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Title: PHYSICAL CHARACTERISTICS OF CROWNVETCH
(CORONILLA VARIA L.) SEEDS ASSOCIATED WITH
VIABILITY AND HARDSEEDEDNESS

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The use of crownvetch (Coronilla varia L.) as a forage crop might be increased considerably if seed with low hard seed content could be made available at reasonable cost. Since mechanical scarification damages a large percentage of crownvetch seeds, this study was initiated to find other ways of reducing hardseededness.

Two approaches to the problem were studied: (a) separation of hard and soft seeds on the basis of differences in physical properties, and (b) boiling water scarification followed by separation of soft seeds after soaking in water.

Attempts to separate hard and soft seeds on the basis of length and width were only partially successful. Long-narrow seeds contained up to 33% less hard seeds than short-wide seeds in some lots, but this relationship did not exist in other lots.

When extreme width separations were carried out, the widest group of seeds were associated with high dead seed content in some lots.

Dark-brown seeds contained more hard seeds than the intermediate and light brown seeds. Dead seeds tended to be concentrated in the light-brown fraction.

Seeds that swelled during the first two hours of soaking in tap water were associated with high dead seed content. Some lots showed an almost complete absence of dead seed in groups that required longer than two hours to swell. Seed dormancy was nearly eliminated by soaking in tap water and redrying.

Immersion for five seconds in boiling water reduced hardseededness without lowering the viability of soft seeds. The percentage of hard seeds remaining after a five-second treatment was further lowered by a second treatment, again without reducing viability. It is the abrupt change in temperature, rather than long exposure to high temperature, that is important in breaking hardseededness.

The viability of hard seeds was high, but usually less than 100%.

Soft seeds were successfully separated from hard seeds, after soaking in tap water, by making a size separation with round-hole screens. Techniques for boiling water scarification and separation of hard and soft seeds were developed.

After separation, swollen soft seeds can be dried to their initial moisture content without apparent damage. Soaked and dried seeds showed good storability and good emergence in greenhouse studies.

Physical Characteristics of Crownvetch (*Coronilla varia* L.) Seeds Associated with Viability and Hardseededness

by

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Typed by Cheryl E. Curb for Adriel E. Garay

To my parents with love.

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PHYSICAL CHARACTERISTICS OF CROWNVETCH (*CORONILLA VARIA* L.) SEEDS ASSOCIATED WITH VIABILITY AND HARDSEEDEDNESS

INTRODUCTION

Crownvetch (*Coronilla varia* L.) is a perennial leguminous plant used for erosion control and beautification, but which has a limited use as a forage crop. In spite of the favorable agronomic attributes of this species, its limited use as a forage crop is due partly to a small seed supply and high cost of seed ($5.00 per lb. at the beginning of this research in 1971). High percentages of hardseededness necessitate high seeding rates which lead to excessive costs of stand establishment.

Hardseededness is a condition of the seedcoat that prevents the seeds from imbibing water. Although viable, hard seeds fail to germinate immediately under favorable environmental conditions. Most crownvetch seed lots are subjected to mechanical scarification to lower the hard seed content, but this practice damages a large percentage of the seed because of their narrow oblong shape.

The use of crownvetch as a forage crop might be increased considerably if seed with low hard seed content could be made available at a reasonable cost. The hard seed content of crownvetch seed lots could conceivably be reduced by (a) an improved scarification technique that did not damage the seeds, or (b) development of a technique for removal of hard seeds with conventional processing equipment. With the above considerations in mind, this study was initiated to find ways of reducing hardseededness in crownvetch seed lots and improve the stand-producing ability of the seed.

The primary objectives of this study were: (a) to determine the degree of association between certain physical characteristics of seeds (length, width, color, rate of swelling) and quality factors (germination, hardseededness, dormancy, dead seeds) that can be used as the basis for upgrading the quality of seed lots, and (b) to determine the feasibility of mechanically separating hard and non-hard seeds by artificially creating physical differences that would allow them to be separated by conventional seed processing equipment.

LITERATURE REVIEW

Relation of Seed Size to Viability and Hardseededness of Legumes

The association of seed size and weight with hardseededness of legume seeds has been studied by few workers. Middleton (26) found a definite relationship between size of seed of Korean lespedeza (*Lespedeza stipulata*) and hardseededness with the small seeds having the highest percentage of hard seeds. Small seed fraction contained more immature seed than did the large seed fraction, but in the samples used, maturity did not obscure the relationship existing between size and hardseededness. Vaughan (41) found that hardseededness was associated with seed size and specific gravity in white clover (*Trifolium repens*), red clover (*T. pratense*) and crimson clover (*T. incarnatum*), the highest percentage of hard seeds being associated with the small-heavy group.

The effect of seed size on viability and emergence was studied extensively by Vaughan (41). He found that viability of white clover increased directly as seed size increased, while the intermediate size of red clover and crimson clover and the smallest seeds of red clover were lowest in viability. Black (5), however, did not find a definite relationship between seed size and germination or emergence of subterranean clover (*T. subterraneum*).

Strickler (37) and Erickson (14), working with birdsfoot trefoil (Lotus corniculatus) and alfalfa (Medicago sativa), respectively, obtained more emergence from long than from medium and more from medium than from short seeds at any planting depth. Beveridge (4), however, did not find a consistent relationship between size and emergence in alfalfa; and stated that no particular merit could be claimed for any one seed size as an aid to achieving rapid stand establishment; Nel and Burgers (27) also concluded that seed size was not a factor of great practical significance in alfalfa culture.

Attempts to identify the factors influencing the seed size and shape in legumes have not yet received full attention. Hagedorn (18), in field peas, found very few normal sized seeds after drought. There were considerably more seeds of small size among peas grown in different places. Factors influencing this variability were not identified. Turril (40) found that variation of shape of seeds of one species or cultivar, or even from one fruit, is often correlated with the arrangement and crowding in the developing fruit. If a large number of ovules are fertilized and develop into seeds they mutually interfere with and compress one another. McKee and Risius (24) found significant differences in cotyledon size between cultivars of crownvetch and even between lots. Differences between lots suggested the influence of environmental conditions during seed development and maturation.

Relation of Seed Coat Color to Viability and Hardseededness

Seed color is an important measure of seed quality (29) and state of maturity (13, 19, 22, 29, 34); and although buyers have always been governed by color (3), classification of color by simple estimation does not give a true index of germinability (1).

Red clover seed samples almost invariably are of three principal colors, violet or purple, yellow and brown. Aberg (1), Osvald and Aberg (28) and Dymond (12) found that brown seeds had a lower germination capacity than yellow and violet seeds and decreased in viability more rapidly during storage. The percentage of brown seeds, therefore, is an important index of viability. Smith (33) found that germination percentage of yellow seeds was consistently higher than that of purple seeds and Martin (22) found that brown seeds were inferior in weight and germination and concluded that brown seeds are considerably inferior in quality to the seeds of the other colors.

Smith (33) stated that darker colored seeds were heavier in alsike clover (*T. hybridum*) and in white clovers, and total germination favored darker color in alsike clover and yellow in white clover. Vaughan (41), considering that seeds of the naturally light colored, small seeded legumes gradually turn dark with age, found that dark colored (brown) seeds of red, white and crimson clover generally were low in germination.

Stewart (35) found discolored alfalfa seed inferior to bright colored seeds. Discolored seeds were noticeably lighter and seemed to germinate more slowly than did the brighter colored fractions. The same author (36) found progressively poorer germination for discolored seeds when germinated in soil, bright olive seeds giving the highest germination. West and Harris (43), working with eight cultivars of alfalfa and two lots of crimson clover, found that a change in seed coat color from yellow to red denotes a loss in viability of the seed. Ayres (3) observed that percentage of shriveled brown seeds of alfalfa was not as great as shriveled green seeds; but found more abnormal sprouts, rotten seeds and less hard seeds within the brown seeds.

Peiffer (29), in crownvetch, found that as seed matured and seed coat color changed from olive green to light brown and to reddish brown, an increase in total germination (normal seedlings plus hard seeds) occurred as did emergence from sand and soil. In addition, the percentage of seed that decayed under laboratory conditions decreased significantly as seed matured.

The relation of seed color to hardseededness has received less attention. Smith (33) found that hard seeds were most frequent in purple and yellow groups of red clover; in yellow seeds in white clover and in green and blackish green in alsike clover. Dymond (12) found yellow seeds of red clover with more hard seeds than the purple. The green or immature seeds gave the lowest percentage of germination but contained high proportion of hard seeds. Brown seeds contained the smallest percentage of hard seeds. Peiffer (29) found that reddish-brown seeds of crownvetch had the highest amount of hard seeds under both germinator and field conditions.

Attempts to identify factors influencing changes in seed coat color in legumes has received some attention. Eastman (13) attributed differences in color of red clover to differences in maturity; but Williams (44) attributed color to both genetic and environmental factors. According to Stevens (34), greenish seed coats and seed pods of sweet clover (_Melilotus_ sp.) are associated with immaturity; and according to Martin (22) when seeds are harvested before the heads are well ripened there is a tendency towards a high percentage of brown seeds. He stated that seeds are green previous to ripening in red clover and pass to yellow and finally to purple. Hartley (19) observed that mottling in seeds of yellow sweet clover (_Melilotus officinalis_) may occur during the later stages of maturity; and Fowlds (16) found that the green and pale yellow colors of white sweet clover (_M. albus_) are inherited as recessive to yellow. West and Harris (43) found that age in storage increased the number of red seeds and reduced yellow seeds in alfalfa and crimson clover.

Relation of Speed of Swelling to Viability

The rate at which seeds imbibe water and swell may be associated with seed viability (9, 15, 21, 32). Peiffer (29, 32) found the rate of imbibition and swelling following immersion in water closely associated with seed viability of crownvetch. As the time required for seed to imbibe water and swell increased, the percentage of seed that decayed decreased. Seeds which were swollen after one hour in water were generally dead or produced abnormal seedlings.

Crosier and Etheredge (10) found that seeds of crotalaria (*Crotalaria* sp.) swollen within one hour in water were either dead or weak, while those that required more than two days to swell usually exceeded 90% germination. Fayemi (15) observed that absorption of water by viable seed of alfalfa, red, crimson, alsike and ladino clover did not occur until after six hours of immersion. Vaughan and Delouche (42) found the rate of seed swelling in red, white and crimson clover closely associated to viability particularly during the first four hours. Seeds swollen at the end of one hour were generally dead and seeds swollen by two hours were low in viability.

West and Harris (43) found that red seed of eight cultivars of alfalfa and two lots of crimson clover absorbed water more readily than yellow seeds and thus could not be considered hard seeds.

Effect of Boiling Water Scarification on Hardseededness and Viability

Mechanical scarification leads to seed injury in crownvetch (6, 31). A method of scarification that will not injure the seed but will permit moisture to penetrate readily to the embryo of every seed is highly desirable (45). Acid treatments have the risk of injury both to the operator and the seed, and the lengthy washing and drying process requires several days for completion (17). For these reasons, considerable interest has been shown in boiling water scarification of legume seeds.

Dropping seeds of black locust (*Robinia pseudoacacia*) in boiling water to increase the early germination has been practiced for many years (46). Soft seeds of honey locust (*Acacia* sp.) that were treated at the rate of one pound per gallon of boiling water and allowed to cool down slowly at room temperature for 15 to 18 hours gave a germination of 95% and field emergence of 92% (11). Immersing for one minute in boiling water increased germination from nothing to about 80% in rose acacia (*Robinia hispida* L.) and from 8 to 92% in clammy locust (*R. viscosa*) (42). Wilson (45) obtained increased germination from 17 to 73% in gray locust and from 3 to 93% in black locust, but observed injury with periods longer than two minutes. Tillotson (39) suggested soaking of locust seeds in water nearly to the boiling point and, after they have swollen, planting them at once, repeating the soaking for all seeds that did not swell the first time. He did not give any recommendation for separation of swollen seeds.

Takahashi and Ripperton (38) described a hot water treatment for Leucaena glauca consisting of heating water to 80C, removing the source of heat and soaking the seeds for two to three hours in the same container. Seeds treated in this way deteriorated rapidly under unfavorable conditions, although germination increased from 40 to 80% right after treatment. Gray (17) found that a very short period of immersion in water at the boiling point was sufficient to render the testa of this species permeable to water, one second resulting in over 80% swelling and five seconds in swelling of all seeds. Immersion for more than three seconds, however, resulted in lower germination, the viability decreasing in proportion to the increasing duration of treatment.

Casey (8) immersed seed of bur clover (Medicago arabica and M. maculata) in boiling water for one minute and increased germination from an original 5 and 10% to over 50%.

Brant (7) and McKee (23) found that any treatment that penetrated the outer or macrosclereid layer of cells just below the curticule of crownvetch seeds leads to uptake of water. Contrasting to mechanical scarification which leads to seed injury, soaking seeds in concentrated sulfuric acid for 15 minutes, a 15 second immersion in boiling water, or a one minute dipping in liquid nitrogen (-160C) makes most hard seeds permeable. In spite of this, Brant (7) concluded that presently there is no practical substitute for a careful job of hulling and scarifying with conventional equipment.

MATERIALS AND METHODS

Seed Lots

Two lots each of three commonly grown varieties of crownvetch were used in this study. The seed lots were obtained from commercial seed sources. The characteristics of these lots were as follows.

Variety	Lot	Year grown	Germination, %	Hard seeds, %	Origin	Class
Chemung	A	1967	37	40	Idaho	Commercial
Chemung	B	1969	10	84	Idaho	Commercial
Emerald	A	1970	62	24	Iowa	Certified
Emerald	B	1970	37	52	Iowa	Certified
Penngift	A	1968	26	30	Penn.	Foundation
Penngift	B	1969	32	45	Penn.	Foundation

General Procedures for Germination Tests

The effects of sizing, color sorting and soaking treatments were evaluated by germinating the seeds according to the methods prescribed in the Rules for Testing Seeds (2). For each test, four samples of 100 seeds each were obtained with a pneumatic seed counter and planted between moist 11.5 x 11.5 cm germination blotters in 12 by 12 by 3 cm plastic boxes. Seeds were then incubated in dark germination chambers at 20C for 14 days. Germination boxes were placed in a Completely Randomized Design (CRD) in the chambers and results were analyzed as a factorial arrangement of treatments.

Preliminary germination counts were made after seven days, at which time the germinated and dead seeds were removed. At the 14 day count total germination, hard seeds, dormant seeds and dead seeds were evaluated.

Relationship of Seed Size, Color and Speed of Swelling to Germination and Hardseededness

Effect of Seed Width

An experiment was conducted with seeds of Chemung (Lot B), Emerald (Lot A) and Penngift (Lot B) to determine if there was an association of seed width and seed viability.

A portion of each lot was separated into six width groups with round-hole screens which were vibrated by an automatic vibrator. These width groups were: over 1/17 inch (widest seeds), 1/17-1/18, 1/18-1/19, 1/19-1/20, 1/20-1/21, and through 1/21 inch (narrowest seeds).

Seeds of each width group were then planted for germination studies.

Effect of Seed Length and Width

A second experiment was designed to determine the relation of length and width to seed quality, as well as the interaction of the two. For this study samples of the six lots were first sized into three length classes and each length class was further sized into three width classes.

Length separations were made with a laboratory model disc separator with R type disc pockets. Seeds that could be lifted with an R4 disc were first removed and designated as the "Short" category. Then the seeds that could be lifted with an R5 disc were removed and designated as the "Medium" category. The remaining seeds not lifted by the R5 disc were designated as "Long."

Each length group was further divided into three different widths using perforated round-hole hand screens of 1/18 and 1/20 inch diameter. "Wide" seeds were those held on the 1/18 screen; "Intermediate" seeds were those passing through the 1/18 and held on the 1/20; and "Narrow" seeds were those passing through the 1/20 inch screen.

As a result, nine size groups were obtained from each seed lot and designated as follows:

	Wide (W)	Intermediate (I)	Narrow (N)
Long (L)	LW	LI	LN
Medium (M)	MW	MI	MN
Short (S)	SW	SI	SN

Seeds from each group were planted for germination studies.

Effect of Seed Coat Color

For this experiment, shriveled, shrunken, moldy and cracked seeds were removed from the seed lots in order to have seed color as the major experimental variable. Samples from the six lots were separated into three color groups: light brown, medium brown, and dark brown.

Seeds from each color group were planted for germination studies.

Speed of Swelling

Effect of temperature on speed of swelling. A preliminary study was conducted to determine the temperature at which crownvetch seeds swell most rapidly when placed in water. Seeds of Chemung (Lot B) and Emerald (Lot B) were placed in plastic boxes and covered with 1 cm of tap water. Boxes containing 100 seeds each were placed in controlled temperature chambers at 5, 10, 20 and 30C. Swollen seed counts were made 1, 2, 3, 4, 5, 6, 9, 20, 24, 28, 35 and 48 hours after placing in water. Swollen seeds were larger, lighter in color, glossier in appearance, and softer in texture than the hard seeds which remained unchanged in appearance.

Relation of speed of swelling to seed quality factors. After the optimum temperature for swelling was determined, seeds of the six lots were placed in plastic boxes containing tap water at 30C. Soft seeds were removed frequently, air-dried and placed into five groups according to the length of time required to become swollen: 0-2, 2-8, 8-24, 24-96 and 96-336 hours (14 days).

Seeds that became swollen between 14 and 90 days were discarded. The hard seeds remaining after 90 days were dipped in boiling water for ten seconds and then placed in tap water at 30C to allow swelling of the treated seeds. Swollen seeds were separated and air dried to form a sixth group of "Over Three Months."

Seeds from each group were planted for germination studies.

Scarification of Hard Seeds by Boiling Water

The boiling water scarification methods of Brant (7), Gray (17) and Wilson (45, 46) were refined to eliminate hard seeds from a seed lot without lowering the viability of the non-hard seeds. The technique involved submerging the seeds briefly in boiling water, then soaking in tap water at 30C to allow swelling of permeable seeds, followed by separation of hard seeds from swollen seeds with a round-hole screen. This treatment was then repeated with the hard seeds that remained.

To determine the optimum period of treatment in boiling water, seeds of Chemung (Lot B) and Emerald (Lot B) were placed in wire mesh containers and submerged in boiling water. Seeds were removed at five-second intervals for 60 seconds. Four samples of 100 seeds were subjected to each treatment period. After removal from the boiling water, the seeds were immediately placed between moist blotters for germination studies to determine the effects of each treatment on hardseededness and viability.

After the safe treatment period was determined, a similar experiment was conducted to determine the optimum heat treatment period for a second cycle of treatment on the hard seeds that resisted the first cycle of treatment. To obtain hard seeds for the second cycle, samples of the same two lots were submerged in boiling water for five seconds, then placed in plastic boxes containing water at 30C for 24 hours to allow swelling of the permeable seeds. Following the soaking period and after the seeds were surface dried, the hard seeds were removed with a round-hole screen. Eighteen 50-seed samples of the hard seeds were placed in wire mesh containers and again placed in boiling water. Three samples were removed after each of the following treatment intervals: 10 and 30 seconds, 1, 2, 3, and 4 minutes. Treated seeds were placed directly between moist blotters for germination studies to determine the effect of each treatment on hardseededness and viability.

Mechanical Separation of Hard and Soft Seeds

Samples of Chemung (Lot A), Emerald (Lot A) and Penngift (Lot B), were separated into six width groups as before, using round-hole screens. Four samples of 200 seeds were obtained from each width group and submerged in boiling water for five seconds. After this treatment seeds were placed in plastic boxes containing tap water at 30C for 24 hours to allow swelling of the permeable seeds.

Swollen seeds were considerably larger than hard seeds, suggesting that they could be separated readily with hand screens. To facilitate screening, the wet seeds were first surface dried by spreading them on absorbant blotters near a forced air heater. The six width groups within each lot were then passed over the same screens used to form the six groups originally. The efficiency (percent recovery of swollen seeds) of each screen was then determined.

Viability of Naturally Soft and Hard Seeds

The viability of naturally soft seeds and hard seeds in two lots of Chemung, Emerald and Penngift was determined. "Naturally Soft Seeds" were obtained by soaking samples in tap water at 30C for 24 hours and discarding the remaining hard seeds.

Hard seeds of these same lots that were recovered after the 14-day germination count of several experiments were scarified by submerging in boiling water for five seconds, then placed in tap water at 30C to allow swelling of permeable seeds. The swollen seeds obtained by this method were termed "Boiling Water Soft Seeds."

Naturally Soft, Boiling Water Soft and untreated seeds within each lot were then planted for germination studies.

Relative Storability of Soft Seeds

Small samples of air-dried Boiling Water Soft Seeds, Naturally Soft Seeds and untreated seeds were placed in sealed containers at 10 and 30C to determine their storability.

Germination studies were conducted after 1, 4 and 10 months.

Greenhouse Emergence of Selected Seed Treatments

The emergence-survival of selected seed categories in Chemung (Lot B), Emerald (Lot A) and Penngift (Lot B) were studied in greenhouse plantings. Within each lot, the following seven categories of seed were selected: (1) untreated seeds, (2) naturally soft seeds, (3) boiling water soft seeds, (4) long-narrow seeds, (5) short-wide seeds, (6) five-second scarification in boiling water, and (7) seeds hand scarified between sand paper.

Fifty seeds from each seed category were planted 1 cm deep in gallon cans filled with unfertilized river bottom loam. Temperature in the greenhouse ranged from 22 to 25C. The experiment was set up in a Completely Randomized Design with each treatment repeated four times. Seedlings were counted daily for 15 days. Since a number of the seedlings died during this period, the figures represent only the number of seedlings that survived. Data were analyzed as a factorial arrangement of treatments.

RESULTS AND DISCUSSION

Relationship of Physical Characteristics of Seeds to Quality Factors

Hard and Dormant Seed Differences among Cultivars and Lots

Cultivar and lot differences in hard and dormant seed content are shown in Table 1. Based on the two lots included in each cultivar, Chemung averaged the highest in hard seed content.

The degree of hardseededness of legume seed lots is known to be affected by the environment in which the seed is produced. Since the crownvetch cultivars were grown in widely separated locations, these data are not sufficient to form conclusions regarding cultivar differences in hardseededness or dormancy.

Table 1. Percent germination, hard, dormant, and dead seed content in crownvetch cultivars and lots.

Cultivar	Lot	Germination	Hard Seeds	Dormant Seeds	Dead Seeds
Chemung	A	42.36	50.00	3.27	4.36
Chemung	B	12.69	85.91	1.16	0.22
Emerald	A	60.05	28.13	7.91	3.61
Emerald	B	30.25	57.08	8.58	4.30
Penngift	A	28.94	37.36	25.69	7.83
Penngift	B	31.86	41.02	23.38	3.36
LSD .01		2.91	2.91	2.23	1.28
LSD .05		2.21	2.21	1.70	0.97
CV. %.		14.03	9.65	11.66	53.80

Effect of Seed Width

The effect of seed width on several quality factors is shown in Table 2. The hard seed content of the various width groups did not differ significantly; however, the widest seeds contained 3 to 4% fewer dormant seeds than the narrower categories.

Table 2. Relation of seed width to percent germination, hard, dormant, and dead seeds in crownvetch. Average of Chemung Lot B, Emerald Lot A, and Penngift Lot B.

Width in inches	Germination	Hard Seeds	Dormant Seeds	Dead Seeds
Over 1/17	29.30	38.69	2.84	26.84
1/17	43.90	39.08	5.09	11.90
1/18	41.25	44.58	5.25	8.91
1/19	43.25	42.33	6.08	8.33
1/20	43.25	44.16	6.50	6.08
Through 1/21	48.66	38.00	6.08	7.33
LSD .01	4.78	8.99	2.75	4.33
LSD .05	3.60	6.75	2.06	3.26
CV. %.	10.67	20.17	48.19	33.98

In Emerald and Penngift, the largest proportion of dead seeds occurred in the widest seed groups (Figure 1). This difference was significant at the .01 level. Since there were only small differences in hardseededness and dormancy due to width, the increased amount of dead seeds was the foremost factor causing low germination in the widest group of seeds.

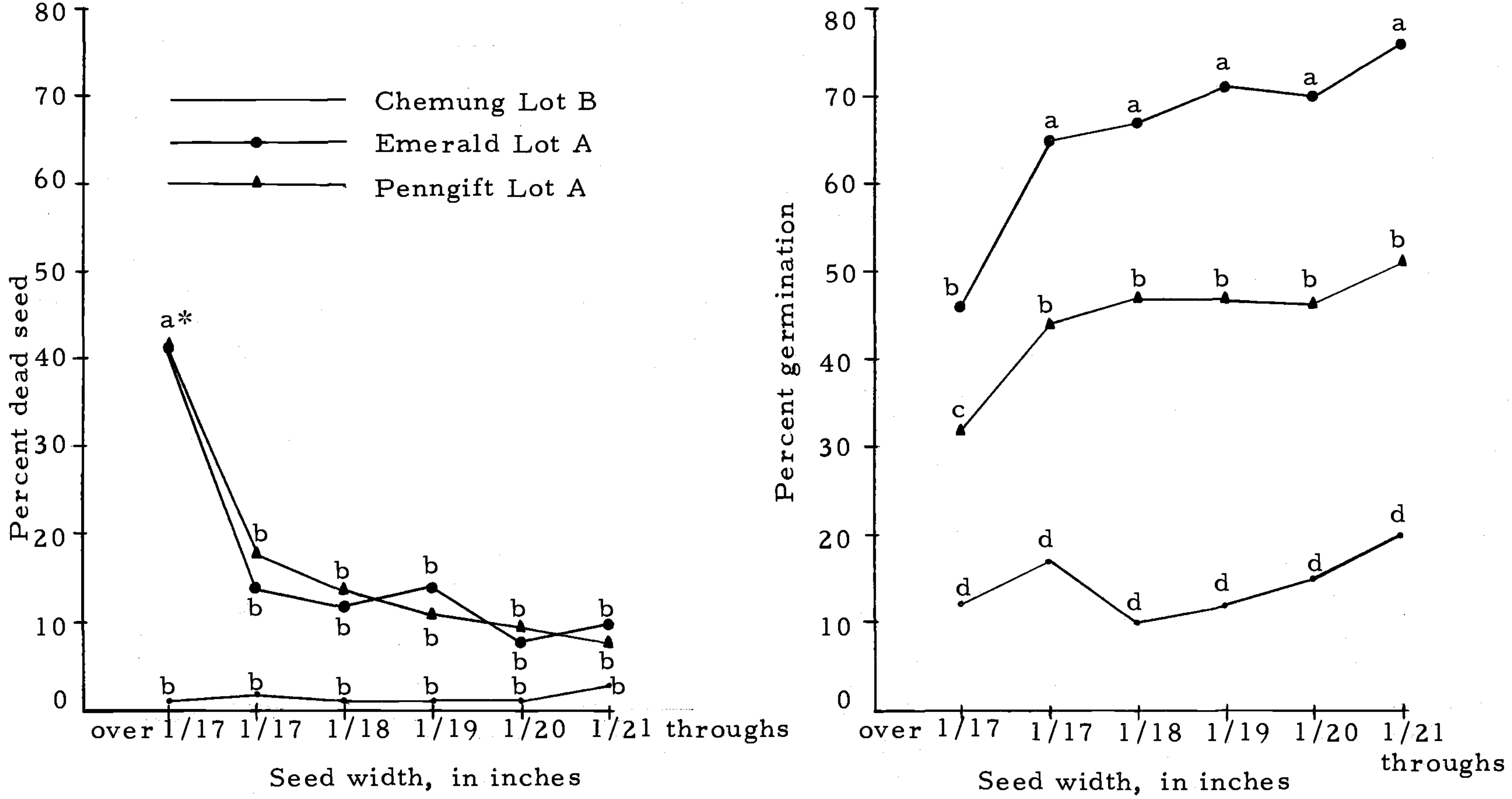


Figure 1. Relation of seed width to dead seed content and germination of crownvetch. One lot/ cultivar.
*There is no difference at .01 level between width groups with the same small letters within each lot.

The widest category of seeds included some deteriorated seeds which were flattened, damaged and moldy looking, indicating _a priori_ the possibility of lower germination. The deteriorated seeds were probably caused by immaturity and high moisture content at harvest. Since round-hole screens separate seeds by their widest diameter, these deteriorated flat seeds were concentrated in the widest group.

Effect of Length and Width

The results of the previous experiment suggested that width groups varied somewhat in hard and dormant seed content, although these differences were not always significant. It was observed that within a uniform width group, seeds varied in length. An experiment was then conducted to study the relationship of width and length and their interactions with the various seed quality factors. For this purpose, two lots each of the three cultivars were sized into three length groups, and each length group further sized into three width groups.

Hard seeds. When the hard seed percentages were averaged over widths, short seeds were found to contain more hard seeds than the medium and long seeds (Table 3). Since short seeds of crownvetch are the smaller seeds, the results are in agreement with data presented by Middleton (26) and Vaughan (41) which showed that smaller seeds of Korean lespedeza and clovers were higher in hard seed content. When averaged over lengths, wide seeds (which could be considered larger seeds) were found to contain more hard seeds than intermediate or narrow seeds. This suggests that in this species, hardseededness is associated with shape of the seed rather than size itself, with long-narrow seeds containing the lowest hard seed content and the short-wide seeds the highest amount.

Table 3. Relation of length and width to percent hard seed in crownvetch. Average of two lots each of three cultivars.

	Width			
Length	Wide	Intermediate	Narrow	Average
Long	47.33	46.50	43.70	45.84
Medium	51.91	51.37	46.00	49.76
Short	56.70	51.83	51.91	53.48
Average	51.98	49.90	47.20	

LSD .01 for all 9 length-width combinations, 3.58
LSD .05 for all 9 length-width combinations, 2.72

Variation in hard seed content for the nine length-width groups within each seed lot and cultivar is shown in Table 4. In Chemung Lot A and B, Emerald Lot A and Penngift Lot B, the wide seed group contained more hard seeds than the narrow groups; but in Emerald Lot B and Penngift Lot A, this tendency was not present. In every cultivar and lot there was a definite association between length and hardseededness, short seeds having more hard seeds than long seeds.

Table 4. Relation of length and width to percent hard seed in six lots of crownvetch.

Cultivar	Lot	Length	Width Wide	 Intermediate	 Narrow
Chemung	A	Long	48.25	44.25	36.00
		Medium	57.50	53.25	38.50
		Short	68.50	54.00	50.76
Chemung	B	Long	87.75	82.75	80.75
		Medium	88.00	83.75	85.00
		Short	91.25	89.75	84.50
Emerald	A	Long	25.75	22.75	20.00
		Medium	33.25	28.50	22.25
		Short	38.00	32.25	30.50
Emerald	B	Long	46.50	55.00	55.75
		Medium	53.75	62.00	55.75
		Short	54.50	62.00	68.50
Penngift	A	Long	35.75	36.00	39.00
		Medium	36.00	40.50	34.75
		Short	38.00	37.50	40.50
Penngift	B	Long	41.00	38.25	30.75
		Medium	45.00	40.25	39.75
		Short	50.00	41.50	42.75

Dormant seeds. When the dormant seed content of lots was averaged over widths, no significant differences were found among lengths; likewise, when averaged over lengths, no differences were found among width groups (Table 5).

Table 5. Relation of length and width to percent dormant seed in crownvetch. Average of two lots each of three cultivars.

	Width			
Length	Wide	Intermediate	Narrow	Average
Long	11.70	12.91	12.83	12.48
Medium	10.00	11.04	12.62	11.22
Short	10.00	11.12	12.79	11.30
Average	10.56	11.69	12.74	

LSD .01 for all 9 length-width combinations, 2.75
LSD .05 for all 9 length-width combinations, 2.09

Two cultivars showed some differences in percentage of dormant seeds in the different size separations (Table 6). The narrow width group of Penngift was associated with high dormant seed content, but there were no differences in dormancy among the length groups. Emerald Lot B contained a high percentage of dormant seeds in the long group, but there were no differences among widths. Dormancy was not associated with length or width in Chemung, and there were few dormant seeds in any size group of this cultivar.

Dead seeds. As shown in Table 7, long seeds showed a slightly higher dead seed content than medium and short seeds, and wide seeds slightly higher dead seed content than intermediate and narrow seeds. Although differences for width groups were very small, the data are in agreement with the results obtained in the preliminary width study. Larger differences in dead seeds among width groups in the preliminary experiment are attributable to more extreme width differences in

Table 6. Relation of length and width to percent dormant seed content in six lots of crownvetch.

Cultivar	Lot	Length	Width: Wide	Width: Intermediate	Width: Narrow
Chemung	A	Long	2.50	3.50	1.75
		Medium	3.75	2.50	2.50
		Short	3.25	5.50	4.25
Chemung	B	Long	1.75	0.75	1.25
		Medium	0.50	0.75	1.00
		Short	1.00	0.50	3.00
Emerald	A	Long	8.25	6.25	8.00
		Medium	9.25	8.00	8.50
		Short	7.25	7.50	8.25
Emerald	B	Long	14.75	16.00	16.00
		Medium	6.50	5.50	2.75
		Short	7.00	4.00	4.75
Penngift	A	Long	28.25	26.50	22.50
		Medium	24.00	20.25	30.00
		Short	22.00	26.75	30.50
Penngift	B	Long	14.75	24.50	27.50
		Medium	16.00	29.25	31.00
		Short	19.00	22.50	26.00

that experiment. In the length-width experiment it was not possible to obtain extreme categories of length and width because of the excessive quantities of seed required.

Table 7. Relation of length and width to percent dead seed content in crownvetch. Average of two lots each of three cultivars.

	Width			
Length	Wide	Intermediate	Narrow	Average
Long	6.70	3.41	3.83	4.64
Medium	4.33	3.79	3.00	3.70
Short	4.87	2.95	2.62	3.48
Average	5.30	3.38	3.15	

LSD .01 for all 9 length-width combinations, 1.57
LSD .05 for all 9 length-width combinations, 1.19

Germination. Germination was inversely related to the variation in hardseededness since no large differences in dead seed and dormancy were present. As a consequence, the long-narrow seeds (which showed the lowest hard seed content) showed the highest germination, while the short-wide seeds (which showed the highest amount of hard seeds) showed the lowest germination (Table 8). Germination differences due to seed shape ranged up to 29% in Chemung Lot A and 21% in Emerald Lot A. These differences are large enough to make it possible to upgrade germination of these lots by removal of hard seeds through width and length separation.

Table 8. Relation of length and width to percent germination in six lots of crownvetch.

Cultivar	Lot	Length	Width Wide	 Intermediate	 Narrow
Chemung	A	Long	40.00	48.00	52.50
		Medium	38.00	40.75	55.00
		Short	26.25	39.00	41.75
Chemung	B	Long	10.50	16.25	17.75
		Medium	11.25	15.50	13.50
		Short	7.50	9.50	10.00
Emerald	A	Long	59.75	67.00	70.00
		Medium	52.75	59.50	64.00
		Short	49.75	58.00	60.00
Emerald	B	Long	30.75	25.00	24.75
		Medium	37.50	30.25	37.00
		Short	37.25	30.00	21.75
Penngift	A	Long	26.50	32.25	32.75
		Medium	30.25	30.50	30.00
		Short	26.50	28.50	24.00
Penngift	B	Long	37.50	34.25	37.50
		Medium	32.75	27.25	28.25
		Short	18.25	32.75	30.25

Effect of Seed Coat Color

The relationships between seed coat color and seed quality factors are shown in Table 9. The dark brown seeds contained more hard seeds than the intermediate and light brown seeds in each cultivar. Differences in Emerald were larger than in Chemung and Penngift.

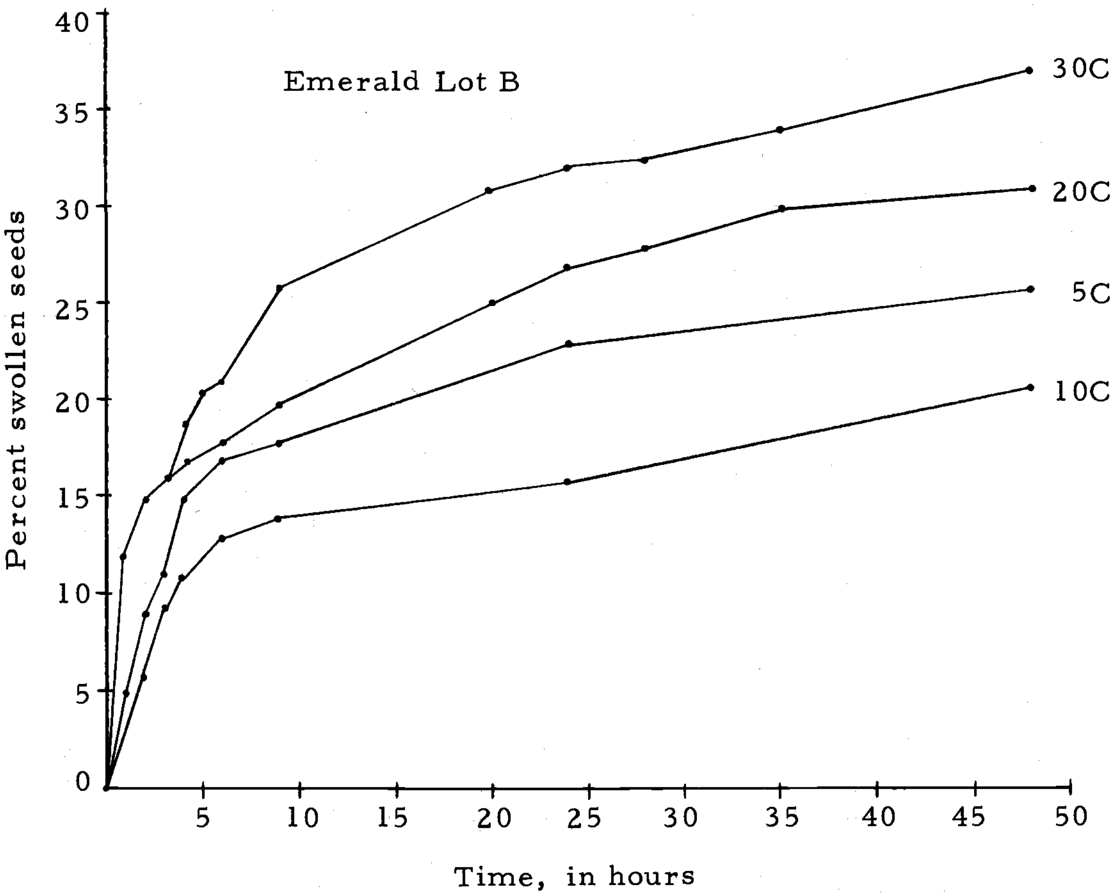
Table 9. Relation of seed coat color to percent germination, hard, dormant, and dead seeds in crownvetch. Average of two lots of each cultivar.

Cultivar	Color	Germination	Hard Seeds	Dormant Seeds	Dead Seeds
Chemung	Light brown	13.16	82.33	1.83	2.66
Chemung	Interm. brown	16.50	82.33	0.66	0.50
Chemung	Dark brown	13.83	85.15	0.50	0.50
Emerald	Light brown	32.16	31.33	6.50	31.16
Emerald	Interm. brown	40.00	45.16	9.16	5.16
Emerald	Dark brown	45.16	45.16	3.83	3.83
Penngift	Light brown	25.40	33.16	25.16	14.16
Penngift	Interm. brown	34.66	32.83	24.00	8.50
Penngift	Dark brown	33.16	36.33	22.50	8.00
LSD .01		7.47	6.29	4.44	5.73
LSD .05		5.56	4.69	3.31	4.26
CV. %.		16.84	7.59	26.59	44.25

Dead seeds tended to be concentrated in the light brown fraction of Emerald and Penngift. Chemung did not show large numbers of dead seeds in any color group, but again the light brown fraction contained more dead seeds. Peiffer (29) also found that light colored seeds were lower in germination.

Speed of Swelling

Effect of temperature on speed of swelling. When soaked in tap water at several temperatures, permeable seeds of Emerald Lot B swelled most rapidly at 30C (Figure 2). Approximately half of the seeds became swollen in from 3 to 5 hours, with a more gradual



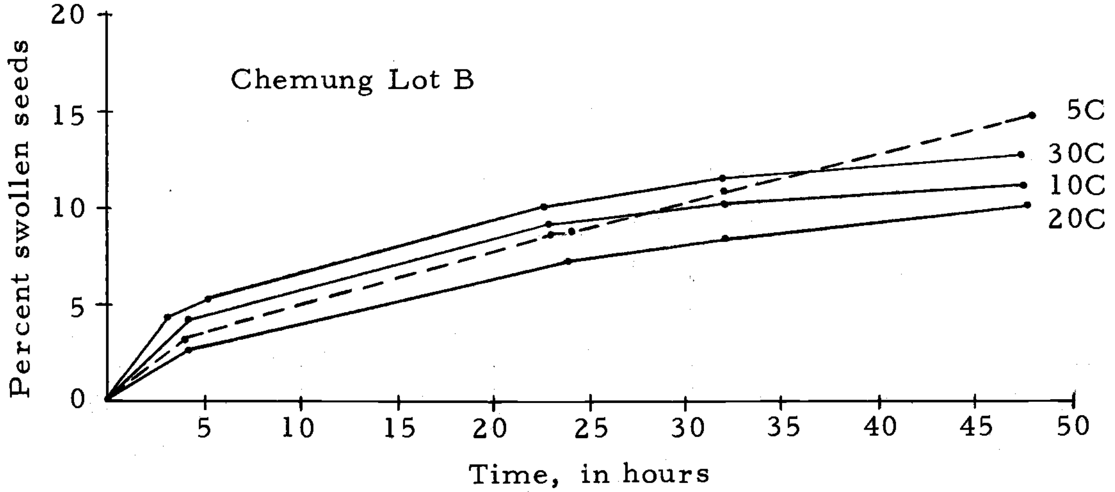


Figure 2. Effect of temperature and length of soaking on rate of seed swelling in Emerald Lot B and Chemung Lot B. Average of four groups of 100 seeds.

increase in number of swollen seeds occurring during the next 45 hours. A similar swelling pattern occurred in Chemung Lot B (Figure 2), but the time-temperature relationship was not as clear because of the very small number of permeable seeds in this cultivar. The increase in swollen seeds after 24 hours was almost negligible in both cultivars. Germinability of seeds was not decreased with periods of soaking up to 42 hours (Appendix Table 18).

Relation of Speed of Swelling to Seed Quality Factors

Dead seeds. The relationship between speed of swelling and dead seed content is presented in Table 10,

Table 10, Relation of speed of swelling to percent dead seed in crownvetch cultivars and lots.

Time to swell, in hours	Cultivars and Lots						
	Chem. Lot A	Chem. Lot B	Emer. Lot A	Emer. Lot B	Penn. Lot A	Penn. Lot B	Average
0-2	59.75a*	63.75a	58.25a	66.50a	41.25a	35.00a	54.08a
2-8	10.00b	14.75b	6.00b	37.25b	39.00a	34.25a	24.00b
8-24	10.25b	12.00b	7.50b	35.00b	36.25a	24.75b	21.45b
24-96	3.25b	7.25b	5.75b	25.50c	23.25b	9.00c	12.33b
96-336	3.00b	5.75b	3.75b	20.50c	16.25b	8.00c	9.54b
Over 3 months	3.00b	2.25b	4.25b	13.25c	10.25b	3.25c	6.08c

* Reading vertically for each seed lot, means followed by the same letter do not differ at the .01 level of significance by L. S. D. (Least Significant Difference).

Seeds that swelled during the first two hours averaged 54% dead seed, with a range of 67% in Emerald Lot B to 35% in Penngift Lot A. Seeds that required longer than two hours to swell contained lower percentages of dead seeds, the proportion decreasing as time to swell increased. This relationship has previously been found in other small-seeded legumes (9, 10, 15, 21, 29, 42) and crownvetch cultivar Penngift (32).

Some lots showed an almost complete absence of dead seed in groups that required longer than two hours to swell (Table 10). In lots such as Emerald Lot A, upgrading of quality by discarding the fast swelling dead seeds would be possible. On the other hand, this approach would not be practical in lots such as Penngift Lot A in which the dead seeds were more evenly distributed among all time-to-swell groups. Large amounts of germinable seeds would be sacrificed in trying to eliminate dead seeds from this type of lot.

Germination. Germination percentages were essentially the inverse of the dead seed percentages (Table 11), with the fastest swelling seeds being lowest in germination.

Table 11. Relation of speed of swelling to percent germination of crownvetch cultivars and lots.

Time to swell, in hours	Cultivars and lots						
	Chem. Lot A	Chem. Lot B	Emer. Lot A	Emer. Lot B	Penn. Lot A	Penn. Lot B	Average
0-2	39.50a*	36.25a	41.50a	33.00a	58.00a	65.00a	45.33a
2-8	89.00b	84.75b	93.25b	61.75b	60.25a	64.25a	76.70b
8-24	87.75b	87.00b	90.50b	63.50b	73.50b	69.00a	76.75b
24-96	94.25b	91.50b	90.50b	72.75c	74.25b	87.50b	84.91b
96-336	95.50b	91.75b	93.75b	76.25c	81.00b	90.00b	88.08b
Over 3 months	96.00b	98.00b	95.25b	75.25c	85.25b	95.50b	90.70c

* Reading vertically for each seed lot, means followed by the same letter do not differ at the .01 level of significance by L. S. D. (Least Significant Difference).

Dormant seeds. There was no relationship between speed of swelling and dormant seed content (Table 12).

Table 12. Percent dormancy of swollen seeds of crownvetch cultivars and lots after soaking in tap water at 30C and redrying.

Time to swell, in hours	Cultivars and lots						
	Chem. Lot A	Chem. Lot B	Emer. Lot A	Emer. Lot B	Penn. Lot A	Penn. Lot B	Average
Control*	6.54a**	8.28a	10.98a	19.95a	40.77a	39.63a	21.00a
0-2	0.75b	0.25b	0.25b	0.50b	0.50b	0.75b	0.50b
2-8	1.00b	0.50b	0.75b	1.00b	1.25b	1.50b	0.95b
8-24	2.00b	1.00b	2.00b	1.00b	2.00b	2.00b	1.75b
24-96	2.75b	1.25b	3.75b	1.75b	4.25b	3.00b	2.79b
96-336	1.50b	3.00b	2.50b	3.25b	2.25b	3.00b	2.37b

* Dormant seed content of control (nonsoaked seeds) are expressed as percentage of total swollen seeds.

** Reading vertically for each seed lot, means followed by the same letter do not differ at the .01 level of significance by L. S. D. (Least Significant Difference).

Seed dormancy was nearly eliminated by soaking for two hours in tap water and redrying. The high percentage of dormancy of non-soaked seeds was probably caused by the presence of inhibitors as demonstrated by Mckee _et al._ (25). While germination inhibitors may be removed by soaking, this alone is not enough to remove dormancy of all crownvetch seeds (Peiffer _et al._, 32). Soaking followed by drying eliminated dormancy, apparently because the cracking of the seedcoat which accompanied drying removed any remaining restriction of germination. These results suggest that soaking and drying may be a useful procedure for overcoming dormancy in germination testing of crownvetch seeds. This method would also reduce the time required for a germination test.

Scarification of Hard Seeds by Boiling Water

The effects of a single boiling water treatment on hardseededness are shown in Figure 3. The effects of a second treatment on the hard seeds remaining after the first treatment are shown in Figure 4.

Effect of Treatments

Effect of a single boiling water treatment. After five seconds of treatment, hard seed content decreased about 25% in Chemung Lot B and 40% in Emerald Lot B. The decline in hardseededness with longer periods of soaking was negligible. Soaking longer than ten seconds

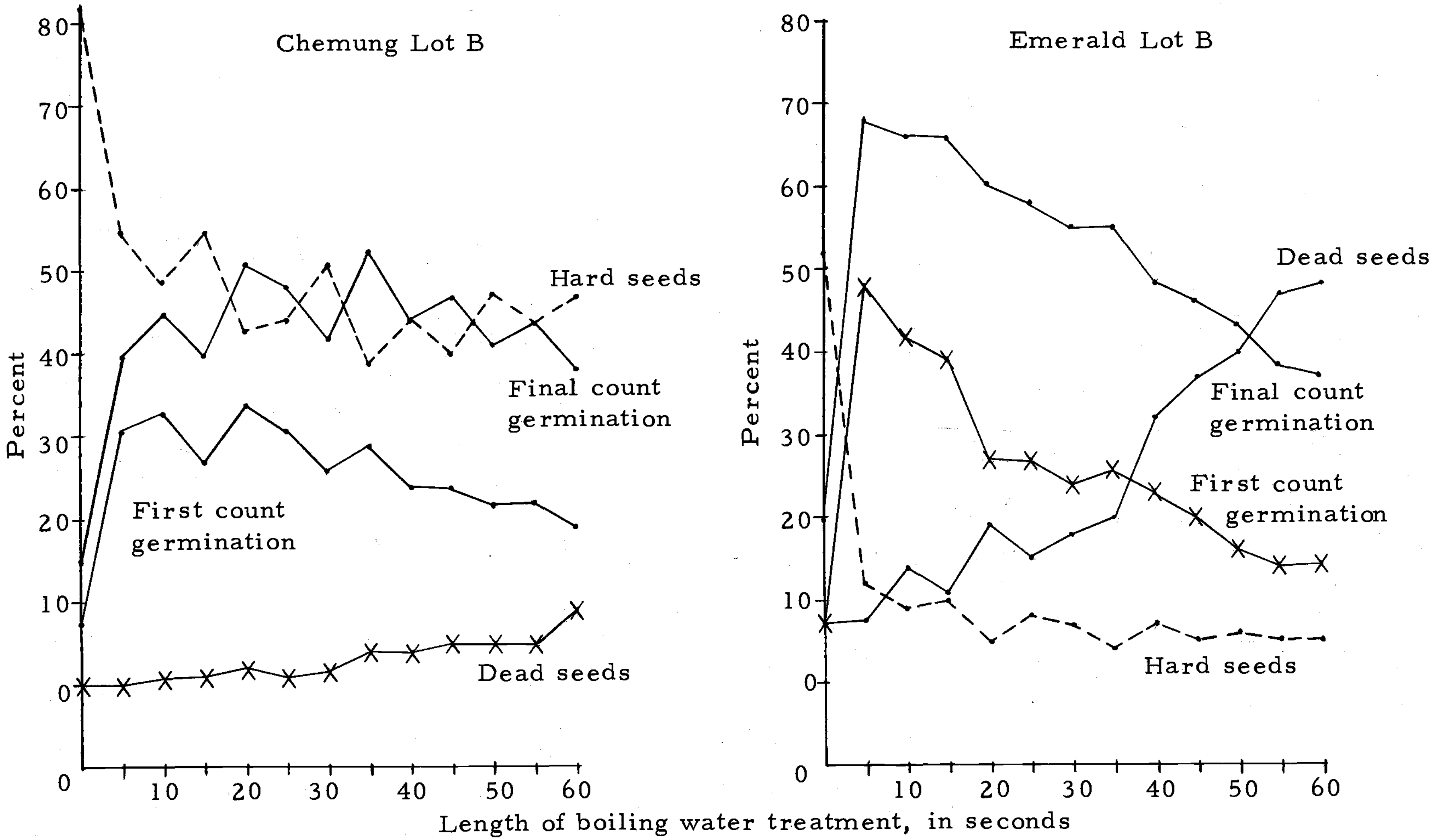


Figure 3. Effect of boiling water treatment on crownvetch seeds.

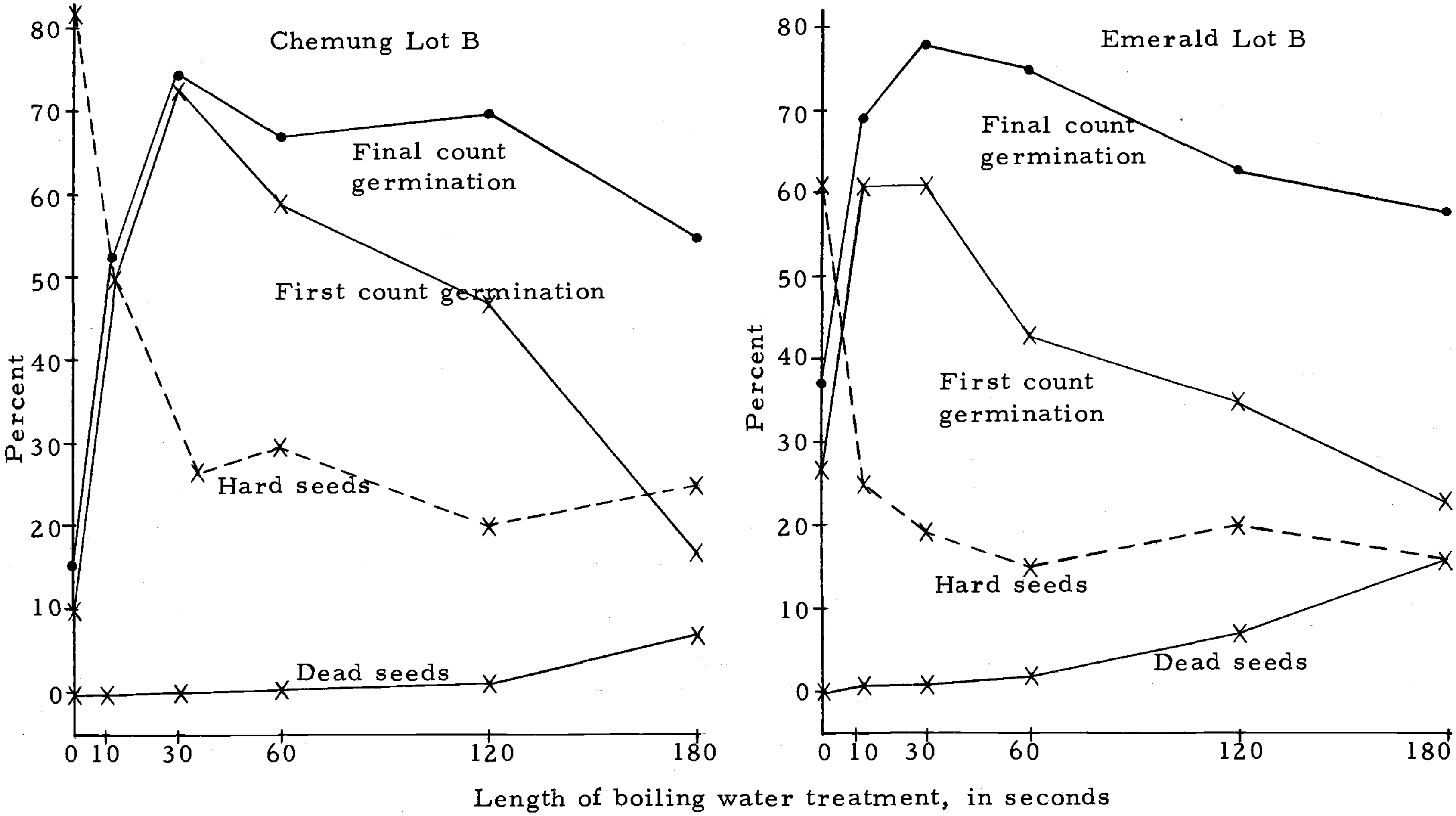


Figure 4. Effect of second cycle boiling water treatment on crownvetch seeds.

increased the number of dead seeds in both seed lots and also decreased the speed of germination (as indicated by the first count germination) in Chemung Lot B. These results indicate that five seconds would be the optimum period of treatment to render the most hard seeds permeable without killing any soft seeds.

Effect of a second boiling water treatment on remaining hard seeds. The hard seeds remaining after a five-second treatment in boiling water were subjected to a second boiling water treatment of 10 to 180 seconds (Figure 4).

The hard seed content of these seeds decreased with treatments up to 30 seconds after which no further reduction of hardseededness occurred. Dead seed content was not increased until the two-minute period in this second cycle, but the speed of germination was decreased with periods longer than 30 seconds. Thus, periods of soaking longer than 30 seconds should be avoided on the second cycle of boiling water scarification.

The cumulative changes in amount of hard seeds and germination after each of the two optimum treatment periods are shown in Figure 5. The initial 82% hard seed content of Chemung was reduced to 55% with a five-second treatment in boiling water. Since the remaining hard seeds were lowered to 52% with ten seconds in the second cycle, only 28% (52% x 55%) hard seed would be left in this lot. In Emerald Lot B the initial 52% was lowered to 12% with the first cycle and to 3% (12%

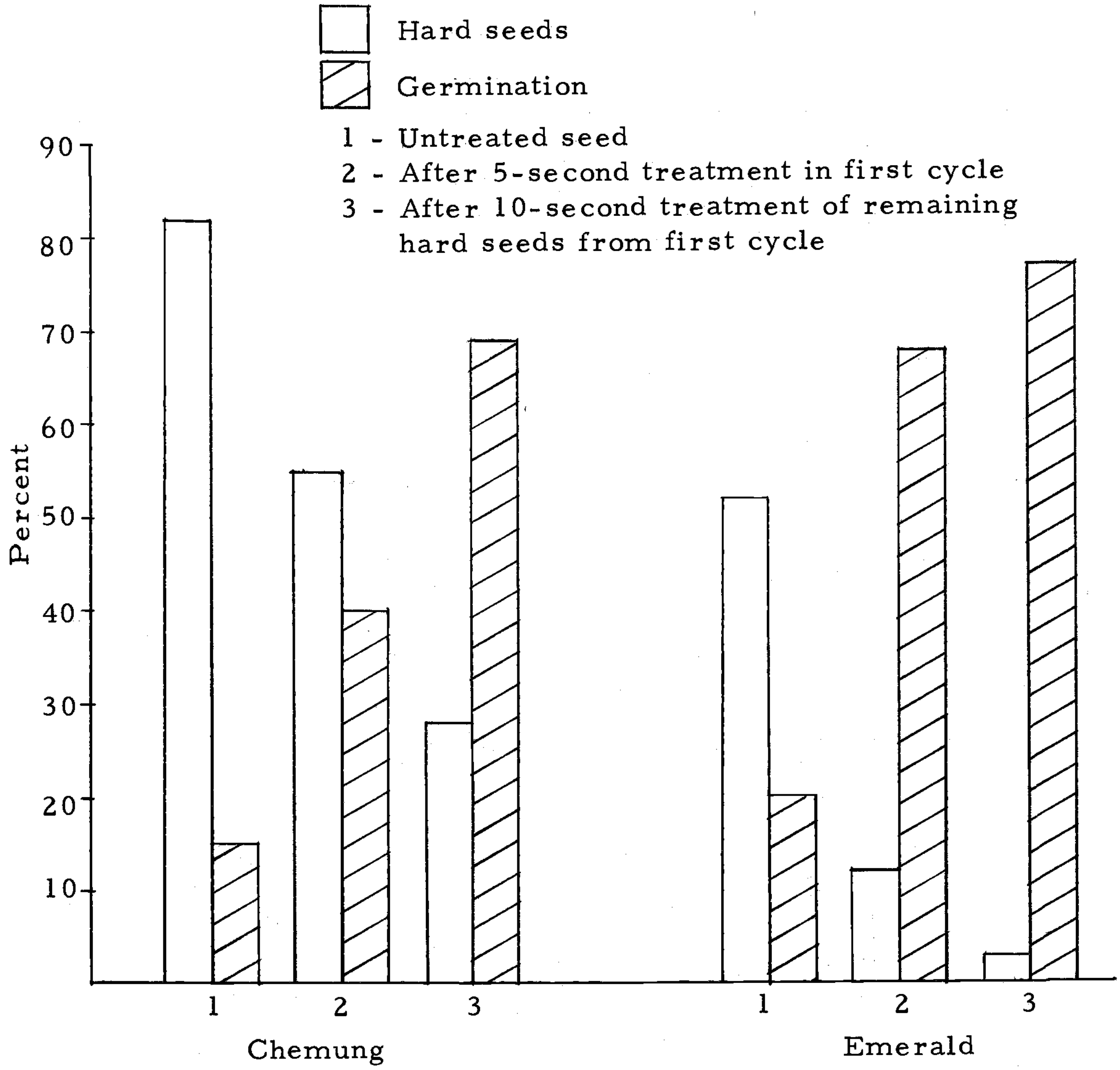


Figure 5. Effect of one and two cycles of boiling water treatment on hard seed content and germination of Chemung Lot B and Emerald Lot B.

x 25%) after the second cycle. Germination increased in proportion to the reduction in hardseededness.

The sudden reduction in hardseededness following the two short soaking periods compared to one long period indicates that it is the abrupt change in temperature rather than long exposure to high temperature that is important in breaking hardseededness. This further emphasizes that rather than trying to break most hardseededness with a single deleteriously long treatment in boiling water, more beneficial effects could be achieved with two or more short cycles. If this approach was to be tried on a practical basis, the seed lot should first be subjected to a five-second treatment in boiling water. If this treatment does not overcome hardseededness to an acceptable level, the seeds that become soft by this treatment should be separated. Only the remaining hard seeds should be subjected to a second treatment of 10 to 30 seconds in boiling water.

Mechanical Separation of Hard and Soft Seeds

Several machines were tried with the aim of separating hard seeds from swollen soft seeds. The most successful approach was to use round-hole screens which separate on the basis of seed width and do not cause damage to the seed.

In a mixture of swollen seeds and hard seeds there is considerable overlapping in width between wide hard seeds and narrow soft seeds after they have swollen. This overlapping can be avoided by dividing the seed lot into several width groups before scarification treatment. Soft seeds will increase in width while hard seeds will not change in width, creating a clearcut difference between soft and hard seeds. Separation can then be made with the same screens originally used to divide the seed lot into width groups.

Using this approach, all hard seeds passed through the screen and the soft seeds remained on the screen, when the screens used were as follows (Table 13): 1/17 inch diameter screen for seeds that were 1/17-1/18 inch width before soaking, 1/18 inch screen for seeds that were 1/18-1/19 inch width before soaking, 1/19 diameter screen for seeds that were 1/19-1/20 inch diameter before soaking, and 1/20 inch diameter screen for seeds that were 1/20-1/21 inch width before soaking.

A good but not perfect separation was obtained from the widest groups of Emerald Lot A and Penngift Lot B. These wide groups included seeds ranging from 1/14 to 1/17 inch in diameter. These extreme width classes represented a very small proportion of the seed lots.

Table 13. Percent separation of soft seeds obtained with round-hole screens from each initial width class in crownvetch lots.

		Seed width class in	Diameter of screen in inches					
Cultivar	Lot	inches	1/14	1/17	1/18	1/19	1/20	1/21
Chemung	B	Over 1/17	100					
Chemung	B	1/17-1/18	92	100				
Chemung	B	1/18-1/19	64	100	100			
Chemung	B	1/19-1/20		100	100	100		
Chemung	B	1/20-1/21		90	100	98	100	
Chemung	B	Through 1/21			60	78	85	100
Emerald	A	Over 1/17	90					
Emerald	A	1/17-1/18	72	100				
Emerald	A	1/18-1/19	57	98	100			
Emerald	A	1/19-1/20		97	100	100		
Emerald	A	1/20-1/21		82	99	100	100	
Emerald	A	Through 1/21			72	80	86	100
Penngift	B	Over 1/17	90					
Penngift	B	1/17-1/18	70	100				
Penngift	B	1/18-1/19	58	88	100			
Penngift	B	1/19-1/20		46	100	100		
Penngift	B	1/20-1/21			82	93	100	
Penngift	B	Through 1/21				56	72	96

Viability of Naturally Soft and Hard Seeds

The germination percentage of the "Naturally Soft Seeds" (seeds that do not require scarification to become permeable to water) and scarified hard seeds of six seed lots is presented in Table 14. Hard seeds averaged 92% germination after boiling water scarification with a range of 85% to 100%. Naturally soft seeds averaged 68% germination with a range of 46% to 88%.

Table 14. Percent germination of "naturally soft seeds" and hard seeds in crownvetch cultivars and lots.

Cultivar	Lot	Naturally soft seeds	Hard seeds
Chemung	A	65	100
Chemung	B	78	92
Emerald	A	78	93
Emerald	B	53	85
Penngift	A	88	97
Penngift	B	46	88
Average		68	92

These results indicate that a portion of the hard seeds remaining at the end of a 14-day germination test may be dead. Treatment of hard seeds with short cycles of boiling water may be very useful in seed testing to determine the dead seed content of hard seeds.

Relative Storability of Soft Seeds

Although hardseededness can be broken effectively and soft seeds can be mechanically separated from the hard seeds, the practicability of the technique is also dependent on the storability of the treated seeds. When stored in sealed glass containers, both "Naturally Soft Seeds" and "Boiling Water Soft Seeds" (hard seeds made permeable by boiling water), showed a slight decline in germination after ten months of storage at 30C (Table 15). Neither seed category showed a decline in germination after ten months at 10C.

Table 15. Percent germination of air-dried soft seeds of crownvetch lots stored at 30 and 10C. Average of Chemung Lot B, Emerald Lot A, and Penngift Lot A.

	Temperature	Length of storage in months			
Seed category	C	0	1	4	10
Untreated	30	32	32	32	38
Naturally Soft	30	84	77	74	75
Boiling Water Soft	30	92	89	87	85
Untreated	10	32	30	32	43
Naturally Soft	10	84	85	82	86
Boiling Water Soft	10	92	90	91	91

Greenhouse Emergence of Selected Seed Treatments

The average daily emergence-survival of selected seed classes from three seed lots when planted in the greenhouse is presented in Figure 6.

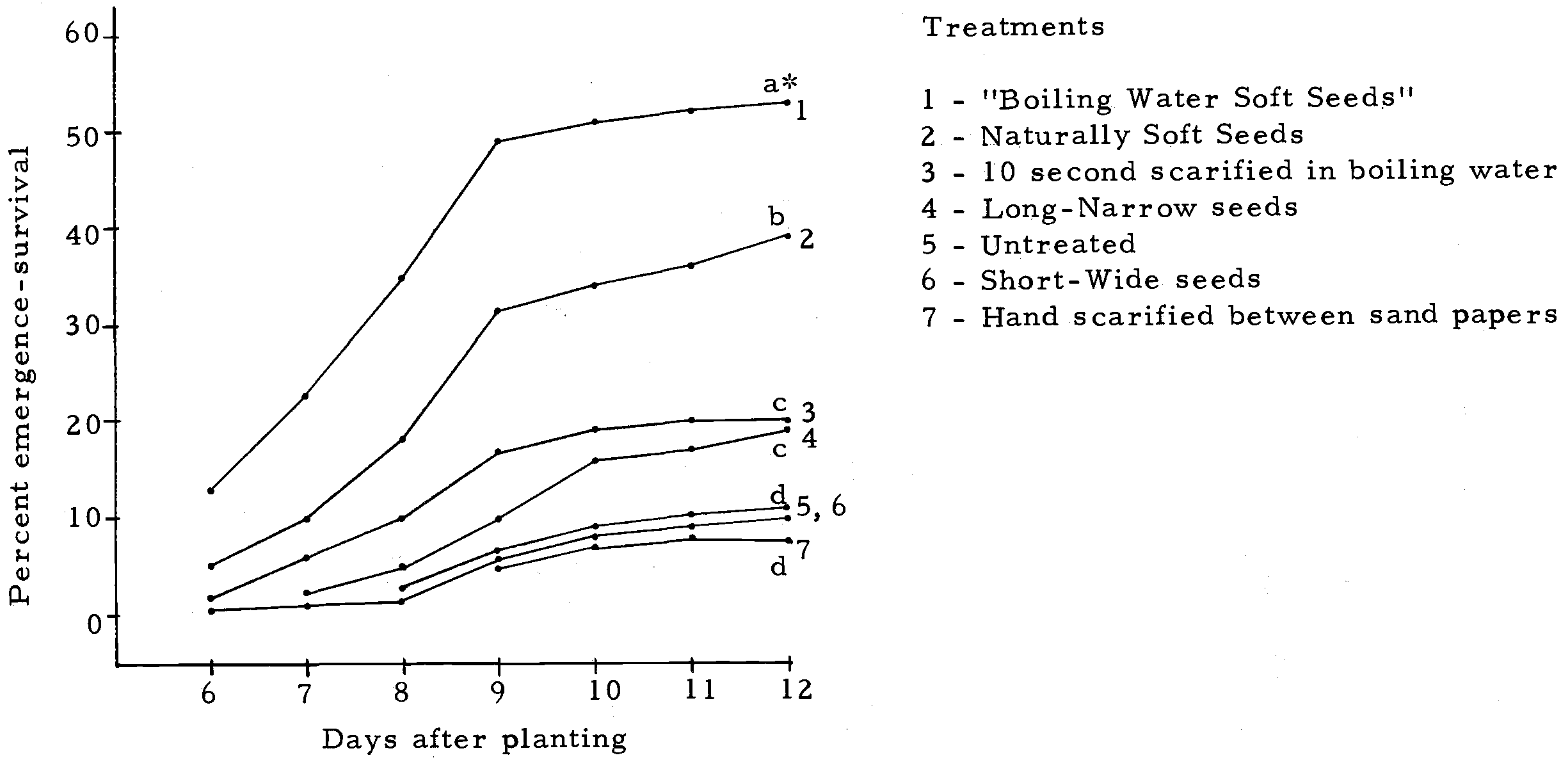


Figure 6. Average emergence-survival of selected seed classes of Crownvetch in the greenhouse. Average of Chemung Lot B, Emerald Lot A, and Penngift Lot B.

*There is no statistical difference at .01 level between treatments with the same small letter at the final date of evaluation.

Emergence-survival of every seed category was lower than germination in the laboratory, but in general, seed categories that showed high germination in the laboratory studies also showed higher emergence-survival in the greenhouse. The "Boiling Water Soft Seeds" and "Naturally Soft Seeds" showed faster emergence and about 40 and 30% higher final emergence-survival than the untreated seeds. The lower emergence of "Naturally Soft Seeds" can be attributed to the higher dead seed content of this seed category.

On the average, the long-narrow seeds (which showed highest germination in the length-width studies) emerged as well as the seeds scarified in boiling water for five seconds and better than the short-wide seeds (which showed the lowest germination in the length-width studies). Untreated seeds, hand scarified seeds between sand papers and short-wide seeds showed the lowest emergence-survival.

GENERAL DISCUSSION

Attempts to separate hard and soft seeds with conventional processing procedures were only partially successful. In some lots, hardseededness tended to be concentrated in certain sizes or shapes, but in other lots, the proportion of hardseededness did not vary much between sizes or shapes. In those lots where hardseededness is associated with shape, a sublot with reduced hardseededness could be created by making the proper length and width separation. The remainder of the seed lot, of course, would have an increased percentage of hardseededness. The sublot with the lowest hard seed content would be the most suitable for planting, while the more hardseeded sublot could remain in storage or be scarified to reduce hardseededness.

In commercial seed processing, artificial size differences are sometimes created when they do not exist naturally. An example of this is the addition of sawdust to moistened buckhorn plantain seeds to make them larger so they can be separated from alfalfa seeds. Similarly, soft seeds of crownvetch may be made wider than hard seeds by soaking them in water. With this width difference, hard and soft seeds may be easily separated with round-hole screens.

It is possible to scarify the hard seeds of a crownvetch seed lot without killing the soft seeds, by combining boiling water scarification and separation of soft seeds. A suggested procedure for doing this is as follows:

1. Subdivide the seed lot into several width groups (sublots) before scarification with a series of round-hole screens.
2. Submerge each sublot in boiling water for five seconds.
3. After removal from boiling water, soak the seeds for 16 hours in water at room temperature to allow the soft seeds to swell. Remove from the water and surface-dry the seeds.
4. Pass each sublot over the same screen that was used to make the original width groups. For example, the sublot that passed through a 1/17 screen but was held by a 1/18 screen, should be passed over a 1/17 screen. Hard seeds will fall through as they did before soaking, but the swollen soft seeds will be held.
5. The hard seeds remaining may be put through a second cycle of boiling water scarification, soaking at room temperature and screening.
6. A third cycle may be necessary for lots with an extreme degree of hardseededness. One cycle may be sufficient for other lots.
7. Swollen seeds should be dried to their original moisture content for safe storage and to permit the use of normal seeding equipment.

As a variation of this procedure, sublots with no hard seeds could also be created without boiling water scarification merely by soaking in tap water and screening off the swollen seeds. The procedure could also be adapted to eliminate fast swelling seeds which are lowest in viability.

The practicability of the procedure described will be dependent on the size of the seed lot, equipment available, need, economics and the extent of hard seededness present.

In seed testing, boiling water scarification provides an efficient way of overcoming hardseededness so that the viability of hard seeds may be determined in a germination test. Dormancy is overcome by soaking, another technique useful in viability determination.

In research, boiling water scarification could be very practical for small lots of seed for experimental plantings. The procedure could likewise be practical for small to medium sized lots used for erosion control and ornamental plantings.

The adoption of boiling water scarification and soft seed separation of several tons of seed may be questioned. Commercial processors might be hesitant to undergo the effort and expense of installing the necessary new equipment. The procedures might seem cumbersome, but probably are no more so than wet seed processing of tomato and cucumber seed or acid or gas delinting of cotton seed.

Additional research may show that the several-cycle approach to boiling water scarification could be applied to other species of legumes as well. Previous workers have frequently concluded boiling water scarification to be impractical because the long treatments required to overcome hardseededness frequently reduced the viability of the soft seeds in the lot. This disadvantage is overcome with the repeated-cycle approach.

SUMMARY AND CONCLUSIONS

Attempts to separate hard and soft seeds of crownvetch on the basis of length and width were only partially successful. Long-narrow seeds contained up to 33% less hard seeds than short-wide seeds in some lots, but this relationship did not exist in other lots.

Wide seeds of Penngift were the least dormant, while medium and short seeds were least dormant in Emerald Lot B.

The highest concentration of dead seeds appeared in the widest seed groups.

Dark brown seeds contained more hard seeds than the intermediate and light-brown seeds. Dead seeds tended to be concentrated in the light-brown fraction.

Seeds that swelled during the first two hours of soaking in tap water averaged 54% dead seed. Seeds that required longer than two hours to swell contained a lower percentage of dead seeds.

Soaking seeds two hours in tap water nearly eliminated dormancy.

Five-second periods of immersion in boiling water reduced hardseededness without lowering the viability of soft seeds. The percentage of hard seeds remaining after a five-second treatment was further lowered by a second treatment, again without reducing viability. It is the abrupt change in temperature, rather than long exposure to high temperature, that is important in breaking hardseededness.

The viability of hard seeds was high, but usually less than 100%.

Soft seeds were successfully separated from hard seeds after soaking in tap water by making a size separation with round-hole screens.

After soaking, swollen soft seeds can be dried to their initial moisture content without apparent damage. Soaked and dried seeds showed good storability and good emergence in greenhouse studies.

On the basis of the data obtained, techniques for boiling water scarification and separation of hard and soft seeds were developed.

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APPENDIX

Appendix Table 1. Analysis of variance of percent germination in the seed width studies, as affected by varieties and width of seeds of crownvetch.

Source	DF	SS	MS	F	SIG.
Variety (V)	2	32067.36	16033.68	819.71	**
Width (W)	5	2686.22	537.24	27.46	**
V x W	10	439.01	43.90	2.24	*
Error	54	1056.71	19.56	--	--
Total	71	36249.31	---	--	--

CV. 10.67%

Appendix Table 2. Analysis of variance of percent hard seeds in the seed width studies, as affected by varieties and width of seeds of crownvetch.

Source	DF	SS	MS	F	SIG.
Variety (V)	2	62306.19	31153.09	451.62	**
Width (W)	5	511.68	102.33	1.48	ns
V x W	10	561.51	56.15	0.81	ns
Error	54	3725.21	68.98	--	--
Total	71	67104.61	--	--	--

CV. 20.17%

Appendix Table 3. Analysis of variance of percent dormant seeds in the seed width studies as affected by varieties and width of seeds of crownvetch.

Source	DF	SS	MS	F	SIG.
Variety (V)	2	1178.77	589.38	91.37	**
Width (W)	5	110.75	22.15	3.43	**
V x W	10	150.24	15.08	2.32	*
Error	54	348.66	6.45	--	--
Total	71	1788.44	--	--	--

CV. 48.19%

** Difference at 1% level.
* Difference at 5% level.
ns No difference at 5% level.

Appendix Table 4. Analysis of variance of hard seeds as affected by variety, quality group, seed length, and width of crownvetch.

Source	DF	SS	MS	F	SIG.
Variety (V)	2	25556.39	17778.19	765.64	**
Group (G)	1	22468.56	22468.56	967.63	**
Length (L)	2	2486.03	1243.01	53.53	**
Width (W)	2	721.81	360.90	15.54	**
V x G	2	16073.62	8036.81	346.11	**
G x L	2	313.92	156.96	6.75	**
G x W	2	1382.37	691.18	29.76	**
V x L	4	196.76	49.19	2.11	ns
V x W	4	804.07	201.01	8.65	**
L x W	4	199.93	49.98	2.15	ns
V x G x L	4	123.93	30.98	1.33	ns
V x G x W	4	154.57	38.64	1.66	ns
G x L x W	4	73.10	18.27	0.78	ns
V x L x W	8	119.75	14.96	0.64	ns
V x G x L x W	8	327.53	40.94	1.96	ns
Total	215	84765.66	--	--	--
Error	162	3763.25	23.22	--	--

CV. 9.65%

Appendix Table 5. Analysis of variance of dormant seeds as affected by variety, quality group, seed length, and seed width of crownvetch.

Source	DF	SS	MS	F	SIG.
Variety (V)	2	19197.84	9598.92	700.14	**
Group (G)	1	4.44	4.44	0.32	ns
Length (L)	2	71.95	35.97	2.62	ns
Width (W)	2	171.23	85.61	6.24	**
V x G	2	179.45	89.72	6.54	**
G x L	2	292.89	146.44	10.68	**
G x W	2	129.62	64.81	4.72	**
V x L	4	350.65	87.66	6.39	**
V x W	4	464.29	116.07	8.46	**
L x W	4	29.18	7.29	0.53	ns
V x G x L	4	294.15	73.53	5.36	**
V x G x W	4	221.51	55.37	4.03	**
G x L x W	4	56.07	14.01	1.02	ns
V x L x W	8	121.87	15.23	1.11	ns
V x G x L x W	8	294.70	36.83	2.68	**
Total	215	24101.66	--	--	--
Error	162	2221.75	13.71	--	--

CV. 11.66%

Appendix Table 6. Analysis of variance of dead seeds as affected by varieties, quality groups, seed length and seed width of crownvetch.

Source	DF	SS	MS	F	SIG.
Variety (V)	2	670.70	335.35	74.35	**
Group (G)	1	6.33	6.33	1.40	ns
Length (L)	2	55.25	27.62	6.12	**
Width (W)	2	200.73	100.36	22.25	**
V x G	2	670.70	335.35	74.35	**
G x L	2	72.70	36.35	8.05	**
G x W	2	1.39	0.69	0.15	ns
V x L	4	66.10	16.52	3.66	**
V x W	4	227.29	56.82	12.59	**
L x W	4	45.82	11.48	2.53	ns
V x G x L	4	59.21	14.80	3.28	*
V x G x W	4	57.18	14.29	3.16	*
G x L x W	4	4.60	1.15	0.25	ns
V x L x W	8	37.98	4.74	1.05	ns
V x G x L x W	8	55.98	6.99	1.54	ns
Total	215	2686.43	--	--	--
Error	162	731.75	4.51	--	--

CV. 53.80%

Appendix Table 7. Effect of length on various quality factors of crownvetch seeds expressed in percentages. Averaged over three cultivars and two lots, three widths and four replications.

Length	Germination	Hard seeds	Dormant seeds	Dead seeds
Long	36.80	45.84	12.48	4.65
Medium	35.22	49.76	11.22	3.70
Short	31.05	54.15	11.30	3.48
LSD .01	2.08	2.08	1.60	0.91
LSD .05	1.58	1.58	1.21	0.69
CV. %	14.03	9.65	11.66	53.80

Appendix Table 8. Effect of width on various quality factors of crownvetch seeds expressed in percentages. Averaged over three cultivars two lots, three lengths and four replications.

Length	Germination	Hard seeds	Dormant seeds	Dead seeds
Wide	32.12	51.98	10.56	5.30
Intermedium	34.66	50.23	11.69	3.38
Narrow	36.29	47.54	12.75	3.15
LSD .01	2.08	2.08	1.60	0.91
LSD .05	1.58	1.58	1.21	0.69
CV. %	14.03	9.65	11.66	53.80

Appendix Table 9. Analysis of variance of hard seeds in the color studies, as affected by varieties, quality groups and seed coat color.

Source	DF	SS	MS	F	SIG.
Variety (V)	2	25191.37	12595.68	778.22	**
Group (G)	1	1102.51	1102.51	68.11	**
Color (C)	2	330.70	165.35	10.21	**
V x G	2	8908.25	4454.12	275.19	**
V x C	4	533.62	133.40	8.24	**
G x C	2	21.81	10.90	0.67	ns
V x G x C	4	128.74	32.18	1.98	ns
Error	36	582.66	16.18	--	--
Total	53	36799.70	--	--	--

CV. 7.59%

Appendix Table 10. Analysis of variance of dormant seeds in the color studies, as affected by varieties, quality groups and seed coat color.

Source	DF	SS	MS	F	SIG.
Variety (V)	2	5049.37	2524.68	308.44	**
Group (G)	1	389.35	389.35	47.56	**
Color (C)	2	31.25	15.62	1.90	ns
V x G	2	898.92	449.46	54.91	**
V x C	4	33.85	8.46	1.03	ns
G x C	2	3.70	1.85	0.22	ns
V x G x C	4	4.51	1.12	0.13	ns
Error	36	294.66	8.18	--	--
Total	53	6705.64	--	--	--

CV. 26.95%

Appendix Table 11. Analysis of variance of dead seeds in the color studies, as affected by variety, quality group and seed coat color of crownvetch.

Source	DF	SS	MS	F	SIG.
Variety (V)	2	1434.33	717.16	53.49	**
Group (G)	1	127.57	127.57	9.51	**
Color (C)	2	1613.44	806.72	60.17	**
V x G	2	925.59	462.79	34.51	**
V x C	4	1395.88	348.97	26.02	**
G x C	2	429.59	214.79	16.02	**
V x G x C	4	403.74	100.93	7.52	**
Error	36	482.66	13.40	--	--
Total	53	6812.83	--	--	--

Appendix Table 12. Analysis of variance of germination in the speed of swelling and seed quality studies in crownvetch.

Source	DF	SS	MS	F	SIG.
Time (t)	5	33069.58	6613.91	16.88	**
Varieties (V)	2	2330.79	1165.39	2.97	ns
T x V	10	6489.37	648.93	1.65	ns
Group w/n V x T	18	7049.23	391.62		
Group (G)	1	3540.25	3540.25	206.22	**
T x G	5	528.66	105.73	6.15	**
V x G	2	2126.37	1063.18	61.93	**
T x V x G	10	853.95	85.39	4.97	**
Error	108	1854.00	17.16	--	--
Total	143	50793.00	--	--	--

Appendix Table 13. Analysis of variance of dormant seeds in the speed of swelling and seed quality studies in crownvetch.

Source	DF	SS	MS	F	SIG.
Time (T)	5	134.30	26.86	1.70	ns
Varieties (V)	2	43.51	21.75	1.38	ns
T x V	10	98.73	9.87	0.62	ns
Group w/n V x T	18	283.24	15.73		
Group (G)	1	12.25	12.25	6.13	ns
T x G	5	110.41	22.08	11.06	**
V x G	2	29.54	14.77	7.40	**
T x V x G	10	131.04	13.10	6.56	**
Error	108	215.50	1.99	--	--
Total	143	775.30	--	--	--

Appendix Table 14. Analysis of variance of dead seeds in the speed of swelling and seed quality studies in crownvetch.

Source	DF	SS	MS	F	SIG.
Time (T)	5	36732.30	7346.46	20.61	**
Variety (V)	2	1745.43	872.71	2.44	ns
T x V	10	6562.06	656.20	1.84	ns
Group w/n T x V	18	6415.74	356.43		
Group (G)	1	3461.36	3461.36	201.74	**
T x G	5	417.05	83.41	4.86	**
V x G	2	1627.18	813.59	47.41	**
T x V x G	10	910.15	91.01	5.30	**
Error	108	1853.00	17.15	--	--
Total	143	53308.55	--	--	--

Appendix Table 15. Analysis of variance of the final greenhouse emergence-survival count of crownvetch.

Source	DF	SS	MS	F	SIG.
Variety (V)	2	412.28	206.14	15.99	**
Treatments (T)	6	5402.48	900.41	69.84	**
V x T	12	603.61	50.30	3.90	**
Error	63	812.18	12.89	--	--
Total	83	7230.57	--	--	--

CV. 28.80%

Appendix Table 16. Percent daily emergence-survival of selected seed categories of crownvetch in the greenhouse.

Cultivar	Lot	Seed Category	Days after planting						
			6	7	8	9	10	11	12
Chemung	B	Untreated	0.5	2.0	2.5	5.0	5.5	6.5	6.5
Chemung	B	Naturally soft seeds	8.5	15.0	25.0	42.5	45.0	47.0	48.0
Chemung	B	Boiling water soft seeds	8.5	15.0	23.5	35.0	36.0	39.5	39.5
Chemung	B	Large-narrow seeds	1.0	1.5	3.0	5.5	6.0	6.5	6.5
Chemung	B	Short-wide seeds	0.0	0.5	0.5	1.0	1.0	1.0	1.5
Chemung	B	10 secs. in boiling water	1.5	4.5	10.5	18.0	19.0	19.0	20.0
Chemung	B	Mechanically scarified	0.5	2.0	3.0	1.0	1.5	1.5	2.0
Emerald	A	Untreated	0.5	1.0	1.5	8.5	12.0	13.5	16.0
Emerald	A	Naturally soft seeds	2.0	7.0	17.0	33.5	37.5	39.5	42.0
Emerald	A	Boiling water soft seeds	8.5	19.0	33.5	51.0	52.0	52.0	54.5
Emerald	A	Large-narrow seeds	0.5	4.0	6.0	12.5	21.5	24.0	29.0
Emerald	A	Short-wide seeds	1.5	1.0	4.5	11.0	14.5	15.0	19.0
Emerald	A	10 secs. in boiling water	2.0	8.0	12.0	20.5	22.5	22.5	23.0
Emerald	A	Mechanically scarified	0.5	2.0	3.5	8.5	10.5	11.5	12.5
Penngift	B	Untreated	0.5	0.5	0.5	3.5	6.0	6.5	6.5
Penngift	B	Naturally soft seeds	2.0	7.0	12.0	18.5	20.5	22.0	25.5
Penngift	B	Boiling water soft seeds	21.0	33.5	48.0	60.5	64.0	64.0	63.5
Penngift	B	Large-narrow seeds	0.0	2.0	5.5	13.0	20.0	20.5	21.5
Penngift	B	Short-wide seeds	0.0	0.5	2.0	6.5	9.0	9.5	10.0
Penngift	B	10 secs. in boiling water	1.0	5.0	6.0	11.0	16.0	17.0	18.0
Penngift	B	Mechanically scarified	0.5	2.0	3.5	5.5	10.5	11.0	8.0

Appendix Table 17. Effect of length of soaking in boiling water and length of soaking in tap water at 30C. on the percent swollen seeds of Emerald Lot B. Average of four groups each of 100 seeds.

Soaking in tap water in hours	Length of soaking in boiling water in seconds												
	0	5	10	15	20	25	30	35	40	45	50	55	60
1	11.50	17.00	15.25	12.00	17.50	19.50	21.25	18.50	15.50	9.75	11.25	9.75	13.75
2	13.50	38.50	28.75	27.75	35.50	34.75	36.50	40.75	39.25	42.25	55.00	36.75	39.25
3	15.50	48.25	40.00	39.25	47.00	47.50	50.00	62.25	61.00	63.75	75.00	58.00	65.75
4	18.75	55.00	59.75	59.50	66.75	59.50	64.50	67.00	66.50	68.00	80.25	67.25	74.50
6	21.25	66.75	67.50	72.25	80.50	73.75	72.75	77.05	77.25	79.75	83.00	79.75	82.75
8	25.00	72.75	75.25	77.75	82.75	78.25	79.25	81.00	83.50	81.00	86.50	84.00	88.00
24	31.75	81.00	83.50	85.25	86.50	85.25	86.50	87.25	89.25	87.75	91.50	87.25	90.25
48	37.00	82.25	84.50	89.00	90.00	87.25	88.00	88.75	91.50	90.00	93.50	89.50	92.25

Appendix Table 18. Germination percentage at different lengths of continuous soaking of swollen seeds in tap water. Average of four groups of 100 seeds in Emerald Lot B.

	Length of soaking in tap water in hours								
	0	18	36	42	66	90	108	130	155
Germination	90	90	87	92	87	77	75	75	56

Appendix Table 19. Germination percentage after different cycles of drying and soaking in tap water. Average of four groups of 100 seeds in Emerald Lot B.

	Cycles of drying and soaking													
	0	1	2	3	4	5	6	7	8	9	10	11	12	13
Germination	91	92	89	88	93	83	83	93	85	88	80	81	80	70

Appendix Table 20. Analysis of variance of percent dead seeds in the seed width studies as affected by varieties and width of seeds of crownvetch.

Source	DF	SS	MS	F	SIG.
Variety (V)	2	3622.11	1811.05	113.39	**
Width (W)	5	3818.67	763.73	47.82	**
V x W	10	2523.24	252.32	15.79	**
Error	54	862.41	15.97	--	--
Total	71	10826.44	--	--	--