57.0	0.0	40.5	2.5
10	250	73.5	10.5	14.0	2.0
10	500	80.0	1.0	16.0	3.0
10	750	64.5	0.0	34.5	1.0
15	250	73.5	12.5	12.0	1.5
15	500	80.0	0.5	16.5	3.0
15	750	71.0	1.0	27.5	1.0
Arrowleaf Clover					
Control (no scarification)		24.0	73.5	2.5	0.0
5	250	27.0	67.5	4.5	2.0
5	500	52.0	41.5	6.5	0.0
5	750	86.0	5.5	8.5	0.5
10	250	28.5	67.5	4.0	1.0
10	500	37.0	58.5	4.0	1.0
10	750	42.0	54.0	3.0	0.5
15	250	27.5	69.5	2.5	0.5
15	500	35.5	61.0	3.5	0.0
15	750	57.0	38.5	5.5	0.0
Lupine					
Control (no scarification)		37.0	62.0	0.0	1.0
5	250	96.5	1.0	1.5	1.5
5	500	97.5	0.0	2.0	0.5
5	750	89.5	0.0	10.0	0.5
10	250	96.5	1.5	1.5	0.5
10	500	97.5	0.0	2.5	0.5
10	750	80.5	0.0	18.5	1.0
15	250	87.5	10.0	1.0	1.0
15	500	98.5	0.0	1.0	0.5
15	750	77.5	0.0	22.5	0.0
Morningglory					
Control (no scarification)		68.0	23.5	2.0	6.5
5	250	64.5	26.0	2.5	6.5
5	500	90.5	3.5	1.5	4.5
5	750	91.0	0.0	1.0	8.0
10	250	68.0	25.0	1.0	6.0
10	500	89.0	5.0	1.0	5.0
10	750	91.0	0.0	2.0	7.0
15	250	69.0	25.0	2.0	3.5
15	500	85.5	6.0	3.0	5.5
15	750	93.0	0.0	4.0	2.5
Dichondra					
Control (no scarification)		52.5	21.5	14.5	11.5
5	250	53.0	23.5	12.0	11.5
5	500	54.5	20.5	14.0	11.0
5	750	67.5	7.0	19.0	6.0
10	250	53.5	22.0	14.0	10.5
10	500	58.5	18.0	15.5	80
10	750	61.0	11.5	17.5	10.0
15	250	53.0	24.0	13.5	9.5
15	500	58.5	9.5	13.5	12.5
15	750	64.5	10.0	15.5	7.5

Evaluation of the scarification process

As seen, the changes in the percentage of seed falling into each of the four germination categories as a result of scarification compared with the control can either improve or degrade the quality of the seed lot. Reduction in hard seed accompanied by an increase in normal germination can be considered an improvement in lot quality. An increase in the number of dead and abnormal seed and a decrease in normal germination lower the qualtiy of the seed lot.

The following formula is proposed to take into account the changes (compared with the control values) in the germination categories as a result of scarification:

$$E_s = \frac{N - H}{2H_c} - \frac{A + D}{N_c + H_c}$$

where

E_s = the overall effectiveness of scarification.
N = the positive or negative change in the percentage of seed exhibiting normal germination compared with the control lot.
H = the positive or negative change in the percentage of hard seed compared with the control lot.
A = the positive or negative change in the percentage of seed exhibiting abnormal germination compared with the control lot.
D = the positive or negative change in the percentage of dead seed compared with the control lot.
H_c = the percentage of hard seed in the control lot.
N_c = the percentage of seed exhibiting normal germination in the control lot.

Table 2. Effectiveness of scarification values (E_s)[1,2]

Seed type	Control	5° slope			10° slope			15° slope		
		250 r/min	500 r/min	750 r/min	250 r/min	500 r/min	750 r/min	250 r/min	500 r/min	750 r/min
Geranium	0.00[a3]	0.03[a]	0.89[c]	0.85[c]	0.09[ab]	0.85[c]	1.00[d]	0.15[b]	0.90[c]	0.87[c]
Alfalfa	0.00[b]	0.30[b]	0.10[b]	-0.35[a]	0.19[b]	0.75[c]	0.02[b]	0.15[b]	0.77[c]	0.33[b]
Arrowleaf clover	0.00[a]	0.02[a]	0.37[d]	0.82[e]	0.05[a]	0.17[bc]	0.25[c]	0.05[a]	0.15[b]	0.43[d]
Lupine	0.00[a]	0.95[e]	0.97[e]	0.83[d]	0.96[e]	0.96[e]	0.66[c]	0.82[d]	0.99[e]	0.61[b]
Morningglory	0.00[b]	-0.13[a]	0.93[de]	0.98[ef]	-0.02[b]	0.87[d]	0.98[ef]	0.02[b]	0.75[c]	1.05[f]
Dichondra	0.00[a]	0.00[a]	0.08[ab]	0.69[d]	0.03[a]	0.26[bc]	0.41[c]	-0.01[a]	0.28[bc]	0.65[d]

[1]Means of two replications.

[2]1.00 indicates optimum scarification; 0 indicates no net improvement from scarification; negative values indicate seed damage.

[3]Values with different letters in a given row indicate a significant difference within a species (P = 0.05) as determined by Duncan's multiple range test.

This formula differs from a handling severity index proposed by Brandenburg (1983) in that it regards the change from hard seed to normally germinating seed as beneficial. The Brandenburg index considers such a change as an increase in the severity of handling.

In this formula, equal importance is arbitrarily assigned to each of the four germination test variables. Numerical values for the overall effectiveness of scarification (E_s) will typically range from 1.00 to -1.00. Positive values indicate an effective scarification procedure (1.00 is the theoretical optimum); values near zero indicate no net improvement as a result of seed scarification; and negative values indicate a procedure that damages seed. Experimental error may produce values greater than 1.00 if there is an indicated decrease in dead seed and/or abnormally germinating seed combined with a nearly complete reduction in hard seed.

The formula was used to calculate values for the effectiveness of scarification using the germination data from the nine replicated test conditions. Resulting E_s values for all six species are shown in Table 2.

Duncan's multiple range test was used to test for significant differences (P = 0.05) between means of test values and control values. In most cases, three groups of E_s values were formed: those determined as optimum, those below optimum because of insufficient scarification (seen as high hard seed content), and those below optimum because of over-scarification (seen as increased abnormally germinating seed).

In geranium seed, the 250-r/min trials at slopes tested did not provide sufficient scarification to reduce hard seed and effectively increase E_s. The most aggressive operating condition, 5° at 750 r/min, increased the number of abnormally germinating seed due to over-scarification resulting in an E_s value significantly less than the optimum (highest) E_s value. The optimum E_s value occurred at an operating condition of 10° and 750 r/min. E_s values for scarified alfalfa seed showed trends similar to those of geranium seed. Over-scarification occurred at 750 r/min at all slopes, and under-scarification at 250 r/min and 10° and 15° slopes. Optimum scarification resulted in significantly higher E_s values at 500 r/min and 10° and 15° slopes.

In tests of arrowleaf clover seed the optimum E_s value occurred at 5° and 750 r/min. At this setting, an average of about 6% hard seed was still present in the sample, indicating a need for further testing at more aggressive operating conditions. Germination tests on seed from less severe operating conditions showed smaller decreases in hard seed content and significantly smaller E_s values.

In lupine seed five E_s values of 0.95 and above, not significantly different, occurred at operating conditions that combined all three slopes with 250 or 500 r/min. The 750-r/min trials showed large increases in abnormally germinating seed and significantly lower E_s values.

In morningglory seed, none of the trials caused excessive scarification as reflected by little or no increase in dead and abnormally germinating seed. No significant difference was found among the E_s values resulting from scarification at 750 r/min and all three slopes. These E_s values were near enough to the theoretical maximum of 1.00 that further testing of more aggressive conditions would not be necessary. Less severe conditions resulted in higher hard seed content and significantly lower E_s values.

For dichondra seed, both the 250- and 500-r/min trials at all slopes did not reduce the hard seed content as greatly as the 750-r/min trials. Significantly higher E_s values resulted from operating conditions that combined a rotor speed of 750 r/min with slopes of 5° and 15°. At these conditions 7% and 10% hard seed, respectively, still remained in the sample; but increases were seen in abnormally germinating seed. This suggests the need for more tests of different combinations of slopes and rotor speeds for dichondra seed.

In our tests, different seed types tended to require varying degrees of scarification to achieve optimum normal germination percentages. Alfalfa seed was easily damaged by aggressive scarification while arrowleaf clover was most resistant to injury. Lupine, morningglory, and geranium seed required moderate scarification, but damage occurred at more aggressive operating conditions. Dichondra seed resisted scarification as seen by high percentages of hard seed at aggressive conditions, but showed a susceptibility to damage at these conditions as seen by increased abnormal germinants. This demonstrates the need for users of scarification equipment to have knowledge of seed scarification requirements and to have equipment capable of providing the optimum level of severity.

Seed scarification is shown to be a valid method of

improving seed lot quality by increasing the percentage of seed germinating in a specified time to form normal seedlings. Seed conditioners must consider the relative needs, benefits, and possible problems of scarification. Where scarification is needed, it may offer considerable benefit. For example, if the time required for germination of hybrid geranium seed is decreased by 65%, the overall planting-to-marketing time for the bedding-plant industry can be reduced about 25%. Scarified seed has been shown to have reduced storage life compared with unscarified seed (Justice and Bass, 1978). A special storage environment (usually low temperature and low humidity) may be necessary to maintain the life of seed that has been scarified in storage. A conditioning sequence that involves scarifying seed after storage immediately prior to planting may be more acceptable.

Other factors that seed conditioners must consider are the cost effectiveness of purchasing and operating scarification equipment, the need for germination tests, dust control, and associated expenses. The experimental scarifier is now commercially available.

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