EFFECTS OF MATURITY AND SEED SIZE ON SEED VIGOR AND PLANT GROWTH IN SNAP BEAN (*Phaseolus vulgaris* L.)

by

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(ABSTRACT)

Stage of maturity at harvest and relative seed size can affect seed vigor. Greenhouse and field studies were conducted to determine the effect of seed maturity on seed vigor, storability, and subsequent plant growth of four cultivars of snap bean (Topcrop, Provider Black, Provider White, and Cherokee Wax). Seeds harvested between physiological maturity (PM) and harvest maturity (HM) showed the highest seed vigor and storability. At PM, seed moisture content was about 55%. A drop in seed fresh weight and a pod color change from green to yellow appear to signal the stage of PM. Delaying harvest past HM reduced seed vigor. The three cultivars with colored seed coats showed higher seed vigor than Provider White.

Climatic and weathering effects on maturity, vigor, and yield of Topcrop and Cherokee Wax seed were evaluated at three locations (L-1, L-2, and L-3) in Sri-Lanka having different agro-climatic conditions. Seeds that developed and matured under cooler conditions (L-1) produced higher yields and had larger size, better color, and higher vigor. Seeds developed and matured faster under warmer conditions (L-3); however, seed vigor and yields were lower and seed vigor dropped prior to HM. Cherokee Wax was the most tolerant to field weathering.

Seeds of Topcrop and Cherokee Wax were separated by weight into three seed sizes (small, medium, and large) and evaluated for crop performance in two plantings (12/90 and 3/91). Field emergence was higher from larger seeds in the second planting, where the soil conditions were more stressful. Seedlings and plants at the flowering stage were larger and pod yields higher from larger seeds. The cultivar × seed size interaction was significant for pod yield per plant. Topcrop showed no differences, while with Cherokee Wax, pod yield per plant increased with increase in seed size during both plantings. Seeds produced from small seeds were similar or higher in vigor, indicating that small seeds could be used for seed production purposes. The data from these experiments indicate that vigor in snap bean seeds can be optimized by harvesting at an early stage after PM and by grading to remove small seeds.

Dedication

To my mother and late father P.B. Herat.

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Chapter 1: Introduction and Literature Review

INTRODUCTION

Snap bean (*Phaseolus vulgaris* L.) is an important vegetable crop grown for fresh market or processing (canned or frozen). The species is also cultivated for dried beans, which are a valuble source of vegetable protein. Further, being a legume, it is a suitable crop for inclusion in a crop rotation program. There is evidence for the origin of *Phaseolus* in the regions of Peru and Mexico in the American continent (Smartt, 1990; Summerfield and Roberts, 1985). Presently, it is cultivated throughout the temperate, tropical, and subtropical areas of the world (George, 1985). Bean is a direct seeded crop, and when using modern precision seeders, high seed vigor is a prerequisite for achieving a desired stand and uniformly mature crops for once-over harvests. The vigor potential of seeds is determined initially by the genotype; however, stage of maturity at harvest and seed size are two factors that can affect seed vigor (ISTA, 1987). In bean seed production, field weathering is an important factor that can reduce seed vigor before the seed crop is harvested, and harvesting at the optimum stage of maturity can reduce this loss in vigor.

Seed vigor is an important physiological attribute of seed quality which affects seedling emergence, plant growth, and yield. According to Association of Official Seed Analysts (AOSA, 1983) "seed vigor comprises those seed properties which determine the potential for rapid, uniform emergence, and development of normal seedlings under a wide range of field conditions."

Physiological maturity (PM) in seeds is normally defined as occuring when the seeds reach maximum dry weight (Harrington, 1972). After this point, further influx of nutrients from the plant ceases (Harrington, 1972), and the seed is merely "stored" on the plant until it drops off or is harvested. Deteriorative changes may occur during the maturation (post-PM stage) period under unfavorable environmental conditions. This is refered to as field weathering. Deterioration is initiated when dry seeds are exposed to moisture and temperature fluctuations which can weaken the seed coats and cause other physiological or pathological changes (Maguire, 1977). Weathering is a major problem in seed production. The severity of weathering is the greatest in warm areas such as the humid subtropics and tropics. For that reason, part of this study is carried out in Sri-Lanka. The concentration of seed production for most crops in localized areas of the U.S. and other countries is persuasive testimony of the influence of environmental factors on seed development and quality. Southern Idaho accounts for approximately 80% of the snap bean seeds produced in the United States

(Webster, 1984). Because of the low rainfall and humidity, bean seeds produced in Idaho are relatively free of pathogenic problems.

Wet weather interacting with cultivar has been reported to be the most important factor affecting seed quality in navy bean in southwestern Ontario (Tu et al., 1988). Cultivar choice, timing of harvesting, and post-harvest management are important factors to be considered for production of high-quality bean seeds. Prolonged humid weather after PM and prior to harvest is an infrequent but serious cause for decreased quality and supply of dry bean seed in Michigan (Copeland et al., 1990). Among horticultural crops, differences in vigor appear to be most pronounced in the large seeded legumes. With wrinkle seeded peas, there have been many reports that germination is not well correlated with field emergence (Matthews and Bradnock, 1967, 1968; Perry, 1967).

Injury from field weathering may be minimized by harvesting the seed crop prior to seed deterioration. Information on the effects of harvest maturity on seed vigor and subsequent plant growth will aid in determining optimum time for harvesting operations. In snap bean there are only a few field studies on the effects of maturity and field conditions on seed vigor. Further, studies to relate its effects on storability and subsequent field performance are scarce.

The reported influences of seed size on field emergence, seedling vigor, yield, and quality of self pollinated crops have been inconsistent and controversial (Rao, 1981). Alam and Locascio (1968) reported that seed size had no effect on percentage germination in bean. However, plant height, fresh weight of plant, and yield of pods increased with increase in seed size. In bean seed lots susceptible to transverse cotyledon cracking, small seeds have given higher percentage germination in laboratory germination tests (Clark and Peck, 1968). In one study, when different sized seeds were planted with the same number of seeds per row, plants from larger seeds outyielded those from small seed. Other investigators (Hardenburg, 1942; Salih, 1981) did not find any significant effect of seed size on yield of field bean. Because of these inconsistent results, it is desirable to examine the relationship of seed size to seed vigor and crop performance.

The objectives of this study were to: 1) determine the effects of seed maturity at harvest on seed vigor, storability, and subsequent plant growth, 2) examine climatic effects on seed development, maturity, and vigor, and, 3) determine effects of seed size on seed vigor, plant growth, and yield.

LITERATURE REVIEW

Seed Vigor

Seed testing minimizes the farmer's risk by assessing the seeds' quality before they are sown. Seed quality comprises several components that may be categorized as genetic, physiological, physical, and pathological. The germination test is universally used as a seed quality test. The Association of Official Seed Analysts (AOSA, 1988) defines germination (in laboratory practice) as, "the emergence and development from the seed embryo of those essential structures which for the kind of seed in question are indicative of the ability to produce a normal plant under favorable conditions." Seeds can be at different levels of deterioration, and loss of the capacity to germinate is the final practical consequence of seed deterioration. Quite often seed lots of good germination perform at different levels in the field, particularly under adverse environmental conditions. This is attributed to differences in seed vigor. There have been several reviews of the literature on seed vigor and field establishment (Bradnock, 1975; Perry, 1976; Powell, 1988; Roberts, 1989).

"Seed vigor comprises those seed properties which determine the potential for rapid, uniform emergence and development of normal seedlings under a wide range of field conditions" (AOSA, 1983). The International Seed Testing Association (ISTA) has adopted the following definition of seed vigor (Perry, 1978): "seed vigor is the sum total of those properties of the seed which determine the level of activity and performance of the seed or seed lot during germination and seedling emergence. Seeds which perform well are termed high vigor seeds, and those which perform poorly are called low vigor seeds." The particular aspects of performance which may show variations associated with differences in seed vigor include: (1) biochemical processes and reactions during germination, such as enzyme reactions and respiratory activity; (2) rate and uniformity of seed germination and seedling growth; (3) rate and uniformity of seedling emergence and growth in the field; and (4) emergence ability of seeds under unfavorable environmental conditions. The effects of vigor may persist to influence mature plant growth, crop uniformity, and yield. The principal known causes of vigor are: (1) genetic constitution; (2) environment and nutrition of the mother plant; (3) stage of maturity at harvest; (4) seed size, weight or specific gravity; (5) mechanical integrity; (6) deterioration and aging; and (7) pathogens (ISTA, 1987).

On the basis of available evidence, the following conclusions have been made on seed deterioration (AOSA, 1983):

- Seed deterioration is an inexorable process which usually commences at the time seeds attain physiological maturity (P.M.); and rate of deterioration is influenced by genotype, seed moisture, and temperature.
- Deterioration of seed is progressive and sequential. Vital systems and functions are progressively and sequentially impaired, because of interdependencies, until seeds become incapable of germination.

- The fundamental deteriorative changes occur at the cellular level, affecting the integrity and functional capacity of nuclear material, membranes, organelles, and biochemical processes involved in germination.
- The consequences of deterioration are manifested as a progressive reduction of performance capabilities of seeds.
- The final consequence of deterioration is the loss of the capacity for germination.
- The lesser consequences of deterioration which precede loss of the capacity to germinate include a progressive reduction in the rapidity, uniformity, and intensity of growth (during germination and emergence) and an increasing sensitivity or decreasing tolerance to environmental stresses.
- Seed vigor and seed deterioration are reciprocal, dimensioned "properties" of a seed or seed lot. Vigor decreases as the level of deterioration increases.

In reviewing the literature on the relationships of seed vigor to crop yield, Tekrony and Dennis (1991) concluded that the effect of seed vigor on yield depends on when the crop is harvested. Crops harvested during early vegetative growth or early reproductive growth showed a consistently positive relationship between seed vigor and yield. With annual crops, where reproductive plant parts are harvested at full maturity, there was no relationship between seed vigor and yield under normal cultural conditions.

The inherent maximum vigor potential of seeds depends on the genotype, but expression is influenced by the environment occuring before and after harvest. Genetic aspects of seed quality have been reviewed by Dickson (1980), and environmental effects on seed development and quality have been reviewed by Delouche (1980).

Seed Characteristics Affecting Seed Vigor

Seed coat color has been shown by several workers to be associated with seed vigor. White-coated cultivars of snap bean were reported to imbibe more rapidly than colored seeds (Morris et al., 1970; Wyatt, 1977; Powell et al., 1986a and 1986b). White seed coats were more permeable to water, while colored seeds had greater seed coat dry weight and thickness (Wyatt, 1977). Field tests involving 47 pairs of snap bean breeding lines, near isogenic except for differences in seed color, demonstrated that colored seed sublines were superior to white-seeded sublines in emergence and vigor (Deakin, 1974). White-seeded cultivars of dwarf french bean had lower field emergence compared to colored cultivars, and they also had higher leachate conductivity (Powell et al., 1986a). Colored testae adhere more tightly to cotyledons than do white testae, and it was suggested that this results in more rapid imbibition for the white seeds (Powell et al., 1986b). Rapid imbibition was associated with greater imbibitional damage in the form of increased dead tissue which coincided solute leakage (Powell et al., 1986b), and this damage was reduced when seeds were imbibed more slowly in polyethylene glycol (PEG).

Colored seed are often more resistant to mechanical damage (Dickson and Boettger, 1976). The resistance, which results in less seed coat cracking, also results in less leakage from seeds during germination and consequently less attack by soil borne fungi (York et al., 1977). Transverse cotyledon cracking (TVC) occurs widely in large-seeded legumes. Dickson et al. (1973) observed correlation of TVC with Ca and Mg content and also noted cultivar differences in snap bean in which TVC ranged from 5 to 94%. Atkin (1958) screened a number of snap bean cultivars for tolerance to mechanical injury. Most of the tolerant lines had colored seed coats.

Physiological and Biochemical Aspects of Seed Vigor

Literature on physiological and biochemical aspects of seed vigor have been reviewed by Abdul-Baki (1980), Roos (1980), Matthews and Powell (1986), and Powell (1988). Seed aging and loss of membrane integrity are causes of low seed vigor (Powell, 1988). Aging involves the process of deterioration, that is, the accumulation of irreversible degenerative changes until eventually, the ability to germinate is lost. The physiological symptoms of aging in grain legumes include reduced rates of germination and emergence, decreased tolerance to suboptimal conditions, and poorer seedling growth (Powell et al., 1984). Kijashko (1984) observed that aged soybean seeds produced smaller, abnormal seedlings which had deformed hypocotyls and poorly developed main roots. Powell et al. (1984) described the biochemical changes that occur during seed aging in grain legumes. These involve changes in solute leakage, enzyme activity, respiration, ATP content, protein and DNA synthesis, and genetic changes. Both natural and accelerated aging lead to a reduced germination, a decrease in the proportion of high vigor seeds, and reduced amylase and protease activity in *Phaseolus aureus, Phaseolus mungo*, and *Vicia faba* (Vimala, 1984). Dourado and Roberts (1984) reported that an increase in chromosomal aberrations, mainly of the chromatid type, occurred even with a small decrease in the viability of barley and pea seed.

Membranes and Vigor. During seed maturation, seed moisture content drops from about 80 to about 10%. As the seed matures, the organelles begin to lose their microscopic organization in varying degrees and to become less active metabolically. The water potential of a mature dry seed can exceed -100 MPa owing to its high matric potential (Bewley and Black, 1985). The ability to develop this extremely low water potentials and to undergo reversible changes in membrane structure and still survive is a critical property of the seeds. When the seed moisture content reaches 12 to 14% (characteristic of a dry seed at maturity), the cells and organelles show signs of shrinkage and alterations of membrane structure and permeability (Edwards, 1976). Simon (1978) described membrane changes that might occur in relation to seed hydration and dehydration. In a hydrated cell membrane, phospholipids form a bilayer. The presence of an aqueous phase on either side of the membrane, as in fully hydrated tissues, "forces" the membrane lipids into this lamellar configuration, assuring its structural and functional integrity.

In grain legumes, reduced seed quality can occur due to the rapid uptake of water during imbibition (Powell et al., 1984). The inrush of water is thought to retard normal reorganization of the membrane and to lead to reduced vigor. This is referred to as imbibitional damage, and has resulted in decreased vigor in dwarf french beans (Powell et al., 1986a, 1986b). Parrish et al. (1982) found aged soybean seed to show reduced turgor following imbibition. Soybean seeds subjected to accelerated aging treatment, showed a marked lowering of early respiration of isolated cotyledons, large increases in the initial leakage of electrolytes, increases in dry weight loss, and decreases in the swelling response of the imbibing seed (Parrish and Leopold, 1978). The authors suggested that these changes were a result of deteriorative changes in the membrane system.

Bean Seed Development and Maturation

The development of pod, seed, and embryo of *Phaseolus vulgaris* from fertilization to maturity was studied by Walbot et al. (1972). They described the reproductive development in nine stages of approximately equal duration using morphological characters of pod, seed, and embryo. The seed growth was reported to follow a diauxic growth pattern (Carr and Skene, 1961; Walbot et al., 1972). Carr and Skene (1961) reported that the embryonic axis remains small until about 23 days after anthesis (DAA) in french bean cultivar 'Hawkesbury Wonder'. Immature embryonic axes placed in culture showed a growth lag before germination in 'Taylor's Horticultural' (Long et al., 1981). The authors suggested that, if abscisic acid (ABA) or water stress is responsible for preventing precocious germination, then it may be that a high level of ABA is maintained or synthesized by the embryonic axes. The ability to germinate after rapid dessication was acquired by axes at 26 DAA. Goodwin and Siddique (1984) reviewed some aspects of bean seed development and vigor. The nitrogen content of the seed increases rapidly during the third week after anthesis, a stage at which the pod growth has already slowed down (Oliker et al., 1978).

The plant hormone ABA has been implicated with fruit maturation. Hsu (1979b) observed two peaks of free ABA in embryos of bean cultivar 'Taylor's Horticultural'. The two peaks were 22 and 28 DAA. The first peak coincided with the first significant drop in embryo water content and the second when the embryo water content was lowered to about 50%. Seeds from plants of cultivar 'Earlywax' stressed at higher temperature (46°C) had higher ABA levels (Makus and Shannon, 1979). Higher ABA/g seed was also observed in plants grown under a 16-hour day as opposed to a 10-hour day. A marked increase in the germination capacity of pea seeds between 20 and 28 DAA was associated with a decline in their ABA content (Eeuwens and Schwabe, 1975).

Influence of Temperature. Halterlein et al. (1980) showed that high temperature during flowering (35/20°C day/night and 35°C constant) reduced the percentage of viable pollen but did not reduce pollen tube growth. The authors suggested that temperature up to 35°C was not likely to limit pod set. Dickson and Boettger (1984) reported that low night temperatures (8° to 12°C) appeared to inhibit ovule viability, while high day temperatures reduced pollen viability. Pechan and Webster (1986) reported that a low percentage (7%) of the pollen grains from red kidney bean aborted, and fertilization of all ovules were ensured. The discrepancy between the number of ovules and the final seed number per pod is due to seed abortion after fertilization.

Temperatures during seed development and maturation can affect seed quality. Siddique and Goodwin (1980a, 1980b) reported that seed quality was higher at low maturation temperatures (18/13°C and 21/16°C). Under Ohio conditions, late planting (May 30) and late harvesting (October 5 or 15) enhanced seed quality of soybean, while early planting (May 1) and early harvest (Sept. 15) decreased seed quality (Adam et al., 1989). Lower seed quality in early plantings was attributed to seeds maturing under higher temperature and humidity.

Seed Maturity and Harvest

Seed moisture content (SMC) is often used as an index of seed maturity (Ellis et al., 1987; Clapham and Barnes, 1990). Seeds attain physiological maturity (PM) at moisture contents ranging from 32 to 35% for corn, sorghum, and rice to 50 to 55% for soybean, peanut, bean, and cotton (Delouche, 1980). Ellis et al., 1987 reported that the PM of six grain legumes (pea, faba bean, chickpea, lentil, soybean, and lupine) coincided with moisture contents of 55 to 60%. Maximum seed quality as determined by viability, seedling abnormalities, and seedling size occured in pea, chickpea, and lupine at PM; however, maximum seed quality occured after PM for soybean (45% SMC), faba bean, and lentil (30% SMC).

Much of this variation was attributed to variation in maturity within each seed crop.

SMC appears to be a useful parameter for harvest decisions in seed crops. An increase in resistance to mechanical damage with no significant loss in seed size and yield was observed in dark red kidney bean when plants were cut at 40 to 50% SMC (Faris and Smith, 1964). Le Deunff and Rachidian (1988) defined three phases of seed development in pea based on differences in SMC. PM was achieved at 55% SMC, when disruption of the vascular connection between the pod and the mother plant occurs. Bennet and Waters (1988) reported that seeds of sweet corn, harvested at 45 to 54% SMC had better stand establishment. Further, sweet corn seed harvested at 38 to 50% SMC performed well after 60 months of storage (Bennet and Rassbaugh, 1990). In 'Sweet Spanish' onion (*Allium cepa* L.), umbels could be harvested with SMCs as high as 66% without any adverse effects on seed size or quality (Steiner and Akintobi, 1986).

A visual indicator of PM is a useful observation that would help in identifying PM in the field. Chamma et al. (1990) suggested that the point when green pods are not found any longer can be used to characterize PM of snap bean seeds. The change of color of the soybean seed from green to yellow indicates PM (Tekrony et al., 1979). SMC at this stage ranged from 50 to 60%. However the bulk of the yellow seed was harvested from yellow, yellow brown, or brown pods, suggesting that appearance of yellow pods can be used as an indicator of PM. The appearance of a black closing layer, which is visible to the naked eye, provides a simple indication of PM for corn (Daynard and Duncan, 1969; Rench and Shaw, 1971).

Inoue and Suzuki (1962) reported that the seeds of bean cultivar 'Masterpiece' showed 100% germination at 35 DAA. Seeds harvested at 15 and 20 DAA , which did not germinate in the fresh condition, showed 100% germination with 20 and 10 days of after ripening. Wijandi and Copeland (1974) compared Michigan-and Idaho-grown navy bean seeds ('Seafarer') and observed significant reduction in germination and seedling vigor when seeds were harvested prior to complete maturity. However, in this study, pods were grouped into pale green, yellow, and brown at harvest stage for the different maturity groups. Siddique and Goodwin (1980a) harvested bean cultivar 'Apollo' at three stages of maturity (yellow/fleshy pod stage, dry pod stage, and 15 days after the dry pod stage), and optimum time of harvest appeared to be the dry pod stage. Seed vigor was measured as percentage of normal seedlings.

Desiccation Tolerance. Desiccation of immature bean seeds was reported to improve germination (Inoue and Suzuki, 1962). However, Dasgupta and Bewley (1982) reported that seeds harvested at 22 DAA were desiccation intolerant, while those at 32 DAA were desiccation tolerant in bean cultivar 'Tailor's Horticultural.' They proposed that desiccation plays a role in permanently suppressing developmental protein synthesis and inducing germination protein synthesis. The embryonic axes undergo a transition from desiccation intolerance to desiccation tolerance in the course of their development (Dasgupta et al., 1982;

Kermode et al., 1986). Matthews (1973a, 1973b) reported that pea seeds can withstand rapid desiccation after removal from the plant only if the seed moisture content had already begun to decline while the seeds were still on the mother plant. This stage was accompanied by a sharp decline in the leaching of electrolytes from the seeds into steep water (Bedford and Matthews, 1976).

Seed Size

Before grading, all seed lots contain seeds of different sizes. This variation is partly due to differences between the seeds harvested from different plants and partly due to differences between seeds borne on the same plant. The variation between plants may be due to genetic and/or environmental factors. However genetic variation is more likely to occur in cross-pollinated species than in self-pollinated species. Maturation temperatures can affect seed size. Kant et al. (1983) reported that maturation of peas at 17.5°C produced larger seeds than those that matured at 24.5°C.

Nakamura (1988) reported that embryos in basal ovular positions in *Phaseolus vulgaris* are more likely to abort or, if they survived, become lighter seeds than stylar embryos. The author suggested that the variation in mature seed size may affect adult characteristics, since large seeds produced larger juvenile plants than small seeds. A similar ovule positional effect has been reported for an outbreeding legume, *Phaseolus coccineus* (Rocha and Stephenson, 1990, 1991). Several authors using various lines of reasoning have speculated that the overproduction of ovules followed by nonrandom seed abortion on the basis of progeny vigor could increase the average vigor of the seed crop (Bawa and Webb, 1984; Stearns, 1987; Westoby and Rice, 1982).

The effect of seed size on plant growth and yield of crops has received much attention by several workers. In reviewing the research work on the influence of seed size on field germination, seedling vigor, yield, and quality in self-pollinated crops, Rao (1981) concluded that the data were inconsistent.

Larger soybean seeds gave greater emergence under simulated soil crust conditions and had greater shoot and root fresh weights than small seed (Longer et al., 1986). Tekrony et al. (1987) reported that field emergence of soybean showed little relationship to seed size. In hill plots, lower yields were associated with small seed size, but there was no relationship between seed size or vigor and yield in row plots. Lima bean plants from large seed produced larger plants and larger beans (Wester, 1964); however, plants from small seed yielded considerably more when not crowded by larger plants.

Clark and Peck (1968) studied the relationship between the size and performance of snap bean seeds. In seed lots showing an appreciable amount of transverse cotyledon cracking (TCC), smaller seeds showed a higher germination percentage than larger seeds. Where the same number of seeds of a single size was planted in separate rows, large seeds out-yielded those with small seeds. Alam and Locascio (1968) reported that neither seed size nor planting depth affected percentage germination in bean; but plant height, fresh and dry weights, and yield increased with seed size. Grabe (1975) showed that bean crops from larger seeds were found to reach harvest size earlier and give higher yields, while other investigators have reported that seed size did not affect seed yield in bean (Hardenburg, 1942; Salih, 1981).

In examining the relationship of protein content and size of of snap bean seeds with growth and yield, Ries (1971) observed that seedling size and yield were more highly correlated with protein per seed than seed size. In this study, phenotypic differences in seed size and protein content were expressed by growing bean under three nitrogen regimes.

In a development analysis of seed size in four common bean cultivars, Hsu (1979a) reported that three different seed parameters (length, weight, and volume), all followed a similar development course in different seed parts (embryo, seed coat, and whole seed). Differences in seed size were attributed to differences in growth rates and not duration of development. The four different cultivars used in this study had different seed sizes.

Seed Vigor Testing Methods

A seed is a living system and is thus subject to degenerative or deteriorative processes. Seed deterioration is an inexorable process which usually commences at the time seeds reach physiological maturity (PM) and proceeds at a rate influenced by genotype and environmental conditions. A final practical consequence of deterioration is the loss of the capacity for germination. The challenge of vigor testing has been to identify parameters which are correlated with seed deterioration (AOSA, 1983). McDonald (1980) considered that a vigor test should be inexpensive, rapid, uncomplicated, reproducible, and correlated with field performance. There is no single vigor test that is suitable for all situations. After reviewing the progress made in the past 25 years, Hampton and Coolbear (1990) concluded that no single test whether germinative, physiological, or biochemical appears to be even appropriate for even a single species under all conditions. A number of vigor test methods have been developed (ISTA, 1987; AOSA, 1983).

Seedling Growth and Evaluation Tests

Seedling growth and evaluation tests are conducted under the same conditions as the standard germination (SG) test, but the seedling growth is measured or evaluated in different ways. These tests generally are inexpensive, relatively rapid, and do not require specialized equipment. There have been two main directions of development.

(1)Seedling Vigor Rating. In this test, the normal seedlings in a SG test are further classified into "strong" and "weak" seedlings. The advantage of this test is that very little work in addition to the SG test is required. However variation in judgement of seedling classification and microorganism infection can affect the separation of "strong" and "weak" seedlings. The above test was proposed for use in vigor assessment of soybean, cotton, peanut, and garden bean (Woodstock, 1976).

(2)Seedling Growth Rate (SGR). Rapid and uniform emergence is an important component in the definition of seed vigor. Therefore, a measurement of

seedling growth rate is a logical seed vigor test. In this test, either linear growth or dry weight are determined at the end of the SG test. Seeds which produce a single straight shoot or root are suitable subjects for linear measurements (ISTA, 1987).

The measurement of seedling dry weight has been suggested by the AOSA vigor testing committee (Woodstock, 1976). The weight of the dry matter from soybean seedlings, excluding the cotyledons, was shown to be correlated with vigor (Edge and Burris, 1970). Within genotypes of corn, there was a relationship between seedling dry weight and emergence (Burris, 1975). A seed vigor test based on epicotyl weight measured loss of vigor in bean seed stored under unfavorable conditions before a loss of viability was detected by the SG test (Manalo and Roos, 1971). The SGR vigor test is a reliable, sensitive indicator of initial vegetative development in the field. However results must be interpreted within genotypes.

Accelerated Aging Tests

The accelerated aging test (AA test) was originally developed as a rapid test for measuring relative storability of seeds (Delouche, 1965; Delouche and Baskin, 1973) and was later used to estimate seed vigor. In this test, the seeds are subjected to the two most important environmental variables which influence seed deterioration: high temperature (40°to 45°C) and high relative humidity (>90%). Exposure is for relatively short periods (48 hours or longer), depending on the species (AOSA, 1983). The seeds are then removed from the imposed stress conditions and germination determined according to ISTA rules. Germination after the AA test is related to seed vigor, storability, and field emergence (Delouche and Baskin, 1973). Sammy et al. (1987) reported that, when the field emergence of different snap bean plantings were combined and averaged, AA test results correlated well with field emergence.

Conductivity Tests

The conductivity test is a measurement of electrolytes leaking from plant tissues. Poor membrane structure and leaky cells are usually associated with deteriorating low vigor seed. This results in a greater loss of electrolytes such as amino acids and other organic acids from imbibing seeds and increases conductivity of the soak water (AOSA, 1983). A higher conductivity, therefore, may indicate a lower vigor seed lot. This test was developed into a vigor test for the prediction of field emergence of wrinkled-seeded garden peas by Matthews and Bradnock (1967). They also found a significant negative correlation between the field emergence of seed samples of peas and french beans and the electrical conductivity of seed steep water (Matthews and Bradnock, 1968).

Sammy et al. (1987) evaluated four seed vigor tests (SG test, AA test, cold soil test, and conductivity test) for their ability to predict the potential field emergence of snap bean. The cold test showed the highest significant correlation followed by the conductivity test. Pandey (1988) reported that buffering capacity of incubation water was highly correlated with electrolyte leakage into single-seed steep water in french bean. Mullet (1978) carried out population studies using the individual conductivity test and found a very high correlation between individual seed conductivity and field emergence in bean cultivars, including ‘Apollo’. A conductivity level of 165 µmho cm^{-1} g^{-1} dry seed was considered as the critical level for bean cultivar “Apollo” by Siddique and Goodwin (1985). They used conductivity measurements on single seeds, and the percentage seed in the low conductivity group and the percentage normal seedlings obtained in the seedling evaluation test were highly correlated.

Nutrients exuded from seeds during germination can also stimulate microorganism activity and secondary infection. A direct correlation has been reported between seed rot and quantity of carbohydrates exuded from seeds of garden bean (Schroth and Snyder, 1961).

Tetrazolium Tests

In seed germination, radicle protrusion and seedling growth are the end results of a series of biochemical events. The level of metabolic activity determines seedling growth rate. Therefore, biochemical tests which measure certain metabolic events in seeds during germination can be used to measure seed vigor. These tests have the advantage of requiring less time than most other tests.

The tetrazolium (TZ) test is based on the action of dehydrogenase to release hydrogen which subsequently reduces the colorless and water-soluble TZ (triphenyl tetrazolium chloride) salt to a red, water insoluble compound called formazan (AOSA, 1983). Therefore living cells turn red, while dead cells remain colorless. The TZ test can be used to estimate vigor as well as viability. Vigor evaluations are made on the basis of the identification, location, and appraisal of sound, weak, and dead embryonic tissues, based on staining pattern. The test has been shown to forecast seed vigor in soybean, corn, cotton, clover, wheat, and pea (AOSA, 1983). The advantage of the test is that it provides a rapid evaluation of the vigor of seeds and requires no elaborate facilities. However the test is subjective, and reproducible results are difficult to achieve.

In many studies on bean seed maturity, seed vigor was evaluated mostly by percentage normal seedlings. However, there can be differences between germination and seed vigor based on vigor tests. Vigor of seeds at different maturity stages under different climatic conditions could be different and interact with cultivar. Further, studies on the influence of seed maturity on storability and subsequent performance of the crop are scarce. With regards to effects of seed size on plant growth and yield, results appear to be inconsistent and could interact with cultivar and environment. No studies have been made on the effects of snap bean seed size on both pod and seed yield and vigor of seeds produced. The influence of seed size on various stages of the crop as it progresses from emergence through juvenile stage to pod and seed yield needs to be addressed.

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Chapter 2: Effects of Seed Maturity and Cultivar on Seed Vigor, Storability, and Plant Growth in Snap Bean (*Phaseolus vulgaris* L.)

ABSTRACT

Harvesting at the optimum stage of maturity can reduce possible vigor losses from field weathering. Greenhouse and field studies were conducted to determine the effects of seed maturity and cultivar on seed vigor, storability, and plant growth in snap bean. Seed lots harvested at different stages of maturity were examined for seed vigor, field emergence, emergence rate, and yield in four cultivars of snap bean (Topcrop, Provider Black, Provider White, and Cherokee Wax). Seed quality was evaluated by standard germination and three seed vigor tests: seedling dry weight, accelerated aging, and conductivity. Seed lots from different maturity stages of two cultivars (Topcrop and Cherokee Wax) were also evaluated for storability at 40°C for 6 months. Seeds harvested between physiological maturity (PM) and harvest maturity (HM) had high seed vigor. At PM, seed moisture content was about 55% and pod color changed from green to yellow. Physiologically mature seeds could be harvested prior to HM without any loss of vigor. However, delaying harvest past HM reduced seed vigor. The three cultivars with colored seed coats showed higher seed vigor, and two of them (Provider Black and Cherokee Wax) had lower imbibition rates than the white-seeded cultivar (Provider White). Seeds harvested between PM and HM had higher storability levels than seeds harvested after HM. Accelerated aging and seedling dry weight tests were found to be suitable for seed vigor evaluation in snap bean.

INTRODUCTION

Seed lots with good germination may perform poorly in the field, particularly under adverse environmental conditions. This is often attributable to differences in seed vigor. There have been several literature reviews on seed vigor and field establishment (Bradnock, 1975; Perry, 1976; Powell, 1988; Roberts, 1989). According to the Association of Official Seed Analysts (AOSA, 1983), "seed vigor comprises those seed properties which determine the potential for rapid, uniform emergence and development of normal seedlings under a wide range of field conditions." The principal known factors that affect seed vigor are genetic constitution, environment and nutrition of the mother plant, stage of maturity at harvest, seed size, mechanical integrity, deterioration and aging, and pathogens (ISTA, 1987). The vigor of seeds at the time they enter storage is an important factor that affects their storage potential (Justice and Bass, 1978). Seed vigor can directly affect the performance of the subsequent crop.

Stage of maturity at harvest is an important factor affecting seed vigor (ISTA, 1987). Typically, three stages can be distinguished in the development of the seed after pollination: cell division, accumulation of food reserves, and maturation. Maximum dry weight is reached at the end of the second stage and normally coincides with the stage of physiological maturity (PM) (Harrington, 1972). The maturation phase, during which seeds dry down is influenced by the weather. Harvest maturity (HM) marks the end of this period, when the seeds lose enough moisture to be mechanically harvested. The seed moisture content of snap bean at this point is about 15 to 20%. When seed crops are grown where cool, dry conditions prevail during the harvest period, seed vigor losses prior to HM may be minimal. However, where crops are grown in suboptimum environment conditions, particularly in the humid tropics and subtropics, the seeds may "weather" or decline in vigor before they are harvested. High temperature and high humidity during the seed maturation period can accentuate the weathering process. Moore (1965a, 1965b, 1966) reported that fracturing of bean hypocotyls, cotyledons, and seed coats can take place during the drying phase from rapid, uneven losses of moisture and the resulting unequal shrinkage of drying tissue.

Seed injury caused by field weathering and high maturation temperatures can lead to abnormal seedlings (Goodwin and Siddique, 1984).

Among horticultural crops, differences in vigor appears to be most pronounced in the large-seeded legumes. With wrinkle seeded peas, there have been many reports that germination is not well correlated with field emergence (Matthews and Bradnock, 1967, 1968; Perry, 1967). Wet weather during maturation interacting with cultivar affected bean seed quality in navy bean in southwestern Ontario (Tu et al., 1988). Prolonged humid weather after PM and prior to harvest is an infrequent but serious cause for decreased quality and supply of dry bean seed in Michigan (Copeland et al., 1990). Such conditions during the post-PM period can favor fungal attack of seeds and can affect performance (Spilker et al., 1981; Vanbruggen et al., 1986).

To minimize field weathering, the seeds may be harvested at the earliest practicable time after PM. Cultivar, timing of harvesting, and post-harvest management are important factors to be considered for production of high quality bean seeds. Limited studies are available on the effects of seed maturity on seed vigor, storability, and subsequent plant growth in snap bean.

An increase in resistance to mechanical damage with no significant loss in seed size and yield were obtained in dark red kidney bean when plants were harvested at 40 to 50% seed moisture (Faris and Smith, 1964). However, seed vigor was not evaluated in this study. Wijandi and Copeland (1974) compared Michigan and Idaho-grown navy bean seed (cultivar 'Seafarer') and observed reduction in germination and seedling vigor when seeds were harvested prior to complete maturity (HM). In their study, pods were harvested at one stage and then grouped into pale green, yellow, and brown for the different maturity groups. Siddique and Goodwin (1980) harvested bean cultivar 'Apollo' at three stages of maturity (yellow/fleshy pod stage, dry pod stage, and 15 days after the dry pod stage); optimum time of harvest appeared to be the dry pod stage. Seed vigor was measured as percentage of normal seedlings. Chamma et al. (1990) suggested that the point when all green pods had changed color can be used to characterize PM of bean seeds. Most of the studies were confined to a single cultivar, and seed vigor was mostly evaluated by normal seedlings. Information on the relations of seed maturity to storability and subsequent field performance is scarce. A study of the effects of seed maturity on seed vigor will be particularly useful for bean seed production programs in the humid tropics and subtropics, where weathering due to unfavorable field conditions are greater.

The objectives of this study were to examine possible effects of (1) seed maturity on seed vigor and subsequent plant growth, (2) cultivar on seed vigor as affected by seed maturity, (3) seed maturity on storability.

MATERIALS AND METHODS

Snap bean seeds of four cultivars (Topcrop, Provider Black, Provider White, and Cherokee Wax) were stored at 5°C until used. All seed lots germinated more than 80% in the rolled towel test (AOSA, 1988).

Greenhouse Study

This experiment with two cultivars was conducted from June through August 1989 at Blacksburg, Virginia (37° N lat. 80° W long.; elevation, 792 m above mean sea level). The greenhouse was maintained between 23°C and 30°C with an evaporative cooling system. 'Topcrop' and 'Cherokee Wax' were grown in 20 × 18-cm plastic pots (Classic 400) in "Sunshine" potting mixture (a peat moss, perlite, vermiculite mix). A 20N:8.6P:16.6K liquid fertilizer was applied (400 ppm) uniformly to all the pots once a week, untill the pods were well formed. A microelement mixture ("Stem") was also applied (120 ppm) to the plants once during the vegetative period. The plants were irrigated uniformly so that no moisture stress was evident during the period of plant growth and seed development.

The experimental arrangement was a 2 × 4 factorial in a randomized complete block design with four replications. The two factors examined were cultivar (Topcrop and Cherokee Wax) and harvest stage (HS-1, HS-2, HS-3, and HS-4). HS-1 was made at the stage when pods started to change color, 33 days after flowering. This stage was close to physiological maturity when maximum dry weight is reached. HS-2, HS-3, and, HS-4 were 40, 48, and 60 days after flowering. Each treatment within a replicate consisted of three pots with one plant per pot.

At harvest, the pods were removed by hand and allowed to dry at ambient conditions in the greenhouse and hand threshed. The seeds were further dried to $\simeq$ 11% seed moisture content and then stored in air tight containers at 5°C till seed vigor evaluations were made.

Field Study

The field experiment was carried out from May through August 1989 at Christiansburg, Virginia (37° N lat. 80° W long.; elevation, 792 m above mean sea level). The minimum and maximum temperatures during the seed development period (flowering to PM) were 16.6 and 27.5°C and during the maturation period were 14.5 and 25.8°C, respectively. The precipitation during these two periods was 13.2 and 10.0 cm. A 15N:13P:12K fertilizer was broadcast at the rate of 400 kg ha^{-1} and incorporated prior to planting. Supplemental irrigation was given when required to minimize moisture stress. Recommended fungicidal and insecticidal spraying were adopted for pest and disease control.

The experimental design was a randomized complete block in a split-plot arrangement with four replications. Main plots consisted of cultivars (Topcrop, Provider Black, Provider White, and Cherokee Wax), and the sub-plots consisted of harvest stages (HS-1, HS-2, HS-3, and HS-4). The four harvest stages were as described for the greenhouse experiment. Each main plot consisted of four 5-m rows, and the spacing was 50 cm between rows and 10 cm in the row. Harvesting, drying, and threshing operations were as described for the greenhouse experiment.

Seed Evaluations

Seed fresh weight, dry weight, and moisture content during seed development. During the seed development period, the seed fresh weight, dry weight, and moisture content (MC) were determined at 3-to 4-day intervals. For this, two seed samples, each made of seed from five randomly selected pods were used. Seed samples were dried in an oven at 103°C for 17 h. Seed MC was expressed on a fresh weight basis (ISTA, 1985).

Hundred-seed weight. The 100-seed weights of the different harvest stages was determined for the four cultivars from four replicates of the seed lots after harvest and processing of seeds. Seed moisture content was $\simeq$ 11%.

Standard germination (SG) test. For the greenhouse study, four replicates of 25 seeds each were tested in rolled paper towels (extra-heavy 'Anchor' germination paper) in a seed germinator at 25°C in the dark. The percentage of normal seedlings was determined after 8 days according to AOSA rules for seed testing (AOSA, 1988). For the field study, four replicates of 100 seeds each were used.

Accelerated aging (AA) test. A technique similar to that described by McDonald and Phaneendranath (1978) was adopted. The seeds were suspended in a single layer on a wire mesh in a plastic container over 100 ml of distilled water. The containers were sealed tight and placed in an incubator maintained at 42°C. After 72 h, the seed samples were taken out, air dried to $\simeq$ 11% seed moisture content, and tested for germination by the rolled paper towel method described under SG test (AOSA, 1988). The seeds from the field experiment were also accelerated aged for 96 h.

Seedling dry weight. After 8 days of the SG test, the total dry weight of all normal seedlings (excluding the cotyledons) was determined. This was expressed both as total seedling dry weight (per 25 seeds sample) and dry weight per seedling.

Conductivity test. Seed moisture content was not adjusted as the MC of the seed lots were $\simeq$ 11% (AOSA, 1983). The method described by the 'Seed Vigor Testing Handbook' (AOSA, 1983) was followed. Four replicates of 25 uninjured seeds were weighed (g) to two decimal places. The seeds were placed in 75 ml of distilled water and incubated at 20°C for 24 h. After incubation, the seeds were gently stirred, and the conductivity (µmhos cm^{-1}) of the seed leachate was measured with a conductivity meter (Electromark Analyzer #4400). The conductivity was expressed per gram of seed (µmhos cm^{-1} g^{-1}).

Seed storability. Seed lots from the four harvest stages of two cultivars, Topcrop and Cherokee Wax, in the field experiment, were evaluated for seed storability. Prior to begining of the experiment, the MC and the germination percentage were determined by the standard methods described earlier. Seed moisture content was $\simeq$ 11%. Subsamples (40 g) of each harvest stage of each cultivar were sealed in glass containers and stored at 40°C for up to 6 months. At monthly intervals, jars were removed from storage, and the germination percentage determined.

Imbibition. Imbibition time courses for the four bean cultivars were determined to examine whether imbibition patterns were related to seed vigor differences. Undamaged seed of uniform size were selected for this study. Initial weights of five seeds were determined on a precision balance, then placed on germination paper (Ahlstrom Filtration. Mount Holly Springs, PA) in a 100 cm^2 polystyrene petri dish with 15 ml of distilled water. Four replicates were used and the containers were placed in the dark in an incubator maintained at 25°C. Seed weights of blotted seeds were measured every hour during the first 12 h and later about every 2 to 5 h for 36 h. The dry weights of seedcoat, embryo, and cotyledons were also determined for the four cultivars from a separate study to see whether seed coat size differed among the four cultivars.

Field evaluation, emergence, emergence rate and pod yield. The bean seed lots harvested from the field experiment in summer 1989 (four cvs. × four harvest stages) were evaluated in the field during the summer 1990 at Christiansburg, Virginia. The experimental design was a randomized complete block design with four replications. In each treatment, 75 seeds were hand sown in a 5-m row, and rows were spaced 1 m apart. All other cultural methods were similar to those described for the field experiment in 1989. Emergence percent, emergence rate, pod yield, pod length, and number of pods kg^{-1} of pods were determined. Emergence rate (ER) was computed as normal seedlings after 12 days, using the following formula (Mugnisjah and Nakamura, 1986);

$$ER = \frac{100}{No.planted}\left(\frac{Normal\ seedlings\ day\ 8}{8} + \frac{Normal\ seedlings\ day\ 12}{12}\right)$$

Statistical analyses

Analyses of variance were performed on the data using a general linear model on SAS (SAS Institute, Inc., 1988). Percentage data were transformed to arcsin $\sqrt{percentage}$ before analysis. The data were also tested by regression analysis using the general linear model procedure of SAS.

RESULTS AND DISCUSSION

Greenhouse Study

Seed fresh weight, dry weight, and moisture content during seed development. Flowering commenced 30 days after planting (DAP). There was little increase in either fresh or dry weights of seeds till about 15 days after flowering (DAF), at which time they increased rapidly; and maximum dry weight was reached around 35 DAF (Fig. 2.1). The seed moisture content (MC) at this stage was ≃ 50 to 55%. After attaining maximum dry weight, the seed MC dropped rapidly untill around 48 DAF, when it reached a steady level. The seed fresh weight also dropped after attaining a maximum level. The initial decline in seed fresh weight appeared to signal physiological maturity. The pods at this stage had just turned yellow, but the pod wall was still fleshy.

Seed vigor parameters. In all parameters tested to evaluate seed vigor, there was no significant interaction between cultivars and harvest stages (Table 2.1). This may be partly due to more uniform growing conditions within greenhouse compared to field conditions. There was no significant difference in the 100-seed weights and standard germination percentage among the four harvest stages. Apparently maximum dry weight (PM) was achieved by HS-1. There was a decreasing trend in seed vigor as determined by the AA test with increasing maturity in both cultivars, but the decline in AA germination was only significant in Cherokee Wax. Conductivity tended to increase with increasing maturity but not

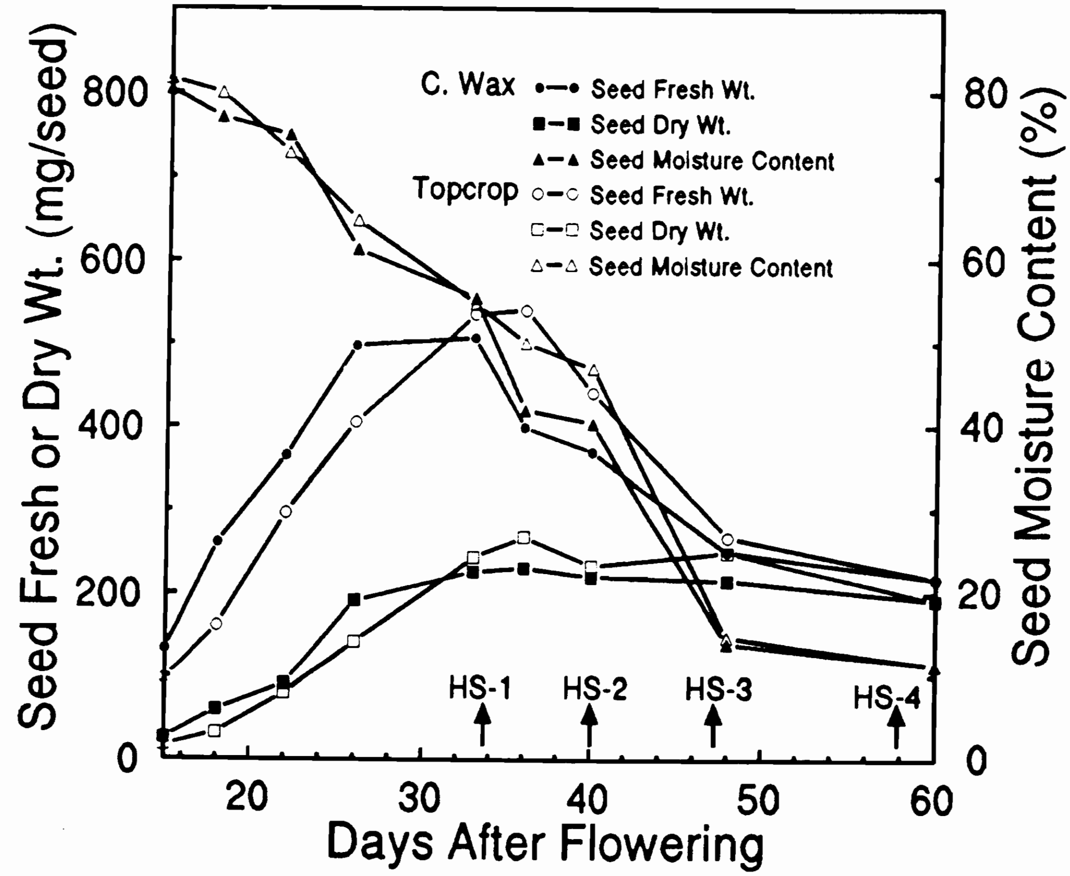

Figure 2.1. Changes in seed fresh weight, dry weight, and moisture content during seed development and maturation of two snap bean cultivars. Plants grown in the greenhouse, 1989. HS = harvest stage.

Table 2.1. Seed weight, germination, and vigor of seed of different harvest stages in bean cultivars, Topcrop and Cherokee Wax, greenhouse experiment, 1989.

Harvest Stage (DAF)†	100-seed weight	Stand. germ.	Seed vigor test			
			AA germ.	Seedling dry wt.		Conductivity
				Total‡	*seedling*$^{-1}$	
	(g)	(%)§	(%)§	(g)	(mg)	(µmhos cm^{-1} g^{-1})
			Topcrop			
HS-1 (33)	29.9	92	65	2.74	119	71
HS-2 (40)	29.8	89	63	2.74	123	80
HS-3 (48)	28.7	85	54	2.44	127	77
HS-4 (60)	32.5	89	58	2.89	118	79
Regression	NS	NS	NS	NS	NS	NS
Mean	**30.3**	**89**	**60**	**2.70**	**122**	**77**
			Cherokee Wax			
HS-1 (33)	25.1	86	83	2.27	106	59
HS-2 (40)	24.7	91	85	2.33	103	62
HS-3 (48)	25.3	88	75	2.24	102	62
HS-4 (60)	24.2	87	71	2.27	103	63
Regression¶	NS	NS	L* Q*	NS	NS	NS
Mean	**24.8**	**88**	**78**	**2.28**	**103**	**62**
Treatment effects						
Cultivar (Cv)	**	NS	**	**	**	*
H. stage (HS)	NS	NS	**	NS	NS	NS
Cv x HS	NS	NS	NS	NS	NS	NS

† Days after flowering.

‡ Dry weight of all normal seedlings from 50 seed replicate in germination test.

§ Percentage data were analyzed after transformation to arcsin $\sqrt{percentage}$.

¶ L, Q indicate linear and quadratic models.

NS, *, ** Nonsignificant or significant at P = 0.05 or 0.01, respectively.

significantly. Of the two cultivars, Cherokee Wax showed a higher vigor level in both the AA and the conductivity tests. The results indicated that maximum vigor was achieved at PM stage (HS-1), and there was some decrease in vigor with increasing maturity. The AA test was able to detect some vigor loss in the harvest stages; but, more significantly, it showed differences between the two cultivars. Apparently, Cherokee Wax is more tolerant to seed aging and vigor loss during maturation than Topcrop.

Field Study

Seed dry weight and moisture content during development. Flowering commenced about 39 DAP, and PM was reached $\simeq$ 35 DAF. The period from PM to HM was about 23 days (Fig. 2.2). The duration from flowering to PM was similar ($\simeq$35 days) in both the greenhouse and the field experiments.

Hundred-seed weight. There was no significant interaction between cultivar and harvest stage on 100-seed weight (Table 2.2). The 100-seed weight was observed to be somewhat lower at HS-1 compared to other harvest stages. There were significant differences among the cultivars, with Topcrop having the highest weight.

Standard germination test (SG test). Germination reached a peak around HS-1 in Topcrop, Provider Black, and Cherokee Wax and then showed a gradual decrease (Table 2.2). The percent of decrease was highest after HS-3 (HM).

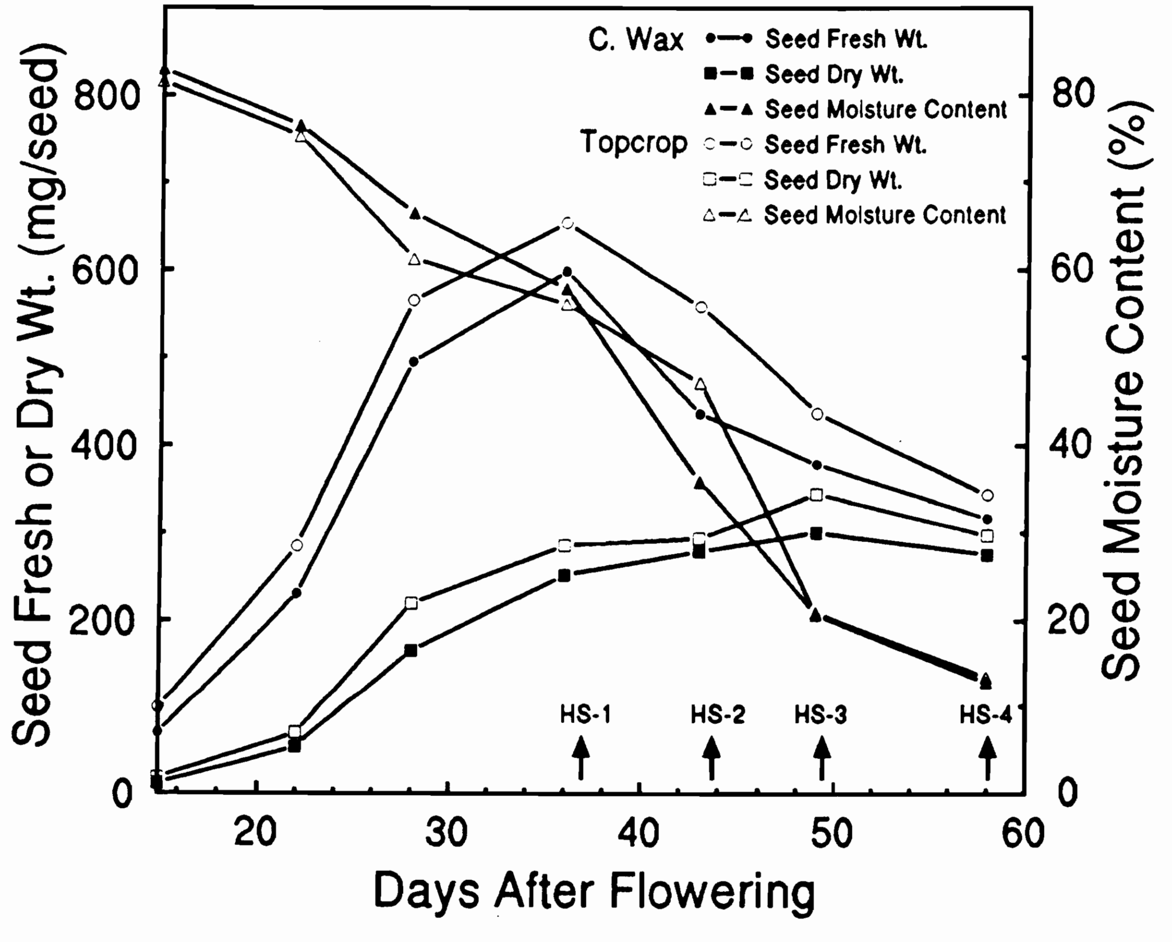

Figure 2.2. Changes in seed fresh weight, dry weight, and moisture content during seed development and maturation of two snap bean cultivars Plants grown in the field, 1989. HS = harvest stage.

Table 2.2. Seed weight, germination and vigor of seed of different harvest stages in bean cultivars, Topcrop, Provider Black, Provider White, and Cherokee Wax, field experiment, 1989.

Harvest stage (DAF)‡	100-seed weight	Stand. germ.	Seed vigor test				
			AA 72 h germ.	AA 96 h germ.	Seedling dry wt.		Conductivity
					Total†	*seedling*$^{-1}$	
	(g)	(%)§	(%)§	(%)§	(g)	(mg)	(µmhos cm^{-1} g^{-1})
			Topcrop				
HS-1 (36)	33.3	83	88	63	2.53	122	65
HS-2 (43)	34.9	82	76	63	2.62	129	74
HS-3 (49)	34.0	83	77	52	2.74	132	72
HS-4 (58)	34.7	73	64	42	2.34	129	92
Regression¶	**NS**	**L**Q****	**L**Q****	**L*Q***	**Q****	**NS**	**L**Q****
Mean	**34.3 a#**	**80**	**76**	**55 b**	**2.56 a**	**128 a**	**76**
			Provider Black				
HS-1 (36)	25.5	85	83	58	2.19	104	74
HS-2 (43)	26.2	82	71	56	2.20	108	77
HS-3 (49)	27.0	79	67	45	2.06	104	90
HS-4 (58)	26.8	67	52	43	1.77	106	79
Regression	**NS**	**L**Q****	**L**Q****	**L**Q****	**L*Q***	**NS**	**NS**
Mean	**26.4 d**	**78**	**68**	**50 b**	**2.06 b**	**106 c**	**80**
			Provider White				
HS-1 (36)	27.2	69	52	47	1.90	110	88
HS-2 (43)	29.4	65	54	43	1.94	119	87
HS-3 (49)	30.2	74	62	43	2.25	122	85
HS-4 (58)	29.1	59	52	26	1.68	114	86
Regression	**NS**	**NS**	**NS**	**L*Q***	**Q***	**NS**	**NS**
Mean	**29.0 c**	**67**	**55**	**39 c**	**1.94 b**	**116 b**	**87**
			Cherokee Wax				
HS-1 (36)	30.5	88	80	71	2.61	119	43
HS-2 (43)	32.7	88	76	70	2.67	121	40
HS-3 (49)	31.6	83	70	69	2.45	118	49
HS-4 (58)	31.8	80	58	67	2.28	115	29
Regression	**NS**	**L**Q****	**L**Q****	**NS**	**L*Q***	**NS**	**NS**
Mean	**31.6 b**	**85**	**71**	**69 a**	**2.50 a**	**118 b**	**40**
Treatment effects							
Cultivar (Cv)	**	**	**	**	**	**	**
H. Stage (HS)	*	**	**	**	**	NS	NS
Cv x HS	NS	*	**	NS	NS	NS	**

† Dry weight of all normal seedlings from 50 seed replicate in germination test.

‡ Days after flowering.

§ Percentage data were analyzed after transformation to arcsin $\sqrt{percentage}$.

¶ L, Q indicate linear and quadratic models.

Apparently seed vigor decreased when harvest was delayed after HM, which may have been due to field weathering. Provider White had the lowest germination percent at all stages of maturity examined. This cultivar appears to be more susceptible to field weathering than the others.

Accelerated aging (AA) test. Accelerated aging treatment for 72 h indicated a similar vigor change with increasing maturity in Topcrop, Provider Black, and Cherokee Wax (Table 2.2). In these cultivars, maximum vigor was acheived at HS-1 followed by a gradual decrease in vigor. The drop in vigor after HS-3 (HM) was relatively larger than that during earlier stages. Provider White had the lowest vigor level at all four harvest stages compared to the other cultivars. Aging the seeds longer (96 h) also showed a vigor drop with increasing maturity in Topcrop, Provider Black, and Provider White. After 96 h, AA seed germination was highest in Cherokee Wax for all maturity stages. These data indicate that Cherokee Wax has the greatest tolerance to field weathering. A similar observation was made in the greenhouse study.

Seedling dry weight (total and seedling^{-1}). Total seedling dry weight increased with HS-2 and HS-3 but decreased significantly after HS-3 (HM) in all four cultivars, indicating a vigor drop with delay in harvest after HM (Table 2.2). The dry weight per seedling did not differ among the harvest stages. One advantage of the dry weight test is that it does not require additional equipment or time; the normal seedlings from the standard germination can be used.

Conductivity test. There was a significant interaction between cultivars and harvest stages (Table 2.2). Conductivity increased significantly with the later harvest stages in Topcrop but was not significant in others. Cherokee Wax had the lowest conductivity level, while Provider White had relatively higher conductivity levels. Apparently, there was less leakage of solutes during imbibition in Cherokee Wax, and the reverse was true for Provider White. The seed coat properties of Cherokee Wax may be partly responsible for its tolerance to solute leakage during imbibition.

Seed storability. Seeds from first three harvest stages in Topcrop and Cherokee Wax maintained their germination over 60% for 4 months (Fig. 2.3). However, germination dropped at a faster rate in HS-4. Cherokee Wax germination dropped below 40% after 2 months of storage at 40°C, while Topcrop germination remained above 40% for 6 months. It appears that Topcrop is more tolerant to high temperatures during storage. The vigor of seeds at the time they enter storage is an important factor that affects their storage life (Justice and Bass, 1978). Therefore, seed crops should be harvested before any loss in vigor occurs in the field. The results indicate that seed harvested between physiological maturity and harvest maturity had higher storage potential, but delays in harvest after HM could decrease this quality.

Imbibition. There were cultivar differences among imbibition rates (Fig. 2.4). White-seeded cultivar Provider White had a high imbibition rate during the first

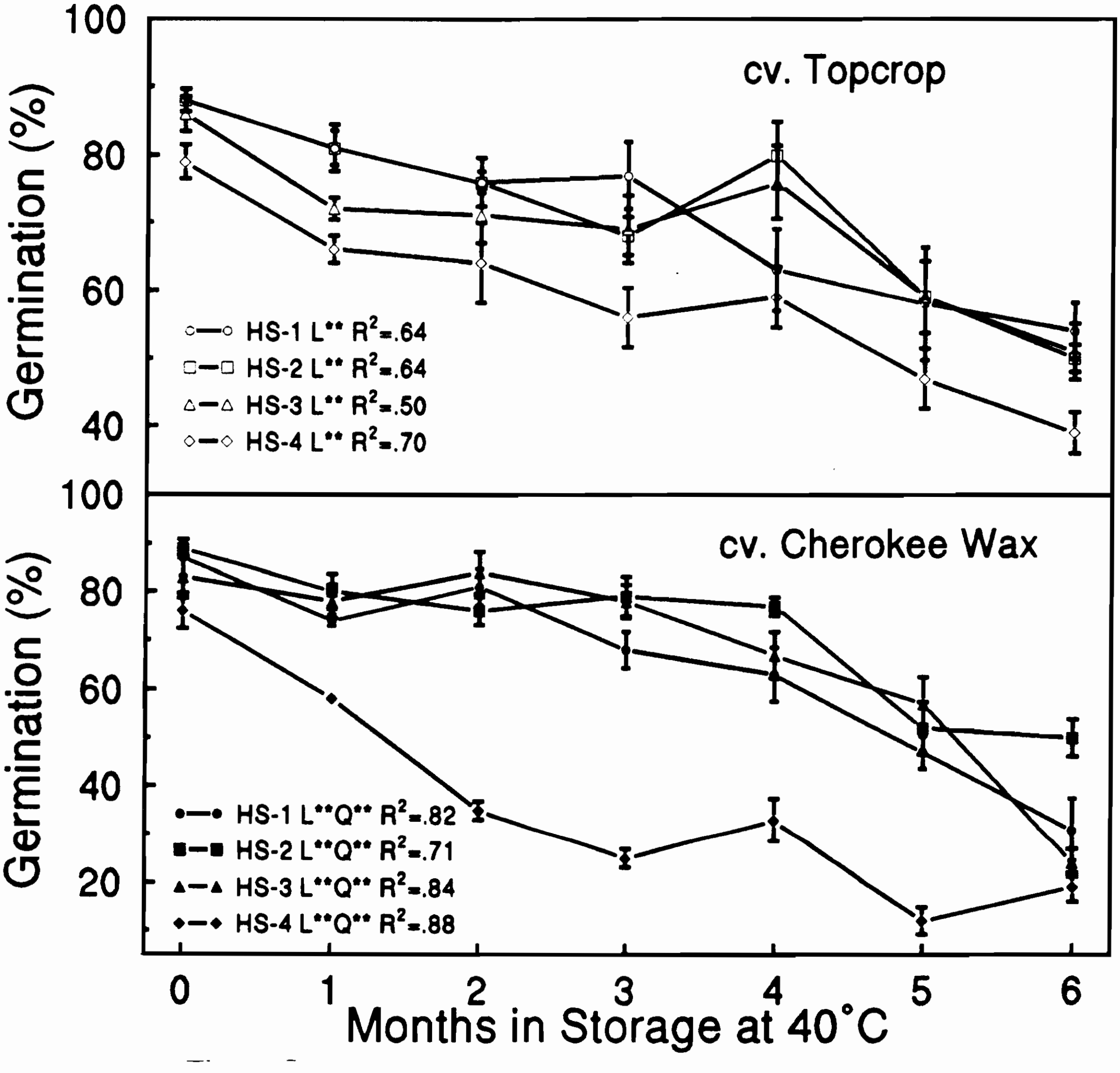

Figure 2.3. Effect of bean seed maturity on storability of two cultivars at 40°C. HS-1, HS-2, HS-3, and HS-4 = harvest stages 1, 2, 3, and 4 respectively.

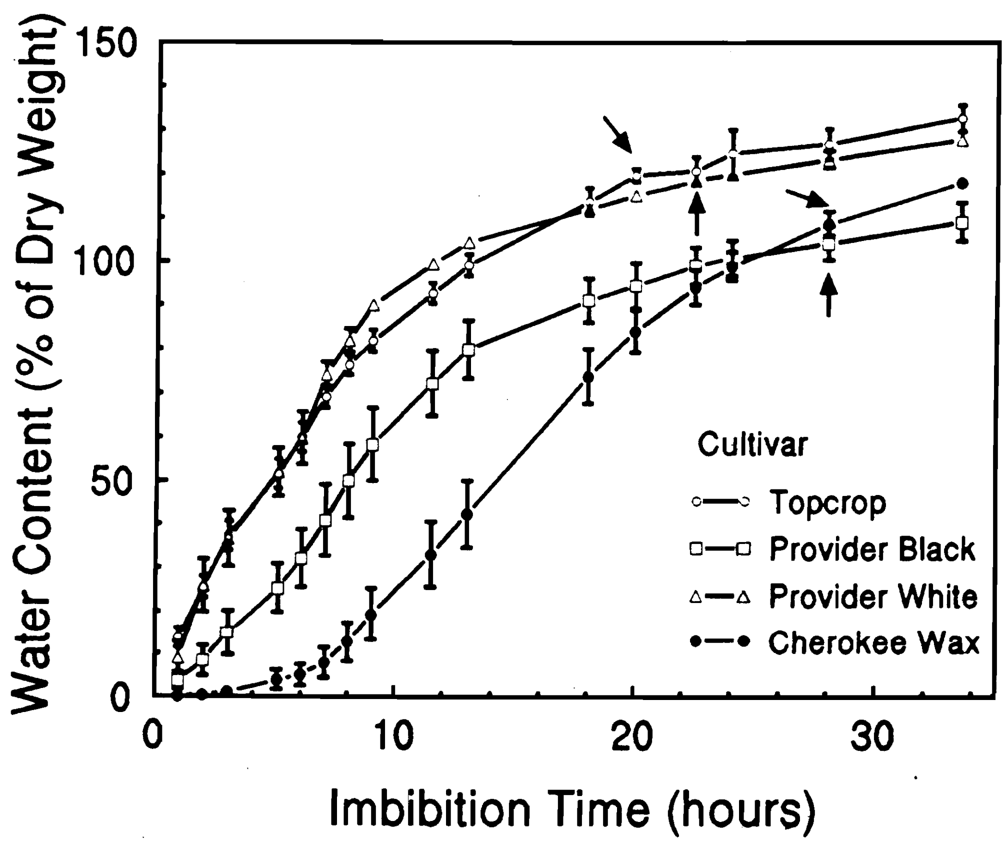

Figure 2.4. Time courses of imbibition for seeds of four snap bean cultivars. Arrows indicate when radicle growth was first observed.

9 h, while the black-seeded Cherokee Wax had the lowest imbibition rate. Topcrop and Provider White had about 4 % and 32 % cotyledon cracks respectively, while Provider Black and Cherokee Wax showed no signs of cotyledon damage. The testa characteristics appeared to have an influence on imbibition rates and also solute leakage during imbibition. The ratio of dry weight of seed coat to cotyledon (mean±SE) was lowest in Provider White (.092±001) and highest in Cherokee Wax (.106±001). In Topcrop and Provider Black, the ratios were .103±002 and .098&001. SE, respectively. The testa characteristics could also have an influence on the rate of field weathering.

Field evaluation, emergence, emergence rate, and pod yield. Laboratory germination and field emergence were similar (Table 2.3). Apparently, stress was minimal during this critical time of field establishment. The mean minimum and maximum air temperatures during the first 2 weeks after planting were 13.3°C and 25.7°C, respectively. Rainfall was 3.3 mm, and supplementary irrigation was provided. Provider White had lower emergence percent compared to other cultivars at all stages of harvest. This drop was larger after HS-3 (HM). Emergence tended to decrease with increase in maturity in the other cultivars, but the differences were not significant. Emergence rates of the different maturity stages were similar in Topcrop, Provider Black, and Cherokee Wax. However, Provider White showed a significant drop in emergence rate at the last harvest stage (HS-4).

Table 2.3. Field emergence, emergence rate, and pod yield of seed from different harvest stages (1989 field study) in bean cultivars, Topcrop, Provider Black, Provider White, and Cherokee Wax.

Harvest stage (DAF)†	Field emergence	Emergence rate	Pod yield
	(%)‡	(% day^{-1})	(kg ha^{-1})
	Topcrop		
HS-1 (36)	83	7.18	10839
HS-2 (43)	88	7.75	11689
HS-3 (49)	82	7.15	10815
HS-4 (58)	81	7.23	10906
Regression	NS	NS	NS
Mean	**84 a§**	**7.33**	**11062**
	Provider Black		
HS-1 (36)	88	7.96	10579
HS-2 (43)	80	6.97	10461
HS-3 (49)	86	7.57	11877
HS-4 (58)	75	6.64	9303
Regression	NS	NS	NS
Mean	**82 a**	**7.28**	**10555**
	Provider White		
HS-1 (36)	70	6.07	12421
HS-2 (43)	74	6.51	10485
HS-3 (49)	77	6.88	10950
HS-4 (58)	62	5.28	10343
Regression¶	Q**	Q**	NS
Mean	**71 b**	**6.18**	**11050**
	Cherokee Wax		
HS-1 (36)	83	7.35	10295
HS-2 (43)	83	7.31	10414
HS-3 (49)	80	7.16	10791
HS-4 (58)	79	7.01	9587
Regression	NS	NS	NS
Mean	**81 a**	**7.21**	**10272**
Treatment effects			
Cultivar (Cv)	**	**	NS
H. stage	**	**	NS
Cv x H. stage	NS	*	NS

† Days after flowering.

‡ Percentage data were analysed after transformation to $\arcsin\sqrt{percentage}$.

§ Mean separation between cultivar means within column by Tukey's HSD ($P \leq 0.05$).

¶ L, Q indicate linear and quadratic models.

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

Pod yield did not differ among the cultivars, but the first three harvest stages tended toward higher yields than HS-4. In this trial, the emergence percent was similar to the laboratory germination, and plant stand was not affected much. Further, after emergence, all cultivars were thinned to a uniform stand. This may partly account for the lack of any differences in pod yield. Reduction in yield can be indirectly related to low seed vigor if plant populations are below a critical level. Pod length and weight were not affected by the harvest stage of the seed (data not shown).

SUMMARY

Seeds harvested prior to HM (when the MC was $\simeq$15 to 20%) but after PM (stage of maximum dry weight) had high seed vigor. Pod yield, pod length, and pod weight of a subsequent crop were not affected by harvest stage; however delaying harvest after HM adversely affected seed vigor and storability. The extent of vigor decline will depend on environmental factors. These data indicate that seeds could be harvested prior to HM without any loss of seed vigor in locations and times when adverse weather may be anticipated. However suitable measures should be taken to dry the pods before threshing. From a practical standpoint, the second harvest stage HS-2, when the seed moisture content is about 40% appears to be a suitable stage for harvest.

Among the four cultivars tested, Cherokee Wax was observed to be the most tolerant to field weathering; while Provider White was the most susceptible to field weathering. It appears that seed coat properties have an influence on the susceptibility to vigor loss.

Moisture content, fresh weight, and dry weight curves during seed development period are very useful in understanding the influence of environment on seed size and vigor and help determine the optimum stage of harvest to avoid field weathering. The drop in the fresh weight of the seed after reaching a maximum level indicates PM. At PM, pod color changed to a yellow and the seed moisture content was $\simeq$55% at PM.

Among the vigor tests examined the AA test appears to be more sensitive in detecting vigor differences in snap bean. Measurement of seedling dry weight (total) was shown to be another easy and practical vigor test, but should be used only to compare seed lots within a cultivar.

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Chapter 3: Climatic and Field Weathering Effects on Seed Yield and Vigor of Snap Bean (*Phaseolus vulgaris* L.)

ABSTRACT

In recent years production of snap bean (*Phaseolus vulgaris* L.) seeds in Sri-Lanka have increased because of governmental decisions to curtail bean seed imports. Both yield and vigor of bean seed produced in Sri-Lanka often has been reduced because of field weathering. Field experiments were conducted at three locations to identify the effects of climate and seed maturity at harvest on seed yield and vigor. Two of the major cultivars of snap bean (Topcrop and Cherokee Wax) produced in Sri-Lanka were grown at three different locations: Rahangala (L-1), Bandarawela (L-2), and Moneragala (L-3). Mean maximum/minimum

temperatures (°C) were 25.4/13.1 at L-1, 23.8/14.9 at L-2 and 33.3/20.7 at L-3. At each location, seed growth, moisture content, and yield were compared; seeds harvested at different stages of maturity were evaluated for germination and seed vigor by the standard germination, accelerated aging, seedling dry weight, and conductivity tests.

Duration of vegetative growth, seed development, and maturation were influenced by the location of seed production. Seeds developed and matured faster under warmer conditions (L-3); however, seed yields and vigor were lower. Seeds that developed and matured under cooler conditions (L-1) produced higher yields and had larger size, better color, and higher vigor. In cooler climatic conditions (L-1), delaying harvest after physiological maturity did not affect seed vigor much; while, in warmer climatic conditions, delayed harvesting reduced subsequent seed vigor. At L-3 (Moneragala), vigor losses were detected even before harvest maturity was achieved. Cherokee Wax was observed to be more tolerant to field weathering conditions than Topcrop. These results indicate that improvement of seed quality may be possible through cultivar selection and breeding. Among the vigor tests compared, accelerated aging appeared to be the most sensitive.

INTRODUCTION

Snap bean is an important vegetable crop grown in the higher elevations of Sri-Lanka, where the temperature is milder and more suitable for development of high bean yields. Approximately 9000 hectares are grown annually (Ministry of Agriculture Food and Cooperatives, 1989). Since 1984, bean seed imports have been curtailed in Sri-Lanka, and an attempt is being made to meet the seed requirement by local production. Basic seed is produced by the Seed Division of the Department of Agriculture, and most of the certified seed is produced through selected contract growers (Samarasinghe, 1987). Weather conditions in Sri-Lanka are often conducive to field weathering. High temperature, high humidity, and unexpected rainfall during the seed maturation period adversely affect seed quality. The extent of field weathering problems in Sri-Lanka have not been studied and documented (Reusche, 1986). Seeds of low quality entering storage will also not store well (Justice and Bass, 1978). Methods permitting early harvest of bean seed crops is an important research priority.

The rapid loss of seed viability, enhanced by high temperature and high humidity in subtropical and tropical areas, results in poor stand establishment at planting (Delouche, 1975; Justice and Bass, 1978; Arulnandhy et al. 1984). Arulnandhy and Herath (1987) reported that storability of soybean seed under humid tropical conditions was correlated with initial germination percentage and smaller seed size. Moore (1971), using tetrazolium testing techniques, was able to show damage to soybean seeds by alternate wetting and drying during simulated delayed harvest situations. Seed deterioration under delayed harvest situations is caused by both physiological and pathological agents (Austin, 1972; McGee, 1986; Sinclair, 1986; Siddique and Goodwin, 1980a, b). The objectives of this study were to (1) examine climatic effects on seed development and maturity, and (2) determine the effects of seed maturation under different climatic conditions on seed yield and vigor.

MATERIALS AND METHODS

Field experiments were carried out at three locations (7° N lat. 81° E long.) having different climatic conditions (Table 3-1): Agricultural Research Station, Rahangala (L-1); Regional Agricultural Research Centre, Bandarawela (L-2); and Agricultural Research Station, Moneragala (L-3). Certified seeds of two cultivars (Topcrop and Cherokee Wax) were obtained from the seed division of the Department of Agriculture. The plantings were made on 12th Dec. 1990 at L-1 and L-2, and on 22nd Dec. 1990 at L-3.

A split-plot randomized complete block design with four replications was used, with cultivars (Topcrop and Cherokee Wax) as the main plots and the four harvest stages as the sub plots. The first harvest (HS-1) was made when over 50% of the pods turned yellow. This stage approximated physiological maturity (PM), defined as the stage when maximum dry weight is reached. The next three harvest stages HS-2, HS-3, and HS-4 were about 1, 2, and 4 weeks after HS-1. Seed fresh weight, dry weight, and moisture content (MC) were monitored during the seed development and maturation period. These were determined from two seed samples, each made of seeds from five randomly selected pods. Seeds were dried in an oven at 103°C for 17 h and MC was expressed on a fresh weight basis (ISTA, 1985). Standard cultural methods were adapted for all locations. Supplemental irrigation was supplied when required to prevent moisture stress. Each sub-plot consisted of two 4-m rows with a spacing of 50 cm between rows and 10 cm within row. At harvest, the pods were removed by hand, allowed to dry, and hand threshed. Seeds were further dried to $\simeq$ 11% seed MC, and 100-seed weight and yield were determined for each treatment. The seeds were stored at 5°C until vigor evaluations were made. Daily minimum and maximum temperatures, precipitation, and relative humidity were measured during the period of the experiment.

Seed Evaluations

Standard germination (SG) test. Four replicates of 50 seeds each were tested in sand medium. The percentage of normal seedlings were determined after 9 days (ISTA, 1985).

Accelerated aging (AA) test. A technique similar to that described by McDonald and Phaneendranath (1978) was adapted. The seeds were suspended in a single layer on a wire mesh in a plastic container over 100 ml of distilled water. The containers were sealed and placed in an incubator maintained at

42°C. After 72 h, the seed samples were taken out, air dried, and tested for germination.

Seedling dry weight. At the end of the germination test, the dry weight of all normal seedlings excluding the cotyledons were determined. This was expressed both as total seedling dry weight (per 50 seeds sown) and dry weight per seedling.

Conductivity test. The method used by the 'Seed Vigor Testing Handbook' was followed (AOSA, 1983). Four replicates of 25 uninjured seeds were weighed (g) to two decimal places. The seeds were placed in 75 ml of distilled water and incubated at 20°C for 24 h. After incubation, the seeds were gently stirred and the conductivity (µmhos cm^{-1}) measured. The conductivity was expressed as µmhos cm^{-1} g^{-1}.

Statistical analyses

Analyses of variance of the data were performed using a general linear model on SAS (SAS Institute, Inc. 1988). Percentage data were transformed to arcsin $\sqrt{percentage}$ before analysis. The data on maturity stages were also tested by regression analysis using a general linear model procedure of SAS.

RESULTS AND DISCUSSION

Climatic conditions of the three locations. Rahangala (L-1) and Bandarawela (L-2) had lower mean temperatures (minimum: 11.9 to 16.4°C, and maximum: 22.3 to 27.6°C) compared to Moneragala (L-3), where the mean minimum and maximum were 20 to 21°C and 32 to 35°C, respectively (Table 3.1). Between locations L-1 and L-2, the mean minimum temperature was relatively lower at L-1 (11.9 to 14.7°C). Relative humidity was lowest (61 to 65%) at L-1 and highest (76 to 90%) at L-2. Overall temperatures increased during the growing season and relatively drier period occured during the seed development and maturation period at all locations.

Seed fresh weight, dry weight, and moisture content (MC). Both days to flowering (45, 35, and 34) and days from flowering to PM (41, 33, and 27) followed a similar trend with the three locations (L-1, L2, and L-3). These data show that days to flowering and days from flowering to PM decreased as the mean temperatures, and particularly the night temperatures, of the production sites increased (Table 3.1). The changes in seed fresh weight, dry weight, and MC during the seed development and maturation periods showed distinct differences in their responses over time at the three locations (Fig. 3.1, 3.2, and 3.3). The seeds developed and matured slowest at L-1 and fastest at L-3, with L-2 being intermediate. The seed maturity curves reflect the effects of the environment on rate of development and maturity of the seeds. These data will be very useful

Table 3.1. Mean climatic data of Rahangala (L-1), Bandarawela (L-2), and Moneragala (L-3) during the vegetative growth, seed development, and seed maturation periods.

	Location		
	Rahangala (L-1)	Bandarawela (L-2)	Moneragala (L-3)
Elevation above mean sea level (m)	1280	1220	152
Max. temp.(°C)			
A†	23.2	22.3	32.5
B	25.5	23.6	32.7
C	27.6	25.6	34.7
Min. Temp.(°C)			
A	14.7	16.4	20.8
B	11.9	12.9	20.0
C	12.7	15.4	20.9
Rainfall (cm)			
A	29.8	35.6	20.5
B	7.9	5.3	7.5
C	0.6	10.1	2.0
R.H. (%)‡			
A	61	90	79
B	59	76	75
C	65	81	76

† A = vegetative period; B = seed development stage (flowering to physiological maturity); C = seed maturation (physiological maturity to end of harvest stage).

‡ R.H. (%) is the mean R.H. determined at 8.30 a.m. and 3.30 p.m..

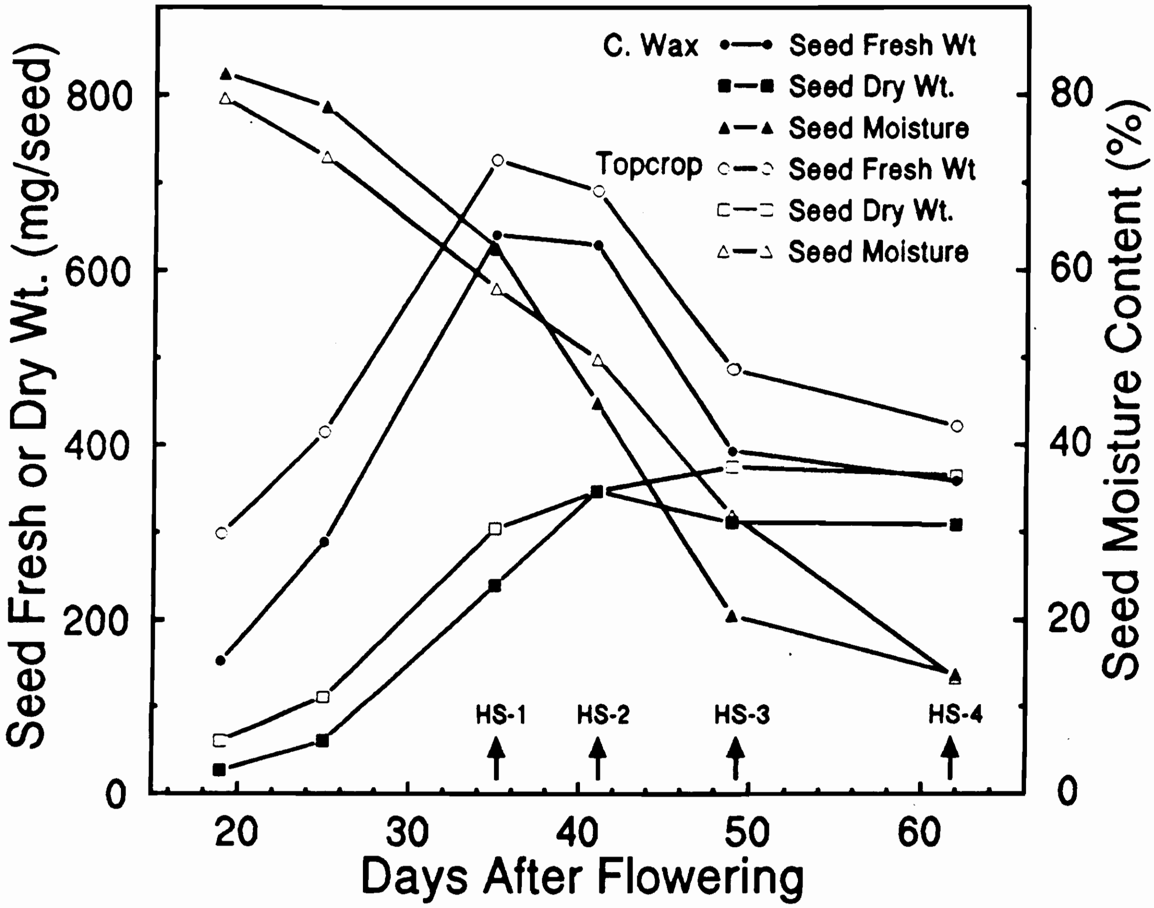

Figure 3.1. Changes in seed fresh weight, dry weight, and moisture content during seed development and maturation of two snap bean cultivars grown at Rahangala (L-1), 1990/91. HS = harvest stage.

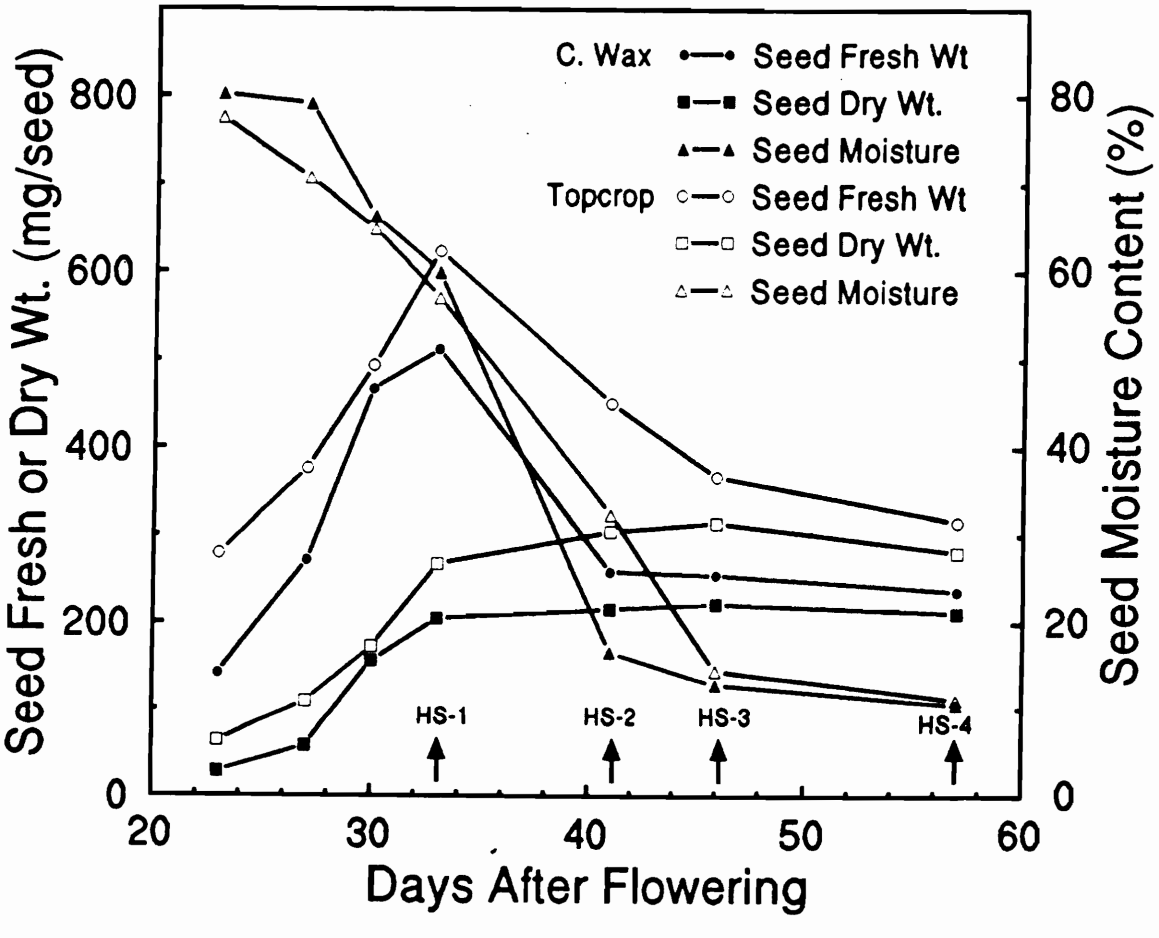

Figure 3.2. Changes in seed fresh weight, dry weight, and moisture content during seed development and maturation of two snap bean cultivars grown at Bandarawela (L-2), 1990/91. HS = harvest stage.

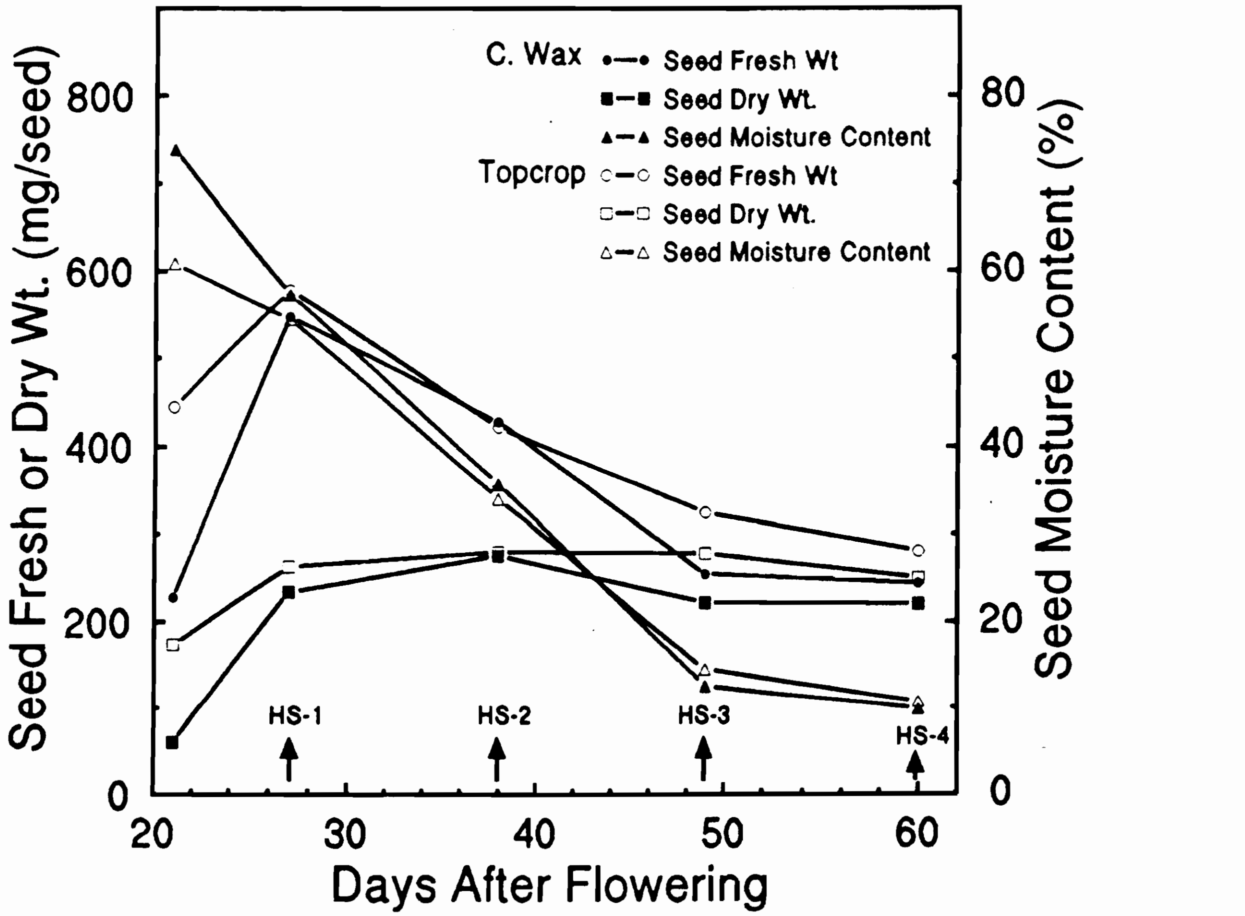

Figure 3.3. Changes in seed fresh weight, dry weight, and moisture content during seed development and maturation of two snap bean cultivars grown at Moneragala (L-3), 1990/91. HS = harvest stage.

in the management of a seed crop. The drop in seed fresh weight coincided with PM. The pattern of development for the two cultivars were similar; however, after reaching PM, seed MC in Cherokee Wax dropped faster than that of Topcrop. This will be useful information in seed production programs.

100-seed weight. Maximum seed weight was achieved around HS-2 in both cultivars at the three locations, except in Topcrop at L-1, where the maximum was reached with HS-3 (Table 3.2.). HS-1 was was made when the pods were begining to turn yellow, and at this stage there was a greater variation among the pods within a plot compared to the other harvest stages. Therefore, some seeds would have been physiologically immature at this time. This would account for the lower 100-seed weight at HS-1. These differences were accentuated under cooler conditions because of the slower maturation rates and would be partly responsible for the lower seed weight even with HS-2 at L-1.

Seed weight of Topcrop was higher than Cherokee Wax at L-1 and L-2. Both cultivars showed the highest weight at L-1, and also the seeds had a darker color. The seeds developed and matured fastest at L-3, but the color and physical quality of the seed appeared to be lower.

Seed yield. At L-1 and L-2, yield increased as the harvest was delayed until the seed reached HM (HS-3), but delaying harvest after HM reduced yield except for Topcrop at L-2 (Table 3.2). The yield at HS-1 was the lowest because of immaturity of the youngest pods (last set pods), while reduced yield at HS-4 is

Table 3.2. 100-seed weight, seed yield, and germination of different harvest stages in bean cultivars, Topcrop and Cherokee Wax (C. Wax) grown at Rahangala (L-1), Bandarawela (L-2), and Moneragala (L-3), 1990/91.

Harvest stage (HS)†	Location L-1 Topcrop	 C. Wax	 L-2 Topcrop	 C. Wax	 L-3 Topcrop	 C. Wax
			100-seed weight (g)			
HS-1	31.0	25.9	27.3	19.9	25.3	21.2
HS-2	35.0	28.2	28.0	22.2	26.4	26.7
HS-3	38.8	29.4	27.6	21.9	26.7	24.1
HS-4	37.9	29.4	27.7	21.5	24.7	24.7
Regression‡	**Q****	**NS**	**NS**	**Q***	**Q***	**Q***
Mean	**35.7**	**28.3**	**27.6**	**21.4**	**25.8**	**24.2**
Treatment effects						
Cultivar (Cv)	**		**		NS	
HS	**		**		**	
Cv x HS	*		NS		**	
			Seed yield (kg ha^{-1})			
HS-1	477	387	630	463	440	223
HS-2	1050	913	950	817	523	317
HS-3	1580	980	947	827	507	277
HS-4	943	910	1013	650	390	243
Regression‡	**Q****	**Q****	**L*Q***	**Q****	**NS**	**Q***
Mean	**1010**	**797**	**883**	**687**	**463**	**263**
Treatment effects						
Cultivar (Cv)	NS		NS		*	
HS	**		**		NS	
Cv x HS	**		NS		NS	
			Standard germination (%)			
HS-1	59	72	72	85	18	48
HS-2	68	85	68	83	38	65
HS-3	80	82	67	80	27	61
HS-4	74	80	67	78	25	59
Regression‡	**Q***	**Q***	**NS**	**NS**	**Q***	**Q***
Mean	**70**	**79**	**68**	**81**	**27**	**58**
Treatment effects						
Cultivar (Cv)	NS		**		*	
HS	**		NS		**	
Cv x HS	NS		NS		NS	

† Harvest stages : HS-1, HS-2, HS-3, and HS-4 for the three locations are L-1 : 35, 41, 49, and 62 days after flowering (DAF); L-2 : 33, 41, 46, and 57 DAF; L-3 : 27. 38, 49, and 60 DAF, respectively.

‡ L, Q indicate linear and quadratic models.

NS, *, ** Nonsignificant or significant at P = 0.05 or 0.01, respectively.

attributed to the increase in unmarketable pods and seeds. At L-3, seed yield reached a maximum at PM (HS-2), but was reduced by 57 and 52% compared to L-1 and L-2, respectively. These data indicate that at all locations optimum seed yield occured when pods were harvested somewhere between HS-2 and HS-3. Although the location × harvest stage interaction was not significant (Table 3.4), delaying harvest until HM (HS-3) appeared to increase seed yield under the cooler climatic conditions of L-1, while a similar delay in harvest at L-3 reduced seed yield. This could be attributed to greater variation in seed maturity within harvested seed lots (HS-1 and HS-2) due to slower maturation at L-1, while at L-3 there was faster maturation and greater chance for field weathering.

Seed yield was highest at L-1 in both cultivars; however, the number of marketable seeds was similar at L-1 and L-2 (data not shown), indicating that the higher seed weight was responsible for the increased yield at L-1 (Table 3.2). Both yield and seed number were the lowest at L-3.

Seed yield tended to be higher in Topcrop at all three locations although not significant at L-1 and L-2. The lower yield in Cherokee Wax at L-3 was due to poor pod set. Halterlain et al. (1980) reported that high temperatures (35/20°C day/night and 35°C constant) reduced the percentage of viable pollen in bean.

Standard germination test (SG test). There was no significant interaction between cultivar and harvest stage at the three locations (Table 3.2). Harvest stages showed significant differences at L-1 and L-3 but not at L-2. Germination increased with HS-2 at L-1 and L-3. The lower germination with HS-1 seed lots is attributed to the immaturity of some of the seeds. However, at L-3, germination decreased even prior to reaching HM. Apparently field weathering effects were greater under the higher temperature conditions at this location. Early harvesting is particularly advantageous under such conditions.

Germination was significantly lower in both cultivars at L-3. Between the two cultivars, Cherokee Wax showed a higher germination at L-2 and L-3. The difference widened at L-3. Evidently, Cherokee Wax is more tolerant to field weathering conditions. The data indicate that delaying harvest after PM results in greater injury to seed quality with increasing temperatures, and the degree of injury depends on the cultivar.

Accelerated aging (AA) test. The vigor levels as determined by the AA test followed closely with the SG test at L-1 (Table 3.3). The presence of some immature seeds in the HS-1 seed lots is probably responsible for the low vigor found in these seeds. At L-2, seed vigor appeared to decline after HS-2, although linear regression values were not significant. This test was not carried out with the seed lots of L-3, because the SG test indicated a considerable decrease in seed quality compared to other locations and also the vigor differences among the different harvest stages were already evident from the SG test. The AA test also indicated a vigor difference between the two cultivars, Cherokee Wax being more tolerant to vigor loss at L-2 compared to L-1. These data provide useful guidance in the management of harvest practices depending on the climatic conditions. Under lower maturation temperatures, the loss in seed vigor with delay in harvest

Table 3.3. Seed vigor parameters of different harvest stages in bean cultivars, Topcrop and Cherokee Wax (C. Wax) grown at Rahangala (L-1), Bandarawela (L-2), and Moneragala (L-3), 1990/91.

Harvest stage (HS)†	Location					
	L-1		L-2		L-3	
	Topcrop	C. Wax	Topcrop	C. Wax	Topcrop	C. Wax
Accelerated aging germination (%)						
HS-1	48	54	43	66		
HS-2	54	67	54	69		
HS-3	68	69	44	61		
HS-4	64	68	42	60		
Regression	**L*Q***	**NS**	**NS**	**NS**		
Mean	**58**	**64**	**46**	**64**		
Treatment effects						
Cultivar (Cv)	*		**			
HS	**		*			
Cv x HS	NS		NS			
Total seedling dry weight (g) ‡						
HS-1	4.11	3.43	3.52	4.16	1.18	2.40
HS-2	4.39	5.39	3.51	4.14	2.34	3.83
HS-3	5.72	5.40	3.19	3.83	1.78	3.59
HS-4	5.55	5.06	3.41	4.02	1.52	3.26
Regression	**L*Q***	**Q***	**NS**	**NS**	**Q***	**Q****
Mean	**4.94**	**4.82**	**3.41**	**4.03**	**1.71**	**3.27**
Treatment effects						
Cultivar (Cv)	NS		NS		*	
HS	**		NS		**	
Cv x HS	*		NS		NS	
Dry weight *seedling*$^{-1}$ (mg)						
HS-1	146	97	98	99	130	100
HS-2	128	127	102	100	123	117
HS-3	145	131	96	96	132	117
HS-4	150	128	102	104	122	112
Regression	**NS**	**Q***	**NS**	**NS**	**NS**	**NS**
Mean	**142**	**121**	**99**	**100**	**127**	**112**
Treatment effects						
Cultivar (Cv)	NS		NS		**	
HS	NS		NS		NS	
Cv x HS	NS		NS		NS	
Conductivity (μmhos *cm*$^{-1}$ *gm*$^{-1}$)						
HS-1	29	23	20	20	101	75
HS-2	27	24	19	19	87	52
HS-3	29	26	22	25	96	35
HS-4	26	26	24	26	119	38
Regression	**NS**	**L*Q***	**L**Q****	**L**Q****	**Q****	**L**Q***
Mean	**28**	**25**	**21**	**23**	**101**	**50**
Treatment effects						
Cultivar (Cv)	*		NS		**	
HS	NS		**		*	
Cv x HS	*		NS		**	

† (HS): HS-1, HS-2, HS-3, and HS-4 for the three locations are L-1 : 35, 41, 49, and 62 days after flowering (DAF); L-2 : 33, 41, 46, and 57 DAF; L-3 : 27. 38, 49, and 60 DAF, respectively.

‡ Dry weight of all normal seedlings from 50 seed replicate in germination test.

NS, *, ** Nonsignificant or significant at P = 0.05 or 0.01, respectively.

appears to be minimum; while, under higher maturation temperatures, early harvesting could reduce field weathering and vigor losses prior to harvest.

Seedling dry weight. Both total seedling dry weight and dry weight per normal seedling were used to compare vigor levels of the different treatments (Table 3.3). No differences were observed among the treatments at L-2 with both these parameters. However, total dry weight measurements of normal seedlings showed vigor differences among harvest stages at L-1 and L-3 which were similar to the trends shown by the SG test. As with the SG and AA tests, seedling vigor was lowest at L-3. One advantage of this test is that it does not incur expensive equipment or additional time, but vigor comparison should be made within seed lots of similar genotypes.

Conductivity. Conductivity measurements are inversely related to seed vigor. A higher conductivity level would indicate a greater leakage of solutes from the seed tissues. A highly significant increase in conductivity was observed with harvest stages HS-3 and HS-4 (Table 3.3) at L-2, indicative of a vigor loss which was not apparent in the SG test (Table 3.2). There was some interaction between cultivars and harvest stages at both locations L-1 and L-3. Seed lots from L-3 showed a distinct increase in conductivity levels compared to other locations at all harvest stages. Between the cultivars, a relatively lower conductivity was observed for Cherokee Wax. Apparently this cultivar is more tolerant to field

Table 3.4. ANOVA of main effects of location, cultivar, harvest stage, and their interactions for seed weight, yield, germination, and vigor parameters †

Source	100-seed weight	Seed yield	Stand. germ.	Seed vigor			
				AA germ.	Seedling Dry wt.		Conductivity
					Total	*seedling*$^{-1}$	
	(g)	(kg/ha)	(%)	(%)	(g)	(mg)	(µmhos *cm*$^{-1}$ *g*$^{-1}$)
Location (LOC)	**	**	**	NS	**	*	**
Cultivar (Cv)	**	**	**	**	**	*	**
LOC x Cv	**	NS	*	**	*	NS	**
Harvest stage (HS)	**	**	**	*	**	NS	**
LOC x HS	**	NS	**	**	**	NS	**
Cv x HS	NS	**	NS	NS	NS	NS	**
LOC x Cv x HS	**	**	NS	NS	NS	NS	**

† Combine analysis for locations, L-1, L-2 and L-3 except in AA germination which included L-1 and L-2 only.

NS, *, ** Nonsignificant or significant at P = 0.05 or 0.01, respectively.

weathering. Matthews and Bradnock (1967, 1968) have reported increased conductivity with low vigor seeds in wrinkle seeded peas.

Significant main effects (location, cultivar, and harvest stage) and their interactions were observed for most measured parameters (Table 3.4). The LOC x Cv. and LOC x HS interactions were significant for all parameters except seed yield and dry weight *seedling*$^{-1}$. These data indicate that choice of cultivar and harvest stage may depend on climatic conditions and location of production. Highly significant main effects and interactions were shown for conductivity measurements indicating that this was a sensitive test.

SUMMARY

Vegetative growth, seed development and maturation periods were all affected by production sites. Temperature appeared to be an important environmental factor influencing this variation. Air temperatures at L-1 were low, and the time to reach PM and HM was longer than at the other two locations. Yield was higher at L-1, and the seeds produced were larger, had a darker color, and were of higher vigor compared to the other locations. Seed yield, germination, and vigor were the lowest at L-3. Of the three locations, L-1 was the most suitable region for snap bean seed production. The number of seed produced was similar for L-1 and L-2; however, seed size was larger at L-1. Future research should determine if the quality differences of the seed produced at each site affect subsequent plant vigor and yield of the snap bean and seed crops.

Loss in vigor from delayed harvest was lowest under the cool maturation temperatures of L-1. At L-3, where the mean air temperatures were highest, there was a significant loss in vigor with delay in harvest after PM. Thus, under adverse conditions, vigor can be lost even before bean seeds reach harvest maturity. In cooler conditions, delaying harvest would probably have little effect on seed vigor; while, in more adverse warmer climates, early harvest would be advantageous to prevent seed vigor loss.

Cherokee Wax showed a higher vigor level by the AA test at locations L-1 and L-2 and by the conductivity test at L-3. This cultivar was more tolerant to field weathering. These results indicate the possibility for improvement in seed vigor through cultivar selection and breeding programs, particularly for locations with warmer conditions. Among the three vigor tests examined, both AA and conductivity appear to be the most sensitive in measuring vigor loss in snap bean. These data demonstrate the value of using an appropriate vigor test when evaluating snap bean seed quality.

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Chapter 4: Effects of Snap Bean Seed Size on Seed Vigor, Plant Growth, and yield

ABSTRACT

The costs and benefits of seed grading are important considerations in producing and marketing vegetable seeds. Seed size of bean and other leguminous species is known to affect plant stand and yield; however, the results have been inconsistent and often interact with the cultivar and the environment. Experiments were conducted at the Regional Agricultural Research Center, Bandarawela, Sri-Lanka, to determine the effects of snap bean (*Phaseolus vulgaris* L.) seed size on emergence, growth, and yield of both pods and seeds. Seeds of two cultivars (Topcrop and Cherokee Wax) were separated by weight into three seed sizes (small, medium, and large) and were evaluated for crop performance in two plantings (12/90 and 3/91). Standard laboratory germination and plant growth (dry weight) at the seedling and flowering stages were significantly higher for larger seeds. Seedling emergence was not affected by seed size in the 12/90 planting, while emergence from small seeds was 56% lower than from large seeds in the 3/91 planting. In both plantings, total pod yield was higher from larger seeds, but the yield difference between small and large seeds was greatest in the 3/91 planting. Lower seedling emergence from the small seeds probably accounted in large measure for the greater yield difference in the 3/91 planting. In both plantings, pod yield per plant was reduced from smaller seed only with Cherokee Wax. Apparently Topcrop was more capable of overcoming the low plant vigor from small seeds than Cherokee Wax. Seed quality of the produced seed crop was the same from plants grown from the different seed sizes, indicating that small seed could be used for seed production purposes.

INTRODUCTION

Modern agricultural practices require high quality seeds which give uniform emergence, vigorous growth, uniform maturity, and high yields. Seed size is one of the principal factors that affect seed vigor (ISTA, 1987). Seedling emergence and yield of a number of vegetable crops have been reported to be influenced by seed size. Larger seeds of lettuce produced greater yields (Scaife and Jones, 1970; Smith et al., 1973). Mean emergence time of carrot decreased and percent emergence increased with increased embryo length of heavier seeds (Gray and Steckel, 1983). Jacobsohn and Globerson (1980) reported that large seeds of carrot resulted in higher root yield in Spring and Summer but the differences diminished in the autumn crop with a longer growing season. Higher seedling stands and yields from larger seeds were also reported for onion (Gamiely et al., 1990) and broccoli (Heather and Sieczka, 1991). Seed size had no effect on germination, percent normal seedlings, and emergence in cabbage; but seedling fresh weight was related to seed size (Liou, 1987). Lima bean plants from larger seeds produced larger plants and larger beans (Wester, 1964). However, plants from small seeds yielded considerably more when not crowded by larger plants.

The effects of seed size on agronomic crops have been inconsistent. Larger soybean seeds gave greater emergence under simulated soil crust conditions and had greater shoot and root fresh weights (Longer et al., 1986). However Tekrony et al. (1987) reported that lower yields were associated with small seed size in hill plots, but there was no relationship between seed size and yield in row plots. Emergence rate, vegetative dry weight, and grain yield (at similar stands) were not influenced consistently by seed size in corn hybrids (Graven and Carter, 1990). After reviewing the research work on the influence of seed size on field germination, seedling vigor, yield, and quality in self pollinated crops, Rao (1981) concluded that there were no consistent results.

Variable yield responses have also been reported with bean (*Phaseolus vulgaris* L.). Clark and Peck (1968) reported that in snap bean seed lots showing an appreciable amount of transverse cotyledon cracking, smaller seeds showed a higher germination percentage than larger seeds. In fields where the same number of seeds of a single size was planted in separate rows, large seeds outyielded small seeds. However, when the same weight of seed was planted in each row, small seeds out-yielded large seeds. Alam and Locascio (1968) observed that seed size did not affect percentage germination in bean, but larger seeds gave higher yields. Higher yields from larger seeds were reported by other workers (Tompkins and Horton, 1973; Grabe, 1975; Smittle et al., 1976; Smittle and Williamson, 1977). Other investigators have reported that seed size did not affect seed yield in bean (Hardenburg, 1942; Salih, 1981). Ries (1971) reported that seedling size and yield of snap bean were more highly correlated with protein per seed than seed size. In this study, phenotypic differences in seed size and protein content were expressed by growing beans under three nitrogen regimes.

Embryos in basal ovular positions in *Phaseolus vulgaris* are more likely to abort or, if they survived, become lighter seeds than stylar embryos (Nakamura, 1988). The variation in mature seed size may affect adult characteristics, since large seeds produced larger juvenile plants than small seeds. A similar ovule positional effect has been reported for an outbreeding legume, *Phaseolus coccineus* (Rocha and Stephenson, 1990, 1991).

In these studies the effect of snap bean seed size on yield and vigor of seeds was not examined. Because of this and variable results from previous studies, additional research is needed to examine the effects of snap bean seed size on plant performance from emergence through pod and seed yield. The objectives of this study were to (1) examine the influence of seed size on seed vigor, plant growth and pod yield and, (2) determine if seed size has an effect on seed yield and vigor.

MATERIALS AND METHODS

Two field experiments were carried out at the Regional Agricultural Research Center, Bandarawela, Sri-Lanka (7° N lat. 81° W long.; 1220 m above mean sea level). The first experiment was planted December 1990 and will be hereafter refered to as 12/90 planting. Seeds of two cultivars (Topcrop and Cherokee Wax), which had not been graded, were hand separated into three seed sizes by weight (small, medium, and large). Mean 100-seed weights of the three seed lots were determined from four replicates (Table 4.1). Four replicates of 50 seeds were tested for the standard germination test, and only the normal seedlings were counted after 9 days for the final germination percent (ISTA, 1985).

A split-plot randomized complete block design with four replications was used with cultivars as the main-plots and the three seed sizes as the sub-plots. Seeds were spaced 10 cm apart in two rows spaced 50 cm apart in a 4-m bed. A basal application of fertilizer (20kg N: 43kg P: 64kg K per ha) was incorporated into the soil before planting. A top dressing of N at 40 kg per ha was given at three weeks after planting. Irrigation was applied when required to prevent any moisture stress. Recommended pest and disease control measures were adopted.

Emergence percent, seedling dry weight, and plant dry weight at the flowering stage were measured. Pod yield was determined by harvesting ten plants in each treatment at the snap bean marketable stage. The pod length and weight were also evaluated at this time. The remaining plants in each plot were allowed to reach harvest maturity, at which stage dry pods were hand harvested and

Table 4.1. Mean 100-seed weights and distribution by weight and number of different seed size grades.

	Cultivar							
	Topcrop				Cherokee Wax			
Seed	100-seed wt (g)		Distribution (%)		100-seed wt (g)		Distribution (%)	
size	Mean	Range	Wt	No.	Mean	Range	Wt	No
			12/90 planting					
Small	24.2	(20-30)			21.9	(15-25)		
Medium	35.4	(30-40)			30.9	(25-35)		
Large	45.8	(40-55)			43.1	(35-50)		
			3/91 planting					
Small	17.8	(15-22)	22	31	16.3	(15-20)	19	26
Medium	26.3	(22-30)	31	32	22.4	(20-26)	40	40
Large	33.5	(30-45)	47	37	27.5	(26-40)	41	34
Ungraded	26.9				22.9			

Table 4.2. Mean climatic data during the plantings 12/90 and 3/91.

	Air temperature (°C)		Soil temp.†	Rainfall
Planting	Min.	Max.	(°C)	(cm)
	Emergence period (≤ 8 days from planting)			
12/28/90	16.6	22.9	21.9	6.3
3/18/91	16.3	26.9	25.0	5.7
	Emergence through harvest			
12/28/90	14.7	22.9	22.2	32.9
3/18/91	17.7	26.3	24.8	15.4

† Soil temperature at 5 cm depth.

threshed and seed yield determined. The seed lots produced were evaluated for 100-seed weight, germination, and vigor (seedling dry weight and conductivity of seed leachate). For conductivity measurements, the method given in the 'Seed vigor testing handbook' (AOSA, 1983) was followed.

Experiment 2 was planted at the same location on March 1991 (3/91 planting). The seeds of the two cultivars Topcrop and Cherokee Wax used for this study were produced at the research station. The seeds were hand separated into three sizes by weight (small, medium, and large). An ungraded control was also used in this experiment. The 100-seed weights (Table 4.1) and the standard germination percent of the different seed lots were determined.

A split-plot, randomized complete block design with four replications was used with cultivars as the main plots and the four seed sizes as the sub-plots. All cultural practices were similar to those described above for the 12/90 planting. Emergence percent, seedling dry weight, plant dry weight at flowering, pod yield, pod length and weight were determined. Minimum and maximum air temperatures, soil temperatures and rainfall during the period of the two experiments were recorded (Table 4.2).

All data were subjected to analyses of variance, using a General Linear model on SAS (SAS Institute, Inc., 1988) with means separated by Tukey's HSD (P = 0.05). Percentage data were transformed to arcsin $\sqrt{percentage}$ before analysis. Also correlation analysis was performed between seed size and other growth parameters.

RESULTS AND DISCUSSION

Standard germination, field emergence, and plant growth . Using standard laboratory procedures, the percent germination of larger seeds was higher than from small seeds in both plantings (Table 4.3). Seedling emergence in the field, however, was not significantly affected by seed size in the 12/90 planting; while, under the more adverse soil conditions in the 3/91 planting, seedling emergence (plant stand) from the small seeds was reduced by 56% compared to the large seeds (Table 4.3). Although rainfall during seedling emergence was similar for both plantings, soil and air temperatures were higher in the 3/91 planting (Table 4.2), resulting in a drier and more hardened (crusted) soil surface.

Dry weight of the young seedlings (2 weeks from seeding) and plants at flowering stage were significantly higher from larger seeds (Table 4.3). The combined effects of reduced plant stand (reduced seedling emergence) and reduced plant vigor (reduced dry weight) associated with small seeds in the 3/91 planting most likely resulted in a corresponding reduced pod yield potential in these plots.

Pod yield ha^{-1} (crop yield). Although there were no significant cultivar × seed-size interactions for pod or seed yield for either planting, the pod yield response to seed size appeared to differ between the two cultivars in the two plantings. With Topcrop, pod yield in the small-seed plots was only 20% lower than the large-seed plots in the 12/90 planting but was 55% lower in the 3/91 planting; while, with Cherokee Wax, pod yield response to seed size was similar

Table 4.3. Effects of seed size on germination, emergence, seedling dry weight, and plant dry weight at flowering of Topcrop and Cherokee Wax (C. Wax) during the 12/90 and 3/91 plantings.

Seed size	12/90 planting			3/91 planting		
	Topcrop	C. Wax	SS mean†	Topcrop	C. Wax	SS mean
		Standard germination (%)				
Small	69	78	73 b‡	59	68	64 c
Medium	77	86	81 a	75	83	79 b
Large	81	85	83 a	88	91	90 a
Ungraded				77	86	82 b
Cv mean	**75**	**83**		**75**	**82**	
Treatment effects						
Cultivar (Cv)	*			**		
Seed size (SS)	**			**		
Cv × SS	NS			NS		
			Emergence (%)			
Small	65	74	70 a	35	33	34 c
Medium	74	75	75 a	61	64	63 b
Large	72	78	75 a	78	76	77 a
Ungraded				59	60	60 b
Cv mean	**70**	**76**		**58**	**58**	
Treatment effects						
Cultivar (Cv)	NS			NS		
Seed size (SS)	NS			**		
Cv × SS	NS			NS		
		Dry weight *seedling*$^{-1}$ (mg)				
Small	233	292	263 c	128	147	138 c
Medium	341	378	360 b	143	149	146 c
Large	498	508	503 a	217	223	220 a
Ungraded				185	168	176 b
Cv mean	**357**	**393**		**168**	**172**	
Treatment effects						
Cultivar (Cv)	NS			NS		
Seed size (SS)	**			**		
Cv × SS	NS			NS		
		Dry wt *plant*$^{-1}$ at flowering (g)				
Small	5.9	5.1	5.4 b	3.7	3.7	3.7 b
Medium	6.9	7.0	6.9 a	5.5	4.7	5.1 a
Large	8.5	6.9	7.7 a	6.1	5.4	5.8 a
Ungraded				5.8	4.9	5.4 a
Cv mean	**7.1**	**6.4**		**5.3**	**4.7**	
Treatment effects						
Cultivar (Cv)	NS			NS		
Seed size (SS)	**			**		
Cv × SS	NS			NS		

† SS mean = seed size mean.

‡ Mean separation within mean effects within columns by Tukey ($P \leq 0.05$).

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

Table 4.4. Effect of seed size on yield of pods of Topcrop and Cherokee Wax (C. Wax) during 12/90 and 3/91 plantings.

Seed	12/90 planting			3/91 planting		
size	Topcrop	C. Wax	SS mean†	Topcrop	C. Wax	SS mean
			Pod yield (kg ha^{-1})			
Small	5846	3933	4889 b‡	3660	3407	3533 c
Medium	7662	5996	6829 a	6607	5127	5867 b
Large	7326	7299	7312 a	8174	6674	7424 a
Ungraded				5347	5147	5247 b
Cv mean	**6945**	**5743**		**5947**	**5089**	
Treatment effects						
Cultivar (Cv)	*			NS		
Seed size (SS)	**			**		
Cv x SS	NS			NS		
			Pod yield $plant^{-1}$ (g)			
Small	48 a	27 b	37	49 a	51 b	50
Medium	48 a	39 a	43	57 a	53 b	55
Large	49 a	45 a	47	58 a	67 a	63
Ungraded				57 a	49 b	53
Cv mean	**48**	**37**		**55**	**55**	
Treatment effects						
Cultivar (Cv)	NS			NS		
Seed size (SS)	**			**		
Cv x SS	**			**		

† SS mean = seed size mean.

‡ Mean separation within mean effects within columns by Tukey ($P \leq 0.05$).

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

in both plantings, 46% and 49% lower in the small-seed plots in 12/90 and 3/91, respectively (Table 4.4). These data indicate that, with the possible exception of Topcrop in the 12/90 planting, the difference in plant vigor among the seed-size plots was transfered to the reproduction phase, resulting in corresponding differences in pod yields. Correlation coefficients between plant vigor (seedling and plant dry weights) and pod yields confirm this relationship (data not shown).

Correlation coefficients (r values) between plant dry weight at flowering and pod yield were highly significant for Cherokee Wax 12/90 (.79**), Topcrop 3/91 (.72**) and Cherokee Wax 3/91(.74**) but not for Topcrop in the 12/90 planting (.41 NS). Thus in the 12/90 planting in which emergence (plant stand) was not affected by seed size, Topcrop was capable of significantly compensating for the effects of low plant vigor during the juvenile stage; however, in the 3/91 planting, a 56% reduction in plant stand resulted in 55% reduction in pod yield. The reduction in seedling emergence from small seeds in the 3/91 planting appears, therefore, to be the major factor responsible for the reduced pod yields, particularly for Topcrop which has a more dwarf plant structure and a more highly concentrated pod set than Cherokee Wax.

There may be a critical plant population below which crop yield can be affected. After emergence, photosynthesis is the major source for growth. However, before the plant becomes autotrophic, there is a transition period during which the seedling uses its stored reserves. During this period the larger seeds may be able to emerge better and become established better than the small seeds, particularly under stress conditions. Advantages from larger seed size under stressful conditions have also been reported for broccoli (Heather and Sieczka, 1991), soybean (Longer et al., 1986) and corn (Graven and Carter, 1990). Apparently, plants of Topcrop have a greater genetic potential to "outgrow" the adverse low vigor effects originating from small seeds. This can be clearly seen in the plant pod yield response to seed size difference in the 12/90 planting.

Pod yield plant^{-1}. There was a highly significant cultivar × seed size interaction for pod yield per plant (Table 4.4). For both plantings, plant yield increased with seed size for Cherokee Wax, while there was no significant difference in plant yield among seed sizes for Topcrop. This interaction is also evident from the correlation coefficients for seed size and plant pod yield (Table 4.5). The r values for Cherokee Wax were highly significant ($r = 0.89^{**}$ and $r = 0.77^{**}$), while those for Topcrop were not significant ($r = 0.05$ and $r = 0.55$). Apparently, Topcrop is more capable of overcoming low vigor in the juvenile growth phase and hence plant pod yield was not significantly affected (Table 4.4). In contrast, Cherokee Wax is less capable of overcoming low vigor in the juvenile phase of growth and hence pod yield per plant was reduced in the low vigor plants originating from small seeds. Of particular importance, these data indicate that crop yield (pod yield *ha*$^{-1}$) of Cherokee Wax could be reduced when using small seeds, even when grown in more ideal soil conditions such as the 12/90 planting.

Table 4.5. Correlation coefficients between seed size and other growth parameters in snap bean cultivars, Topcrop and Cherokee Wax.

Growth parameter	Cultivar			
	12/90 planting		3/91 planting	
	Topcrop	Cherokee Wax	Topcrop	Cherokee Wax
	(r - values)			
Stand. germination	0.72 **	0.49	0.97 **	0.93 **
Emergence	0.44	0.32	0.96 **	0.90 **
Seedling dry wt. at emergence	0.96 **	0.95 **	0.95 **	0.92 **
Plant dry wt. at flowering	0.74 **	0.57 *	0.79 **	0.69 **
Pod yield (total)	0.55	0.83 **	0.84 **	0.76 **
Pod yield *plant*$^{-1}$	0.05	0.89 **	0.55	0.77 **
Seed yield (total)	0.48	0.62 *		

*, ** indicate significance at P = 0.05 and 0.01, respectively.

Table 4.6. Seed yield, 100-seed weight, and vigor of seed produced from different seed sizes in two bean cultivars, 1990/91 season.

Main effects	Seed yield	100-seed wt.	Stand. germ. test†	Seed vigor		
				Seedling dry wt.		Conductivity
				Total‡	*seedling*$^{-1}$	
	kg *ha*$^{-1}$	(g)	(%)	(g)	(mg)	(µmhos *cm*$^{-1}$ *g*$^{-1}$)
Cultivar (Cv)						
Topcrop	1079 a§	33.5 a	72 a	4.88 a	135 a	14.6 a
C. Wax	971 a	28.0 b	75 a	4.24 a	113 a	14.5 a
Seed size (SS)						
Small	877 b	31.0 a	79 a	5.10 a	130 a	15.6 a
Medium	1090 a	30.8 a	74 ab	4.46 ab	121 a	14.6 ab
Large	1109 a	30.5 a	68 b	4.11 b	122 a	13.4 b
Cv x SS§	NS	NS	NS	NS	NS	NS

† Percentage data were analyzed after transformation to arcsin $\sqrt{percentage}$.

‡ Dry weight of all normal seedlings from 50 seed replicate in germination test.

§ Mean separation within main effects within column by Tukey's ($P \leq 0.05$).

NS, *, ** Non significant, significant at $P \leq 0.05$ and $P \leq 0.01$, respectively.

Yield, Weight, and vigor of seed produced from the 12/90 planting. Seed yield was 20 and 21% lower in plots sown with small seeds compared to medium and large seeds (Table 4.6). Although the conductivity was slightly higher for the seeds produced from small seeds, no difference in 100-seed weight or seedling dry weight were found among the seeds produced (Table 4.6). Standard germination and total seedling dry weight of the seeds produced from small seeds were higher than from large seeds. Thus, in four of the five quality tests, seeds produced from small seeds was either equal or superior to that of seeds produced from large seeds (Table 4.6). Since the plants from small seeds were smaller than those from larger seeds, the interplant competition was less with the small plants and could have resulted in production of higher quality seed.

Although not conclusive, these data indicate that the inherent low vigor of small seeds is probably not transfered to future seed generations and that small seeds could be used for production of bean seed crops. Possibly, planting the smaller seeds at higher density would compensate at least partially for the smaller plant size and lower plant yields, thus increasing the crop seed yields produced from small seeds.

SUMMARY

Standard laboratory germination and field emergence tended to be the lowest with small seeds; in particular seedling emergence from small seeds was low under the adverse soil conditions of the 3/91 planting. Growth during the seedling and flowering stages were lower in plants from small seeds, indicating a possible loss of yield potential. The cultivar × seed size interaction was significant for pod yield per plant. Topcrop showed no difference while Cherokee Wax showed an increase in pod yield per plant as seed size increased. Apparently, Topcrop was more capable of overcoming the low plant vigor from small seeds than Cherokee wax. This interaction could be of particular importance for seed production and grading of bean. Future research should be conducted to substantiate these data and identify the physiological factors responsible for this interaction.

Pod yield (yield ha^{-1}) was lowest in plots sown with small seed. The difference in vegetative growth and pod yield between small-seed and large-seed plots was enhanced in the 3/91 planting. The large reduction in seedling emergence (56%) from small seeds of both cultivars in the 3/91 planting is probably the major factor responsible for this difference. Although seed yield (yield ha^{-1}) was lowest from plants grown from small seeds, the quality of the produced seed was not adversely affected. Thus, small seeds of acceptable quality can be used for seed production purposes.

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Final Summary

Seed crops should be harvested at the optimum stage of maturity when maximum vigor is achieved. Further delays in harvesting would lead to field weathering losses in seed vigor. Snap bean seed harvested between physiological maturity (PM) and harvest maturity (HM) had high seed vigor. Pod yield, pod length, and pod weight were not affected by these harvest stages. However, delaying harvest after HM affected seed vigor and storability adversely, which could be attributed to field weathering effects on seed. These findings indicate that seed could be harvested prior to HM without any loss of seed vigor provided seeds have achieved PM.

Seeds that matured under the cooler conditions at L-1 (Rahangala) had the highest seed weight, yield, and vigor of the three locations. Under the maturation environment of L-1 field weathering effects appeared to be minimal and there was no significant loss of seed vigor between PM and HM. Seed number per hectare were similar at L-1 and L-2 (Bandarawela); therefore the higher yields at L-1 were due to larger seed size. Further studies should be carried out to compare the pod and seed yield performance from seeds produced at L-1 and L-2. Seeds that matured under the warmer conditions at L-3 (Moneragala) showed the lowest vigor and seed vigor declined even prior to reaching HM. These data have important practical implications. In warmer areas of snap bean seed production or when environmental conditions are condusive for field weathering, harvesting prior to HM would be advantageous.

Identification of the stage of PM in the field is helpful in management of bean seed crops. The change of pod color to yellow seems to indicate PM. Seed moisture content at this stage is about 55% and seed fresh weight dropped after this stage. In the field studies, seed weight and vigor showed an increase at HS-2 for all locations. The lower vigor at HS-1 could be attributed to the immaturity of some of the seeds. This is because peak flowering and pod set duration lasts for some time (about 10 days). Consequently, at HS-1 some seeds are immature, but with HS-2 most of the seeds are at PM. Therefore, from a practical stand point, HS-2 was a more suitable stage of harvest than HS-1.

Cultivar differences in seed vigor were observed. Cherokee Wax was found to be the most tolerant to field weathering among the cultivars tested. This cultivar also showed a much lower imbibition rate during the initial 10 h of imbibition and had a higher seed coat/cotyledon weight than the other cultivars. These seed coat properties appear to be related to resistance to field weathering and should be further investigated. With susceptible cultivars, harvesting should be made at an earlier stage soon after attaining PM.

The question of whether seed grading is necessary in snap bean seed production was addressed in two experiments planted in 12/90 and 3/91. Seed size had no effect on emergence in the first planting under more ideal soil conditions. However, field emergence from the larger seeds was higher than from small seeds during the second planting where the soil during the emergence period was relatively drier and more crusted than the soil at the first planting. Larger seeds thus appear to have an advantage under such stressful soil conditions.

At both plantings, seedling size at emergence and plant size at flowering stage were larger from larger seeds. In both plantings total pod yield (kg ha^{-1}) was higher from larger seeds than from small seeds. However, the yield response to larger seeds was greater during the second planting, probably because of the significant differences in seedling emergence. In both plantings pod yield per plant showed a significant response to seed size only in Cherokee Wax. Apparently, Topcrop is more capable of overcoming the low vigor from small seeds than is Cherokee Wax. This indicates that seed grading will be more important with Cherokee Wax. This aspect also should be further investigated.

Although seed yield was lowest from plants grown from small seeds, the germination and vigor of the seeds produced was not affected. The data indicates that small seeds of acceptable quality can be used for seed production purposes. The influence of seed size on pod yield was higher than on seed yield. This indicates that seed size or grading may be more important for fresh pod production than for a seed crop. The proportion of lower vigor seeds (small) was about 20% by weight in both Topcrop and Cherokee Wax. The data from these studies indicate that vigor of snap bean seed could be optimized by harvesting at the proper stage of maturity to prevent field weathering and by grading to remove the small seeds.

VITA

Lakshman Gamini Herat was born in Colombo, Sri-Lanka on May 26, 1945. He received his primary and secondary education at St. Anthony's College, Kandy, where he successfully completed General Certificate of Education (Advance Level) Examination in 1965. In 1965 he was admitted to the University of Sri-Lanka, Peradeniya campus and received his Bachelor of Science Degree in Agriculture in 1969. After this he was employed as an Experimental Officer in the Department of Agriculture, Sri-Lanka from 1970 to 1975, and as a Research Officer from 1976 to present. He received his Master of Science Degree in Horticulture in 1981 from the University of Bath, U.K.. In March 1988 he entered the Graduate School at Virginia Polytechnic Institute and State University, Blacksburg and was awarded a Doctor of Philosophy Degree in Horticulture in April 1992. Lakshman is married to Gayathri and they have two children, Dilini and Naren.

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