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Effect of Cultivar Mixtures on Yield of Common Beans (Phaseolus vulgaris L.) and on Development of Anthracnose, Angular Leaf Spot and Halo Blight

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# EFFECT OF CULTIVAR MIXTURES ON YIELD OF COMMON BEANS (*Phaseolus vulgaris* L.) AND ON DEVELOPMENT OF ANTHRACNOSE, ANGULAR LEAF SPOT AND HALO BLIGHT

By

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## ABSTRACT

# EFFECT OF CULTIVAR MIXTURES ON YIELD OF COMMON BEANS (*Phaseolus vulgaris* L.) AND ON DEVELOPMENT OF ANTHRACNOSE, ANGULAR LEAF SPOT AND HALO BLIGHT

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In East Africa beans are grown in mixtures of different genotypes and in association with different crop species, as a pre-cautionary measure against biotic and abiotic hazards and for food diversity. There are claims, particularly in small-seeded cereals, that variety mixtures restrict disease development, and produce increased and stable yields.

Studies were conducted to assess the progress of anthracnose, angular leaf spot and halo blight in varieties of common dry beans in pure stand, varities in different mixtures, and in $F_2$ populations in separate experiments for two seasons. Source of inoculum was from spreader rows. A control experiment, without any of the three diseases but with most of the entries in the disease experiments, was conducted. Yields of varieties in pure stand and in the mixtures were also measured.

Under moderate levels of disease pressure, mixtures effectively reduced disease progress in the susceptible varieties as compared to the pure stand for anthracnose, angular leaf spot and halo blight. Halo blight infection

remained moderate during the two seasons. However, under high disease pressure of anthracnose and angular leaf spot, mixtures did not effectively reduce disease levels on the susceptible plants.

Mixtures tended to have intermediate yields when compared to varieties in pure stand and most of them yielded below their higher yielding mixture components. Some mixtures yielded above the mean yield of their components in pure stand. The increase in yield in the mixtures under disease conditions was not necessarily related directly to reduction in disease incidence. Yields for both mixtures and the varieties in pure stand varied between the two seasons.

There was strong competition between the genotypes in the mixtures. The yield and yield components of individual genotypes in the mixtures were different in different mixtures as compared to their performance in pure stand. The competitive abilities of the genotypes in the mixtures varied between the two seasons. Favorable intergenotypic interactions may have contributed to increased yields in the mixtures.

DEDICATION

To all members of my family with love

and

to all subsistence farmers, who for centuries have grown their crops in mixtures of different genotypes in different species, thus preserving the most needed genetic variability.

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# CHAPTER 1

## 1.0 INTRODUCTION

Common beans (*Phaseolus vulgaris* L.) is one of the important food crops in many countries. Beans provide proteins in the diets of many people in East Africa (CIAT, 1981) and in many other third world countries who cannot afford to buy animal products. In East Africa beans are used mainly for on-farm consumption; any surplus is taken to the market (CIAT, 1981).

In East Africa, beans are used mainly as dry grains, although fresh seeds at physiological maturity are used because they are tender and tasty (Njugunah *et al*. 1981, Karel *et al*. 1981 and Rubaihayo *et al*. 1981). Green leaves and pods are also used as a relish in Malawi and Tanzania (Karel *et al*. 1981 and Mughogho *et al*. 1981). The diverse use of beans could be one of the reasons why farmers maintain mixtures of different genotypes which could be harvested for different purposes over a longer period of time.

Although beans are widely grown, productivity is quite low. Diseases, insects and abiotic factors significantly reduce yields (CIAT, 1981). Diseases that are common in East Africa are anthracnose caused by *Colletotrichum* *lindemuthianum* (Sacc. & Magn.) Scribner, angular leaf spot caused by *Phaeoisariopsis griseola* Sacc., rust caused by *Uromyces appendiculatus* (Pers.) Unger, halo blight caused by *Pseudomonas syringae* pv *phaseolicola* Sacc., common and fuscous blight caused by *Xanthomonas phaseoli* (E.F. Sm.) Dows. and *X. phaseoli* var *fuscans* (Burk.) Starr and Burk., bean common mosaic virus and several minor diseases.

Diseases can be controlled by breeding for resistence and use of fungicides. However, breeding for disease resistance and use of fungicides and also the planting of clean disease-free seed and sanitation cannot be regarded as an ultimate solution in developing countries because chemicals are too expensive and unavailable. Likewise breeding programs which take too long to produce resistance cultivars and the utilization of vertical resistance system used in many breeding programs is not always a reliable long term solution. The vertical resistance may eventually be overcome by virulent strains of the pathogen. Certified seed is not always available and effective crop rotation is not feasible because farms are small. Under the conditions of subsistence farming other important strategies for disease control, such as growing heterogeneous populations, can be used. This strategy has been used by subsistence farmers who have been growing their crops under heterogeneous populations for many centuries (Erskine 1973, Simmonds, 1962 and 1978).

In East Africa, where agriculture mainly is at the subsistence farming level, beans are grown in association with other crops, chiefly cereals other crops depending on the region (CIAT, 1981). Farm sizes are also small and discrete. In this system, beans are always composed of mixtures of different genotypes differing in many characters such as plant types, different maturity and seed characteristics (Martin 1984 and Ayeh 1988). According to Voss (1988), 96% of 120 farmers interviewed in Burundi said they plant mixtures because of increased yield and high yield stability and assurance of getting a crop. There is also a probable variation in disease reactions (Bokosi 1986).

In subsistence agriculture, disease epidemics are uncommon, and yields are low but stable (Simmonds 1978 and Browning 1974). In Western agriculture, beans and other crops are grown in sole cropping using uniform cultivars characterized by narrow genetic bases (NAS 1972). In such a system yields are high but disease epidemics and abiotic hazards can cause problems.

Natural ecosystems as well as subsistence farming methods involving heterogeneous crop populations have a tendency towards stability, although yields are often low (Simmonds 1962, 1978 and Browning and Frey 1969). On the other hand, Western agricultural ecosystems have tended towards instability despite the high yields. There is a need to increase yields in subsistence agriculture without reducing the benefits of growing beans in mixtures of different genotypes (Voss 1988). This could be achieved by growing high yielding improved cultivars in mixtures.

There are studies which set forth the advantages of growing crops in heterogeneous populations (Simmonds 1962, Jensen 1965, Borlaug 1959, Frey and Maldonado 1967 and Wolfe 1978 and 1985). The advantages are that disease spread is restricted in heterogeneous populations, that yield is occasionally increased and there occurs some improvement in yield stability across different environments. Many small farmers grow mixtures as a risk-reducing strategy.

Mixtures of different genotypes have additional advantages over the other types of heterogeneous populations such as multilines and line mixtures (Wolfe 1978 and Frey 1982). In a mixture, a proportion of heterogeneous populations may prove resistant to host specific and host non-specific pathogens and certain abiotic stresses. In addition mixture components can be selected without elaborate and time consuming breeding efforts.

Research work on the role of mixtures in restricting disease development, increasing yield and stability has been done on small cereal grains such as oats, barley, wheat, rice and legumes such as chickpeas. There is very little work done on mixtures in common beans. This research was therefore undertaken with objectives of studying the following:

1. The effect of mixtures of commercial bean cultivars on the development of anthracnose, angular leaf spot and halo blight diseases;
2. The effects of mixtures on yield and yield components under disease and disease-free conditions;
3. The behavior of $F_2$ segregating populations under disease and disease-free conditions.

# CHAPTER 2

## 2.0 LITERATURE REVIEW

### 2.1 Bean Diseases

Diseases which significantly reduce yields are one of the many problems associated with growing beans (Sherf and MacNab 1986, Schwartz and Galvez 1980 and CIAT 1981). The diseases considered here are three of the major diseases of beans endemic in East and Central Africa. These diseases are anthracnose caused by *Colletotrichum lindemuthianum* (Sacc. & Magn.) Scrib., angular leaf spot caused by *Phaesisariopsis griseola* (Sacc.) Ferraris, and halo blight caused by *Pseudomonas syringae* pv *phaseolicola* (Burk.) Dows. Anthracnose is a seed borne fungal disease that attacks all plant parts above the ground forming dark brown lesions on leaves and stems (Zaumeyer and Thomas 1957, and Schwartz and Galvez 1980). On the leaves, lesions mainly appear on the veins mainly on the underside of the leaf. Symptoms appear as brick-red in color but pinkish spore masses may appear during moist weather. Lesions also appear on the hypocotyl and the pods .

Angular leaf spot is a fungal disease which affects all the aerial parts of the bean plant, but the most common infection is on the leaves (Schwartz and Galvez and Sherf and MacNab 1986). Symptoms on the leaves appear as grey spots changing to light brown as the leaf ages. Lesions are restricted by veins resulting in characteristic angular shapes. Stems and branches exhibit elongated lesions. Pod lesions appear as oval to circular spots with reddish brown centers surrounded by darker coloured borders.

Halo blight is a seed borne bacterial disease that also affects all above ground parts of the plant (Zaumeyer and Thomas 1957 and Schwartz and Galvez 1980). Initial leaf symptoms appear as small, brown water-soaked spots on the underside of the leaf, later a halo-like zone of yellow tissue develops around the water-soaked area. Leaf malformation, stunting and foliage chlorosis may appear in case of systemic necrosis. Lesions on the pods appear as green water-soaked spots which may enlarge and coalesce. Reddish, necrotic longitudinal lesions characterize symptoms on the stems.

These diseases require cool temperatures, particularly in cases of anthracnose and halo blight, for successful development (Schwartz and Galvez 1980 and Sherf and MacNab 1986). Moderate rainfall at frequent intervals, splashing rain and wind together with the movement of people and animals can help in the dissemination of anthracnose. Temperature range for anthracnose development is 13-26½C with 17½C being the optimum.

Angular leaf spots is disseminated by splashing rain or wind from infested plant debris in the soil or by spores from sporulating lesions on infected plants. A temperature range of 20-25½C, high humidity or free moisture are optimal conditions for disease development.

Halo blight is so infectious that under conditions favorable for disease development and spread one infected seed in 16,000 is sufficient to supply inoculum for a severe outbreak (Sherf and MacNab 1986). Cool (16-20½C), moist conditions can cause symptoms in 2-5 days, but symptoms develop in 6-10 days at 24-28½C. Symptoms seldom develop above 27½C although numerous water soaked lesions may be evident.

Halo blight is disseminated by contact between plants, splashing or wind driven rain, hail, overhead irrigation water, wind borne droplets of dew and plant exudates, insects, animals and farm equipments.

Breeding for resistance to anthracnose has been used in North America and Europe as the method of control of this disease (Shwartz and Galvez 1980 and Zaumeyer and Meiners 1975). Resistance to particular races of anthracnose is controlled by single, double and triple factors (Burkholder 1918, McRostie 1919 and Mastenbroek 1960). Cardenas <u>et al.</u> (1964) and Muhalet <u>et al.</u> (1981) have found genetic resistence to anthracnose controlled by duplicate and complementary factors and an allellomorphic series.

Resistance to angular leaf spots is conferred by recessive and dominant genes (Schwartz and Galvez 1980 and Acquaah 1988). However, most cultivars have been tested only against local isolates of the fungus. In this case, the use of mixtures may be a better alternative because a heterogeneous population can provide a more general type of resistance since there is not enough knowledge of the pathogen variability.

Pathogenic variation occurs in halo blight (Coyne and Shuster 1974 and Msuku 1984). Both specific and general resistance to this organism are well known (Schwartz and Galvez 1980). Also, independent genes govern resistance to the leaves, pods and plant systemic chlorotic reactions (Baggett and Frazier 1967 and Coyne and Shuster 1974).

## 2.2 Plant and Cropping Ecosystems

### 2.2.1 Natural ecosystems

Natural ecosystems seldom consist of uniform species (Burdon 1978 and Frey 1982), and almost certainly never of a single genotype. In the past, the occurrence of diseases in natural ecosystems was not seen as an important issue (Browning 1974). Browning (1974) and Mundt and Browning (1985) suggested that the knowledge of mechanisms of disease development in natural ecosystems can help with the management of diseases in agricultural ecosystems. In natural ecosystems, the pathogens and their hosts are in equilibrium (Browning 1984 and Wolfe 1985), which is profitable to both hosts and the pathogens. The stability of pathogen populations solves the hosts' problem of maintenance of resistance to diseases (Day 1974). In this situation the pathogen can survive without eliminating the host (Mode, 1958 and Persson, 1966). Therefore, in such systems epidemics are uncommon. This state of equilibrium is caused by diversity in both host and pathogen (Anikstar and Wahl 1979 and Browning 1974).

In natural ecosystems, co-evolution allows for the selection for resistance/susceptibility in the host and avirulence/virulence loci in the pathogen in frequencies that enable the host and the pathogen to coexist (Parlevliet and Zadoks 1977 and Persson 1966). An example of this co-evolution is found in rusts and mildews pathogens of small grains in their centers of origin (Browning 1974) where susceptible plants and avirulent races are not eliminated from the diverse population in which selection pressure on host and pathogen is minimized.

### 2.2.2 Subsistence farming ecosystems

Subsistence farmers have developed systems of exploiting genetic diversity through centuries of experience (Erskine 1973). The cultural practice of growing heterogeneous populations is useful in stabilizing yields against diseases and fluctuating environmental conditions (Simmonds 1962 and Erskine 1973). The heterogeneous crop populations in subsistence agriculture are achieved by growing a wide range of crop species and also by growing genetically heterogeneous populations of each species. Subsistence agriculture, therefore, mimics natural plant communities, where plant pathogens are potentially present all the time. In this system, where a range of plant species is found with each having a different pattern of genetic resistance, every individual is potentially affected by only a proportion of the host specific pathogens present (Burdon 1978).

Agriculture in rural communities is also characterized by discrete small farms. The diversity in crops and the discontinuity among farms can help check epidemic developments. Yields, although stable, are low in subsistence farming (Simmonds 1978). Yields can be improved by introducing improved cultivars, but they have to be grown in heterogeneous populations to maintain diversity which is important in achieving a measure of stability (Voss 1988).

### 2.2.3 Western agricultural ecosystem

Western agriculture by its nature has eliminated interspecific diversity, and plant breeders have further eliminated intraspecific diversity by producing single pure line cultivars of many crops (Browning and Frey 1969). The majority of ecosystems in Western agriculture are highly simplified (Burdon 1978), because single species or genotypes with a narrow genetic base are grown at high densities over very large areas (NAS 1972). Day (1974) reported that the gene base of 15 of the world's leading food crops is very narrow. Large areas of unprotected and genetically uniform crop plants invite destruction by disease epidemics (NAS 1972). The use of pure line cultivars have, with the stabilizing tendencies of the pathogen, given rise to new virulent biotypes which may attack new varieties (Suneson 1960, Browning and Frey 1969, Wolfe 1978 and Wolfe and Barrett 1980).

## 2.3 Deployment of Vertical Resistance and Disease Epidemics

The discovery of Mendelian type resistance to wheat yellow rust by Biffen (1905), and that of pathogenic specialization on crop species and on different varieties (Johnson 1961 and Stakman and Christensen 1960), changed the breeding approach for disease resistance. Plant breeders extensively incorporated major genes for resistance into commercial crop varieties. Van der Plank (1963) called this type of resistance vertical resistance (VR). VR by its nature is effective against specific but not all races of the pathogens. Although VR has contributed to disease control and high yields, it has not been successful on the long term basis (Burdon and Shattock 1980). Each time a new resistant cultivar is developed and grown over a large area, a deviant in the pathogen population, virulent on the new resistant cultivar, increases without competition (Suneson 1960, Johnson 1961 Browning and Frey 1969, Barrett and Wolfe 1980 and Wolfe and Barrett 1980). Suneson (1960) called this vicious cycle a "boom and bust" cycle.

## 2.4 Genetic Diversity

An alternative disease control approach is to diversify the genetic base of the host so that directional selection for virulence to a VR gene is reduced. Rosen (1949) suggested the use of planned heterogeneity in modern crop varieties to provide stability of protection to disease using host resistance. Jensen (1952) suggested the use of multilines in cereals. A multiline is a mixture of isolines or near isolines isogenic for a single disease resistance set of genes. Suneson (1960) also suggested the use of non-uniform crop varieties to break the vicious cycle. Wolfe (1978) and Wolfe and Barrett (1980) proposed the use of cultivar mixtures in disease control.

Variety mixtures, however, have more advantages than the multilines (Barrett 1978, Burdon 1978, Wolfe and Barrett 1980, 1982 Wolfe 1978, Wolfe et al 1981). The multilines approach (Jensen 1952 and Jensen and Kent 1962) does not allow for maximum genetic diversity because they are designed for a single target disease. The variety mixtures have resistance to a particular target disease, nevertheless the variation in the genetic background of the varieties can provide some (partial) control to non-target pathogens and environmental fluctuations (Wolfe 1978 and Wolfe et al. 1981). Another advantage of variety mixtures is that they permit breeders to move new varieties with superior agronomic traits and yielding ability into agricultural production more rapidly than if they were to be converted into multilines (Groenewagen and Zadoks 1979, quoted by Frey 1982). Variety mixtures may have yield synergism and yield stability (Wolfe 1978, and Wolfe and Barrett 1980).

The main problem of variety mixture often is lack of agricultural and/or commercial uniformity. However, they can be used in places where uniformity is not a strict agronomic requirement and when the use of end product does not require uniformity such as animal feeds (Sammons and Baenzinger 1985).

## 2.5 Disease Spread in Pure Stand and in Mixtures

Van der Plank (1963) postulated that the pathogen increases from initial inoculum at a specific rate over time, and results in a certain proportion of susceptible tissue. VR is race specific and is conferred by single or a few major genes. It reduces the initial inoculum but does not affect the rate of disease increase. HR, on the other hand, is thought to be conferred by many genes and is race non-specific. HR does not provide a high level of disease resistance and does not prevent the initial inoculum, but it reduces the rate of infection.

Diseases in pure stands of cultivars carrying VR genes can be reduced if the resistance is effective against all races of the pathogen thus keeping the initial inoculum very low for all the races. However, VR by itself has permitted the development of great epidemics (Suneson 1960 and Van der Plank 1968) since new virulent races evolve and multiply.

Variety mixtures with more than one VR gene should decrease the initial inoculum as compared to pure lines (Van der Plank 1968, Browning and Frey 1969, Wolfe 1978, Luthra and Rao 1979, and Mundt and Browning 1985). Variety mixtures tend to reduce infection rates similar to HR genes (Browning and Frey 1969 Burdon 1978 and Luthra and Rao

1979). The reduction of infection rate is more important than the reduction of the initial inoculum (Mundt and Browning 1985 and Mundt and Leonard 1986).

2.6 <u>Variety Mixtures and Disease Control</u>

Mixing varieties differing in reaction to spores produced on the other varieties would likely restrict the rate of epidemic development (Burdon, 1978). Variety mixtures have two components of heterogeneity, namely, the specific resistance genes and the diverse genetic background (Wolfe 1978). The additional heterogeneity of the different host backgrounds has a further advantage in increasing the likelihood of diversity in resistance to other non-target pathogens present as well as buffering capacity against environment variations (Wolfe, 1978).

The number of diseases occurring in a mixed stand is often less than that which would be predicted in a pure stand (Anikstar and Wahl 1979). Early research with mixtures of resistant and susceptible varieties indicated that the presence of a resistant variety diminishes disease infection. Tozzetti, in the 18$^{th}$ Century, was probably the first person to observe reduction of rust infection in interspecific mixtures of wheat and oats (Wolfe 1985). Rosen (1949) proposed mixing populations of any one cross rather than going for uniformity for the management of both crown rust and *Helminthosporium* blight of oats. Quantitative data on the effect of mixing of resistant and susceptible varieties in a 50:50 ratio on oat stem rust was obtained by Browning (1957). He observed that much less rust developed on the susceptible variety in the mixture than in the pure stand. Suneson (1960) also observed the reduction of stem rust of oats on the susceptible component in a mixture composed of a ratio of 1 susceptible : 3 resistant. This shows the buffering effects of diversification on crop pests.

More studies of mixtures of components possessing differing resistance genes have shown substantial reduction of disease infection. Berger (1973) studied the infection rate of *Cercospora apii* in mixed populations of susceptible and tolerant celery. Disease incidence and infection rates of *Cercospora* blight on the susceptible variety decreased as the percentage of tolerant plants in the population increased. The protective effect was, however, lost at a disease incidence above 25%. In this case, tolerance was effective only against low levels of spore abundance.

Wolfe (1978) and Wolfe and Barrett (1980) reported a dramatic reduction of powdery mildew caused by *Erysiphe graminis* f. sp. *hordei* in a three-component spring barley mixture of up to 50% of the means of the components in pure stand. The reduction lasted throughout the season. White (1982) studied the effect of barley mixtures in an equal proportions of resistant and susceptible varieties under natural infection. She observed that at low levels of disease, the mixture had an infection level less than half that expected from the mean infection percentage of the two components. Wolfe and Minchin (1979) observed that mildew infection in a three-component variety mixture of barley decreased from 19.9% to 9.9% as compared to their components in pure stand. Wolfe et al. (1981) also observed a mean infection percentage of between 8.0% to 23.3% on four cultivars in pure stand and 0.5% to 10% in the four-component mixture. In 15 two-way mixtures of six barley varieties, Wolfe and Barrett (1982) observed a 40% reduction in infection as well as an average 60% reduction in 20 three-way mixtures, when averaged over two seasons. With appropriate mixtures of spring barley, Wolfe (1985) reported a reduction of mildew infection of up to 80% as compared to the pure varieties. Utility of defeated resistance genes to powdery mildew in spring barley mixtures was studied by Mastenbroek (1984) under spontaneous mildew infection. The mixtures were composed of different combinations of four varieties, three of which had defeated resistance genes and one of which was resistant. The average reduction of the infection level in the mixtures was 38%. Disease increase was observed in some mixtures which were composed of varieties with defeated resistance genes. Priestly et al. (1988) examined powdery mildew development in a three component mixtures of spring barley and winter wheat under natural conditions. Reduction in the percentage of leaf area infected with mildew as a result of variety mixing was observed in barley.

Jerger et al. (1981) examined epidemic development of Septoria nodorum, which has not been shown to exhibit race specialization, in two wheat cultivars differing in partial resistance. The cultivars were mixed in five different ratios. The disease level, although low, was reduced almost to that of the more resistant cultivar. Even the presence of only 25% of the more resistant cultivar reduced the disease level to that of the more resistant one. In another experiment, Jeger et al. (1981) studied the effect of mixing two winter wheat cultivars differing widely in reaction to S. nodorum and a mixture of two winter barley varieties differing in reaction to Rynchosporium secalis. Five mixture ratios were used for each host. For both diseases at the last sampling, the disease incidences in both pure cultivars and the mixtures were significantly lower than in the susceptible one. However, barley mixtures were more effective against R. secalis than the wheat mixture against S. nodorum.

McDonald et al. (1988) tested two-, three-, and four-component barley mixtures with respect to control of scald disease caused by R. secalis. The mixture components differing in resistance and susceptibility to four pathotypes of R. secalis were selected from parents of Composite Cross II (CCII) of barley from the 45$^{th}$ generation of CCII. All the barley plots were inoculated with the mixture of the four laboratory grown pathotypes. They found that 5% of the 37 parental mixtures had a positive effect, whereas 27% of the 45 $F_{45}$ mixtures had positive effects. McDonald et al. (1988) concluded that selection had acted on the CCII population to increase the frequency of genotypes that are suitable in the mixture than in the pure stand. They also concluded that 45 years of coevolution with the populations of the pathogen in Davis (California) had lead to an increase in the frequency of lines and/or combinations of lines that provide protection against the endemic pathogen population. McDonald et al. (1988) observed that in years of severe disease only one of the six mixtures containing 33% susceptible lines had significantly higher levels of scald than the mixtures of resistant lines. Even in mixtures with 50% and 67% susceptible lines, some of them had less disease. They concluded that even in years with high disease levels substitution of up to 50% susceptible lines into the mixtures does not always lead to increased levels of disease. In the year with low levels of scald, more mixtures showed positive effects. These results are similar to those of Berger (1973), White (1982) and Karjalainen (1986).

The severity of wheat stem rust caused by *Puccinia graminis* f. sp. *tritici* was studied by Alexander et al. (1986) in monoculture and in a mixture of resistant and susceptible varieties composed in different proportions. They found that the levels of rust gradually decreased as the proportion of the resistant plants was increased in the mixture. They also suggested that the reduced epidemic spread in mixtures probably resulted from reduced initial infection per plot. This is due to the small number of susceptible plants and the low probability that the spores will land on the isolated susceptible tissue.

The build up of brown spot of rice caused by _Drechslera oryzae_, was reduced in the susceptible variety when mixed in different ratios and designs with highly resistant and moderately resistant varieties (Misra, 1985). A significant control of _Helminthosporium victoriae_ was also observed by Ayanru and Browning (1977) in the mixtures of highly resistant and highly susceptible varieties of oats. Sitch and Whittington (1983), studied the development of swede (_Brassicca napus_) powdery mildew caused by _Erysiphe polygoni_ on the components of five mixed populations of partially resistant and highly susceptible varieties under natural infection. They found that the initial disease levels were similar in all mixture compositions. The disease level on the susceptible variety increased slowly as the percentage of the resistant component was increased. As the season progressed the early disease control was lost. Also, the average amount of disease in the mixture was less than would be expected from the means of the components in pure stand. The departure from expectation was greater as the proportion of the resistant component was increased.

## 2.7 Mechanisms of Disease Control in Mixtures

Several suggestions have been made concerning the mechanisms of disease control in mixtures (Browning and Frey

1969, Johnson and Allen 1975, Wolfe 1978, Chin and Wolfe 1984, and Wolfe and Barrett 1980). Browning and Frey (1969), working with oat multilines, suggested that multilines will reduce the initial inoculum, $X_o$ by reducing the probability of any spores landing on the susceptible plants. Luthra and Rao (1977) had similar results with wheat multilines. In both cases the infection rate, r, was also reduced because spores were being trapped on the resistant plants (Browning and Frey 1969, Luthra and Rao 1979 and Trenbath 1977).

In mixtures, the major factors operating to restrict disease development are reduced density of susceptible plants, the barrier of resistant plants between the susceptible ones and induced resistance (Burdon 1978 and Wolfe and Chin 1984). From the results of experiments on the spread of powdery mildew on barley variety mixtures, Chin and Wolfe (1984) concluded that the three mechanisms were indeed operating. When the density of the susceptible plants is reduced, the amount of inoculum available for subsequent dispersal within the stand is also reduced (Barrett 1978, Wolfe 1978 and Wolfe and Barrett 1980). Replacement of the susceptible plants by resistant ones increases the distance between the susceptible ones; resistant plants can also act as a barrier to trap spores. The influence of the barrier effect have been studied by Burdon and Whitbread (1979) and Chin and Wolfe (1984). It is a phenomenon where spores are trapped on the resistant plants. Johnson and Allen (1975) suggested that induced resistance can be an additional mechanism of disease control in mixtures. Induced resistance is caused by non-virulent spores landing on a host and apparently protecting it from other spores which are capable of infecting because of the acquired resistance.

The relative importance of each of the mechanisms varies depending on the stage of crop and epidemic development, and on the host genotypes and pathogen (Chin and Wolfe, 1984). In the early stage of plant growth, the reduction of disease is due mainly to reduced density effect. Later, the barrier effect and induced resistance become important and the induced resistance becomes more important toward the end of the growing season. Modification of microclimate is also important as a measure of reducing disease according to Burdon (1978) and Sitch and Wittington (1983).

## 2.8 Yield Potential of Mixtures

### 2.8.1 General

Mixtures have other advantages over the monocultures other than slowing the spread of disease. Mixtures have been shown to have a greater stability of performance across diverse environments (Simmonds 1962, Frey and Maldonado 1967 and Ayeh 1988). Occasional high yields over their components in pure stands have also been observed in mixtures. The reason why mixtures seem to be advantageous lies in the interaction between genotypes and the environment. Better utilization of environmental resources such as water, light and nutrients under suboptimal conditions can partly account for yield advantage of mixtures over the monoculture (Frey and Maldonado 1967 and Trenbath 1974). The way each cultivar responds to a range of environments may be unique to that cultivar and in many cases such differences are difficult to measure or predict (Wolfe and Barrett 1980). In a stressful environment, mixtures are likely to compensate for yield losses, thus providing a more stable performance.

Even in the absence of intergenotypic interactions, mixtures would be more stable than their components provided at least one component line responds differently in the environment (Marshall and Brown 1973). However, Clay and Allard (1969) observed that in some cases barley mixtures can be less stable than their components.

Yields of mixtures can be affected by several factors, including inherent yielding abilities of each cultivar, mixture composition, effects of disease level on yield and the effect of plant competition among and within cultivars (Alexander *et al*. 1986).

### 2.8.2 Yield under disease conditions

In a mixture under disease conditions, failure of any component to utilize its share of environmental resources because of the disease will be compensated by other components of the mixture (Burdon and Shattock 1980). The use of mixtures in disease-prone agricultural situations provides greater stability in yield than may be expected from comparable pure stands (Burdon 1978). Some cases have, however, shown no demonstrable yield advantage (Alexander et al. 1986 and Priestly et al. 1988). Lack of demonstrable yield advantage could be due to insufficient restriction of disease infection to limit the damage or due to negative interaction between varieties.

Wolfe (1978) observed positive correlations between increased yield of the barley mixture and mildew severity at different sites. Wolfe et al. (1981) recorded an overall average yield of the mixtures of 106.5% over the weighted means of the components grown alone. At more than seven sites where mildew was considered important, the average yield of the mixtures was about 109%. In seven sites where mildew was absent or unimportant the average yield was about 103% of the weighted means of the components (Wolfe and Barrett, 1980 and Wolfe et al. 1981). Chin and Wolfe (1984) also observed that the mixtures of susceptible and resistant varieties of spring barley to mildew yielded higher than the means of their components in pure stand. Mixtures were also higher yielding, though not significantly so, than the highest yielding variety in pure stand.

Mixtures of different proportions of two spring wheat varieties did not yield significantly greater than the respective means of their components in pure stand (Jeger et al. 1981). The results could have been due to low levels of the disease, Septoria nodorum. With winter wheat, however, there was an advantage of mixing over the pure stand irrespective of S. nodorum infection. In another similar experiment with winter barley, the effect of binary mixtures in different proportions of resistant and susceptible varieties on grain yield in the absence of Rhyachosporium secalis was almost linear (Jeger et al. 1981). In this case there were no competitive effects between the varieties. In the presence of R. secalis, however, mixtures appeared to have an advantage over the pure stand. They assumed that in this case competitive and complementary effects were present.

Wolfe (1978) could not separate the increase in yield from the contribution due to mixing alone and from that due to disease control. Jeger et al. (1981) cautioned that care has to be taken when ascribing yield benefits obtained from disease reductions. In another study, Chin and Wolfe (1984) were not able to determine proportion of yield increase in the mixture due directly to disease control or to the interaction between the disease control and the environmental effects or to the environmental effects alone.

Priestly et al. (1988) compared the average yields of the pure component varieties and four mixtures each for spring barley and winter wheat made of three-components in equal proportions. In 90% of the comparisons, yields and ranking orders of the mixtures were found to be intermediate between the highest and the lowest yielding pure components irrespective of the fungicide treatment. Few mixtures did significantly better than their component means under disease conditions. One spring barley mixture had significantly greater yield than the mean of its components over nine trials. Its yield increase was directly correlated to disease restriction. Priestly et al. (1988) concluded that there was a definite tendency for mixtures to yield significantly higher than their component pure varieties when grown without fungicides. Marshall (1977) also had similar results.

Karjalainen (1986), working with mixtures of spring wheat in 1:1 ratios of susceptible (S) and moderately resistant (MR) varieties, observed that yield reductions caused by S. nodorum were variable depending on the levels of infection. Under low disease levels, the induced yield reductions was 4.3% (S) and 4.5% (MR), under moderate disease levels the reduction was 10.5% (S), 4.5 (MR) and 3.7 to 6.3% in the mixtures. Grain yield reductions under heavy infection were 21% (S) 20% (MR) and 18% for mixtures. These data indicate that mixtures can reduce disease-induced yield loss under low and moderate infection conditions only. From this study too, it was observed that the yield benefits of mixtures over the pure components did not seem remarkable.

Ayanru and Browning (1977) suggested buffering of highly susceptible plants to Helminthosporium victoriae by highly resistant plants. Blends with 80% and 90% highly resistant plants had yields consistently higher than those of highly resistant plants in pure stand. They concluded that the yield increase in blends over those of pure stand could be attributed to the degree of protection of the highly susceptible plants by the highly resistant ones.

2.8.3 Yield under disease-free conditions

In the absence of disease, mixtures may give higher yields than their component means through more efficient utilization of environmental resources. In pure stand, when all the plants are genetically identical and morphologically similar, they compete for the same ecological resources. In a mixture, where components differ, the total ecological resource available is greater, thus greater yields can be realized (Frey and Maldonado 1967 and Shorter and Frey 1979).

Simmonds (1962) reviewed work done on mixtures of small cereals. He found that in eight out of nine series of experiments the average yields of mixtures were 3-5% above the weighted means of their components.

Frey and Maldonado (1967) used six varieties of oats and their 57 mixture combinations composited from two, three, four, five and six varities, to study their productivity at early and late planting dates. The mean relative yield, which is the actual yield of a mixture divided by the mean of its components, was 100% for early planting and 104% for late planting. Advantages of heterogeneous oat populations increased as the environment became more stressful. They suggested that undamaged plants in a mixture increased their productivity by utilizing nutrients and moisture which the damaged plants could no longer use. The mixture showed greater stability in yield when tested in several environments.

The yield advantages of oat cultivar mixtures were due to specific combinations of lines over different planting dates (Frey and Maldonado 1967). Shorter and Frey (1979) observed that the highest yielding oat mixtures were composed of the highest yielding pure lines and no mixture exceeded the highest yielding pure line significantly. Their data showed little synergistic effects on grain and straw yield from mixing pure lines. Alexander et al. (1986) also suggested that mixtures can be affected by inherent yielding ability of the components.

Baker and Briggs (1984) used well adapted materials of spring barley of uniform maturity and similar plant height to study the performance of biblends and uniblends. They found that there were no significant differences between the average performance in uniblends and biblends from whole plots and single plants. Their study also showed the absence of significant interaction in biblends. This indicated that the yield of each biblend could be predicted on the basis of the average performance of its two components.

Hoekstra et al. (1985a and 1985b) observed that the ability of a corn hybrid to yield in pure stand does not necessarily reflect on its ability to yield in mixture. Under severe moisture stress, mixtures yielded 6% more grain on the average than expected on the basis of pure stand yields. They suggested that under stress conditions, hybrids in mixtures may interact positively to produce higher yields than the expected. Negative interactions may also occur. Mixtures were also more stable than their pure stand components in average performance over two years (Hoekstra 1985a and 1985b).

Sammons and Baenzinger (1985) evaluated the performance of 11 blends of winter wheat mixed in equal proportions in two-, three- and four-way blends. Advantages of several mixture populations relative to some of the component lines in pure stand were observed for yield, lodging resistance and winter survival. Their observations suggested that well constructed blends can yield as well as the best components. Components which yield poorly but have other desirable characters can be included in a blend without causing unacceptable yield losses. However, no blend exceeded the best yielding cultivar in pure stand in any environment.

Bacon et al. (1987) compared the yield of four soft red wheat blends and their eight pure line cultivar components for three years on three types of soil. No consistent yield advantage was observed since the yield of only one blend on one soil type was significantly different from the mean of the components averaged over three years. On silt loam soil yields of all four blends were more stable across years.

Yield increase of up to 25% was observed in some mixtures of six sugar cane varieties grown in mixtures of equal proportions of two- or three-components for first and ratoon crops for three years. The transgression in yield was attributed to partial or temporal complementarity of the components (Trenbath, 1974).

Schweitzer et al. (1986) evaluated the performance of soybean mixtures composed of different maturity periods and height grown in narrow spacing. The mixtures consisted of different biblends. In the combinations of relatively early maturity cultivars, there was undercompensation. Undercompensation was suggested as due to relative similarities in maturity while over- compensation was due to diversity of the components in mixtures in terms of height and relative maturity. Mumaw and Weber (1957) and Probst (1957) also noted that mixtures of equal proportions of soybean varieties exhibited a maximum yield advantage when paired varieties were most diverse in height, relative maturity and lodging potential. They observed the average yield advantage of 0.5% for mixtures of like characters and 2.7% for the mixtures of unlike characters. Mumaw and Weber (1957) observed that, on the average, composites of two varieties of soybeans yielded 2% higher than the means of their pure component lines. However, Probst (1957) did not see any superiority in yield over the highest yielding variety for four years, but the best blend in all the years nearly equaled or exceeded the average of the low yielding varieties comprising the blend.

In flax, Gubbles and Kenaschuck (1987) found the yield response of blends was linear with five cultivar ratios. The yield of 1:1 blends averaged 110% of the mean of the components and one blend averaged higher than the high yielding component. On the average, the blends yielded 102.5% of the mean of the components. The higher the yield potential of each component, the higher the yield potential of the blend. Under usual conditions, blends stabilized yield by producing yield midway between the components in pure stand. Thus, under good conditions there is no advantage of growing the components in the same fields. But under adverse conditions, the blends can compensate for the weakness and result in acceptable yields. Alexander et al. (1986) and Shorter and Frey (1979) also suggested that mixtures made of higher yielding components have better performance.

## 2.9 Yield Stability in the Mixtures

The advantages of mixtures does not lie only in yield transgression but in their stability. Greater stability of yields is a characteristic of mixtures (Trenbath, 1974). Increased stability is encountered more frequently than increased yields. Stability of performance can be achieved through individual buffering and populational buffering (Allard and Bradshaw 1964). Individual buffering results from developmental and physiological flexibility of the individual in the population. Population buffering results from coexistence and interaction of different genotypes in the population. Genetical homozygous populations rely on individual buffering but both mechanisms are present in a genetical heterogeneous population. The buffering could be in terms of horizontal resistance or result from other environmental circumstances. Experimental observations show that under certain circumstances, interpopulation genetic diversity may substantially increase stability of performance in crop species. Even in the absence of intergenotypic competition a mixture would be more stable than its components provided at least one component line responded differentially to at least one environment (Marshall and Brown 1973). Mixtures showed greater stability of performance across diverse environmental factor (Jensen 1952, Simmonds 1962 and Trenbath 1974). However, Clay and Allard (1969), working with barley, found mixtures of pure line varieties were on the average less stable than their most stable components.

Erskine (1973) showed yield stability above that of component lines is attainable by simple mixing in some cases. Shorter and Frey (1979) found GE variance for grain and straw yields of oat mixtures was smaller than that of oat lines grown in monoculture. Kapur *et al*. (1988) observed that the number of millable canes, sucrose content and cane yield in the mixture was more stable than in pure stand. Working with common beans Ayeh (1988), found that an $F_2$ population and the most complex of several mixtures were very stable across enviroments although not significantly different from some pure genotypes. Similar results were obtained by Bacon *et al*. (1986) in wheat, Priestly *et al*. (1988)in wheat, Gubble and Kanaschuk (1987) in flax and Hoekstra *et al*. (1985a) in corn. Rao and Prasad (1984) showed yield stability of one of the mixtures of wheat was due to mechanical support of a tall genotype by the shorter components. In pure stand the tall variety lodged as a result of heavy rains and strong winds. Great gains in stability could occur from a systematic search for components which in combination would exhibit a high degree of population buffering.

## 2.10 Intergenotypic Competition in the Mixtures

Mixtures have different yield responses under different environments and mixture compositions. This could be due to intergenotypic competition. If intergenotypic competition is operating, the performance of the mixtures of different genotypes may not be indicative of performance of its pure line components (Martin and Alexander 1986). Schutz *et al*. (1968) described four types of intergenotypic competition. They were complementary where one genotype increased in yield while the other one decreased; neutral where genotypes have no influence on each other; undercompensatory where one genotype showed no change in yield whereas the other one decreased in yield; and overcompensatory where one genotype did not change in yield whereas the other one increased.

Suneson (1949) showed how yield and disease records in pure stand were meaningless to competitive ability in mixed stand. He observed that for over 16 years, a component with significantly better yield and leaf disease records in pure stand was dominated in the mixed stand by a variety that had the poorest leaf disease record and lowest yield. Baker (1977) observed the relative performance of inbred lines in mixtures did not relate directly to their relative performance in pure stand. Short genotypes were shown to be at competitive disadvantage in mechanical mixtures of tall and dwarf wheat (Khalifa and Qualset 1974).

Interactions and deviations of 28 biblends of wheat genotypes from average performance of the two uniblend components were detected for grain yield and grain protein content (Martin and Alexander 1986). In the absence of intergenotypic competition, the biblend performance was found to be an additive function of the uniblend performance (Baker and Briggs 1984 and Martin and Alexander 1986). In some cases intergenotypic competition reduced grain yield in biblends without producing a proportionate compensation for test weight and grain protein.

Schweitzer et al. (1986) evaluated the performance of binary mixtures of soybeans of different maturity periods and plant heights in different proportions. They found undercompensation, which was suggested to be due to relative similarities. They also found overcompensation which was said to be due to diversity of the components of the mixtures in terms of height and relative maturity. Alexander et al. (1986) observed that the susceptible cultivar had higher yield than expected from the monoculture data while the resistant cultivar had lower yield than predicted from the monoculture data for the proportions studied.

Rao and Prasad (1984) observed that intergenotypic competition was strong in the mixtures of tall, medium and dwarf genotypes. The dwarf genotypes rendered support to the taller one which would have lodged in monoculture, but the yield of the shorter genotype was suppressed. However, the taller genotype more than compensated for the losses in the dwarf genotype. Plant height in this case conferred high competitionSchweitzer et al. 1986, Rao and Prasad 1984 and Trenbath 1974). Rao and Prasad (1984) expressed the competition as the percentage gain or loss of a genotype in mixed stand as compared to its pure stand performance. A non-linear relationship of yield and yield components between the mixtures and their components in pure stands as the proportions of the mixtures are varied also indicated an evidence of competition (Valentine 1982, Alexander et al. 1986 and Schweitzer et al. 1986).

## 2.11 Effective Composition of Mixtures

The most effective composition of mixtures in terms of percentage of resistant plants or the number of components per mixture is not known (Mundt and Browning 1985). In addition, the level of resistance adequate for the mixture may vary with different environments and different crop species. In natural ecosystems, Browning (1974) found that

30% resistant plants backed up with general resistance was adequate to control crown rust in wild oats.

Field studies showed that two equiproportional barley mixtures of resistant and susceptible cultivars provided considerable protection against mildews (Wolfe 1978 and Wolfe and Barrett 1980). A three-equiproportion barley variety mixture differing in resistance reduced the mildew incidence to about 50% of the mean incidence of the components in pure stand (Wolfe 1978). However, Mastenbroek (1984) concluded that binary mixtures were unable to suppress barley mildew infection. The level of wheat stem rust was reduced when the proportion of the resistant cultivar was increased to 60% in a binary mixture (Alexander et al., 1986).

The composition of mixtures of beans studied from 42 households in Rwanda showed that mixtures varied between 6 and 29 varieties with the mean of 19.8 varieties (Voss 1988). Ferguson and Sprecher (1987) observed an average composition of 12.9 varieties in Malawi. Research from Burundi indicated positive interactions among bean varieties in mixture was evident only when the number of varieties was six or more (Voss 1988). However, few of the varieties are always in proportion of 50%-90%.

With S. nodorum, the presence of only 25% of the more resistant cultivar in a mixture reduced the disease severity of less resistant genotypes (Jeger et al., 1981). Browning and Frey (1981) observed that an oat line mixture composed of several resistant lines provided adequate protection against severe crown rust epidemics, while a two-component mixture with approximately the same percentage of resistant plants did not. But in a lesser epidemic, the two-component mixture was adequate.

# CHAPTER 3

## 3.0 MATERIALS AND METHODS

### 3.1 Genetic Study

Genetic mechanisms of inheritance for the three diseases, anthracnose, angular leaf spot and halo blight were studied in the greenhouse during the spring of 1986 and fall of 1987. Parental bean genotypes, $F_1$ and $F_2$ progenies were screened for the resistance to the respective races or isolates of the particular disease. The $F_2$ progenies were screened for their reaction to the respective isolates in spring of 1987.

Isolates used in this study were kindly supplied by Dr. A.W. Saettler, Michigan State University. Bean varieties used were obtained from the Bean Program at Michigan State University.

#### 3.1.1 Anthracnose

Resistance to Á-race of anthracnose was evaluated in 18 bean genotypes. A laboratory grown culture was used to evaluate the seedlings.

Cultures were grown on bean pod agar (BPA). For BPA medium preparation, 10 g of navy bean (C-20) seeds were steamed in 100 ml distilled water for one hour. Beans were then macerated in mortar and pestle and filtered through a double layer of cheese cloth. 20 g of agar (Difco) and 20 g of ground bean pod flour were dissolved in 900 ml of distilled water. The filtrate from the cooked beans was also added, thoroughly stirred and steamed for 30 minutes. The medium was then subdivided into 250 ml lots into prescription bottles and autoclaved at 250½F and 15 psi for 20 minutes. The medium was allowed to cool and transferred into sterile petri plates. Cultures were transferred by either small agar blocks from sporulating culture onto fresh plates, or 2 ml of highly concentrated inoculum was evenly spread on fresh plates. Plates were incubated at 21½C for 5 to 7 days.

Spores from sporulating plates were dislodged by using a microscope slide after adding 2 ml distilled water. Spores were washed through double layer cheese cloth and washed with distilled water into a flask. Spores were adjusted to about 6-7 x $10^5$ spores/ml. Tween 80 (Polyoxythene sorbitan monoolate), a wetting agent, was added at a 0.05 v/v and thoroughly mixed.

Eighteen genotypes of beans were screened for their reaction to the Á-race. Seedlings at fully expanded first trifoliate stage were inoculated using atomized spray to liquid run-off. Plants were then immediately transferred into a mist chamber set at near 100% R.H. After 5 to 7 days plants were assessed for disease symptoms. Plants were then transferred to the greenhouse benches and reassessed after five days for final disease symptoms. A scale of 0-5 was used for disease assessment, i.e. no disease symptoms observed to 100% infection.

Cultivar C-20 (susceptible) and the breeding line B83002 (resistant) were crossed. Their $F_1$ and $F_2$ progenies were evaluated for reaction to the Á-race. $X^2$-tests with Yates' correction factor were used to determine segregation ratios in the $F_2$.

More $F_2$ seeds were raised in the green house for field planting.

3.1.2 Angular leaf spot

The Michigan-5 isolate of angular leaf spot was used in this study. Bean genotypes, $F_1$ and $F_2$ progenies were evaluated.

Cultures of the isolate were maintained on V-8 juice agar medium. Medium was prepared by procedures made available in Dr. Saettler's laboratory. 3 g $CaCO_3$ was mixed with 18 g Bacto agar and 200 ml V-8 juice and dissolved in 800 ml distilled water. The mixture was steamed for 30 minutes to dissolve agar. The medium was then subdivided into lots of 250 ml in prescription bottles, autoclaved at 250½F and 15 psi for 20 minutes. The medium was cooled, and poured into sterile petri plates and allowed to solidify before use.

Cultures were grown by transferring highly concentrated spore drops in sterile distilled water onto fresh plates. Plates were then incubated at 25½C for 5-7 days.

For inoculum preparation, spores from sporulating plates were dislodged by scraping with a spatula after addition of 2 ml distilled water. Spores were filtered through cheese cloth. Spore concentration was standardized to 2-3 x $10^4$ conidia/ml. A haemocytometer was used for counting the conidia. Tween 80 was thoroughly mixed with the inoculum at 0.05 v/v.

About 18 bean genotypes were evaluated for their reaction to the Michigan-5 isolate. Seedlings at the first trifoliate stage were inoculated by atomized sprayer to liquid run-off. Seedlings were immediately transferred to the mist chamber at near 100 R.H. After 5-7 days plants were evaluated using a scale of 0-9 with 0 as no symptoms and 9 as severe infection. Plants were transferred to green-house benches and plants were again reevaluated to confirm the reaction.

Variety Montcalm (susceptible) and a breeding line GO 5686 (resistant) were selected and crossed. Their $F_1$ and $F_2$ progenies were evaluated. The $F_2$ segregating ratios were determined by using the $X^2$-test with Yates' correction factor. Sufficient amount of $F_2$ seed was grown in the green-house for field planting.

3.1.3 Halo blight

In this study, Michigan-1 isolate of halo blight was used to evaluate bean varieties, $F_1$ and $F_2$ progenies. The isolate was cultured on Kings medium B (KMB). Normally, after incubation at 25½C for 36-48 hours, the culture was ready for inoculum preparation. Buffered distilled water was prepared by addition of 70 ml $Na_2HPO_4$ and 30 ml $KH_2PO_4$ to 900 ml of distilled water. Bacteria were dislodged by scraping the colonies with a microscope slide after addition of 2 ml distilled water to the plate. Inoculum was then diluted in buffered distilled water to optical density of 0.05 to 0.07 at a wave length of 620 Å using a spectronic calorimeter (Bausch and Lomb Co.).

Seedlings at the first trifoliate were inoculated by using an atomizer sprayer to liquid run-off. Eighteen bean genotypes were evaluated. Plants were left on the greenhouse bench. Plants were evaluated after five days. All the plants were tagged and reevaluated after one week. A disease record was taken twice for every plant for confirmation of the reaction. A scale of 0-9 was used for disease assessment. Montcalm (R) and Taylor (S) were selected and crossed to generate $F_1$ and $F_2$ progenies. The progenies were evaluated for their reaction to the Michigan-1 isolate. The $F_2$ segregation ratios were determine as for the other experiments. More $F_2$ seed was grown in the greenhouse for field work.

## 3.2 Evaluation of Mixtures

Field experiments were conducted during the Summer of 1987 and 1988 at the Department of Crops and Soil Sciences Agronomy Farm in East Lansing. The experiments were designed to study disease development, yield and yield components and plant traits in a mixture of genotypes and also in pure stand for each genotype. Four experiments were conducted for anthracnose, angular leaf spot and halo blight. A control experiment was also conducted, where most of the treatments from the three experiments were combined. The control experiment was not inoculated with any of the pathogens. Each experiment was planted in isolation and maximum care was taken to avoid cross-contamination.

Plot sizes, the number of rows per plot and harvest area were the same for all four experiments. The experimental design used was RCB with 3 replications. Plot size was 5 rows 5.10 m long. The harvest area was from the 3 center rows of 4 m x 1.5 m. Disease assessments, yield and components of yield and plant height were taken from the harvest area. Plants for dry weight measurements were sampled from an area adjacent to but outside the harvest area. Land was plowed, harrowed, fertilizer and herbicide applied as recommended.

### 3.2.1 Anthracnose

Ten treatment combinations were used in this experiment as shown in Table 1.

Each plot was surrounded by two spreader rows of Domino on all sides in the 1987 season. The spreader rows were planted a week before the rest of the plots. For the 1988 season variety Black Magic was used because seed of Domino was in short supply. Only one spreader row, instead

Table 1. Treatment combinations for the anthracnose experiment.

| Treatments | Mixture ratio |
|---|---|
| 1. Domino/Black Magic* (S) | Pure stand |
| 2. C-20 (S) | Pure stand |
| 3. Montcalm (R) | Pure stand |
| 4. Seafarer (R) | Pure stand |
| 5. Domino/Black Magic: C-20 | 1:1 |
| 6. Domino/Black Magic: Seafarer | 1:1 |
| 7. Montcalm: Seafarer | 1:1 |
| 8. B83302 x C-20 (3R:1S) | $F_2$ |
| 9. Montcalm: Domino/Black Magic | 3:1 |
| 10. C-20: Montcalm: Domino/Black Magic: Seafarer | 1:1:1:1 |

* cv Black Magic was used in 1988.

R = Resistant; S = Susceptible.

of two, was planted in 1988 and it was planted at the same time as the rest of the plots. It was thought two spreader rows planted earlier than the rest of the field supplied too heavy inoculum which facilitated a fast disease spread. The spreader rows were drilled by hand.

Mixtures were compounded by seed numbers because seeds were of different weights and sizes. Seeds were planted by hand according to the mixture combinations within the rows. For example, in a 1:1 ratio (R:S) mixture, seeds were drilled in alternate way. For the 3:1 ratio mixture, the three seeds of one kind were planted together followed by the single seed of the other kind. In the mixtures involving four genotypes in a 1:1:1:1 ratio, the four groups were planted together but randomly within the row. Spreader rows for all the experiments were planted on May 27, 1987. The spreader rows for the 1988 season were planted at the same time as the rest of the plots. The anthracnose experiment was planted on June 7, 1987 and June 21 in the 1988 season. The spreader rows were inoculated on June 22 in 1987 and July 19, 1987.

When plants in the spreader rows were two to three weeks old they were sprayed with inoculum of the Á-race at the concentration of about 2 x $10^6$ spores/ml, by using a knapsack sprayer, to liquid run-off. The sprayer nozzle was placed down in such a way to confine drift only to the spreader rows. Inoculations were done on cloudy days or after rain or during late afternoon. The field was irrigated by sprinklers occasionally to promote disease development and in some cases to alleviate drought. During the 1988 season the field was irrigated during the first part of the season because of severe drought. Times of inoculation and the irrigation were the same for angular leaf spot and halo blight nurseries.

Ten plants of each genotype in all the plots were selected at random within the harvest area and tagged, except for the $F_2$ populations. Plant type, plant, leaf and flowers colors were used to identify the genotypes (Table 2). Selected plants were used for disease assessments, yield and yield components and plant height measurements. Disease was assessed on the whole plant basis. Disease on the pods was assessed separately. A disease scale of 0-5, i.e. no disease symptoms to very high infection was used. All the $F_2$ plants in the plot were assessed for the disease development.

3.2.2 Angular leaf spot

Conditions and factors were similar to anthracnose except that seven different treatments were used (Table 3). Two rows of Montcalm were used as spreader rows in the 1987 season but a single row of Taylor was used in the 1988 season. There was a change of variety due to insufficient seeds. Only one spreader row was used because the two

Table 2. Specific characters selected to identify bean varieties used in the mixtures.

| Varieties | Plant type | Seed size | Seed colour | Flower colour | Leaf colour | Maturity period |
|---|---|---|---|---|---|---|
| Domino | II | small | black | purple | DG | IL |
| Black Magic | II | small | black | purple | DG | IL |
| C-20 | II | small | navy | white | G | IL |
| Seafarer | I | small | navy | white | G | E |
| Montcalm | I | large | DRK | white | G | I |
| Taylor | I | medium | cranberry | pink | LG | E |
| MIC | III | medium | cranberry | pink | G | L |
| Cardinal | I | medium | cranberry | pink | G | I |

DG = Dark green; G = green; LG = light green; E = early; I = intermediate; L = late; IL = intermediate late.

Table 3. Treatment combinations for the angular leaf spot experiment.

| Treatments | Mixture ratio |
|---|---|
| 1. Domino/Black Magic* (R) | Pure stand |
| 2. C-20 (R) | Pure stand |
| 3. Montcalm (S) | Pure stand |
| 4. Taylor (S) | Pure stand |
| 5. Montcalm x GO 5686 (3S:1R) | $F_2$ |
| 6. Montcalm: C-20 | 3:1 |
| 7. C-20: Montcalm: Taylor: Domino/Black Magic | 1:1:1:1 |

* cv Black Magic was used in 1988.

R = Resistant; S = Susceptible.

spreader rows seemed to have provided an over-abundance of inoculum. In 1988, the first leaves that dropped due to disease infection in the spreader rows were removed from the field to reduce the inoculum source.

The experiment was planted on June 7 and 8 in 1987 and June 21 in 1988. The spreader rows were inoculated on June 16 in 1987 and on July 15 in 1988. The spreader rows were sprayed with spores of the Michigan-5 isolate at a concentration of about $2.7 \times 10^4$ conidia/ml. The inoculation method was the same as that for anthracnose.

Plants were inoculated during the late afternoon on a cloudy day.

3.2.3 Halo blight

The conditions for this experiment were similar to those for the anthracnose and angular leaf spot experiments. Seven different treatments were used as shown in Table 4. For spreader rows cv Charlevoix was used in the spreader rows, with two rows for 1987, and cv Taylor was used in 1988 in a single spreader row.

The experiment was planted on June 8 and 9 in 1987 and on June 20 in 1988. The spreader rows were inoculated with isolate Michigan-1 on June 20 and 30 in 1987 and July 17 1988. Inoculum density was standardized at an optical density of 0.1-0.2 because of hot weather and the potential for poor disease development.

Table 4. Treatment combinations for the halo blight experiment.

| Treatments | Mixture ratio |
|---|---|
| 1. C-20 (R) | Pure stand |
| 2. Montcalm (R) | Pure stand |
| 3. Taylor (S) | Pure stand |
| 4. MIC/Cardinal* (S) | Pure stand |
| 5. Montcalm x Taylor (7R:9S) | $F_2$ |
| 6. Montcalm: Taylor | 7:9 |
| 7. C-20: Montcalm: Taylor: MIC/Cardinal | 1:1:1:1 |

* cv Cardinal was used in 1988.

R = Resistant; S = Susceptible.

### 3.3 Yield and Yield Components

Yields and yield components were determined in the anthracnose, angular leaf spot and halo blight experiments, and the control experiment.

The treatment combinations for the control experiment are given in Table 5. The experiment was planted on June 2 1987 and June 20, 1988. Ten plants per genotype in all the treatments, except for the $F_2$ plants, were selected at random and tagged. These selected plants were used for the measurements of yield and yield components. For the other three experiments, the same plants used for disease assessment were used for yield and yield component measurements.

At harvest maturity tagged plants were pulled by hand according to genotypes and placed in labeled paper bags. Pods per 10 plants were counted. Plants were dried in forced hot air driers for 2 to 5 days and threshed manually. Grain yield was determined for the 10 plants per genotype or expressed per 10 plants. Seeds were counted to determine the number of seeds per 10 plants and seeds per pod. Hundred seed weight was also determined.

The remaining plants in the harvest area were harvested together according to the genotype. The criterion used for genotype identification was plant type, pod color, seed size and seed color (Table 2). Plants were dried in forced hot air driers as above and shelled manually and weighed. The 100 seed weight per genotype was determined. The seed

Table 5. Treatment combinations for the control experiment.

| Treatments | Mixture ratio |
|---|---|
| 1. Domino/Black Magic* | Pure stand |
| 2. C-20 | Pure stand |
| 3. Montcalm | Pure stand |
| 4. Taylor | Pure stand |
| 5. Seafarer | Pure stand |
| 6. MIC/Cardinal** | Pure stand |
| 7. Montcalm x GO 5686 | $F_2$ |
| 8. B83302 x C-20 | $F_2$ |
| 9. Montcalm x Taylor | $F_2$ |
| 10. Montcalm: C-20 | 3:1 |
| 11. Montcal: Taylor | 7:9 |
| 12. Montcalm: Domino/Black Magic | 3:1 |
| 13. C-20: Montcalm: Taylor: MIC/Cardinal | 1:1:1:1 |
| 14. C-20: Montcalm: Taylor: Domino/Black Magic | 1:1:1:1 |
| 15. C-20: Montcalm: Seafarer: Domino/Black Magic | 1:1:1:1 |

* cv Black Magic was used in 1988.

** cv Cardinal was used in 1988.

weights were combined with those from the selected 10 plants to get the total weight per genotype in the harvest area. The total grain weights of all the genotypes were combined to get the total yield per harvest area.

For the $F_2$ populations, plants in the harvest area were bulk harvested, dried and threshed manually and seed weight determined.

3.4 Other Plant Traits

In all four experiments, heights of the selected plants were measured at physiological maturity. The height was taken from the ground level to the growth tip in the 1987 season. In the 1988 season, heights of the type II and III plants were measured from the ground level to the canopy level and from the ground level to the tip of the plant. For the type I the height was measured from the ground level to the growing tip.

Plants were sampled at full bloom and at physiological maturity for dry matter determination. The aim of this exercise was to see the relative interactions between plants in the mixtures and in the monocultures. Plant height was also measured as above during the sampling. Plants were sampled from outside the harvest area but the plants on the outermost edges of the plot were avoided because of border effect.

Two to four plants at full bloom were selected at random per genotype, depending on the availability of the plants. After measuring the height, plants were clipped at ground level and placed in labeled paper bags. Plants were dried in forced hot air driers for five to seven days and dry weight of the plants was then determined.

At physiological maturity, two to four plants were selected at random per genotype. Plant height was measured. Plants were clipped at the ground level, pods were separated and counted. Pods and the remaining plant parts were dried and weighed separately. No samples were taken in the plots with $F_2$ populations.

Least Significant Difference (LSD) was used to rank the means of the tratments. The observed and the expected yield of the mixtures were compared by using t-test, using the error mean square ($s^2$) of contrast.

$$t = \frac{\text{Observed - Expected}}{\sqrt{s^2 \text{ contrasts}}}$$

where $s^2$ contrast $= \Sigma k_i^2 \frac{s^2}{n}$

n = number of observations (replications)

$k_i$ = coefficients of the mixture components.

The expected yield of the mixture is the weighted means of the components in pure stand.

CHAPTER 4

# 4.0 RESULTS

## 4.1 Evaluation of Genotypes, $F_1$ and $F_2$ progenies

### 4.1.1 General

This study was undertaken to identify the reaction of 18 bean (*Phaseolus vulgaris L.*) genotypes for their reaction to anthracnose, angular leaf spot and halo blight. Based on the results, suitable genotypes were selected for use in the mixture compositions. Other characters of the selected genotypes are given in Table 2. $F_1$ and $F_2$ progenies were evaluated to describe or characterize the genetic systems and the genes that confer resistance to pathogens in the study. The information from the $F_2$ segregation ratios of resistant (R): susceptible (S) plants was then used to formulate the mechanical mixtures with the same ratios of R and S components.

### 4.1.2 Anthracnose

Eighteen genotypes of beans were evaluated for their reaction to the Á-race of *Colletotrichum lindemuthianum*. Six genotypes were resistant, eleven susceptible and one moderately susceptible.

The results for the reaction of $F_1$ and $F_2$ plants from a cross of B83302(R) x C-20(S) to the Á-race are given in

Table 6. $F_1$ plants expressed the resistance of the dominant "Are" gene, and the $F_2$ plants segregated in a ratio of 3R:1S with a satisfactory fit determined by Chi-Square Test.

4.1.3 Angular Leaf Spot

The same bean genotypes used for anthracnose were evaluated for their reaction to the Michigan-5 isolate of *Phaeoisariopsis griseola*. Six genotypes were resistant, three moderately resistant, eight susceptible and one moderately susceptible.

$F_1$ and $F_2$ progenies from a cross of Montcalm (S) x GO 5686 (R) were evaluated for their reaction to the Michigan-5 isolate and the results are summarized in Table 7. The $F_1$ plants were susceptible indicating that the resistance in this cross was recessive. From the $X^2$-test, the $F_2$ plants segregated into a 1R:3S ratio, indicating that a single recessive gene in GO 5686 confers resistance to the Michigan-5 isolate.

4.1.4 Halo blight

The 18 genotypes were evaluated for reaction to the Michigan-1 isolate of *Pseudomonas syringae* pv *phaseolicola*. Eleven genotypes had a resistant reaction, five were susceptible and two moderately susceptible.

$F_1$ and $F_2$ progenies from a cross of Montcalm (R) x Taylor (S) were evaluated for their reaction to the Michigan-1 isolate. The $F_1$ plants showed a susceptible reaction in the green-house, indicating that the resistance

Table 6. Parental, $F_1$ and $F_2$ reactions to Á-race of <u>Colletotrichum</u> <u>lindemuthianum</u> and expected ratio of Resistant (R) and Susceptible (S) plants.

Parents: B83302(R) x C-20(S)

$F_1$: R

| $F_2$: Phenotypes | Observed | Expected | $X^2$ | $P^*$ between |
|---|---|---|---|---|
| Resistant | 158 | 154 | 0.080 | |
| Susceptible | 48 | 52 | 0.236 | |
| Total | 206 | 206 | 0.316 | 0.75 - .50 |

Expected Ratio = 3R:1S

R = 0-2 score on 0-5 scale

S = 3-5 score on 0-5 scale

* P > 0.05 indicates $X^2$ value is a good fit for the expected ratio.

Table 7. Parental, $F_1$ and $F_2$ reactions to Michigan-5 isolate of *Phaeoisariopsis griseola* and expected ratio of Resistant (R) and Susceptible (S) plants.

Parents: Montcalm(S) x G05686(R)

$F_1$: S

| $F_2$: Phenotypes | Observed | Expected | $X^2$ | $P^*$ between |
|---|---|---|---|---|
| Resistant | 51 | 45 | 0.672 | |
| Susceptible | 129 | 135 | 0.224 | |
| Total | 180 | 180 | 0.896 | 0.50-0.25 |

Expected Ratio = 1R:3S

R = 0-3 on 0-9 scale

S = 4-9 on 0-9 scale

* $P > 0.05$ indicates $X^2$ is a good fit for the expected ratio.

in Montcalm is conferred by recessive gene(s). The segregation in the $F_2$ plants was studied by evaluating 177 plants. The segregation ratio of 7R:9S was observed (Table 8), and a satisfactory fit was determined using Chi-Square Test indicating two complementary recessive genes confer resistance.

## 4.2 Disease Development in Varieties in Pure Stand and in Mixtures

### 4.2.1 Anthracnose

Disease records for anthracnose were taken approximately on a weekly basis and the first recording was made as soon as the symptoms appeared. The records were taken until the maximum levels for the disease were attained.

Levels of the disease were higher in 1987 than in the 1988 season, which may have been due to the use of two spreader rows in 1987. Only one spreader row was used in 1988. The summer of 1988 was also much hotter than in 1987.

The means of disease scores for anthracnose in 1987 on Domino and C-20, the susceptible varieties, in pure stand and in mixtures with resistant and/or susceptible varieties are given in Table 9. There were no disease symptoms observed on resistant components in pure stand or in mixtures. The levels of the disease progress curves, showing the levels of anthracnose present in 1987 on Domino and C-20, are shown on Figures 1 (a) and 1(b).

Table 8. Parental, $F_1$ and $F_2$ reactions to Michigan-1 isolate of _Pseudomonas_ _syringae_ pv _phaseolicola_ and expected ratio of Resistant (R) and Susceptible (S) plants.

Parents: Montcalm(R) x Taylor(S)

$F_1$: S

| $F_2$: Phenotypes | Observed | Expected | $X^2$ | $P^*$ between |
|---|---|---|---|---|
| Resistant | 69 | 77 | 0.731 | |
| Susceptible | 108 | 100 | 0.563 | |
| Total | 177 | 177 | 1.294 | 0.50-0.25 |

Expected Ratio = 7R:9S

R = 0-2 score on 0-5 scale

S = 3-5 score on 0-5 scale

* P > 0.05 indicates $X^2$ is a good fit for the expected ratio.

Table 9. Mean disease scores (0-5 scale) on the leaves and the pods for C-20 and Domino in pure stand and in mixtures for Á-race of C. lindemuthianum in 1987 season.

| Varieties and Mixture Components | SCORING DATES | | | | | |
|---|---|---|---|---|---|---|
| | Leaves | | | | | Pods |
| | 7-2 | 7-9 | 7-16 | 7-24 | 8-3 | At harvest |
| 1 | 0.80a | 2.77a | 3.60ab | 3.80a | 4.00ab | 3.37ab |
| 2 | 0.57b | 1.70b | 3.23ab | 3.53a | 3.87b | 4.07a |
| 3 | 0.90a | 2.87a | 3.87a | 4.10a | 4.40a | 3.67ab |
| 4 | 0.90a | 2.07ab | 3.53ab | 4.20a | 4.40a | 3.47ab |
| 5 | 0.83a | 2.53ab | 3.23ab | 3.70a | 4.00ab | 3.57ab |
| 6 | 0.83a | 2.50ab | 3.13b | 3.77a | 3.93ab | 3.93b |
| 7 | 0.83a | 2.27ab | 3.33ab | 3.63a | 4.17ab | 3.07b |
| 8 | 0.83a | 2.30ab | 3.33ab | 3.77a | 4.03ab | 3.47ab |
| Means | 0.81 | 2.38 | 3.41 | 3.81a | 4.10 | 3.45 |
| CV% | 15.8 | 21.4 | 11.3 | 10.0 | 7.3 | 16.5 |

Numbers within columns followed by the same letter are not significantly different at P = .05.

Inoculation date: 6-22-1987

Varieties and Mixture Components:

1. Domino (S)
2. C-20 (S)
3. Domino: C-20 (1:1)
4. C-20: Domino (1:1)
5. Domino: Seafarer (R) (1:1)
6. Domino: Montcalm (R) (1:3)
7. Domino: C-20: Seafarer: Montcalm (1:1:1:1)
8. C-20: Domino: Seafarer: Montcalm (1:1:1:1)

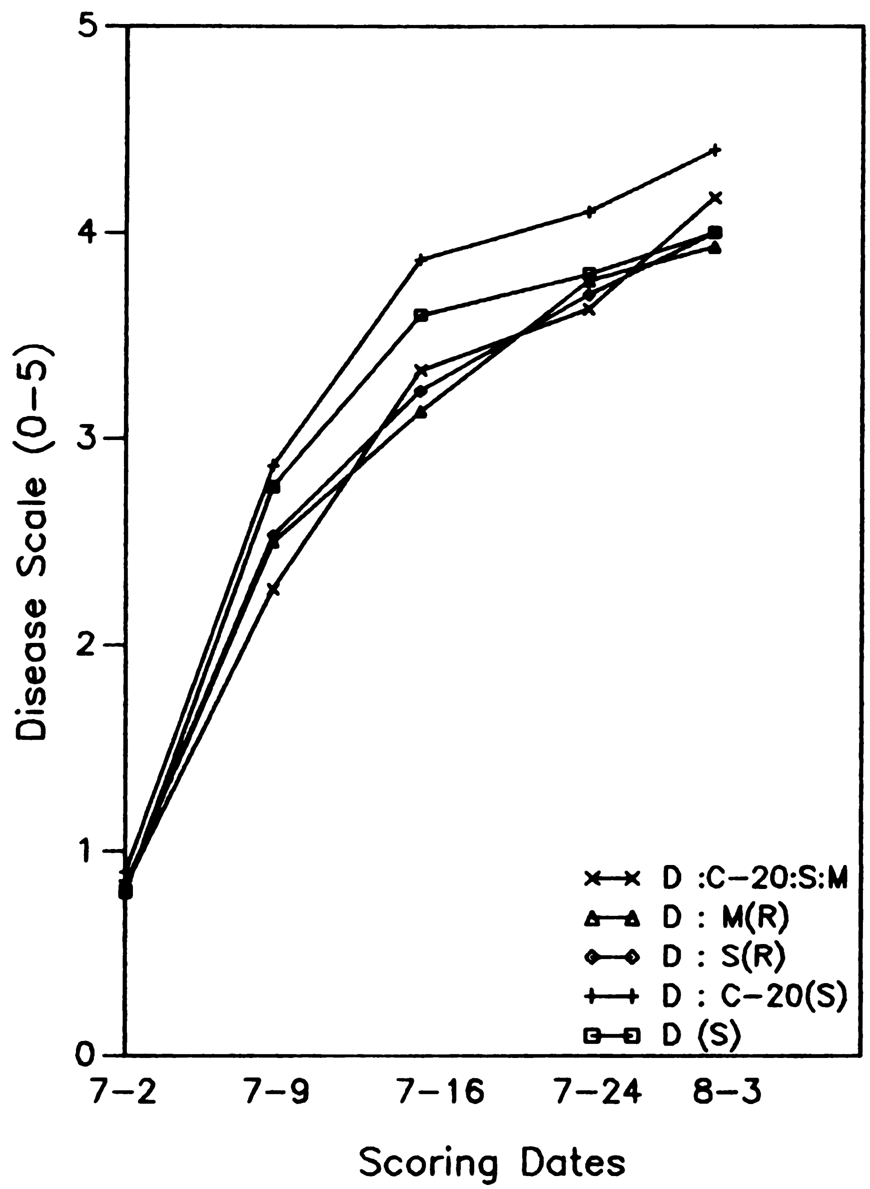


Figure 1(a). Anthracnose progress curves of Domino in pure stand and in mixtures in 1987 season.

D = Domino  S = Seafarer  M = Montcalm

(R) = Resistant  (S) = Susceptible

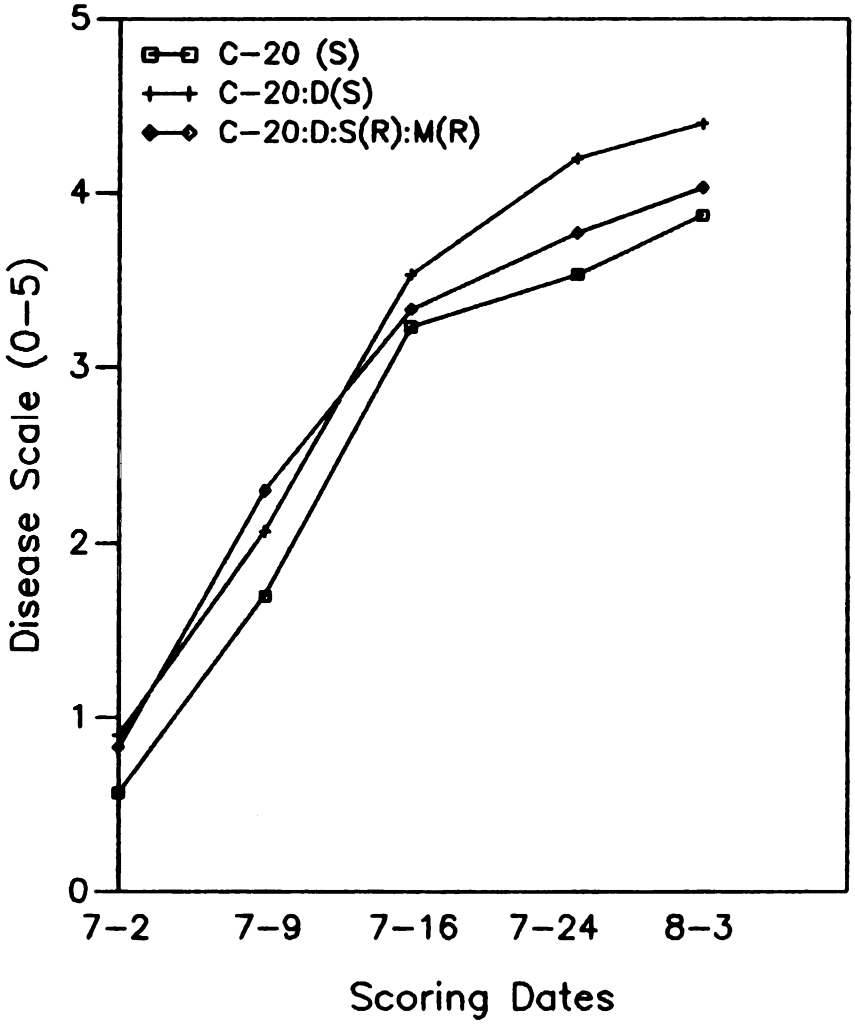


Figure 1(b). Anthracnose progress curves of C-20 in pure stand and in mixtures in 1987 season.

D = Domino S = Seafarer M = Montcalm

(R) = Resistant (S) = Susceptible

There were no statistically significant differences between the disease levels in Domino and C-20 in pure stand and with different components for all the recordings. The initial disease levels were similar for all the combinations (Table 9, Figures 1a and 1b). The rates of disease increase between the first and the second dates of assessment were very high for Domino in pure stand and in all the combinations compared to the later stage of the epidemic (Figure 1a). There were variations in disease levels for Domino depending on the combination. At the second assessment date, Domino in pure stand and in mixtures with C-20 had higher disease levels than other combinations.

Domino in the mixtures with resistant varieties, Montcalm and Seafarer, in all the three combination (5, 6 and 7) as shown in Table 9, Figure 1a, had lower disease levels. The rate of disease development was also low after the first week of recording.

Disease levels on C-20 in the 1987 season were similar to those on Domino, except that C-20 in pure stand had lower disease levels throughout the recording period (Table 6 and Figure 1b). This could be due to interplot interference,that is, the plots of C-20 were bordered by plots of resistant varieties.

C-20 in all the combinations had high disease levels and displayed high rates of disease development. After the second week of recording, disease incidence started to level off. The highest disease level was when C-20 was mixed with

Domino. Lower disease levels were observed when C-20 was mixed with Montcalm, Seafarer and Domino. Montcalm and Seafarer probably gave some protection as they had in the case of Domino.

Means of disease scores and disease progress curves for anthracnose in the 1988 season are given in Table 10, Figures 2a and 2b. Black Magic, susceptible and a sister selection of Domino, was used instead of Domino in 1988 because seeds of Domino were in short supply.

The patterns of disease levels and the rates of disease development in 1988 were different from those of the 1987 season. The initial disease levels were different, although not statistically so, for Black Magic and C-20 in different combinations. The disease levels at the third time of scoring were not different statistically but the levels at the last scoring and on the pods were significantly different (Table 10). Disease progressed very rapidly for the first two weeks and thereafter levelled off (Figure 2a). Black Magic in mixture with C-20 had the highest disease level but the disease level was lower when it was mixed with the resistant Montcalm or Seafarer, which had no disease, similar to the 1987 season. The resistant varieties are believed to have given some protection to the susceptible Black Magic. The resistant varieties in the presence of susceptible C-20 also provided some protection.

Disease levels and progression in C-20 in pure stand and in the mixtures were similar to that of Black Magic

Table 10. Mean disease scores (0-5 scale) on the leaves and the pods for C-20 and Black Magic in pure stand and in mixtures for Á-race of *C. lindemuthianum* in 1988 season.

| Varieties and Mixture Components | SCORING DATES | | | | | |
|---|---|---|---|---|---|---|
| | Leaves | | | | Pods | |
| | 8-13 | 8-19 | 8-26 | 9-6 | 9-6 | At harvest |
| 1 | 0.83ab | 2.43a | 3.47a | 3.73a | 3.73a | 4.23a |
| 2 | 1.10a | 2.50a | 3.47a | 4.00a | 3.67ab | 4.03ab |
| 3 | 0.93ab | 2.37a | 3.43a | 3.73a | 3.57abc | 4.13a |
| 4 | 0.80ab | 2.60a | 3.53a | 3.97a | 3.53abc | 3.80abc |
| 5 | 0.53ab | 1.73b | 2.90a | 3.17bc | 3.00de | 3.63abc |
| 6 | 0.43b | 1.73b | 3.20a | 3.33b | 3.10cd | 3.87ab |
| 7 | 0.63ab | 2.10ab | 3.13a | 3.27bc | 3.20bcd | 3.23c |
| 8 | 0.47b | 1.80b | 3.03a | 2.93c | 2.60e | 3.43bc |
| Means | 0.72 | 2.16 | 3.27 | 3.52 | 3.30 | 3.80 |
| CV% | 48.8 | 13.3 | 11.6 | 6.3 | 8.4 | 9.5 |

Numbers within columns followed by the same letter are not significantly different at P = .05.

Inoculation date: 7-19-1988

Varieties and mixture components:

1. Black Magic (S)
2. C-20 (S)
3. Black Magic: C-20 (1:1)
4. C-20: Black Magic (1:1)
5. Black Magic: Seafarer (R) (1:1)
6. Black Magic: Montcalm (R) (1:3)
7. Black Magic: C-20: Montcalm: Seafarer (1:1:1:1)
8. C-20: Black Magic: Montcalm: Seafarer (1:1:1:1)

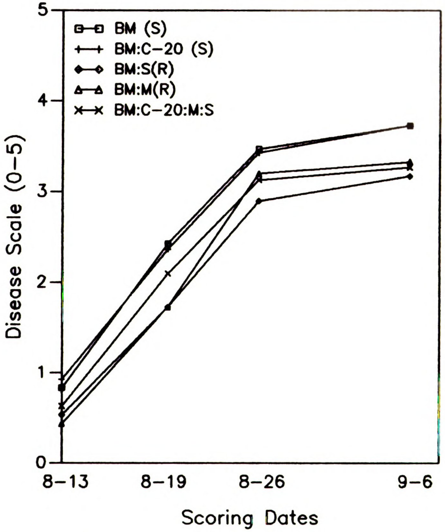


Figure 2(a). Anthracnose progress curves of Black Magic in pure stand and in mixtures in 1988 season.

BM = Black Magic  S = Seafarer  M = Montcalm

(R) = Resistant  (S) = Susceptible

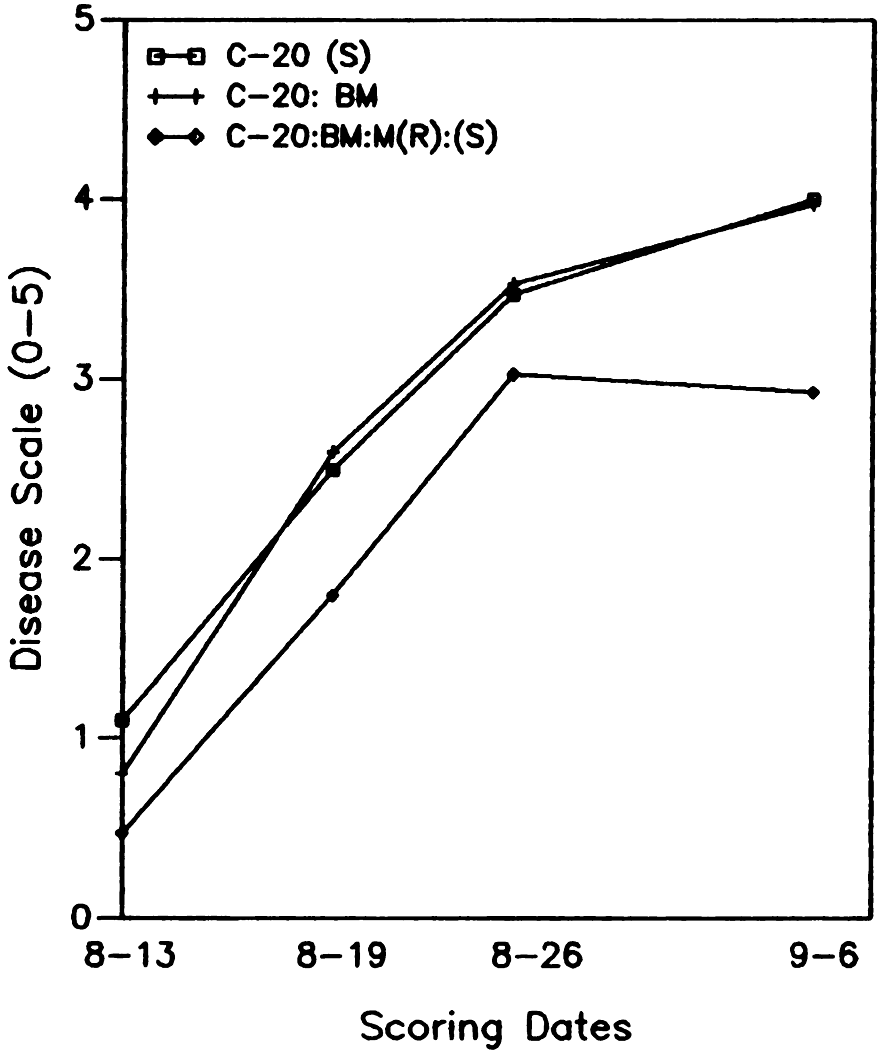


Figure 2(b) Anthracnose progress curves of C–20 in pure stand and in mixture in 1988 season.

BM = Black Magic   S = Seafarer   M = Montcalm

(R) = Resistant   (S) = Susceptible

(Figures 2a and 2b). Disease levels and progression were high when C-20 was mixed with Black Magic as compared to the mixture with two resistant varieties (Figure 2b).

Unlike 1987, the symptoms on the pods were significantly different for the different combinations (Table 10). Disease levels on the pods of both Black Magic and C-20 were significantly low when they were in a four-component mixture. This could have resulted from protection afforded by the resistant varieties. Alternatively, Montcalm and Seafarer, being determinate and earlier maturing, may have created a microenvironment that was not conducive to greater disease development.

4.2.2 <u>Angular leaf spot</u>

As with anthracnose, there was a high incidence of angular leaf spot in the 1987 season. The high disease epidemic may have resulted from the use of two spreader rows, producing excessive inoculum.

There were no significant differences in disease levels for Montcalm and Taylor, the susceptible varieties, in pure stand or in mixtures with the resistant varieties, C-20 and Domino. No disease symptoms were observed on C-20 and Domino, thus no disease reaction was recorded. Mean disease scores and disease progress curves are shown in Table 11, Figures 3a and 3b. For both Montcalm and Taylor, disease progress was very rapid throughout the recording period until the maximum level was reached. The resistant varieties did not appear to give any protection.

Table 11. Mean disease scores (0-9 scale) on the leaves and the pods for Taylor and Montcalm in pure stand and in mixtures for Michigan-5 isolate of *P. griseola* in 1987 season.

| Varieties and Mixture Components | SCORING DATES | | | | | |
|---|---|---|---|---|---|---|
| | Leaves | | | | | Pods |
| | 7-7 | 7-17 | 7-23 | 7-28 | 8-9 | At harvest |
| 1 | 0.80a | 3.77a | 6.47a | 7.93a | 9.00a | 6.20b |
| 2 | 0.53ab | 3.70a | 6.50a | 7.83a | 8.53a | 8.77a |
| 3 | 0.27ab | 3.23a | 6.43a | 8.03a | 9.00a | 8.37a |
| 4 | 0.23ab | 3.17a | 6.90a | 8.60a | 9.00a | 5.13b |
| 5 | 0.13b | 2.90a | 6.33a | 8.23a | 9.00a | 8.43a |
| Means | 0.39 | 3.35 | 6.53 | 8.13 | 8.9 | 7.31 |
| CV% | 84.2 | 21.6 | 7.7 | 5.8 | 4.11 | 14.9 |

Numbers within columns followed by the same letter are not significantly different at P = .05.

Inoculation date: 8-23-1989

Varieties and mixture components:

1. Montcalm (S)
2. Montcalm: C-20 (R) (3:1)
3. Montcalm: C-20: Domino (R): Taylor (1:1:1:1)
4. Taylor (R)
5. Taylor: Montcalm: C-20: Domino (1:1:1:1)

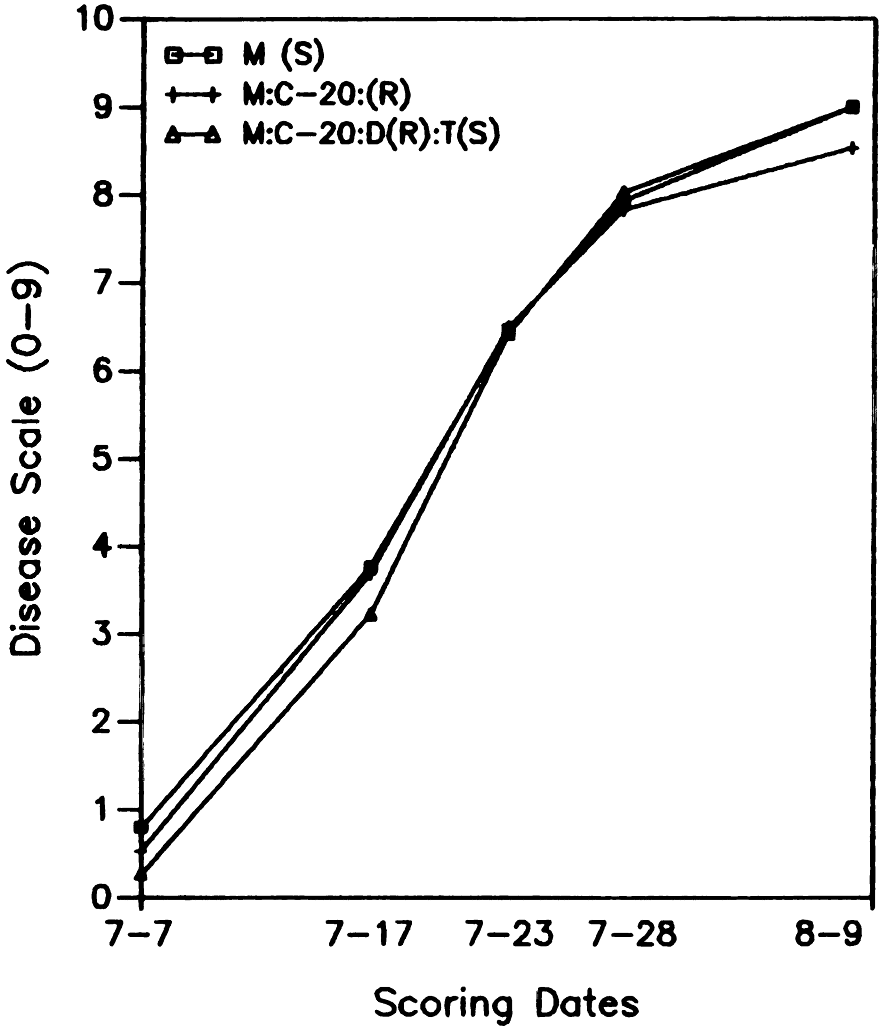


Figure 3(a). Angular leaf spot progress curves of Montcalm in pure stand and in mixtures in 1987 season.

M = Montcalm D = Domino T = Taylor

(R) = Resistant (S) = Susceptible

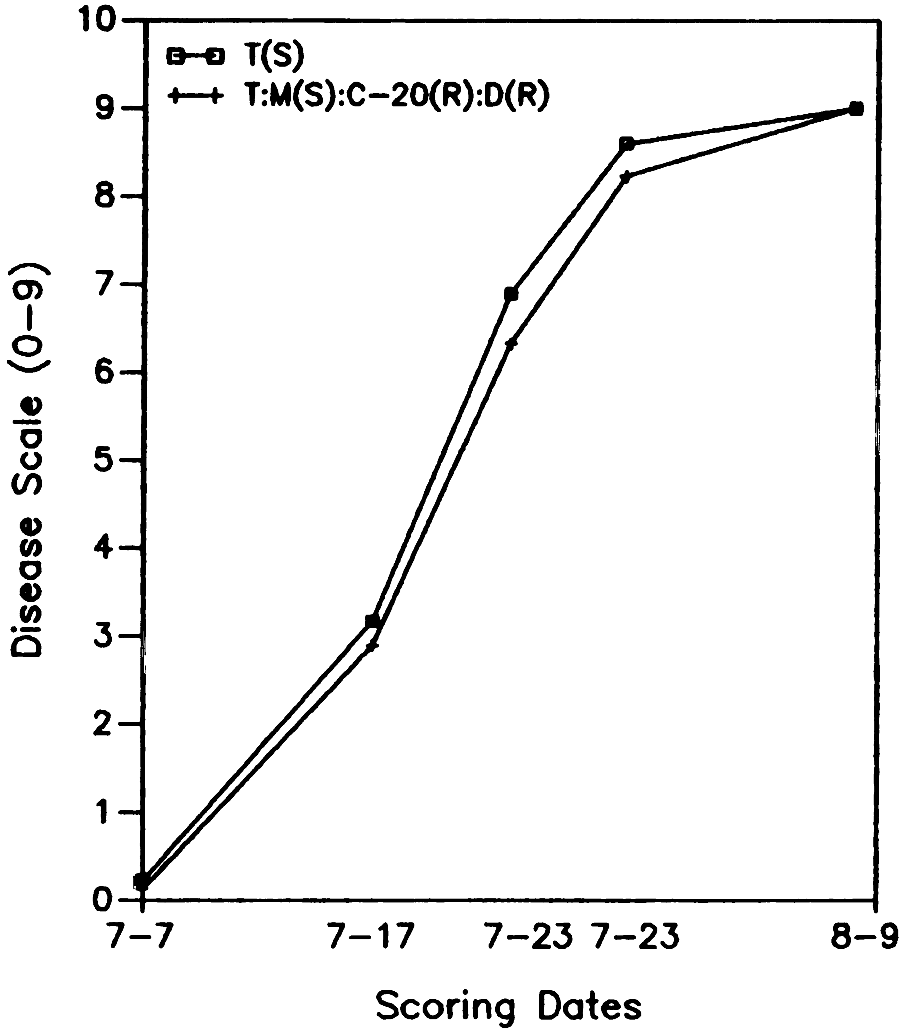


Figure 3(b). Angular leaf spot progress curves of Taylor in pure stand and in mixture in 1987 season.

T = Taylor M = Montcalm D = Domino

(R) = Resistant (S) = Susceptible

Disease levels on the pods of Montcalm and Taylor were lower in mixtures than in pure stands. This could have been due to unfavorable conditions for disease development because plants in pure stand were defoliated by the disease thus exposing the pods. With reduced canopy cover no moisture was retained in the plant microenvironment. The resistant varieties in the mixtures were Type II and late maturing. Their dense foliage may have provided shading and moisture retention in the canopy. This in turn could have provided a microenvironment suitable for disease development on the pods.

Disease patterns and progress curves for angular leaf spot in the 1988 season were different from those of 1987. The epidemic level of the disease was low in 1988 as compared to 1987 probably because only one spreader row was used. Also, the first leaves that dropped from the spreader rows were removed in an attempt to reduce the amount of inoculum.

The initial disease levels were significantly different (Table 12, Figures 4a and 4b). Montcalm in pure stand had the highest initial disease level. There were no statistical differences in disease levels during the second scoring but Montcalm and Taylor in pure stand tended to have higher levels than in the mixtures. Both varieties in the mixture with resistant varieties had low disease levels.

For the first two weeks the disease progress was slow on Montcalm and Taylor in pure stand and in the mixtures.

Table 12. Mean disease scores (0-9 scale) on the leaves and the pods for Taylor and Montcalm in pure stand and in mixtures for Michigan-5 isolate of _P. griseola_ in 1988 season.

| Varieties and Mixture Components | SCORING DATES | | | | | | |
|---|---|---|---|---|---|---|---|
| | Leaves | | | | | | Pods |
| | 7-28 | 8-4 | 8-10 | 8-15 | 8-21 | 8-28 | At harvest |
| 1 | 0.67a | 0.97a | 2.10a | 5.20a | 7.03a | 8.50a | 8.53a |
| 2 | 0.23b | 0.50b | 1.17b | 3.57b | 6.07a | 8.30a | 8.47a |
| 3 | 0.30b | 0.50b | 1.10b | 3.20b | 6.30a | 8.70a | 8.13a |
| 4 | 0.17b | 0.80ab | 1.63ab | 3.97b | 7.47a | 8.83a | 8.63a |
| 5 | 0.20b | 0.53b | 1.20b | 3.33b | 6.87a | 8.80a | 8.47a |
| Means | 0.31 | 0.66 | 1.44 | 3.85 | 6.75 | 8.63 | 8.45 |
| CV% | 45.0 | 29.6 | 24.9 | 11.1 | 12.0 | 3.4 | 4.4 |

Numbers within columns followed by the same letter are not significantly different at P = .05.

Inoculation date: 7-15-1988

Varieties and mixture components:

1. _Montcalm_ (S)
2. _Montcalm_: C-20 (R) (3:1)
3. _Montcalm_: C-20: Black Magic (R): Taylor (1:1:1:1)
4. _Taylor_ (S)
5. _Taylor_: Montcalm: C-20: Black Magic (1:1:1:1)

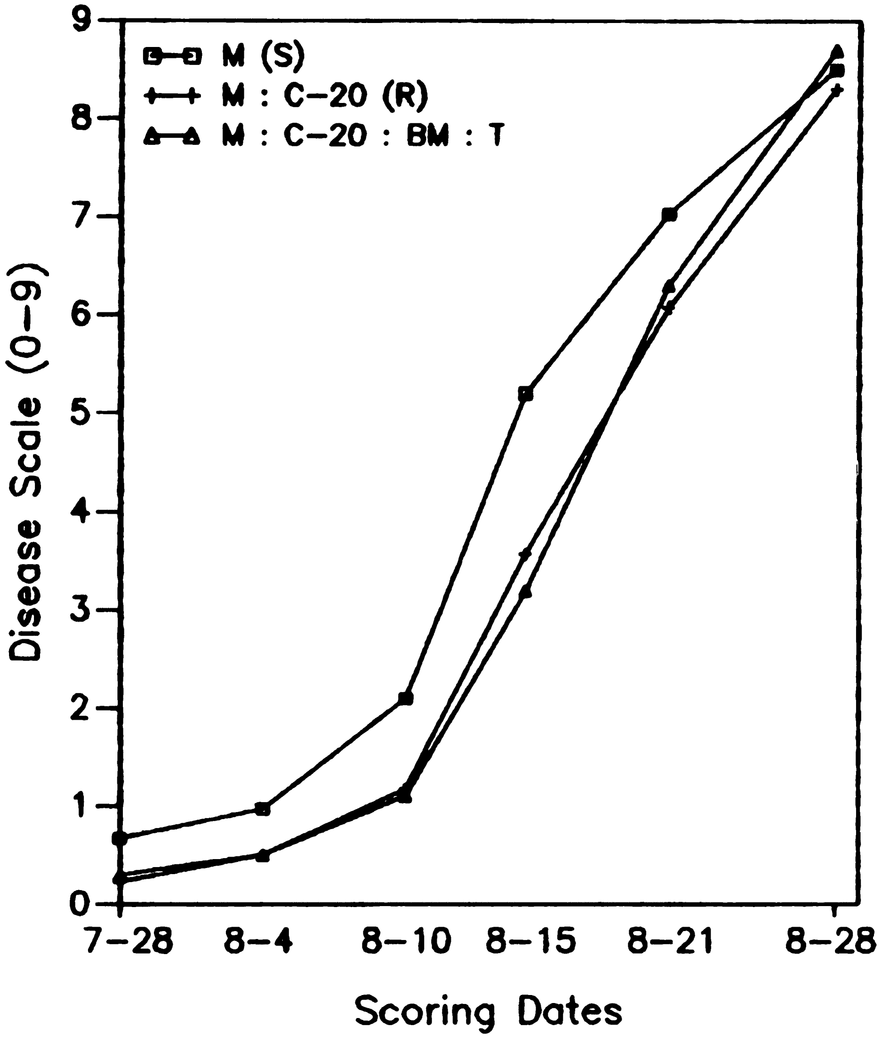


Fig 4(a). Angular leaf spot progress curves of Montcalm in pure stand and in mixture in 1988 season

T = Taylor M = Montcalm BM = Black Magic

R = Resistant S = Susceptible

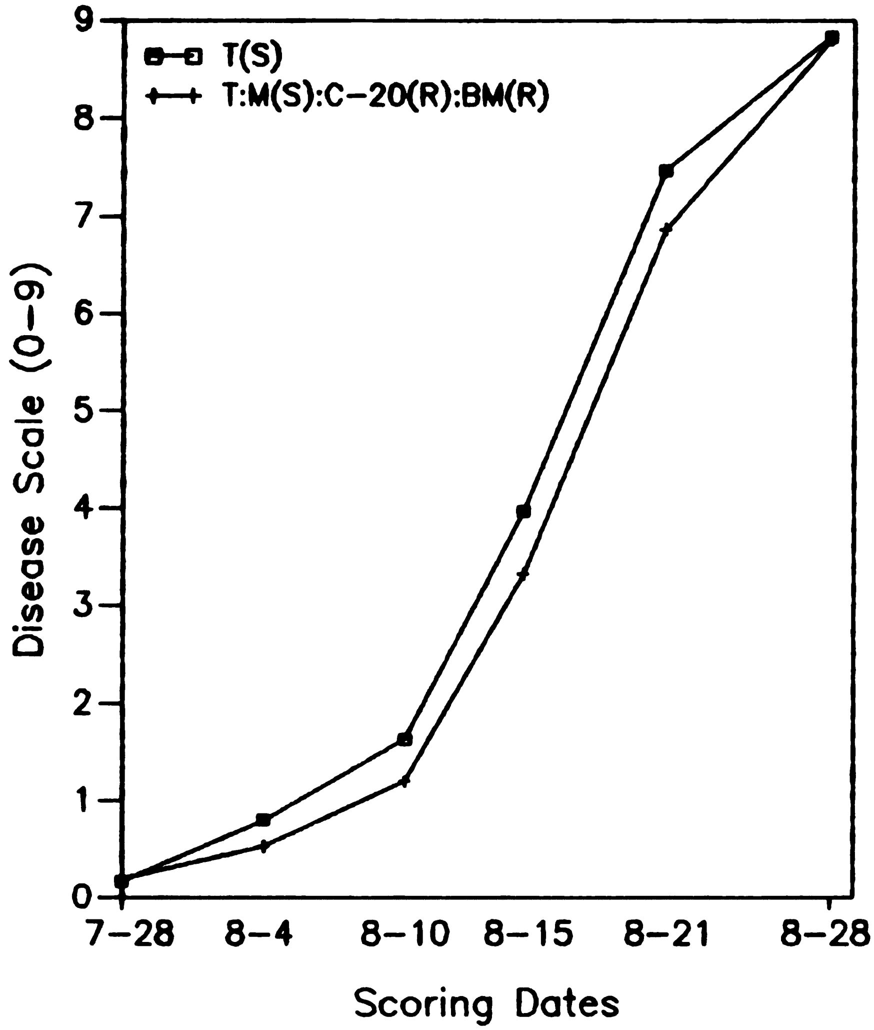


Fig 4(b). Angular leaf spot progress curves of Taylor in pure stand and in mixture in 1988 season

T = Taylor M = Montcalm BM = Black Magic

(R) = Resistant (S) = Susceptible

Later, disease progressed very rapidly until the maximum level was reached (Figures 4a and 4b).

There were no significant differences for the disease levels on pods in the 1988 season, unlike 1987. This was probably due to wet weather during pod filling, at physiological maturity, and during the harvest period.

4.2.3 Halo blight

There was no serious incidence of halo blight disease. The disease reached only intermediate levels in both 1987 and 1988 seasons. Hot and dry summers might have contributed to slow disease development. Halo blight is favored by cool (16-20½C) and moist conditions.

Mean disease scores for the 1987 season are given in Table 13. The disease progress curves of Taylor (susceptible) and MIC (moderately resistant) in pure stand and in the mixtures with resistant varieties Montcalm and C-20 are shown in Figure 5. There were significant differences in disease levels on Taylor and MIC except for the second assessment. The high CV for the second scoring data is an indication of very variable scores. However, Taylor in pure stand had the highest disease level.

The initial disease levels were similar in pure stand and in mixtures (Figure 5). Disease progress for Taylor in pure stand was very high for the first three weeks and then leveled off. The disease progress for Taylor in the mixtures increased rapidly only for the first two weeks. The resistant varieties appeared to protect Taylor. The

Table 13. Mean disease scores (0-9 scale) on the leaves and the pods for Taylor and MIC in pure stand and in mixtures for Michigan-1 isolate of _P. s._ pv _phaseolicola_ in 1987 season.

| Varieties and Mixture Components | SCORING DATES | | | | | |
|---|---|---|---|---|---|---|
| | Leaves | | | | | Pods |
| | 7-5 | 7-14 | 7-21 | 7-26 | 8-6 | 8-6 |
| 1 | 0.33a | 1.80a | 3.93a | 5.40a | 5.87a | 1.77ab |
| 2 | 0.13b | 0.40a | 1.33c | 1.73b | 2.30c | 0.53b |
| 3 | 0.20b | 1.57a | 3.87a | 4.20a | 5.23a | 1.53ab |
| 4 | 0.13b | 0.47a | 3.27ab | 3.93a | 4.57ab | 2.40a |
| 5 | 0.17b | 0.57a | 1.47bc | 1.87b | 2.87bc | 0.30b |
| Means | 0.19 | 0.96 | 2.77 | 3.43 | 4.12 | 1.31 |
| CV% | 37.2 | 88.3 | 36.6 | 26.2 | 22.7 | 65.5 |

Numbers within columns followed by the same letter are not significantly different at P = .05.

Inoculation date: 6-30-1987

Varieties and mixture components:

1. _Taylor_ (S)
2. _MIC_ (MS)
3. _Taylor_: Montcalm (R) (9:7)
4. _Taylor_: Montcalm: C-20R: MIC (1:1:1:1)
5. _MIC_: Taylor: C-20: Montcalm (1:1:1:1)

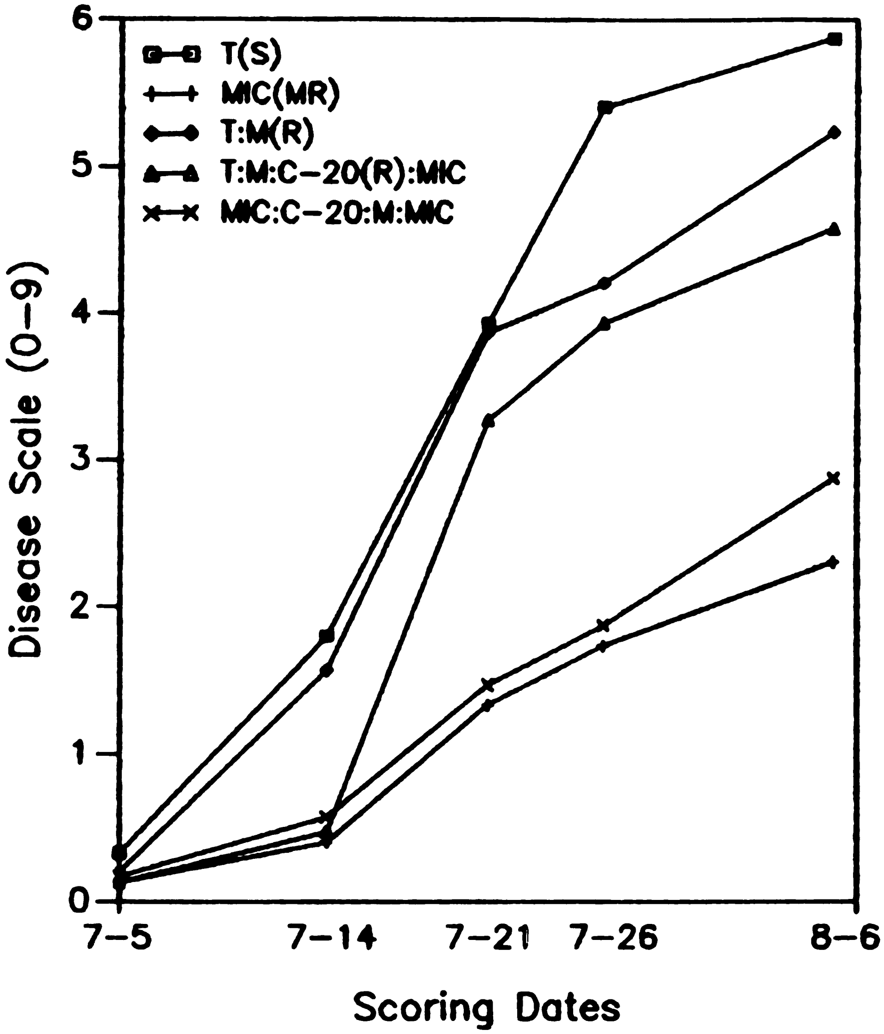


Figure 5. Halo blight progress curve of Taylor and MIC in pure stand and in mixtures in 1987 season

T = Taylor M = Montcalm

(R)=Resistant (MR)=Moderately Resistant

(S)=Susceptible

four-component mixture was more effective than the two-component mixture. Possibly, MIC which is only moderately susceptible contributed to the protective role.

MIC in pure stand and in the mixture had lower disease levels as well as lower disease progress. The level in the mixture was slightly high which could have been due to additional inoculum produced on Taylor.

Disease patterns for the 1988 season were similar to 1987. Cardinal (moderately resistant), which is earlier maturing than MIC, was used because of late planting in 1988. The results for the mean disease scores are summarized in Table 14. There were significant differences in disease scores between Taylor and Cardinal. The initial disease levels were high for Taylor in pure stand in the four-component mixtures. The disease progress for Taylor for all the combinations was very rapid throughout the season although Taylor in mixture with Montcalm had a low initial level (Figure 6). Cardinal had similar disease levels and progress in pure stand and in mixture.

Both mixtures protected Taylor although the four-component mixture was slightly less protective than the two component mixture. The effect of microenvironment may have played a role. The four-component mixture had C-20 which is a Type II and a late maturing variety. Taylor, being a short variety, may have been shaded, thus, altering the microenvironment and increasing the level of disease.

Table 14. Mean disease scores (0-9 scale) on the leaves for varieties Taylor and Cardinal in pure stand and in mixtures for Michigan-1 isolate of *P. s.* pv *phaseolicola* in 1988 season.

| Varieties and Mixture Components | SCORING DATES Leaves | | | |
|---|---|---|---|---|
| | 8-12 | 8-16 | 8-23 | 8-31 |
| 1 | 1.80a | 4.40a | 5.67a | 6.30a |
| 2 | 0.80bc | 1.73b | 2.00c | 2.30c |
| 3 | 0.87bc | 2.23b | 3.37bc | 4.30b |
| 4 | 1.87ab | 3.23ab | 4.37ab | 5.03b |
| 5 | 0.63c | 1.70b | 2.20c | 2.27c |
| Means | 1.33 | 2.66 | 3.52 | 4.04 |
| CV% | 37.8 | 32.9 | 22.3 | 11.9 |

Numbers within columns followed by the same letter are not significantly different at P = .05.

Inoculation date: 7-17-1988

Varieties and mixture components:

1. Taylor (s)
2. Cardinal (MS)
3. Taylor: Montcalm (R) (9:7)
4. Taylor: Montcalm: C-20 (R): Cardinal (1:1:1:1)
5. Cardinal: Taylor: Montcalm: C-20 (1:1:1:1)

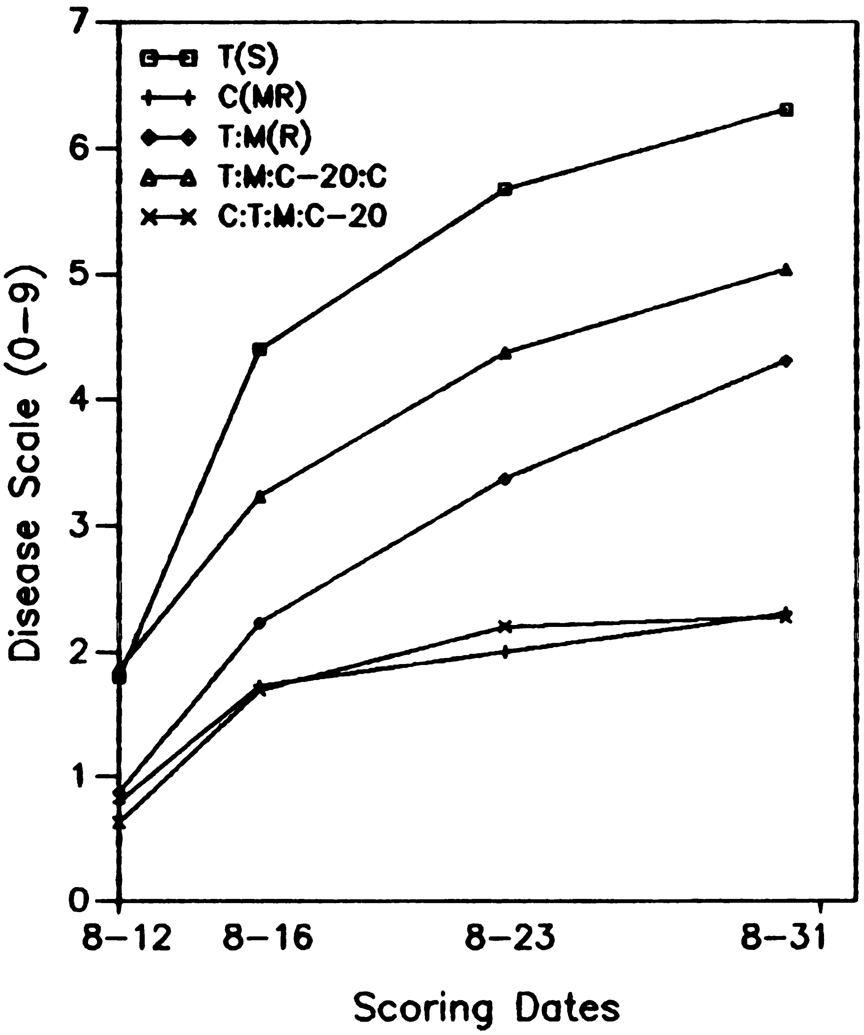


Figure 6. Halo blight progress curves of Taylor and Cardinal in pure stand and in mixtures in 1988 season.

T = Taylor C = Cardinal M = Montcalm

(R)=Resistant (MR)=Moderately Resistant

(S)=Susceptible

## 4.3 Disease Development in $F_2$ Populations

### 4.3.1 Anthracnose

The development of anthracnose was assessed weekly in the field on individual $F_2$ plants from population of B83002 (R) x C-20 (S) inoculated with the Á-race of anthracnose. The source of inoculum was the spreader rows. The resistance in B83002 is conferred by a single dominant gene, the "Are". The greenhouse inoculation results indicated a segregation ratio of 3R:1S. About 250 plants per replication were assessed in three replications. Results for the mean disease scores for 1987 and 1988 seasons are given in Table 15. Disease developed very slowly and there were fewer plants with disease as compared to the expected segregation ratio, at every scoring time. But at the last two scoring date the ratio of R:S was 3:1.

### 4.3.2 Angular leaf spot

About 250 $F_2$ plants per replication from a cross of Montcalm(S) x GO 5686(R) were evaluated in three replications for their reaction to the Michigan-5 isolate. Assessments were made approximately on a weekly basis. Data from the greenhouse evaluation indicated that the $F_2$ population segregated into 1R:3S. The results for the disease assessments are summarized in Tables 16 and 17. Disease development was very slow in the $F_2$ populations, particularly in the 1987 season, as compared to disease development in the mechanical mixtures. At every recording

Table 15. Disease development in the $F_2$ segregating populations of B83302 (R) x C-20 (S) for the reaction to Á-race of *C. lindemuthianum* in the field during the 1987 and 1988 seasons.

| Scale | Scoring dates | | | | | |
|---|---|---|---|---|---|---|
| | 1987 | | | | 1988 | |
| | 7-3 | 7-10 | 7-17 | 7-25 | 8-17 | 8-27 |
| 0 | 219 | 200 | 172 | 171 | 184 | 174 |
| 1 | 20 | 16 | 12 | 11 | 5 | 1 |
| 2 | 15 | 13 | 10 | 12 | 7 | 4 |
| 3 | 1 | 19 | 25 | 20 | 19 | 11 |
| 4 | 0 | 6 | 21 | 24 | 11 | 19 |
| 5 | 0 | 0 | 10 | 16 | 3 | 22 |
| R | 254 | 229 | 201 | 194 | 199 | 179 |
| S | 1 | 26 | 57 | 60 | 34 | 51 |

Table 16. Disease development in the $F_2$ segregating population of GO5686 (R) x Montcalm (S) for the reaction to Michigan-5 isolate of *P. griseola* in the field during the 1987 season.

| Scale | Scoring dates | | | | |
|---|---|---|---|---|---|
| | 7-8 | 7-16 | 7-23 | 7-28 | 9-5 |
| 0 | 234 | 193 | 188 | 183 | 68 |
| 1 | 7 | 5 | 5 | 7 | 7 |
| 2 | 6 | 7 | 3 | 7 | 20 |
| 3 | 5 | 12 | 3 | 4 | 3 |
| 4 | 3 | 20 | 4 | 2 | 13 |
| 5 | 0 | 12 | 18 | 6 | 14 |
| 6 | 0 | 5 | 22 | 8 | 10 |
| 7 | 0 | 0 | 0 | 10 | 19 |
| 8 | 0 | 0 | 0 | 21 | 23 |
| 9 | 0 | 0 | 0 | 8 | 79 |
| R | 252 | 213 | 197 | 201 | 97 |
| S | 3 | 37 | 57 | 54 | 157 |

Table 17. Disease development in the $F_2$ segregating population of GO 5686 (R) x Montcalm (S) for the reaction to Michigan-5 isolate of *P. griseola* in the field during the 1988 season.

| Scale | Scoring dates | | | | |
|---|---|---|---|---|---|
| | 7-29 | 8-12 | 8-17 | 8-22 | 9-2 |
| 0 | 223 | 182 | 156 | 147 | 106 |
| 1 | 8 | 19 | 7 | 2 | 1 |
| 2 | 6 | 12 | 11 | 7 | 5 |
| 3 | 5 | 13 | 5 | 3 | 1 |
| 4 | 1 | 11 | 20 | 11 | 7 |
| 5 | 2 | 6 | 17 | 9 | 14 |
| 6 | 0 | 2 | 14 | 14 | 14 |
| 7 | 0 | 0 | 13 | 30 | 26 |
| 8 | 0 | 0 | 1 | 23 | 53 |
| 9 | 0 | 0 | 0 | 1 | 19 |
| R | 241 | 226 | 180 | 159 | 112 |
| S | 3 | 19 | 65 | 86 | 132 |

time there were more disease-free plants than expected. Even at the end of the season there were more disease-free plants than expected, as compared to the greenhouse results. The last recording was not done in the 1988 season due to frost damage.

Plants in this $F_2$ population were very variable for many characters, including plant type, maturity period, and branching habit. The variability and the protection of susceptible plants by resistant plants may have contributed to the low disease development.

4.3.3 Halo blight

Halo blight did not establish well in either the 1987 or 1988 seasons due to hot and dry summers. The $F_2$ population from the cross of Montcalm(R) x Taylor(S) was planted in the field as one of the entries in the halo blight experiment. From the greenhouse evaluation of the population for its reaction to the Michigan-1 isolate, a segregation ratio of 7R:9S was observed. Complementary recessive genes seem to be conferring susceptibility.

Disease development was assessed on a weekly basis both for the 1987 and 1988 on about 200 plants per replication. The mean disease scores are recorded in Tables 18 and 19. Disease developed very slowly and at every recording more disease-free plants than expected were observed.

For the latter part of 1988 disease started to develop fast. At the last scoring date more plants developed symptoms although the segregation ratio was still less than

Table 18. Disease development in the $F_2$ segregating population of Montcalm (R) x Taylor (S) for the reaction to Michigan-1 isolate of *P. s.* pv *phaseolicola* in the field during the 1987 season.

| Scale | Scoring dates | | | | |
|---|---|---|---|---|---|
| | 7-6 | 7-13 | 7-22 | 7-28 | 8-7 |
| 0 | 224 | 209 | 134 | 97 | 72 |
| 1 | 21 | 28 | 41 | 35 | 20 |
| 2 | 4 | 3 | 38 | 53 | 35 |
| 3 | 0 | 2 | 29 | 49 | 48 |
| 4 | 0 | 3 | 5 | 9 | 16 |
| 5 | 0 | 0 | 0 | 1 | 2 |
| R | 148 | 241 | 215 | 185 | 127 |
| S | 1 | 5 | 34 | 58 | 66 |

Table 19. Disease development in the $F_2$ segregating population of Montcalm (R) x Taylor (S) for the reaction to Michigan-1 isolate of *P. s.* pv *phaseolicola* in the field during the 1988 season.

| Scale | Scoring dates | | | |
|---|---|---|---|---|
| | 8-7 | 8-16 | 8-25 | 9-1 |
| 0 | 141 | 90 | 57 | 50 |
| 1 | 22 | 12 | 6 | 7 |
| 2 | 15 | 14 | 15 | 13 |
| 3 | 8 | 21 | 13 | 11 |
| 4 | 1 | 21 | 26 | 19 |
| 5 | 2 | 9 | 15 | 14 |
| 6 | 0 | 13 | 33 | 32 |
| 7 | 0 | 2 | 10 | 13 |
| 8 | 0 | 0 | 11 | 19 |
| 9 | 0 | 1 | 2 | 3 |
| R | 185 | 139 | 91 | 84 |
| S | 3 | 47 | 97 | 97 |

the expected ratio of 7R:9S. In this case hot weather could have been one of the causes of slow disease development. Plant variability and complexity of the $F_2$ population as well as protection of susceptible plants by the resistant segregants could have been an additional reason.

## 4.4 Grain Yield, Yield Components and Plant Traits

### 4.4.1 Control

#### 4.4.1.1 Seed yield

This is a "control" experiment because it was not inoculated with any of the pathogen used in the other experiments. The entries in this experiment represent those entries involved in the anthracnose, angular leaf spot and halo blight experiments.

Seed yield in kg/ha and the ranks of the entries in 1987, 1988 and the two years combined are given in Table 20. Yields were generally high for both seasons with an average of 2520 kg/ha and 2731 kg/ha for the 1987 and the 1988 seasons, respectively. There were variations in both seasons for yield and rank for the different varieties and mixtures.

C-20 and Domino were the first and second highest yielding varieties, and the four-component mixture consisting of C-20 : Montcalm : Seafarer : Domino was the third highest yielder in 1987. The $F_2$ population and some of the mixtures were in the intermediate range. Montcalm, Taylor and Seafarer were among the lowest yielders, while a

Table 20. Seed yield (kg/ha) of varieties and variety mixtures from a non-inoculated experiment for the 1987, 1988 and for the two seasons combined.

| Varieties/$F_2$'s/Mixtures | Years 1987 | 1988 | 2 years combined |
|---|---|---|---|
| Domino/Black Magic | 3268ab | 2852a-e | 3060a |
| C-20 | 3457a | 2470def | 2964ab |
| Montcalm | 1828ef | 2376f | 2102g |
| Taylor | 1736ef | 2896a-d | 2316efg |
| Seafarer | 2119def | 2472def | 2295fg |
| MIC/Cardinal | 2984abc | 2978abc | 2981ab |
| Montcalm x GO 5686 ($F_2$) | 2748a-d | -- | -- |
| B 83302 x C-20 ($F_2$) | 2617bcd | 3092ab | 2855abc |
| Montcalm x Taylor ($F_2$) | 2607bcd | 2836a-e | 2722a-e |
| Montcalm: C-20 | 2431cde | 2424ef | 2427d-g |
| Montcalm: Taylor | 1569f | 2865a-d | 2217g |
| Montcalm: Domino/Black Magic | 2222def | 2718b-f | 2467c-g |
| C-20: Montcalm: Taylor: MIC/Cardinal | 2699bcd | 2586c-f | 2643b-f |
| C-20: Montcalm: Taylor: Domino/Black Magic | 2442cde | 3165a | 2804a-d |
| C-20: Montcalm: Seafarer: Domino/Black Magic | 3072abc | 2503def | 2788a-d |
| Means | 2520 | 2730 | 2617 |
| CV% | 17.0 | 9.5 | 13.5 |

Numbers within columns followed by the same letter are not significantly different at P = .05.

mixture of Montcalm : Taylor was the lowest in yield. This mixture performed poorly because Taylor had poor germination.

In the 1988 season, the four-component mixture of C-20 : Montcalm : Taylor : Black Magic and the $F_2$ population of B83302 x C-20 were the highest yielders (Table 20). The high yielding four-component mixture was different from that of 1987 because Seafarer yielded poorly in the mixture in the 1988 season (Table 21). Cardinal and Taylor and the Montcalm : Taylor mixture yielded better than Black Magic and C-20 because the latter, being full season varieties, were damaged by frost while the former escaped frost. Certain plants were damaged by frost because of late planting due to drought at the beginning of the season. As in 1987, some varieties, mixtures and $F_2$ populations were intermediate in performance in 1988. Montcalm and the two-component mixture of Montcalm : C-20 were the poorest yielders.

The yield difference between the mixtures and the means of their components are given in Table 21. The positive numbers are in the favor of the observed performance of mixtures and varieties in the mixtures. The negative numbers show that the mixtures or their components yielded poorer than would be predicted from stands.

Table 21. Observed and the expected seed yield (kg/ha) of varieties in pure stand and in mixtures from a non-inoculated experiment in the 1987 and the 1988 seasons.

| | 1987 | | | 1988 | | |
|---|---|---|---|---|---|---|
| Varieties | Observed | Expected | Difference | Observed | Expected | Difference |
| PURE STAND | | | | | | |
| Domino/Black Magic | 3268 | | | 2852 | | |
| C-20 | 3458 | | | 2470 | | |
| Montcalm | 1828 | | | 2375 | | |
| Taylor | 1737 | | | 2896 | | |
| Seafarer | 2119 | | | 2472 | | |
| MIC/Cardinal | 2984 | | | 2978 | | |
| MIXTURES | | | | | | |
| Montcalm | 1595 | 1371 | | 977 | 1782 | |
| C-20 | 835 | 865 | | 1447 | 618 | |
| | 2431 | 2235 | 195 | 2424 | 2400 | 24 |
| Montcalm | 1044 | 800 | | 1015 | 1039 | |
| Taylor | 525 | 977 | | 1850 | 1629 | |
| | 1569 | 1776 | -207 | 2865 | 2668 | 196 |
| Montcalm | 1534 | 1371 | | 1394 | 1782 | |
| Domino/Black Magic | 687 | 817 | | 1319 | 713 | |
| | 2222 | 2188 | 34 | 2713 | 2495 | 218 |
| C-20 | 1019 | 865 | | 1160 | 618 | |
| Montcalm | 760 | 457 | | 323 | 594 | |
| Taylor | 175 | 434 | | 744 | 724 | |
| MIC/Cardinal | 744 | 746 | | 361 | 745 | |
| | 2699 | 2501 | 198 | 2586 | 2680 | -92 |
| C-20 | 982 | 865 | | 998 | 618 | |
| Montcalm | 456 | 457 | | 333 | 594 | |
| Taylor | 147 | 434 | | 620 | 724 | |
| Domino/Black Magic | 856 | 817 | | 1215 | 713 | |
| | 2441 | 2573 | -132 | 3165 | 2649 | 517* |
| C-20 | 1127 | 865 | | 951 | 618 | |
| Montcalm | 564 | 457 | | 337 | 594 | |
| Seafarer | 357 | 530 | | 103 | 618 | |
| Domino/Black Magic | 1024 | 817 | | 1113 | 713 | |
| | 3072 | 2668 | 404* | 2503 | 2543 | -39 |
| Mean (Components) | 2566 | --- | | 2674 | --- | |
| Mean (Mixtures) | 2406 | 2324 | | 2709 | 2572 | |
| s.e. | 429 | | | 259 | | |

* Significantly higher ($P \leq 0.05$).

Expected seed yield of mixture components = yield of components, calculated from the yield in pure stand, according to components rarios in the mixture.

4.4.1.2 Yielding ability (%) and mean relative yield (%)

The yield of the mixture is the ratio of the mixture yield to that of the high yielding mixture component in pure stand, expressed in percentage (Rao and Prasad 1984). The yielding abilities of the mixtures are summarized in Table 22. The yielding abilities ranged from 68.0% to 88.8% in 1987. These values indicate that mixtures yielded below their high yielding components in the pure stand and all of them had at least one of components that yielded below the expected value (Table 21).

Mixtures in 1988 had improved yielding abilities, ranging from 86.8% to 109.3%. The two-component mixtures yielded close to their highest yielding components. A four-component mixture composed of C-20 : Montcalm : Taylor : Black Magic yielded 9.3% above the highest yielding component. In this mixture, the type II, high yielding full season components, C-20 and Black Magic, yielded higher than the expected value although the other two components yielded below the expected values (Table 21). The other four-component mixtures had lower yielding ability compared to other mixtures. Some of the components yielded very poorly and could not be compensated by the good yielders.

The mean relative yields of the mixtures are summarized in Table 22. The mean relative yield of the mixtures is the ratio of the yield of the mixture to the mean yield of the components in pure stand expressed in percentage (Rao and

Table 22. Yielding ability and mean relative yield of mixtures of bean varieties under control (no-inoculation), anthracnose, angular leaf spot and halo blight experiments in 1987 and 1988 seasons.

| Experiments | Yielding Ability (%) 1987 | Yielding Ability (%) 1988 | Mean Relative Yield (%) 1987 | Mean Relative Yield (%) 1988 |
|---|---|---|---|---|
| **Non-Inoculated** | | | | |
| Mont: C-20 (3:1)* | 70.3 | 98.1 | 108.7 | 101.0 |
| Mont: Taylor (7:9) | 85.4 | 98.9 | 88.3 | 107.4 |
| Mont: Dom/BM (3:1) | 68.0 | 95.2 | 101.5 | 108.4 |
| C-20: Mont: Taylor: MIC/Card (1:1:1:1) | 78.0 | 86.8 | 107.9 | 96.5 |
| C-20: Mont: Taylor: Dom/BM (1:1:1:1) | 70.6 | 109.3 | 94.9 | 119.5 |
| C-20: Mont: Seaf: Dom/BM (1:1:1:1) | 88.8 | 87.8 | 115.1 | 98.5 |
| **Anthracnose** | | | | |
| Dom/BM: C-20 (1:1) | 80.5 | 107.5 | 82.9 | 110.4 |
| Dom: Seaf (1:1) | 95.9 | 93.5 | 101.0 | 106.1 |
| Mont: Seaf (1:1) | 97.4 | 100.2 | 102.6 | 103.4 |
| Mont: Dom/BM (3:1) | 99.7 | 97.1 | 100.0 | 100.6 |
| C-20: Mont: Dom/BM: Seaf (1:1:1:1) | 90.4 | 96.4 | 99.2 | 110.1 |
| **Halo Blight** | | | | |
| Mont: Taylor (7:9) | 116.2 | 97.6 | 120.0 | 105.2 |
| C-20: Mont: Taylor: MIC/Card (1:1:1:1) | 83.9 | 92.6 | 115.9 | 105.6 |
| **Angular Leaf Spot** | | | | |
| Mont: C-20 (3:1) | 75.3 | 80.3 | 144.7 | 110.6 |
| C-20: Mont: Taylor: Dom/BM (1:1:1:1) | 85.8 | 98.6 | 119.8 | 122.1 |

* For complete variety names and their reaction to diseases, see Tables 1 and 3-5.

Prasd, 1984). The values were variable for the individual mixtures and across the seasons. The mean relative yields ranged from 88.3% to 115.1% in 1987. Three mixtures outyielded the means of their components by 15.1%, 8.7% and 7.9%; one mixture equalled the mean yield of its component and two yielded below the means of their components. C-20 : Montcalm : Seafarer : Domino mixture significantly outyielded the mean of its components in pure stand by 15.1%.

In 1988, there seemed to be a reverse performance in mixtures. The mixtures that yielded below the means of their components in 1987 yielded above their component means in 1988. This could have been due to seasonal changes or to the use of different components in some mixtures. Type III cv MIC was replaced with Type I cv Cardinal Black Magic in 1988, which could account for difference in performance of mixtures between seasons. The relative mean yield ranged from 96.5% to 119.5% and three mixtures yielded above their mean components by 19.5%, 8.4% and 7.4%. One mixture yielded about the same and two other mixtures yielded 3.5% and 1.5% below the means of their components in pure stand. C-20 : Montcalm : Black Magic was significantly higher yielding than the mean of the components in pure stand.

#### 4.4.1.3 Inter-genotypic interactions

The performance of the mixtures and their components were variable in different mixtures and in the two seasons.

The differences between the observed and the expected yield of the mixtures and their components are given in Table 21.

Montcalm had favorable interactions in all the mixtures in 1987 except in a four-component mixture of C-20 : Montcalm : Taylor : Domino. Interestingly, Montcalm had a negative interaction, that is, it yielded below the expected in all the mixtures in 1988. The expected values were calculated from the yields of the pure components according to component ratios in the mixture. Montcalm, being a large seeded variety with large leaves, may have aggressively competed with the other small seeded varieties with small leaves which are slow growing like C-20 and Domino in 1987.

Taylor did not perform well in the mixtures in 1987 due to poor germination. The seedlings from re-seeding did not compete with the older seedlings. Taylor also had poor performance in the two-component mixture. Seafarer and Cardinal did not compete well with the other varieties and MIC was neutral in the mixtures.

C-20 and Domino, when mixed with 75% Montcalm in two-component mixtures, yielded poorly in 1987 but they had positive interactions when they were in four-component mixtures. In 1988, C-20 and Black Magic showed a positive interaction even when Montcalm was 75% in the mixture. Montcalm in these combinations yielded below the expected values. C-20 and Black Magic had positive interactions in all the other mixtures.

These results show that performance of mixtures and their components are sensitive to environmental (seasonal) changes, composition of the mixture, and interactions between different components.

4.4.2 Anthracnose

4.4.2.1 Seed yield

Yields were generally high for the 1987 season with an average of 2544 kg/ha (Table 23). The $F_2$ population of B83302 (R) x C-20 (S) was the highest yielder. Seafarer, in pure stand and two mixtures composed, respectively, of Domino : Seafarer and Montcalm : Seafarer were the second highest yielders. Domino and C-20, the susceptible varieties, yielded poorly and their mixture was the lowest yielder. These low yields were due mainly to disease pressure (Tables 9 and 10). However, Montcalm and the other two mixtures composed of Montcalm : Domino and C-20 : Montcalm : Domino : Seafarer had similar yields to that of the susceptible varieties. In this season, therefore, the mixtures occupied the ranks of high yielding, intermediate and the lowest yielders.

As in the 1987 season, yields in the 1988 season were equivalent to those of 1987 with an average of 2558 kg/ha (Table 23). The $F_2$ population was also the highest yielder and Black Magic (S) and C-20 (S) were the lowest yielders. The two-component mixture of Montcalm (R) : Seafarer (R) was the second highest while Seafarer and the four-component mixture were the third highest yielders. Montcalm, Black

Table 23. Seed yield (kg/ha) of varieties and variety mixtures from the experiment inoculated with <u>C. lindemuthianum</u> for the 1987, 1988 and the two seasons combined.

| Varieties/$F_2$'s/Mixtures | Years 1987 | 1988 | 2 years combined |
|---|---|---|---|
| Domino/Black Magic | 2413bc | 2060d | 2237cd |
| C-20 | 2274bc | 2175cd | 2224cd |
| Montcalm | 2412bc | 2533bcd | 2472bcd |
| Seafarer | 2683b | 2701bc | 2692b |
| Domino/Black Magic: C-20 | 1942c | 2337bcd | 2140d |
| Domino/Black Magic: Seafarer | 2574b | 2527bcd | 2551bc |
| Montcalm: Seafarer | 2613b | 2706b | 2660b |
| B 83302 x C-20 ($F_2$) | 3695a | 3475a | 3585a |
| Montcalm: Domino/BM | 2406bc | 2458bcd | 2432bcd |
| C-20: Montcalm: Domino/Black Magic: Seafarer | 2426bc | 2605bc | 2515bc |
| Means | 2544 | 2558 | 2551 |
| CV% | 12.3 | 12.1 | 12.6 |

Numbers within columns followed by the same letter are not significantly different at P = .05.

Magic : C-20, Black Magic : Seafarer and Montcalm : Black Magic had intermediate yields. In this 1988 season, varieties and mixtures changed ranks compared to the 1987 season. One mixture, Montcalm : Seafarer, outyielded all the varieties in pure stand and the others were intermediate in yield.

#### 4.4.2.2 Yielding ability (%) and mean mean relative yield (%)

The Yielding Ability data (Table 22) shows that no mixture yielded above their high yielding component in pure stand in 1987. The yielding abilities ranged from 80.5% to 99.7%. However, two mixtures, Montcalm : Seafarer and Montcalm : Domino, almost equalled the yield of their high yielding components. Domino : C-20 mixture had significantly the lowest yielding ability because both yielded below the expected values in the mixture (Table 24). The yielding abilities of the mixtures in 1988 was similar to that of the previous season except Black Magic : C-20 had a yielding ability of 107.5%. The yielding ability values ranged from 93.5% to 107.5%.

The mean relative yields were different for both seasons (Table 22), ranging from 82.9% to 102.6% in 1987 and 100.6% to 110.4% in 1988. The yield of four mixtures were similar to the means of their components in pure stand except that Montcalm : Seafarer yielded 2.6% above the mean of its components. Montcalm : Black Magic yielded only 0.6% above the means of the two components and the other mixtures

Table 24. Observed and the expected seed yield (kg/ha) of varieties in pure stand and in mixtures from the experiment inoculated with C. lindemuthianum in the 1987 and the 1988 seasons.

| Varieties/$F_2$ | 1987 | | | 1988 | | |
|---|---|---|---|---|---|---|
| Mixtures | Observed | Expected | Difference | Observed | Expected | Difference |
| Domino/Black Magic | 2413 | | | 2060 | | |
| C-20 | 2274 | | | 2175 | | |
| Montcalm | 2412 | | | 2533 | | |
| Seafarer | 2683 | | | 2701 | | |
| Domino/Black Magic | 1161 | 1207 | | 1407 | 1030 | |
| C-20 | 781 | 1137 | | 930 | 1087 | |
| | 1942 | 2343 | -401* | 2337 | 2117 | 219 |
| Domino/Black Magic | 1340 | 1207 | | 2152 | 1030 | |
| Seafarer | 1235 | 1342 | | 375 | 1351 | |
| | 2574 | 2548 | 26 | 2527 | 2381 | 146 |
| Montcalm | 1599 | 1206 | | 1963 | 1266 | |
| Seafarer | 1014 | 1342 | | 743 | 1351 | |
| | 2613 | 2547 | 66 | 2706 | 2617 | 89 |
| Montcalm | 1960 | 1804 | | 1388 | 1899 | |
| Domino/Black Magic | 445 | 603 | | 1071 | 545 | |
| | 2406 | 2407 | -1 | 2459 | 2445 | 14 |
| C-20 | 502 | 568 | | 1009 | 544 | |
| Montcalm | 834 | 603 | | 407 | 633 | |
| Domino/Black Magic | 552 | 603 | | 1047 | 515 | |
| Seafarer | 538 | 671 | | 143 | 675 | |
| | 2426 | 2445 | -20 | 2605 | 2367 | 238* |
| Mean (Components) | 2445 | -- | | 2305 | -- | |
| Mean (Mixtures) | 2392 | 2454 | | 2527 | 2385 | |
| s.e. | 312 | | | 309 | | |

*Significantly higher ($P \leq 0.05$).

Expected seed yield of mixture components = yield of components, calculated from the yield in pure stand, according to components ratios in the mixture.

yielded from 3.4% to 10.4% above the means of their components in 1988. The mixture response, therefore, was generally more favorable for some mixtures in 1988 than in the 1987. This could be due to less anthracnose intensity and a seasonal climatic difference which resulted in lower yields of C-20 and Black Magic.

4.4.2.3 <u>Inter-genotypic interactions</u>

The inter-genotypic interaction in these mixtures is similar for the two seasons, except for the mixture involving Domino/Black Magic : C-20. The interaction is of the complementary type (Schutz and Brim 1967) in that one genotype shows an increase in yield and the other genotype shows an equal decrease. Most of the components in the mixtures showed the complementary type of interaction (Table 24). The mixtures whose components exhibited overcompensatory patterns of interaction did have a yield advantage over the means of their component in pure stand.

The Domino : C-20 mixture showed an undercompensatory pattern of interaction because Domino had a small decrease in yield in the mixture while C-20 had a large decrease (Table 24). The net loss of the mixture was 401 kg/ha which was significant as compared to the expected value. The Black Magic : C-20 mixture had a higher yield than that of Domino : C-20 in 1987 because Black Magic yielded higher than expected and C-20 had less yield decrease. There was a net increase of 219 kg/ha. The Black Magic : Seafarer mixture had an incomplete overcompensatory interaction as well as the four-component mixture in the 1988 season. These two mixtures, therefore, yielded slightly above the means of their components.

4.4.3 <u>Angular leaf spot</u>

4.4.3.1 <u>Seed yield</u>

Seed yields in kg/ha for the 1987 and 1988 seasons and the average of the two seasons are summarized in Table 25. The mean yield for the 1987 season was 2177 kg/ha and 2359 kg/ha for the 1988 season. The average yield for the two seasons was 2291 kg/ha.

Domino and C-20 in pure stand were the highest yielders in 1987. These are type II, full season and high yielding varieties with resistance to angular leaf spot. Montcalm and Taylor, the susceptible varieties, were the lowest yielders, the differences being attributable in part to the disease. The four-component mixture C-20 : Montcalm : Taylor : Domino, consisting of 2R:2S varieties, was the third highest yielder. The significant increase in the mixture yield compared to the expected value, which is the mean of the components in pure stand, was contributed by C-20 and slightly by Domino (Table 26). Montcalm and Taylor did not contribute to the increased yield because they had essentially neutral interaction because their observed and expected yields were similar. The two-component mixture of 3 parts Montcalm : 1 part C-20 was the fourth highest yielder in 1987. Yield in this mixture was contributed by C-20; Montcalm did not contribute yield (Table 26). The

Table 25. Seed yield (kg/ha) of varieties and variety mixtures from the experiment inoculated with P. griseola for the 1987, 1988 and the two seasons combined.

| Varieties/$F_2$/Mixtures | Years 1987 | 1988 | 2 years combined |
|---|---|---|---|
| Domino/Black Magic | 2799a | 2880a | 2840 |
| C-20 | 2980a | 2498bc | 2739 |
| Montcalm | 1074e | 1586e | 1330 |
| Taylor | 1685d | 2342cd | 2013 |
| Montcalm x GO 5686 ($F_2$) | 1897cd | --- | --- |
| Montcalm: C-20 | 2244bc | 2006d | 2125 |
| C-20: Montcalm: Taylor: Domino/Black Magic | 2557ad | 2841ab | 2699 |
| Means | 2177 | 2358 | 2291 |
| CV% | 11.1 | 8.2 | 9.5 |

Numbers within columns followed by the same letter are not significantly different at P = .05.

Table 26. Observed and the expected seed yield (kg/ha) of varieties in pure stand and in mixtures from the experiment inoculated with P. griseola in the 1987 and 1988 seasons.

| Varieties/$F_2$ Mixtures | 1987 | | | 1988 | | |
|---|---|---|---|---|---|---|
| | Obs. | Exp. | Diff. | Obs. | Exp. | Diff. |
| Domino/Black Magic | 2799 | | | 2880 | | |
| C-20 | 2980 | | | 2498 | | |
| Montcalm | 1074 | | | 1586 | | |
| Taylor | 1685 | | | 2342 | | |
| Montcalm | 872 | 806 | | 885 | 1190 | |
| C-20 | 1372 | 745 | | 1121 | 624 | |
| | 2244 | 1551 | 693* | 2006 | 1814 | 192 |
| C-20 | 1074 | 745 | | 851 | 624 | |
| Montcalm | 276 | 269 | | 325 | 397 | |
| Taylor | 421 | 421 | | 588 | 585 | |
| Domino/Black Magic | 787 | 700 | | 1078 | 720ts | |
| | 2557 | 2134 | 423* | 2841 | 2327 | 514** |
| Mean (Components) | 2134 | | | 2327 | | |
| Mean (Mixtures) | 2401 | 1843 | | 2423 | 2070 | |
| s.e. | 242 | | | 194 | | |

* Significantly higher ($P \leq 0.05$).

** Significantly higher ($P \leq 0.01$).

Expected seed yield of mixture components = yield of components, calculated from the yield in pure stand, according to components ratios in the mixture.

yields in the 1988 season were similar to those of 1987 but there were different rankings for the varieties; Black Magic and the four-component mixtures were high yielding entries. C-20 had a lower yield than in the 1987 season because of frost damage. The yield of Taylor was above the two-component mixture. Montcalm was the lowest yielder. The $F_2$ population had intermediate yield in 1987 but the population was killed by frost in 1988. Montcalm in both mixtures in 1988 yielded below the expected values (Table 26). There was no difference between the observed and the expected values for Taylor. C-20, Domino and Black Magic yielded above the expected values.

The mixtures, however, were intermediate in yield in both seasons and none of them outyielded the high yielding varieties. The four-component mixture in 1988 had a yield close to that of the high yielding variety.

#### 4.4.3.2 Yielding ability (%) and mean relative yield (%)

From the Yielding Ability data (Table 22), none of the mixtures equaled the yield of the high yielding component. The four-component mixture had a yielding ability of 85.8%, while the two-component mixture had 75.8% for the 1987 season. The yielding ability of the mixtures improved in the 1988 season. The four-component mixture almost equaled the yield of the highest yielding component, Black Magic. The two-component mixture had a yielding ability of 80.3% compared to 75.3% in 1987. This is partly due to the overall low yield of this mixture and its highest yielding component, C-20, as compared to the 1987 season (Table 26). Thus, there was less difference between the mixture and its high yielding component.

The mean relative yield of the mixtures was high for both seasons, ranging from 110.6% to 144.7% (Table 22). There were seasonal and mixture differences. The mean relative yield for the two-component mixture was 144.7% in 1987 and 110.6% in 1988. The mean relative yield of the four-component mixture was 119.8% and 122.1% for the two seasons. In this experiment, therefore, mixtures significantly outyielded the means of their components for both seasons. The mixtures, however, did not yield above the highest yielding components.

4.4.3.3 Inter-genotypic interactions

The two mixtures in this experiment outyielded the means of their components in pure stand because of the favorable interactions between the components. For the two-component mixture consisting of 3 Montcalm : 1 C-20, Montcalm yielded only 65.8 kg/ha above the expected value whereas C-20 yielded 627.4 kg/ha more than its expected value in 1987 (Table 26). Although the proportion of C-20 in the mixture was only 25%, it exhibited a higher competitive ability. In 1988, Montcalm in the same mixture yielded 304.5 kg/ha below the expected value and C-20 yielded 496.2 kg/ha more than expected. The net gain was lower than that of the previous year. Frost damage on C-20 and the high disease incidence on Montcalm due to the wet Fall adversely affected their yields.

In the four-component mixture (Table 26), Montcalm and Taylor did not contribute any additional yield above the expected values for both seasons. Disease infection, inferior yield and less competitive abilities could have accounted for their low yield in the mixtures as compared to C-20, Domino and Black Magic. C-20, Black Magic and Domino, to a less extent, yielded above their expected values. These are high yielding Type II and full season varieties. They may have utilized well the resources that are not fully utilized by Montcalm and Taylor which are susceptible to angular leaf spot and earlier maturing. However, a similar pattern was also observed in the control experiment.

There were seasonal and varietal variations in plant interactions. Montcalm yielded below the expected value for the two mixtures in the 1988 but was similar to the expected value in 1987. C-20 was less competitive in 1988 which may be due to frost and leaf hopper damage. Taylor remained neutral in both seasons.

### 4.4.4 Halo blight

#### 4.4.4.1 Seed yield

Mean yields were high for the two seasons (Table 27) possibly because of low disease levels. The mean yield for the 1987 season was 2775 kg/ha; C-20 was the highest yielding cultivar. The $F_2$ population and the mixtures of Montcalm : Taylor and C-20 : Montcalm : Taylor : MIC were

Table 27. Seed yield (kg/ha) of varieties and variety mixtures from the experiment inoculated with P. s. pv phaseolicola for the 1987, 1988 and the two seasons combined.

| Varieties/$F_2$'s/Mixtures | Years 1987 | 1988 | 2 years combined |
|---|---|---|---|
| C-20 | 3569a | 2555ab | 3062a |
| Montcalm | 2584c | 2648ab | 2616bc |
| Taylor | 2442c | 2307b | 2375c |
| MIC/Cardinal | 1747d | 2997a | 2372c |
| Montcalm x Taylor ($F_2$) | 3078b | 2864a | 2971a |
| Montcalm: Taylor | 3005b | 2583ab | 2794ab |
| C-20: Montcalm: Taylor: MIC/Cardinal | 2996b | 2775a | 2886ab |
| Means | 2775 | 2676 | 2725 |
| CV% | 6.8 | 9.8 | 8.6 |

Numbers within columns followed by the same letter are not significantly different at P = .05.

among the high yielders after C-20, but they were not significantly different from each other. Montcalm and Taylor were low yielders; MIC was the lowest yielder.

Although none of the mixtures outyielded the highest yielding variety, C-20, they were both intermediate and outyielded three of their components in pure stand. MIC yielded low because of its late maturity and consequent exposure to damage from fall rain.

Yields for the 1988 season were high with an average of 2676 kg/ha (Table 27). Cardinal, the $F_2$ population and the four-component mixtures were the highest yielders but not significantly different from each other. Montcalm and the two-component mixture and C-20 were the second highest yielders, and Taylor was the lowest yielder. C-20 was affected by frost, which contributed to the lower performance than in the 1987 season. The four-component mixture yielded as high as the highest yielding variety, Cardinal, for the 1988 season. The two-component mixture was intermediate in yield. From the mean of the two seasons C-20 and the $F_2$ population were the highest yielders.

#### 4.4.4.2 Yielding ability (%) and mean relative yield (%)

The two-component mixture in 1987 outyielded both components (Table 27) and its yielding ability was 116.2% (Table 22). The four-component mixture had a yielding ability of 83.9%. The mixtures almost equaled the yield of their best components in 1988, having a yielding ability of

97.6% for the two component mixture and 92.6% for the four-component mixtures (Table 22). The mean relative yield was high for both seasons, ranging from 105.2% to 120.0%. The two mixtures had superior performance as compared to mean yields of their components in 1987. In 1988, mixtures yielded about 5% above the mean yield of their components. Although the mixtures did not outyield the best component, they yielded above the means of their components, and they maintained the intermediate position for both seasons.

4.4.4.3 Inter-genotypic interactions

There were variable interactions for the components in the two mixtures for both seasons. Taylor and Montcalm, in the two-component mixture, both interacted favorably and both had significantly increased yield above their expected values. They contributed 501 kg/ha above their mean yields in pure stand in 1987 (Table 28). In 1988 Montcalm did not yield above the expected value and Taylor had a smaller than expected value as compared to 1987. Thus the yield of the mixture was much different from that of the mean value of the components.

There were also variable interactions between genotypes in the four-component mixtures (Table 28). C-20 maintained a higher yield than expected for the two seasons. Montcalm had a low yield for the two seasons while Taylor had a low yield for the 1987 season and a high yield for the 1988 season. MIC had a higher yield and Cardinal had a lower

Table 28. Observed and the expected seed yield (kg/ha) of varieties in pure stand and in mixtures from the experiment inoculated with P. s. pv phaseolicola in the 1987 and the 1988 seasons.

| Varieties/$F_2$ Mixtures | 1987 | | | 1988 | | |
|---|---|---|---|---|---|---|
| | Obs. | Exp. | Diff. | Obs. | Exp. | Diff. |
| C-20 | 3569 | | | 2555 | | |
| Montcalm | 2584 | | | 2648 | | |
| Taylor | 2442 | | | 2307 | | |
| MIC/Cardinal | 1747 | | | 2997 | | |
| Montcalm | 1340 | 1131 | | 1159 | 1159 | |
| Taylor | 1666 | 1374 | | 1424 | 1298 | |
| | 3005 | 2504 | 501** | 2583 | 2456 | 127 |
| C-20 | 1231 | 892 | | 1055 | 639 | |
| Montcalm | 607 | 646 | | 447 | 662 | |
| Taylor | 463 | 611 | | 773 | 577 | |
| MIC/Cardinal | 695 | 437 | | 500 | 749 | |
| | 2996 | 2586 | 410* | 2775 | 2627 | 148 |
| Mean (Components) | 2586 | | | 2627 | | |
| Mean (Mixtures) | 3001 | 2545 | | 2679 | 2541 | |
| s.e. | 189 | | | 262 | | |

* Significantly higher ($P \leqslant 0.05$).

** Significantly higher ($P \leqslant 0.01$).

Expected seed yield of mixture components = yield of components, calculated from the yield in pure stand, according to components ratios in the mixture.

yield than expected. The tall, full season varieties seemed to show superior competitive ability.

## 4.5 Seed and Yield Components

### 4.5.1 Control

The yield and yield components and plant height of the genotypes in pure stand and in the different mixtures were ranked by using Least Significant Difference (LSD) at P = 0.05. Components measured were pods/10 plants, seed weight/10 plants, seed number/10 plants, seeds/pod, 100 seed weight, plant height (canopy) and plant height (tip). Results are summarized in Tables 29, 30 and 31 for 1987, 1988 and the two seasons combined.

There were significant differences in yield and yield components and plant height between the genotypes in pure stand and in the mixtures and between the two seasons. Genotypes also behaved differently in different mixtures. Comparisons were made as to whether the values of the yield components and plant height for the genotypes in the mixtures increased, decreased or remained the same with respect to their values in the pure stand, using the LSD rankings.

In the two-component mixtures of 3 Montcalm : 1 C-20, 7 Montcalm : 9 Taylor and 3 Montcalm : 1 Domino, Montcalm had higher values in the mixtures than in the pure stand except for seeds/pods and plant height for the 1987 season (Table 29). For the other genotypes, C-20, Taylor and Domino, most components of yield ranked lower in the mixtures than in the

Table 29. Yield and yield components and plant height of varieties in pure stand and in variety mixtures in a non-inoculated field experiment grown during the 1987 season.

| Varieties | Pods/ 10 Plants | Seed wt/ 10 Plants (g) | Seed No./ 10 Plants | Seeds/ Pod | Plant ht (can)* (cm) | 100 Seed wt (g) |
|---|---|---|---|---|---|---|
| Pure Stand | | | | | | |
| 1. Domino | 188.3ef | 158.6d-g | 784.3bc | 4.2a | 57.1c | 20.5jk |
| 2. C-20 | 255.7bcd | 193.0b-e | 745.3cd | 2.9def | 65.6b | 23.8gh |
| 3. Montcalm | 79.0ijk | 127.9ghi | 307.3fgh | 3.8ab | 47.6ef | 42.3f |
| 4. Taylor | 74.3ijk | 110.8hij | 236.0f-i | 3.2b-f | 31.8i | 47.8c |
| 5. Seafarer | 218.0de | 154.6e-h | 820.0bc | 3.7a-d | 42.7fg | 18.2kl |
| 6. MIC/Cardinal | 104.0hij | 153.6e-h | 278.0f-i | 2.7f | 85.8a | 53.8b |
| Varieties in Mixtures | | | | | | |
| 10. Montcalm | 110.3hi | 137.2f-i | 328.3fg | 3.0def | 39.3gh | 43.7def |
| C-20 | 236.7cd | 182.4c-f | 836.7bc | 3.5a-e | 53.8cd | 21.6hij |
| 11. Montcalm | 130.3gh | 177.3c-f | 412.7ef | 3.2b-f | 38.2gh | 42.7ef |
| Taylor | 61.3jk | 96.0ijk | 223.7ghi | 3.7a-d | 29.3i | 45.2d |
| 12. Montcalm | 108.3hij | 145.3fgh | 307.7fgh | 2.8ef | 42.3gh | 43.2def |
| Domino | 184.7ef | 152.3e-h | 687.7cd | 3.7a-d | 53.2cd | 22.3g-j |
| 13. C-20 | 294.7ab | 223.5abc | 944.3ab | 3.2b-f | 57.4c | 24.1g |
| Montcalm | 105.3hij | 143.2fgh | 332.7fg | 3.2b-f | 40.0gh | 44.9de |
| Taylor | 44.7k | 66.1jk | 144.0hi | 3.2b-f | 27.6i | 45.0de |
| MIC | 102.3hij | 180.9c-f | 320.3fgh | 3.1b-f | 67.0b | 59.5a |
| 14. C-20 | 277.3abc | 234.4ab | 1026.7a | 3.8abc | 58.0c | 22.9g-j |
| Montcalm | 100.7hij | 129.8ghi | 315.3fgh | 3.2b-f | 37.9gh | 42.3f |
| Taylor | 34.7k | 52.8k | 113.0i | 3.3b-f | 29.8i | 44.2def |
| Domino | 236.0cd | 192.1b-e | 843.0bc | 3.6a-e | 48.9de | 21.0ij |
| 15. C-20 | 309.3a | 259.0a | 1081.0a | 3.5a-e | 56.9c | 23.2ghi |
| Montcalm | 107.3hij | 136.8f-i | 322.3fg | 3.0c-f | 39.1gh | 41.8f |
| Seafarer | 168.0fg | 109.6hij | 571.7de | 3.4a-f | 37.4h | 17.5l |
| Domino | 228.3de | 204.9bcd | 932.0ab | 4.2a | 49.8de | 21.5hij |
| Means | 156.7 | 155.1 | 538.1 | 3.4 | 47.4 | 34.7 |
| CV% | 18.5 | 18.3 | 20.0 | 14.1 | 6.7 | 4.3 |

* can = canopy

Numbers within columns followed by the same letter are not significantly different at P = .05.

Table 30. Yield and yield components and plant height of varieties in pure stand and in variety mixtures in a non-inoculated field experiment grown during the 1988 season.

| Varieties | Pods/ 10 Plants | Seed wt/ 10 Plants (g) | Seed No./ 10 Plants | Seeds/ Pod | Plant ht (can)* (cm) | 100 Seed wt (g) | Plant ht(tip) (cm) |
|---|---|---|---|---|---|---|---|
| Pure Stand | | | | | | | |
| 1. Black Magic | 197.3ef | 197.2d-j | 1054.0cd | 5.4a | 57.4ab | 19.1g | 87.2cd |
| 2. C-20 | 256.0de | 188.2e-j | 1040.0d | 4.0bcd | 59.2a | 19.4g | 95.0bc |
| 3. Montcalm | 133.0fgh | 207.4c-i | 371.0e | 2.8fgh | 44.7efg | 57.0bcd | 44.7e |
| 4. Taylor | 122.0gh | 229.4b-f | 448.0e | 3.6b-f | 40.9fg | 58.0b | 40.9e |
| 5. Seafarer | 369.7a | 290.6a-d | 1213.0bcd | 3.3b-g | 47.9cde | 22.1g | 48.0e |
| 6. Cardinal | 133.7fgh | 216.8c-h | 360.3e | 2.7fgh | 43.1efg | 63.7a | 43.1e |
| Varieties in Mixtures | | | | | | | |
| 10. Montcalm | 91.0gh | 126.4h-k | 237.3e | 2.6fgh | 43.0efg | 55.4bcd | 43.0e |
| C-20 | 412.0a | 334.8a | 1683.0a | 4.1bc | 54.2abc | 20.2g | 99.8ab |
| 11. Montcalm | 110.0gh | 181.4e-j | 334.3e | 3.0d-h | 42.6efg | 55.3bcd | 42.7e |
| Taylor | 126.7fgh | 227.3b-g | 437.3e | 3.4b-g | 40.1fg | 51.4ef | 40.1e |
| 12. Montcalm | 127.0fgh | 211.5c-h | 389.0e | 3.0e-h | 48.1cde | 56.4bcd | 48.1e |
| Black Magic | 195.3bcd | 329.8a | 1606.7a | 5.4a | 54.0abc | 20.3g | 96.5bc |
| 13. C-20 | 369.3a | 304.9abc | 1541.0ab | 4.2b | 58.1ab | 20.2g | 107.9a |
| Montcalm | 91.0gh | 156.2f-j | 303.7e | 3.3b-g | 42.5efg | 54.9b-e | 42.5e |
| Taylor | 120.0gh | 159.5f-j | 314.7e | 2.6gh | 39.4g | 47.9f | 39.4e |
| Cardinal | 77.7h | 111.6ijk | 195.7e | 2.5gh | 41.8efg | 57.4bc | 41.8e |
| 14. C-20 | 347.7abc | 257.0a-e | 1372.3abc | 4.0b-e | 55.6ab | 19.5g | 97.8b |
| Montcalm | 81.3ghc | 130.9g-k | 239.0e | 2.8fgh | 46.2def | 54.3cde | 46.2e |
| Taylor | 88.7gh | 139.4f-k | 275.0e | 3.1c-h | 38.6g | 49.0f | 38.6e |
| Black Magic | 289.7bcd | 318.4ab | 1618.7a | 5.6a | 53.3abc | 18.7g | 80.0d |
| 15. C-20 | 361.3abd | 276.5a-e | 1485.7ab | 4.1b | 59.2a | 19.1g | 95.3bc |
| Montcalm | 78.7h | 100.1jk | 195.3e | 2.5gh | 43.6efg | 53.7de | 43.7e |
| Seafarer | 153.0fg | 58.4k | 313.3e | 2.2h | 44.1efg | 19.2g | 44.1e |
| Black Magic | 282.3cd | 285.9a-d | 1496.0ab | 5.2a | 52.3bcd | 19.2g | 79.9d |
| Means | 196.4 | 210.0 | 771.8 | 3.6 | 47.9 | 38.8 | 61.9 |
| CV% | 22.3 | 28.2 | 26.2 | 17.3 | 8.2 | 5.6 | 9.7 |

* can = canopy

Numbers within columns followed by the same letter are not significantly different at P = .05.

Table 31. Yield and yield components and plant height of varieties in pure stand and in variety mixtures in a non-inoculated field experiment for the 1987 and 1988 seasons combined.

| Varieties | Pods/ 10 Plants | Seed wt/ 10 Plants (g) | Seed No./ 10 Plants | Seeds/ Pod | Plant ht (can)* (cm) | 100 Seed wt (g) |
|---|---|---|---|---|---|---|
| Pure Stand | | | | | | |
| 1. Domino/Black Magic | 192.8d | 177.9c-f | 919.2c | 4.8a | 57.3bc | 19.8fg |
| 2. C-20 | 255.8bc | 190.6bcd | 892.7c | 3.5b-f | 62.4a | 21.6ef |
| 3. Montcalm | 106.0f | 167.7d-g | 339.2de | 3.3b-h | 46.2e | 49.7c |
| 4. Taylor | 98.2fg | 170.1c-g | 342.0de | 3.4b-g | 36.4hi | 52.9b |
| 5. Seafarer | 293.8ab | 222.6abc | 1016.5bc | 3.5b-e | 45.3ef | 20.2efg |
| 6. MIC/Cardinal | 118.8ef | 185.2cde | 319.2de | 2.7h | 64.5a | 58.8a |
| Varieties in Mixtures | | | | | | |
| 10. Montcalm | 100.7fg | 131.8e-j | 282.8de | 2.8gh | 41.1fg | 49.6c |
| C-20 | 324.3a | 258.6a | 1259.8a | 3.8bc | 54.0bcd | 20.9ef |
| 11. Montcalm | 120.2ef | 179.4c-f | 373.5de | 3.1d-h | 40.4gh | 49.0c |
| Taylor | 94.0fg | 161.6d-h | 330.5de | 3.6b-e | 34.7i | 48.3cd |
| 12. Montcalm | 117.7f | 178.4c-f | 348.3de | 2.9e-h | 45.2ef | 49.8c |
| Domino/Black Magic | 240.0c | 241.1ab | 1147.2ab | 4.6a | 53.6cd | 21.3ef |
| 13. C-20 | 332.0a | 264.2a | 1242.7a | 3.7bcd | 57.8bc | 22.1e |
| Montcalm | 98.2fg | 149.7d-i | 318.2de | 3.3b-h | 41.2fg | 49.9c |
| Taylor | 82.3fg | 112.8hij | 229.3e | 2.9e-h | 33.5i | 46.5d |
| MIC/Cardinal | 90.0fg | 146.3d-i | 258.0de | 2.8gh | 54.4bcd | 58.4a |
| 14. C-20 | 312.5a | 245.7a | 1199.5ab | 3.9b | 56.8bc | 21.2ef |
| Montcalm | 91.0fg | 130.4f-j | 277.2de | 3.0e-h | 42.1efg | 48.3cd |
| Taylor | 61.7f | 96.1ij | 194.0e | 3.2c-h | 34.2i | 46.6d |
| Domino/Black Magic | 262.8bc | 255.4a | 1230.8a | 4.6a | 51.1d | 19.8fg |
| 15. C-20 | 335.3a | 267.8a | 1283.3a | 3.8bc | 58.1b | 21.2ef |
| Montcalm | 93.0fg | 118.5g-j | 258.8de | 2.8h | 41.4fg | 47.8cd |
| Seafarer | 160.5de | 84.0j | 442.5d | 2.8fgh | 40.7g | 18.4f |
| Domino/Black Magic | 255.3bc | 245.4a | 1214.0a | 4.7a | 51.1d | 20.4efg |
| Means | 176.5 | 182.5 | 655.0 | 3.5 | 47.6 | 36.8 |
| CV% | 21.0 | 25.8 | 25.2 | 16.4 | 7.8 | 5.1 |

* can = canopy

Numbers within columns followed by the same letter are not significantly different at P = .05.

pure stand. Seeds/10 plants and seeds/pod for C-20, seeds/pod for Taylor and 100 seed weight for Domino were the only components that were above the values in the pure stand.

The data on seed yield in these mixtures (Table 21) also shows that Montcalm had positive interactions in the mixtures. Taylor and Domino had lower yields than expected and C-20 had essentially the same yield as the expected value.

In the 1988 season, the reverse situation appears to have occurred in the mixtures of Montcalm : C-20 and Montcalm : Black Magic. Montcalm had the same values for most of the components of yield as in the pure stand and few of them had lower values. Similarly, C-20 and Black Magic in the mixtures had higher values for yield components in the pure stand, except for 100-seed weight and seeds/pod, which remained the same. The yields of these genotypes (Table 21) showed that C-20 and Black Magic yielded above their expected values while Montcalm yielded below its expected value.

Montcalm and Taylor in their mixture in 1988 displayed a similar trend as the other two-component mixtures. Most yield components for Taylor were the same as in the pure stand except for pods/plant which was above the value in the pure stand. Pods/10 plants and seed weight/10 plants for Montcalm were below the expected values which may have been key components because Montcalm yielded almost the same value in the mixture as the expected value (Table 21) while Taylor yielded above the expected value.

Similar trends for the yield components in the four-component mixtures as in the two-component mixtures were observed in 1988 (Table 30). Yield components for Montcalm, C-20, Domino and Cardinal were consistently above the expected values in their respective mixtures. The performance of these genotypes in the mixtures reflected the trend of their yield components. Montcalm in the mixture of C-20 : Montcalm : Taylor : Domino had most of its components the same as expected in the pure stand and its performance in the mixture was as expected. Taylor and Seafarer had values for most of their yield components below expected values and their yield performance was also inferior in the mixtures. In 1988, Montcalm did not perform well; C-20 and Black Magic performed well, with most of their components of yield in the mixtures above the values in pure stand. Taylor, Seafarer and Cardinal were inferior as in the 1987 season. The results imply that components of yield are associated with the competitive abilities of the genotypes in the mixtures. Plant height did not show any association with the changes in the components of yield and the yield performance. Plants tended to be shorter in the mixtures than in the pure stand.

4.5.2 <u>Anthracnose</u>

The components of yield of the genotypes in four, two-component mixtures and one, four-component mixture were compared to their values in the pure stand in both 1987 and 1988 and the two seasons combined (Tables 32, 33 and 34). There were differences between the components of yield in the mixtures which either increased, decreased or remained the same with respect to their values in the pure stand.

In the Domino : C-20 mixture, although both varieties are similarly susceptible and type II growth habit, they differed in the yield component traits in the mixture. Domino had some of its components of yield above, the same, or below the expected values (Table 32), whereas the components were lower for C-20 in the mixture except for seeds/pod. The yield of C-20 was 356 kg/ha below the expected value, and 45 kg/ha lower than the expected value for Domino (Table 24).

All the components of yield for Domino were above the expected values in the Domino : Seafarer mixture but low in the Montcalm : Domino mixture. Seafarer had inferior performance in the two-component mixture; Montcalm performed well when mixed with Domino or Seafarer. The yield data (Table 24) supports the performance of the genotypes in terms of the components of yield.

The genotypes in the two-component mixture had different interactions in terms of components in 1988 as compared to the 1987 season. Black Magic and C-20 were similar in their behavior (Table 33). Interestingly, Black Magic yielded above, while C-20 yielded somewhat below the expected values. Seafarer performed poorly in all the

Table 32. Yield and yield components and plant height of varieties in pure stand and in variety mixtures in a field experiment inoculated with <u>Colletotrichum</u> <u>lindemuthianum</u> grown during the 1987 season.

| Varieties | Pods/ 10 Plants | Seed wt/ 10 Plants (g) | Seed No./ 10 Plants | Seeds/ Pod | Plant ht (can)* (cm) | 100 Seed wt (g) |
|---|---|---|---|---|---|---|
| Pure Stand | | | | | | |
| 1. Domino | 167.7ef | 133.9b-e | 700.0cde | 4.2ab | 47.8abc | 18.3de |
| 2. C-20 | 230.0ab | 143.1a-e | 763.7cde | 3.2d | 52.4a | 18.0e |
| 3. Montcalm | 98.0h | 169.4abc | 357.3f | 3.5bcd | 42.6c | 46.1a |
| 4. Seafarer | 256.0a | 176.6ab | 1062.7a | 4.2ab | 51.0ab | 17.2e |
| Varieties in Mixtures | | | | | | |
| 5. Domino | 178.7def | 130.2cde | 759.0cde | 4.2a | 49.3abc | 15.4g |
| C-20 | 199.7b-e | 114.7e | 655.0de | 3.3cd | 49.9abc | 15.8fg |
| 6. Domino | 205.0bcd | 162.9a-d | 827.3bcd | 4.0abc | 53.6a | 19.9bc |
| Seafarer | 230.0ab | 162.6a-d | 965.3ab | 4.0abc | 46.9abc | 17.1ef |
| 7. Montcalm | 99.7h | 167.5abc | 358.0f | 3.6a-d | 49.2abc | 46.3a |
| Seafarer | 198.3b-e | 122.3de | 736.7cde | 3.7a-d | 49.2abc | 17.5e |
| 9. Montcalm | 105.3h | 166.0abc | 351.3f | 3.4cd | 43.6bc | 46.4a |
| Domino | 150.3fg | 108.6e | 599.3e | 4.0abc | 49.8abc | 19.4cd |
| 10. C-20 | 225.3ab | 144.5a-e | 770.3b-e | 3.4bcd | 53.4a | 20.9b |
| Montcalm | 117.0gh | 183.2a | 389.0f | 3.4cd | 45.4abc | 47.2a |
| Domino | 184.3c-f | 141.7a-e | 790.0b-e | 4.3a | 53.3a | 18.1de |
| Seafarer | 217.7bc | 143.2a-e | 863.0bc | 4.0abc | 51.1ab | 17.1ef |
| Means | 179.0 | 148.2 | 684.3 | 3.8 | 49.3 | 25.1 |
| CV% | 11.8 | 17.4 | 17.4 | 11.9 | 10.2 | 3.3 |

* can = canopy

Numbers within columns followed by the same letter are not significantly different at P = .05.

Table 33. Yield and yield components and plant height of varieties in pure stand and in variety mixtures in a field experiment inoculated with C. lindemuthianum for the 1988 season.

| Varieties | Pods/ 10 Plants | Seed wt/ 10 Plants (g) | Seed No./ 10 Plants | Seeds/ Pod | Plant ht (can)* (cm) | 100 Seed wt (g) | Plant ht(tip) (cm) |
|---|---|---|---|---|---|---|---|
| Pure Stand | | | | | | | |
| 1. Black Magic | 232.3cd | 166.6c-f | 1009.3bc | 4.3bcd | 53.5a | 16.6g | 76.1d |
| 2. C-20 | 228.7cd | 154.7def | 937.3c | 4.2bcd | 53.3a | 17.7fg | 100.8a |
| 3. Montcalm | 129.0fgh | 189.3b-f | 360.7e | 2.8e | 44.9de | 53.3b | 44.9e |
| 4. Seafarer | 452.3a | 304.6a | 1524.3a | 3.4cde | 46.3de | 20.9d | 46.3e |
| Varieties in Mixtures | | | | | | | |
| 5. Black Magic | 178.0def | 135.9d-g | 803.0cd | 4.4bc | 51.8abc | 16.6g | 86.2bc |
| C-20 | 212.0cde | 200.6b-e | 1003.3c | 4.7ab | 52.0abc | 17.7fg | 93.2b |
| 6. Black Magic | 315.7b | 258.1ab | 1529.0a | 4.8ab | 53.4a | 17.2fg | 76.4d |
| Seafarer | 196.0c-f | 111.3fg | 576.7de | 2.8e | 44.7de | 20.5de | 44.7e |
| 7. Montcalm | 155.3efg | 252.5ab | 486.7de | 3.1de | 48.4bcd | 52.8b | 48.4e |
| Seafarer | 315.0b | 157.2def | 793.7cd | 2.6e | 47.5cde | 21.2d | 47.5e |
| 9. Montcalm | 82.3h | 122.5d-g | 237.3e | 2.9e | 46.3de | 55.4a | 46.3e |
| Black Magic | 237.3cd | 254.9ab | 1359.0ab | 5.8a | 53.7a | 18.3fg | 83.1cd |
| 10. C-20 | 257.0bc | 205.2bcd | 1127.0bc | 4.3bcd | 51.6abc | 18.8ef | 100.9a |
| Montcalm | 90.3gh | 118.8efg | 242.3e | 2.7e | 44.6de | 48.6c | 44.6e |
| Black Magic | 237.3cd | 241.6abc | 1360.7ab | 5.7a | 52.9ab | 17.9fg | 79.5cd |
| Seafarer | 129.0fgh | 65.6g | 360.3e | 2.8e | 43.0e | 17.9fg | 43.0e |
| Means | 215.5 | 183.7 | 856.9 | 3.8 | 49.2 | 27.0 | 66.4 |
| CV% | 19.7 | 27.1 | 24.7 | 19.8 | 5.6 | 4.0 | 6.6 |

* can = canopy

Numbers within columns followed by the same letter are not significantly different at P = .05.

Table 34. Yield and yield components and plant height of varieties in pure stand and in variety mixtures in a field experiment inoculated with C. lindemuthianum for the 1987 and 1988 seasons combined.

| Varieties | Pods/ 10 Plants | Seed wt/ 10 Plants (g) | Seed No./ 10 Plants | Seeds/ Pod | Plant ht (can)* (cm) | 100 Seed wt (g) |
|---|---|---|---|---|---|---|
| Pure Stand | | | | | | |
| 1. Domino/BM | 200.0def | 150.3c-f | 854.7cde | 4.3a-d | 50.7a-d | 17.4efg |
| 2. C-20 | 229.3bcd | 148.9c-f | 850.5cde | 3.7cde | 52.8abc | 17.9de |
| 3. Montcalm | 113.5g | 179.4bcd | 359.0fg | 3.1e | 43.8f | 49.3a |
| 4. Seafarer | 354.2a | 240.6a | 1293.5a | 3.8cde | 48.6b-e | 19.1cde |
| Varieties in Mixtures | | | | | | |
| 5. Domino/BM | 178.3ef | 133.1ef | 781.0de | 4.3a-d | 50.5a-d | 16.0g |
| C-20 | 205.8c-f | 157.6cde | 829.2cde | 4.0a-e | 50.9a-d | 16.8fg |
| 6. Domino/BM | 260.3b | 210.5ab | 1178.2ab | 4.4abc | 53.5a | 18.5cde |
| Seafarer | 213.0cde | 137.0def | 771.0de | 3.4de | 45.8ef | 18.8cde |
| 7. Montcalm | 127.5g | 210.0ab | 422.3fg | 3.4de | 48.8a-e | 49.6ab |
| Seafarer | 256.7b | 139.7def | 765.2de | 3.1e | 48.3c-f | 19.4cd |
| 9. Montcalm | 93.8g | 144.2def | 294.3g | 3.1e | 45.0ef | 50.9a |
| Domino/BM | 193.8def | 181.8bcd | 979.2bcd | 4.9ab | 51.8abc | 18.9cde |
| 10. C-20 | 241.2bc | 174.9b-e | 948.7bcd | 3.9b-e | 52.5abc | 19.9c |
| Montcalm | 103.7g | 151.0cde | 315.7g | 3.0e | 45.0ef | 47.9b |
| Domino/BM | 210.8c-f | 191.7bc | 1075.3abc | 5.0a | 53.1ab | 18.0def |
| Seafarer | 173.3f | 104.4f | 611.7ef | 3.4de | 47.0def | 17.5efg |
| Means | 197.2 | 165.9 | 770.6 | 3.8 | 49.3 | 26.0 |
| CV% | 17.0 | 20.1 | 23.1 | 16.5 | 8.2 | 4.0 |

* can = canopy

Numbers within columns followed by the same letter are not significantly different at P = .05.

mixtures and Black Magic performed well in all the mixtures. Montcalm did well when mixed with Seafarer but poorly when mixed with Black Magic. The yield data (Table 24) follows the patterns of the components of yield. The interactions in the two-component mixture was of the complementary type except that Domino : C-20 had an undercompensatory interaction in 1987. In 1988, Black Magic : C-20 and Black Magic : Seafarer had a pattern close to overcompensatory.

The four-component mixtures were variable in both seasons (Tables 31 and 32). In the 1987 season, most of the components of yield for Montcalm in the mixtures were above the expected values in the pure stand except for the seeds/10 plants. Most of the components of yield for Montcalm in the mixture in 1988 were below the expected values except for seeds/10 plants and seeds/pod which were the same as expected. Seafarer was an inferior competitor in both seasons and C-20, Domino and Black Magic were aggressive competitors except that C-20 was less aggressive in 1987. The yields of the genotypes in the mixtures and their expected values are given in Table 24. The performance in yield related well to the magnitude of the components of yield for different genotypes in different mixture combinations.

### 4.5.3 Angular leaf spot

The components of yield for the genotypes in pure stand and in the mixture in the experiment inoculated with angular leaf spot are summarized in Tables 35, 36 and 37 for the 1987, 1988 and the two seasons combined.

In the two-component mixture of Montcalm : C-20, Montcalm had seeds/pod higher and 100 seed weight lower than in the pure stand and the rest of components were the same as the values in pure stands in 1987 (Table 35). In 1988 all the components of yield were the same as or below the pure stand values for Montcalm (Table 36). C-20 had all of its components of yield above the expected values except for the 100 seed weight in 1987 and seeds/pod and 100 seed weight for 1988.

These data compare well with the yield data (Table 26) that C-20 yielded above the expected values for the two seasons. Montcalm yielded close to the expected value in 1987 and 305 kg/ha below the expected value in 1988.

For the four-component mixture, there was no major contrast for the yield components between the genotypes in 1987. Montcalm had some of its yield components higher, lower or the same as expected values while Taylor had most of its components similar to the expected values. None of the components of yield were below the expected values for C-20, Domino or Black Magic. Similarly, Montcalm and Taylor had yields similar to the expected (Table 26), Domino had a slight increase, and C-20 yielded above the expected value.

Data for the 1988 season showed that Montcalm and Taylor, in the four-component mixture, had much reduced components of yield and C-20 and Black Magic had higher

Table 35. Yield and yield components and plant height of varieties in pure stand and in variety mixtures in a field experiment inoculated with Phaeoisariopsis griseola during the 1987 season.

| Varieties | Pods/ 10 Plants | Seed wt/ 10 Plants (g) | Seed No./ 10 Plants | Seeds/ Pod | Plant ht (can)* (cm) | 100 Seed wt (g) |
|---|---|---|---|---|---|---|
| Pure Stand | | | | | | |
| 1. Domino | 203.3c | 190.6b | 907.3b | 4.4ab | 56.7abc | 19.7e |
| 2. C-20 | 262.3b | 190.5b | 859.0b | 3.2def | 64.1ab | 23.8d |
| 3. Montcalm | 74.0d | 66.1c | 184.7c | 2.5g | 44.3cd | 36.5a |
| 4. Taylor | 72.0d | 95.7c | 299.3c | 4.2b | 36.5d | 31.0c |
| Varieties in Mixtures | | | | | | |
| 6. Montcalm | 79.7d | 72.0c | 211.7c | 2.7fg | 47.3cd | 33.9b |
| C-20 | 347.3a | 288.5a | 1216.3a | 3.5cd | 63.9ab | 24.2d |
| 7. C-20 | 291.7b | 234.6b | 1005.0ab | 3.4de | 66.7a | 25.0d |
| Montcalm | 73.7d | 74.0c | 211.0c | 2.8efg | 46.2cd | 33.8b |
| Taylor | 76.7d | 94.8c | 307.0c | 4.0bc | 45.5cd | 30.6c |
| Domino | 213.7c | 218.3b | 1036.0ab | 4.9a | 52.1bc | 20.8e |
| Means | 169.4 | 152.5 | 623.7 | 3.6 | 52.3 | 27.9 |
| CV% | 16.2 | 17.2 | 24.6 | 10.7 | 14.8 | 3.8 |

* can = canopy

Numbers within columns followed by the same letter are not significantly different at P = .05.

Table 36. Yield and yield components and plant height of varieties in pure stand and in variety mixtures in a field experiment inoculated with P. griseola grown during the 1988 season.

| Varieties | Pods/ 10 Plants | Seed wt/ 10 Plants (g) | Seed No./ 10 Plants | Seeds/ Pod | Plant ht (can)* (cm) | 100 Seed wt (g) | Plant ht(tip) (cm) |
|---|---|---|---|---|---|---|---|
| Pure Stand | | | | | | | |
| 1. Black Magic | 225.0c | 227.6b | 1222.3bc | 5.4a | 53.5b | 18.2c | 80.3c |
| 2. C-20 | 249.0bc | 162.2c | 939.7d | 3.8b | 54.0b | 18.2c | 90.7b |
| 3. Montcalm | 81.7de | 111.4de | 232.3ef | 2.9cd | 48.1cd | 48.0a | 48.1d |
| 4. Taylor | 110.0d | 147.9cd | 374.3e | 3.4bc | 44.9d | 42.0b | 44.9d |
| Varieties in Mixtures | | | | | | | |
| 6. Montcalm | 74.7de | 90.8e | 182.3f | 2.4d | 50.5bc | 48.5a | 50.5d |
| C-20 | 469.3a | 335.1a | 1783.7a | 3.8b | 52.5bc | 19.1c | 101.6a |
| 7. C-20 | 292.7b | 211.0b | 1172.3c | 4.0b | 58.7a | 18.9c | 107.0a |
| Montcalm | 59.0e | 92.8e | 224.0ef | 3.7b | 50.1bc | 46.7a | 50.1d |
| Taylor | 91.7de | 113.7de | 271.3ef | 2.9cd | 48.2cd | 40.6b | 48.2d |
| Black Magic | 265.0bc | 252.1b | 1370.7b | 5.1a | 59.2a | 18.7c | 89.8b |
| Means | 191.8 | 174.5 | 777.3 | 3.8 | 52.0 | 31.9 | 71.1 |
| CV% | 15.0 | 15.7 | 14.4 | 11.2 | 5.2 | 4.2 | 5.9 |

* can = canopy

Numbers within columns followed by the same letter are not significantly different at P = .05.

Table 37. Yield and yield components and plant height of varieties in pure stand and in variety mixtures in a field experiment inoculated with P. griseola for the 1987 and 1988 seasons combined.

| Varieties | Pods/ 10 Plants | Seed wt/ 10 Plants (g) | Seed No./ 10 Plants | Seeds/ Pod | Plant ht (can)* (cm) | 100 Seed wt (g) |
|---|---|---|---|---|---|---|
| Pure Stand | | | | | | |
| 1. Black Magic | 214.2d | 209.1b | 1064.8b | 4.9a | 55.1bc | 19.0f |
| 2. C-20 | 255.7c | 176.4c | 899.3c | 3.5bc | 59.1ab | 21.0de |
| 3. Montcalm | 77.8e | 88.8e | 208.5d | 2.7d | 46.2de | 42.3a |
| 4. Taylor | 91.0e | 121.8d | 336.8d | 3.8b | 40.8e | 36.5c |
| Varieties in Mixtures | | | | | | |
| 6. Montcalm | 77.2e | 81.4e | 197.0d | 2.6d | 48.9cd | 41.2ab |
| C-20 | 408.3a | 311.8a | 1500.0a | 3.7bc | 58.2ab | 21.6d |
| 7. C-20 | 292.2b | 222.8b | 1088.7b | 3.7bc | 62.7a | 22.0d |
| Montcalm | 66.3e | 83.4e | 217.5d | 3.3c | 48.1d | 40.3b |
| Taylor | 84.2e | 104.2de | 289.2d | 3.5bc | 46.9de | 35.6c |
| Black Magic | 239.3cd | 235.2b | 1203.3b | 5.0a | 55.6b | 19.7ef |
| Means | 180.6 | 163.5 | 700.5 | 3.7 | 52.2 | 29.9 |
| CV% | 15.4 | 16.1 | 18.7 | 11.4 | 10.9 | 4.1 |

* can = canopy

Numbers within columns followed by the same letter are not significantly different at P = .05.

values as compared to 1987. Yield data (Table 26) support the yield component data, that C-20 and Black Magic yielded higher than the expected, Montcalm yielded the same and Taylor exhibited a slight reduction in yield as compared to expected.

### 4.5.4 Halo blight

Components of yield of the genotypes in pure stand and in the mixtures in the halo blight experiment are summarized in Tables 38, 39 and 40. In the two-component mixture, in 1987, all the components of yield of Taylor were above the expected values (Table 38). Montcalm and Taylor in the same mixture had similar values for the components of yield for the 1988 season. Montcalm had lower 100 seed weight (Table 39). Montcalm and Taylor both had yield increases in the mixtures as compared to the pure stand in 1987 (Table 38). In 1988, Montcalm had the same yield in the mixture as the expected value but Taylor had a slight increase in yield over the expected value.

In 1987, C-20 and MIC had a greater response in components of yield in the four-component mixture than either Montcalm and Taylor (Table 38). The yield data also show that Taylor yielded almost the same as the expected value and Montcalm had lower yield than the expected value. C-20 and MIC yielded above the expected values in the mixture. In the same four-component mixture, C-20 and Taylor had higher components of yield than Montcalm and Cardinal in 1988 (Table 39). These genotypes also had

Table 38. Yield and yield components and plant height of varieties in pure stand and in variety mixtures in a field experiment inoculated with *Pseudomonas syringae* pv *phaseolicola* during the 1987 season.

| Varieties | Pods/ 10 Plants | Seed wt/ 10 Plants (g) | Seed No./ 10 Plants | Seeds/ Pod | Plant ht (can)* (cm) | 100 Seed wt (g) |
|---|---|---|---|---|---|---|
| Pure Stand | | | | | | |
| 1. C-20 | 290.0b | 238.2a | 1097.3b | 3.8ab | 73.2b | 21.0d |
| 2. Montcalm | 138.0c | 186.6b | 419.0c | 3.1cd | 45.3c | 46.1a |
| 3. Taylor | 90.3ef | 136.0cd | 345.3cde | 3.8ab | 35.9d | 40.5bc |
| 4. MIC | 92.3def | 126.5cd | 276.0ef | 3.1cd | 75.4ab | 45.6a |
| Varieties in Mixtures | | | | | | |
| 6. Montcalm | 119.3cd | 194.2b | 405.7cd | 3.4bc | 46.1c | 45.4a |
| Taylor | 91.7ef | 153.8c | 371.0cd | 4.1a | 35.9d | 42.0b |
| 7. C-20 | 318.7a | 259.2a | 1192.0a | 3.8ab | 78.9a | 21.0d |
| Montcalm | 96.0def | 150.4c | 329.0de | 3.5bc | 48.8c | 45.3a |
| Taylor | 69.3f | 107.3d | 242.3f | 3.5abc | 34.6d | 38.3c |
| MIC | 100.0de | 126.6cd | 281.0ef | 2.8d | 76.7ab | 46.7a |
| Means | 140.6 | 167.9 | 495.9 | 3.5 | 55.1 | 39.2 |
| CV% | 11.3 | 10.7 | 10.1 | 10.0 | 5.2 | 3.6 |

* can = canopy

Numbers within columns followed by the same letter are not significantly different at P = .05.

Table 39. Yield and yield components and plant height of varieties in pure stand and in variety mixtures in a field experiment inoculated with *P. s.* pv *phaseolicola* during the 1988 season.

| Varieties | Pods/ 10 Plants | Seed wt/ 10 Plants (g) | Seed No./ 10 Plants | Seeds/ Pod | Plant ht (can)* (cm) | 100 Seed wt (g) | Plant ht(tip) (cm) |
|---|---|---|---|---|---|---|---|
| Pure Stand | | | | | | | |
| 1. C-20 | 274.7b | 195.6bc | 1130.3b | 4.1ab | 54.0ab | 18.2f | 78.9b |
| 2. Montcalm | 117.3cd | 184.6bc | 339.7c | 3.0c | 47.0c | 55.0cd | 47.0cd |
| 3. Taylor | 89.7cd | 142.6c | 305.3c | 3.4bc | 41.0e | 49.5e | 41.0f |
| 4. Cardinal | 137.3c | 245.5ab | 403.0c | 3.0c | 48.2c | 66.4a | 48.2c |
| Varieties in Mixtures | | | | | | | |
| 6. Montcalm | 102.0cd | 173.6bc | 304.0c | 3.0c | 46.5cd | 53.4d | 46.5cde |
| Taylor | 98.7cd | 151.7c | 302.3c | 3.0c | 41.5e | 48.9e | 41.5ef |
| 7. C-20 | 364.3a | 320.0a | 1765.7a | 4.8a | 58.7a | 17.5f | 109.7a |
| Montcalm | 90.0cd | 146.4c | 262.0c | 2.9c | 45.7cde | 56.5c | 45.7c-f |
| Taylor | 109.7cd | 174.7bc | 358.7c | 3.3bc | 42.0de | 49.6e | 42.0def |
| Cardinal | 76.6d | 120.7c | 204.7c | 2.7c | 49.1bc | 60.3b | 49.1c |
| Means | 146.0 | 185.6 | 537.6 | 3.3 | 47.4 | 47.5 | 55.0 |
| CV% | 21.7 | 26.0 | 37.2 | 14.7 | 6.1 | 3.1 | 5.5 |

* can = canopy

Numbers within columns followed by the same letter are not significantly different at P = .05.

Table 40. Yield and yield components and plant height of varieties in pure stand and variety mixtures in a field experiment inoculated with P. s. pv phaseolicola for the 1987 and 1988 seasons combined.

| Varieties | Pods/ 10 Plants | Seed wt/ 10 Plants (g) | Seed No./ 10 Plants | Seeds/ Pod | Plant ht (can)* (cm) | 100 Seed wt (g) |
|---|---|---|---|---|---|---|
| Pure Stand | | | | | | |
| 1. C-20 | 282.3b | 216.9b | 1113.8b | 4.0ab | 63.6b | 19.6e |
| 2. Montcalm | 127.7c | 185.6bc | 379.3c | 3.0de | 46.2c | 50.6c |
| 3. Taylor | 90.0d | 139.3d | 325.3c | 3.6bc | 38.4d | 45.0d |
| 4. Cardinal | 114.8cd | 186.0bc | 339.5c | 3.0de | 61.8b | 56.0a |
| Varieties in Mixtures | | | | | | |
| 6. Montcalm | 110.7cd | 183.9bc | 354.8c | 3.2cde | 46.3c | 49.4c |
| Taylor | 95.2d | 152.7cd | 336.7c | 3.5bc | 38.7d | 45.5d |
| 7. C-20 | 341.5a | 289.6a | 1478.8a | 4.3ac | 68.8a | 19.3e |
| Montcalm | 93.0d | 148.4cd | 295.5c | 3.2cde | 47.3c | 50.9c |
| Taylor | 89.5d | 141.0d | 300.5c | 3.4cd | 38.3d | 44.0d |
| Cardinal | 88.3d | 123.7d | 242.8c | 2.7e | 62.9b | 53.5b |
| Means | 143.3 | 176.7 | 516.7 | 3.4 | 51.2 | 43.4 |
| CV% | 17.2 | 20.4 | 28.1 | 12.2 | 5.6 | 3.3 |

* can = canopy

Numbers within columns followed by the same letter are not significantly different at P = .05.

higher yields in the mixture than expected, whereas Montcalm and Taylor had lower yields in the mixture. In all the experiments, plant height was not a critical factor because it did not seem to be related to performance. There was no specific patterns as to which components of yield were affected most, which ones affected least, or which ones were not affected by mixing in all the experiments. This may reflect the complexity of the plant interactions in the mixtures. Different forms of interactions are involved and different forms of stress may be involved at different times during the plant growth.

## 4.6 Plant Traits

Plant traits were evaluated in the same way as the components of yield. The samples were taken outside the harvest area, as explained under section of Materials and Methods.

Traits measured were plant height (canopy), plant height (tip) and plant weight at full bloom. At physiological maturity, plant height (can.), plant height (tip), pods/plant, pod weight and plant weight were measured. Plant weight was taken as the weight of the remaining plant parts after the pods were separated. Plants had dropped most of their leaves when samples were taken at physiological maturity. Measurements of the plant height from the ground level to the top of the plants were taken to see if plant height would change in different mixtures as compared to the pure stand. Plant weights were taken at full bloom and at physiological maturity to see if genotypes changed in different mixtures. Results are summarized in Tables 41 to 52.

In all the four experiments the data on plant traits had similar trends as the components of yield and the performance of the genotypes in the mixtures when compared to values in the pure stand. Plant height at full bloom and at physiological maturity was not a critical factor and did not seem to relate to the performance of the genotypes in the mixtures.

Table 41. Means of plant traits, per plant, of varieties in pure stand and in mixtures at full bloom and at physiological maturity in a non-inoculated experiment during the 1987 season.

| | Full Bloom | | Physiological Maturity | | | |
|---|---|---|---|---|---|---|
| Varieties | Plant ht (can) (cm) | Plant wt (g) | Plant ht (can) (cm) | Pod No. | Pod wt wt (g) | Plant wt (g) |
| Pure Stand | | | | | | |
| 1. Domino | 54.7a | 20.8b-e | 56.5c | 25.7abc | 28.9a | 16.9d-g |
| 2. C-20 | 50.5abc | 32.5a | 56.8c | 29.9a | 21.8bcd | 20.8b-e |
| 3. Montcalm | 39.7d-g | 19.1b-f | 44.8e-h | 11.3hij | 20.8b-f | 16.1d-g |
| 4. Taylor | 30.7gh | 12.1efg | 30.4ijk | 7.8ijk | 14.4f-i | 8.3hij |
| 5. Seafarer | 39.6d-g | 15.6d-g | 41.7gh | 32.6a | 26.3ab | 17.3c-f |
| 6. MIC | 52.7ab | 26.6abc | 85.5a | 19.7c-f | 15.8d-h | 28.9a |
| Varieties in Mixtures | | | | | | |
| 10. Montcalm | 40.0def | 26.5a-d | 39.3hij | 12.2g-j | 21.3b-e | 21.3bcd |
| C-20 | 51.2abc | 23.7a-d | 52.7c-f | 27.7ab | 19.3c-g | 18.7b-f |
| 11. Montcalm | 31.8fgh | 29.5ab | 38.0h-k | 14.2e-i | 23.1abc | 21.3bcd |
| Taylor | 20.3i | 7.7g | 28.6jk | 5.3jk | 8.8ij | 7.2ij |
| 12. Montcalm | 42.2cde | 24.4a-d | 43.3fgh | 13.0f-i | 22.8a-d | 19.0b-f |
| Domino | 50.3abc | 15.7d-g | 55.5cd | 16.7d-h | 16.9c-g | 10.4ghi |
| 13. C-20 | 45.8a-d | 16.2c-g | 53.9c-f | 31.7a | 22.7a-d | 20.4b-e |
| Montcalm | 39.3d-g | 26.7abc | 40.7hi | 11.7hij | 18.8c-g | 14.5e-h |
| Taylor | 26.3hi | 9.4fg | 28.4k | 4.2k | 9.1hij | 4.4j |
| MIC | 52.1ab | 26.7abc | 72.5b | 16.6d-h | 14.3f-i | 23.9ab |
| 14. C-20 | 42.2cde | 20.6b-e | 55.0cde | 29.2a | 20.5b-f | 23.5abc |
| Montcalm | 39.5d-g | 25.8a-d | 37.3hijk | 9.7h-k | 14.3e-i | 14.0fgh |
| Taylor | 23.3hi | 8.7fg | 28.4jk | 3.8k | 6.3j | 3.6j |
| Domino | 50.0abc | 22.0a-e | 52.5c-g | 19.0c-g | 19.7b-g | 13.4f-i |
| 15. C-20 | 47.0a-d | 20.7b-e | 68.3b | 21.5bcd | 13.2g-j | 21.8bcd |
| Montcalm | 43.7b-e | 24.8a-d | 38.8h-k | 12.7f-i | 19.2c-g | 22.1bcd |
| Seafarer | 36.4efg | 17.8c-g | 39.2h-k | 29.6a | 18.9c-g | 9.7hij |
| Domino | 45.5a-e | 24.9a-d | 45.4d-h | 21.0b-e | 20.3b-f | 13.4f-i |
| Means | 41.4 | 20.8 | 47.2 | 17.8 | 18.2 | 16.3 |
| CV% | 13.7 | 31.9 | 14.1 | 24.3 | 23.4 | 23.3 |

* can = canopy

Numbers within columns followed by the same letter are not significantly different at P = .05.

Table 42. Means of plant traits, per plant, of varieties in pure stand and in mixtures at full bloom and at physiological maturity in a non-inoculated experiment during the 1988 season.

| | Full Bloom | | | Physiological Maturity | | | | |
|---|---|---|---|---|---|---|---|---|
| Varieties | Plant ht (can) (cm) | Plant ht (tip) (cm) | Plant wt (g) | Plant ht (can) (cm) | Plant ht (tip) (cm) | Pod No. | Pod wt (g) | Plant wt (g) |
| Pure Stand | | | | | | | | |
| 1. Black Magic | 56.7a | 68.1bc | 21.7a | 60.4bc | 76.5d | 26.8de | 33.9b-e | 15.0b-e |
| 2. C-20 | 47.8b-e | 88.8a | 18.3a-d | 63.7abc | 110.0ab | 28.2de | 28.1d-g | 17.6b |
| 3. Montcalm | 39.3fg | 39.4d | 14.2b-e | 42.3ef | 42.3efg | 12.3f-i | 32.6b-f | 13.2b-f |
| 4. Taylor | 38.7fg | 38.7d | 13.7cde | 41.8ef | 41.8efg | 14.6fg | 26.8efg | 15.8bc |
| 5. Seafarer | 46.6c-f | 46.6d | 19.6ab | 47.7ef | 47.7ef | 44.7a | 38.9abc | 18.2ab |
| 6. Cardinal | 39.9fg | 38.9d | 14.6b-e | 45.6ef | 45.6efg | 16.3fg | 31.4b-f | 13.9b-f |
| Varieties in Mixtures | | | | | | | | |
| 10. Montcalm | 40.7efg | 40.7d | 18.7abc | 45.7ef | 45.7efg | 12.0f-i | 19.3gh | 17.1bc |
| C-20 | 47.7b-e | 73.3b | 17.4a-e | 65.5ab | 106.8b | 41.3ab | 44.4a | 18.8ab |
| 11. Montcalm | 41.3efg | 41.3d | 13.1de | 45.4ef | 45.4efg | 17.3f | 32.6b-f | 14.1b-f |
| Taylor | 37.8g | 37.8d | 12.5e | 41.0f | 41.0efg | 12.8f-i | 26.0efg | 13.5b-f |
| 12. Montcalm | 43.5d-g | 43.5d | 18.8abc | 47.3ef | 46.4efg | 12.1f-i | 24.2fgh | 15.1bcd |
| Black Magic | 50.7a-d | 60.3c | 13.6cde | 59.2bc | 79.3cd | 28.1de | 40.1ab | 17.6b |
| 13. C-20 | 55.3ab | 86.1a | 16.7a-e | 68.8a | 109.6ab | 46.5a | 40.5ab | 25.8a |
| Montcalm | 41.7efg | 41.7d | 13.8cde | 44.0ef | 44.0efg | 8.0hij | 16.7hij | 9.4c-f |
| Taylor | 40.2efg | 40.0d | 16.3a-e | 40.3f | 39.2g | 13.4fgh | 24.5fgh | 11.5b-f |
| Cardinal | 45.5c-g | 45.5d | 13.7cde | 43.5ef | 43.5efg | 8.2hij | 16.1hij | 6.2f |
| 14. C-20 | 52.7abc | 75.2b | 13.4cde | 68.8a | 116.8a | 35.3bc | 28.1d-g | 17.2bc |
| Montcalm | 39.7fg | 39.7d | 15.1b-e | 43.7ef | 43.7efg | 4.8j | 10.3ij | 7.4def |
| Taylor | 38.5g | 38.5d | 12.4e | 40.2f | 40.3fg | 6.6ij | 16.8hij | 9.5c-f |
| Black Magic | 55.9a | 61.4c | 17.3a-e | 56.8cd | 86.7c | 25.6de | 36.8a-d | 12.8b-f |
| 15. C-20 | 50.0a-d | 94.5a | 18.8abc | 66.7ab | 115.8a | 31.6cd | 29.5def | 14.5b-e |
| Montcalm | 43.6d-g | 43.6d | 17.7a-e | 44.8ef | 44.9efg | 10.3g-j | 19.3ghi | 11.6b-f |
| Seafarer | 44.7d-g | 44.7d | 13.0de | 49.4de | 49.4e | 11.1ghi | 9.2j | 7.0ef |
| Black Magic | 56.2a | 59.5c | 17.0a-e | 56.7cd | 81.8cd | 24.8e | 30.1c-f | 16.2bc |
| Means | 45.6 | 53.6 | 15.9 | 51.2 | 64.3 | 20.5 | 27.3 | 14.1 |
| CV% | 10.6 | 12.1 | 21.2 | 9.3 | 7.9 | 18.3 | 20.5 | 34.4 |

* can = canopy

Numbers within columns followed by the same letter are not significantly different at P = .05.

Table 43. Means of plant traits, per plant, of varieties in pure stand and in mixtures at full bloom and at physiological maturity in a non-inoculated experiment for the 1987 and 1988 seasons combined.

| | Full Bloom | | Physiological Maturity | | | |
|---|---|---|---|---|---|---|
| Varieties | Plant ht (can) (cm) | Plant wt (g) | Plant ht (can) (cm) | Pod No. | Pod wt (g) | Plant wt (g) |
| Pure Stand | | | | | | |
| 1. Domino/Black Magic | 55.7a | 21.2a-d | 58.5cd | 26.3de | 31.4a | 16.0b-g |
| 2. C-20 | 49.1b-e | 35.4a | 60.3bcd | 29.1cd | 25.0bcd | 19.2a-d |
| 3. Montcalm | 39.5f-i | 16.7b-f | 43.4g | 11.8hij | 26.7abc | 14.7d-h |
| 4. Taylor | 34.7h-k | 12.9fgh | 36.1hij | 11.2hij | 20.6d-g | 12.1f-j |
| 5. Seafarer | 43.1def | 17.6b-f | 44.7fg | 38.6a | 32.6a | 17.8a-e |
| 6. MIC/Cardinal | 45.8c-f | 20.6a-e | 65.6ab | 18.0fg | 23.6b-e | 21.4ab |
| Varieties in Mixtures | | | | | | |
| 10. Montcalm | 40.3fgh | 22.6ab | 42.5gh | 12.1hij | 20.6d-g | 19.2a-d |
| C-20 | 49.4a-d | 20.6a-e | 59.1bcd | 34.5ab | 31.8a | 18.7a-d |
| 11. Montcalm | 36.6g-j | 21.3a-d | 41.7ghi | 15.8gh | 27.8ab | 17.7a-e |
| Taylor | 29.1k | 10.1h | 34.8ij | 9.0ijk | 17.4f-j | 10.4hij |
| 12. Montcalm | 42.8efg | 21.6abc | 45.3fg | 12.6hi | 23.5b-e | 17.1b-f |
| Domino/Black Magic | 50.5abc | 14.6e-h | 57.3cde | 22.4ef | 28.5ab | 14.2d-h |
| 13. C-20 | 50.6abc | 16.5c-g | 61.4a-d | 39.1a | 31.6a | 23.1a |
| Montcalm | 40.5fgh | 20.2a-e | 42.3gh | 9.8ijk | 17.7e-i | 12.0f-j |
| Taylor | 33.3ijk | 12.8fgh | 34.3j | 8.8ijk | 16.8f-j | 7.9ij |
| MIC/Cardinal | 48.8b-e | 20.2a-e | 58.0cd | 12.4hi | 15.2g-j | 15.0c-h |
| 14. C-20 | 47.4b-e | 17.0b-f | 61.9abc | 32.3bc | 24.3bcd | 20.4abc |
| Montcalm | 39.6f-i | 20.4a-e | 40.5g-j | 7.3jk | 12.4ij | 10.7g-j |
| Taylor | 30.9jk | 10.6gh | 34.3j | 5.2k | 11.5j | 6.6j |
| Domino/Black Magic | 53.0ab | 19.7a-e | 54.7de | 22.3ef | 28.3ab | 13.1e-i |
| 15. C-20 | 48.5b-e | 19.8a-e | 67.5a | 26.6de | 21.3c-f | 18.2a-e |
| Montcalm | 43.6def | 21.2a-d | 41.8gh | 11.5hij | 19.3d-h | 16.8b-f |
| Seafarer | 40.5fgh | 15.4d-h | 44.3ef | 20.3fg | 14.1hij | 8.4ij |
| Domino/Black Magic | 50.8abc | 21.0a-d | 51.0ef | 22.9ef | 25.2bcd | 14.8c-h |
| Means | 43.5 | 18.3 | 49.2 | 19.2 | 22.8 | 15.2 |
| CV% | 12.8 | 28.9 | 12.4 | 23.0 | 23.2 | 31.8 |

* can = canopy

Numbers within columns followed by the same letter are not significantly different at P = .05.

Table 44. Means of plant traits, per plant, of varieties in pure stand and in mixtures at full bloom and at physiological maturity in an experiment inoculated with C. lindemuthianum during the 1987 season.

| Varieties | Full Bloom: Plant ht (can) (cm) | Full Bloom: Plant wt (g) | Physiological Maturity: Plant ht (can) (cm) | Pod No. | Pod wt wt (g) | Plant wt (g) |
|---|---|---|---|---|---|---|
| Pure Stand | | | | | | |
| 1. Domino | 46.0bc | 14.3a-d | 54.1ab | 23.3cd | 18.3a-d | 9.3a-d |
| 2. C-20 | 49.4ab | 18.3ab | 57.3a | 25.6bc | 19.4a-d | 11.5a |
| 3. Montcalm | 40.7cd | 17.2abc | 40.3e | 13.7fgh | 22.1a | 11.2ab |
| 4. Seafarer | 48.2ab | 14.0a-d | 48.8bcd | 31.3ab | 20.8ab | 10.1abc |
| Varieties in Mixtures | | | | | | |
| 5. Domino | 45.2bc | 13.1a-d | 47.3b-e | 18.5def | 15.4cde | 6.3d |
| C-20 | 50.5ab | 14.2a-d | 55.0ab | 22.3cde | 14.8cde | 10.1abc |
| 6. Domino | 54.0a | 14.1a-d | 54.2ab | 18.4def | 17.2a-d | 8.4a-d |
| Seafarer | 44.5bcd | 16.3a-d | 47.7b-e | 31.8a | 19.8abc | 10.3abc |
| 7. Montcalm | 48.3ab | 16.8abc | 47.2b-e | 12.1gh | 21.9ab | 11.5a |
| Seafarer | 48.8ab | 12.0bcd | 50.3abc | 27.2abc | 18.6a-d | 10.3abc |
| 9. Montcalm | 37.7d | 14.4a-d | 40.9de | 12.9fgh | 21.5ab | 11.3ab |
| Domino | 44.2bcd | 11.0cd | 48.4b-e | 16.8efg | 14.4de | 8.8a-d |
| 10. C-20 | 48.4ab | 13.3a-d | 57.7a | 17.5efg | 11.8e | 8.0bcd |
| Montcalm | 43.8bcd | 19.6a | 43.7cde | 10.0h | 18.8a-d | 7.9bcd |
| Domino | 47.0abc | 10.2d | 51.8abc | 17.8d-g | 16.7b-e | 7.7cd |
| Seafarer | 46.6bc | 18.3ab | 45.7cde | 26.2abc | 16.8b-e | 8.8a-d |
| Means | 46.5 | 14.8 | 49.4 | 20.3 | 18.0 | 9.5 |
| CV% | 9.1 | 26.5 | 10.0 | 17.1 | 17.3 | 22.2 |

* can = canopy

Numbers within columns followed by the same letter are not significantly different at P = .05.

Table 45. Means of plant traits, per plant, of varieties in pure stand and in mixtures at full bloom and at physiological maturity in an experiment inoculated with C. lindemuthianum during the 1988 season.

| | Full Bloom | | | Physiological Maturity | | | | |
|---|---|---|---|---|---|---|---|---|
| Varieties | Plant ht (can) (cm) | Plant ht (tip) (cm) | Plant wt (g) | Plant ht (can) (cm) | Plant ht (tip) (cm) | Pod No. | Pod wt (g) | Plant wt (g) |
| Pure Stand | | | | | | | | |
| 1. Domino | 57.3a | 65.9c | 21.9ab | 57.7b | 71.9b | 24.2de | 24.2bcd | 12.6a-d |
| 2. C-20 | 53.7abc | 87.2b | 17.7bc | 64.1a | 113.3a | 31.4bcd | 21.8cd | 13.4a-d |
| 3. Montcalm | 42.3i | 42.3f | 21.4ab | 44.3f | 44.3c | 13.7fg | 25.3bcd | 16.6ab |
| 4. Seafarer | 47.9d-h | 48.0ef | 18.3bc | 46.5ef | 46.5c | 41.0a | 29.8ab | 15.8abc |
| Varieties in Mixtures | | | | | | | | |
| 5. Domino | 52.3a-e | 59.0cd | 19.6bc | 56.9bc | 80.0b | 21.0ef | 19.6d | 9.1de |
| C-20 | 52.7a-d | 100.3a | 20.8ab | 58.3b | 100.7a | 35.7ab | 34.9a | 18.2a |
| 6. Domino | 51.7b-e | 57.3cde | 17.4bc | 51.8c-e | 66.5b | 34.5abc | 35.8a | 13.8a-d |
| Seafarer | 47.3e-i | 47.3ef | 13.2c | 47.0ef | 47.0c | 20.5ef | 17.5def | 11.1b-e |
| 7. Montcalm | 46.2f-i | 46.2f | 28.0a | 45.5f | 45.5c | 13.0fg | 28.4abc | 15.4abc |
| Seafarer | 49.7c-f | 49.7def | 15.8bc | 49.8def | 49.8c | 26.0cde | 18.7de | 10.1cde |
| 9. Montcalm | 45.6f-i | 45.6f | 22.8ab | 46.3ef | 46.3c | 11.5g | 22.0bcd | 14.5a-d |
| Domino | 49.3c-g | 67.3c | 19.3bc | 53.7bcd | 75.2b | 32.5a-d | 28.6abc | 16.5ab |
| 10. C-20 | 55.3ab | 88.5b | 21.2ab | 57.5bc | 103.3a | 33.2abc | 25.0bcd | 18.3de |
| Montcalm | 43.8hi | 46.4f | 27.3a | 44.4f | 44.4c | 13.8fg | 11.4ef | 6.1e |
| Domino | 52.2b-e | 65.2c | 19.7bc | 58.0b | 80.2b | 28.0b-e | 27.9abc | 13.9a-d |
| Seafarer | 44.5ghi | 44.5f | 13.1c | 45.9f | 45.9c | 14.2fg | 10.3f | 5.3e |
| Means | 49.5 | 60.0 | 19.9 | 51.7 | 66.3 | 24.6 | 23.8 | 12.5 |
| CV% | 6.2 | 10.8 | 21.9 | 6.6 | 13.3 | 21.4 | 20.1 | 30.0 |

* can = canopy

Numbers within columns followed by the same letter are not significantly different at P = .05.

Table 46. Means of plant traits, per plant, of varieties in pure stand and in mixtures at full bloom and at physiological maturity in an experiment inoculated with C. lindemuthianum for the 1987 and 1988 seasons combined.

| | Full Bloom | | Physiological Maturity | | | |
|---|---|---|---|---|---|---|
| Varieties | Plant ht (can) (cm) | Plant wt (g) | Plant ht (can) (cm) | Pod No. | Pod wt wt (g) | Plant wt (g) |
| Pure Stand | | | | | | |
| 1. Domino/Black Magic | 51.7ab | 18.1bcd | 55.9a-d | 23.8cde | 21.3bcd | 11.0abc |
| 2. C-20 | 51.5abc | 18.0bcd | 60.7a | 28.5bc | 20.6bcd | 12.5ab |
| 3. Montcalm | 41.5f | 19.3abc | 42.3j | 13.7f | 23.7ab | 13.9a |
| 4. Seafarer | 48.1b-e | 16.2cd | 47.7f-i | 36.2a | 25.3ab | 13.0ab |
| Varieties in Mixtures | | | | | | |
| 5. Domino/Black Magic | 48.8a-d | 16.4cd | 52.1c-f | 19.8e | 17.5def | 7.7cd |
| C-20 | 51.6ab | 17.5cd | 56.6abc | 29.0b | 24.9ab | 14.1a |
| 6. Domino/Black Magic | 52.8a | 15.7cd | 53.0b-e | 26.5bcd | 26.5a | 11.1abc |
| Seafarer | 45.9de | 14.7cd | 47.3f-i | 26.2bcd | 18.7cde | 10.7abc |
| 7. Montcalm | 47.3cde | 22.4ab | 46.4g-j | 12.6f | 25.2ab | 13.5ab |
| Seafarer | 49.3a-d | 13.9d | 50.1e-h | 26.6bcd | 18.6cde | 10.2bcd |
| 9. Montcalm | 41.6f | 18.6bcd | 43.6ij | 12.2f | 21.8a-d | 12.9ab |
| Domino/Black Magic | 46.8de | 15.1cd | 51.1d-g | 24.7b-e | 21.5bcd | 12.7ab |
| 10. C-20 | 51.9ab | 17.3cd | 57.6ab | 25.3bcd | 18.4cde | 8.1cd |
| Montcalm | 43.8ef | 23.6a | 44.1ij | 11.9f | 15.1ef | 7.0d |
| Domino/Black Magic | 49.6a-d | 15.0cd | 54.9b-e | 22.9de | 22.3abc | 10.8abc |
| Seafarer | 45.5def | 15.7cd | 45.8hij | 20.2e | 13.5f | 7.0d |
| Means | 48.0 | 17.3 | 50.6 | 22.5 | 20.9 | 11.0 |
| CV% | 7.7 | 23.5 | 8.4 | 19.6 | 19.7 | 27.5 |

* can = canopy

Numbers within columns followed by the same letter are not significantly different at P = .05.

Table 47. Means of plant traits, per plant, of varieties in pure stand and in mixtures at full bloom and at physiological maturity in an experiment inoculated with P. griseola during the 1987 season.

| Varieties | Full Bloom | | Physiological Maturity | | | |
|---|---|---|---|---|---|---|
| | Plant ht (can) (cm) | Plant wt (g) | Plant ht (can) (cm) | Pod No. | Pod wt wt (g) | Plant wt (g) |
| Pure Stand | | | | | | |
| 1. Domino | 60.2ab | 19.1b | 60.7b | 22.5ab | 13.7ab | 17.0b |
| 2. C-20 | 64.3a | 25.3a | 64.5ab | 26.2a | 13.3ab | 21.5a |
| 3. Montcalm | 38.5cde | 12.6cd | 43.8cd | 6.8c | 7.9d | 8.7d |
| 4. Taylor | 31.3e | 7.9d | 38.2d | 8.8c | 12.5abc | 4.5e |
| Varieties in Mixtures | | | | | | |
| 6. Montcalm | 43.3c | 16.5bc | 42.7cd | 8.0c | 9.4cd | 11.5cd |
| C-20 | 59.2ab | 25.0a | 70.7a | 26.0a | 9.4cd | 23.4a |
| 7. C-20 | 60.1ab | 17.4bc | 61.9b | 25.8a | 11.3bcd | 23.5a |
| Montcalm | 41.0cd | 12.1cd | 46.8c | 9.5c | 12.6abc | 13.6c |
| Taylor | 33.7de | 8.1d | 38.8d | 8.7c | 13.4ab | 4.8e |
| Domino | 55.8b | 15.6bc | 58.2b | 20.0b | 14.7a | 16.8b |
| Means | 48.7 | 16.0 | 52.6 | 16.2 | 11.8 | 14.5 |
| CV% | 9.3 | 20.7 | 8.7 | 14.6 | 16.5 | 12.3 |

* can = canopy

Numbers within columns followed by the same letter are not significantly different at P = .05.

Table 48. Means of plant traits, per plant, of varieties in pure stand and in mixtures at full bloom and at physiological maturity in an experiment inoculated with P. griseola during the 1988 season.

| | Full Bloom | | | Physiological Maturity | | | | |
|---|---|---|---|---|---|---|---|---|
| Varieties | Plant ht (can) (cm) | Plant ht (tip) (cm) | Plant wt (g) | Plant ht (can) (cm) | Plant ht (tip) (cm) | Pod No. | Pod wt (g) | Plant wt (g) |
| Pure Stand | | | | | | | | |
| 1. Black Magic | 53.1a | 74.2b | 21.6abc | 63.6a | 76.9c | 24.9a | 29.0a | 10.5bc |
| 2. C-20 | 52.0a | 97.0a | 22.6ab | 64.4a | 110.6b | 24.9a | 18.9bc | 10.0bc |
| 3. Montcalm | 40.0c | 40.3c | 9.7e | 43.3b | 43.3d | 8.0c | 15.5c | 8.4c |
| 4. Taylor | 39.2c | 39.2c | 10.0e | 45.8b | 45.8d | 11.7bc | 18.3bc | 8.1c |
| Varieties in Mixtures | | | | | | | | |
| 6. Montcalm | 43.1bc | 43.2c | 16.9b-e | 44.8b | 44.8d | 9.0c | 16.5c | 9.2c |
| C-20 | 49.5ab | 104.8a | 21.1abc | 66.7a | 120.0a | 27.6a | 33.6a | 14.1ab |
| 7. C-20 | 50.5a | 97.0a | 26.9a | 66.7a | 118.3ab | 31.8a | 26.7ab | 14.7a |
| Montcalm | 40.7c | 40.7c | 14.3cde | 44.8b | 44.8d | 6.8c | 11.3c | 7.5c |
| Taylor | 39.7c | 39.7c | 12.8de | 44.2b | 44.2d | 7.5c | 11.9c | 7.3c |
| Black Magic | 53.3a | 76.0b | 20.4a-d | 60.0a | 85.8c | 21.6ab | 26.7ab | 10.0bc |
| Means | 46.1 | 65.2 | 17.6 | 54.4 | 73.5 | 17.4 | 20.8 | 10.0 |
| CV% | 8.5 | 12.8 | 26.1 | 7.2 | 7.4 | 36.3 | 24.5 | 24.5 |

* can = canopy

Numbers within columns followed by the same letter are not significantly different at P = .05.

Table 49. Means of plant traits, per plant, of varieties in pure stand and in mixtures at full bloom and at physiological maturity in an experiment inoculated with P. griseola for the 1987 and 1988 seasons combined.

| | Full Bloom | | Physiological Maturity | | | |
|---|---|---|---|---|---|---|
| Varieties | Plant ht (can) (cm) | Plant wt (g) | Plant ht (can) (cm) | Pod No. | Pod wt wt (g) | Plant wt (g) |
| Pure Stand | | | | | | |
| 1. Domino/Black Magic | 56.6a | 20.4abc | 62.1bc | 23.7ab | 21.4a | 13.8b |
| 2. C-20 | 58.1a | 24.0a | 64.5ab | 25.5ab | 16.1bc | 15.8b |
| 3. Montcalm | 39.4bcd | 11.1e | 43.6d | 7.4c | 11.7c | 8.6cd |
| 4. Taylor | 35.3d | 8.9e | 42.0d | 10.3d | 15.2bc | 6.3d |
| Varieties in Mixtures | | | | | | |
| 6. Montcalm | 43.2b | 16.7cd | 43.8d | 8.5c | 13.0c | 10.4c |
| C-20 | 54.3a | 23.1a | 68.7a | 26.8a | 21.5a | 18.8a |
| 7. C-20 | 55.3a | 22.2ab | 64.3abc | 28.8a | 19.0ab | 19.1a |
| Montcalm | 40.8bc | 13.2de | 45.8d | 8.2c | 12.0c | 10.6c |
| Taylor | 36.7cd | 10.4e | 41.5d | 8.1c | 12.7c | 6.1d |
| Domino | 54.6a | 18.0bc | 59.1c | 20.8b | 20.7a | 13.4b |
| Means | 47.4 | 16.8 | 53.5 | 16.8 | 16.3 | 12.3 |
| CV% | 8.8 | 23.7 | 8.6 | 27.7 | 23.9 | 17.8 |

* can = canopy

Numbers within columns followed by the same letter are not significantly different at P = .05.

Table 50. Means of plant traits, per plant, of varieties in pure stand and in mixtures at full bloom and at physiological maturity in an experiment inoculated with P. s. pv phaseolicola during the 1987 season.

| | Full Bloom | | Physiological Maturity | | | |
|---|---|---|---|---|---|---|
| Varieties | Plant ht (can) (cm) | Plant wt (g) | Plant ht (can) (cm) | Pod No. | Pod wt wt (g) | Plant wt (g) |
| Pure Stand | | | | | | |
| 1. C-20 | 64.5a | 18.2ab | 63.5b | 21.3b | 22.5bcd | 13.4abc |
| 2. Montcalm | 45.7d | 18.1ab | 45.8c | 16.8bc | 33.2a | 17.7a |
| 3. Taylor | 35.3e | 10.2c | 36.6d | 10.4de | 21.4bcd | 10.3cd |
| 4. MIC | 59.0ab | 16.9ab | 89.4a | 15.3cd | 15.4cd | 17.0a |
| Varieties in Mixtures | | | | | | |
| 6. Montcalm | 47.0cd | 16.6b | 50.2c | 12.2cde | 26.7ab | 11.1bcd |
| Taylor | 35.5e | 14.1bc | 35.8d | 12.0cde | 22.5bcd | 10.6cd |
| 7. C-20 | 53.8bc | 16.9ab | 63.5b | 27.8a | 23.1bc | 16.6ab |
| Montcalm | 43.7d | 13.8bc | 49.2c | 12.7cde | 28.1ab | 12.7abc |
| Taylor | 32.5e | 11.0c | 35.3d | 7.7e | 14.1d | 6.5d |
| MIC | 63.0a | 22.0a | 86.7a | 15.3cd | 17.0cd | 17.6a |
| Means | 48.0 | 15.8 | 55.6 | 15.2 | 22.4 | 13.3 |
| CV% | 9.4 | 19.4 | 8.3 | 20.0 | 22.7 | 24.7 |

* can = canopy

Numbers within columns followed by the same letter are not significantly different at P = .05.

Table 51. Means of plant traits, per plant, of varieties in pure stand and in mixtures at full bloom and at physiological maturity in an experiment inoculated with P. s. pv phaseolicola during the 1988 season.

| | Full Bloom | | | Physiological Maturity | | | | |
|---|---|---|---|---|---|---|---|---|
| Varieties | Plant ht (can) (cm) | Plant ht (tip) (cm) | Plant wt (g) | Plant ht (can) (cm) | Plant ht (tip) (cm) | Pod No. | Pod wt (g) | Plant wt (g) |
| Pure Stand | | | | | | | | |
| 1. C-20 | 51.8a | 117.3a | 26.9a | 63.0a | 112.4a | 30.9b | 24.8ab | 11.8b |
| 2. Montcalm | 42.9b-e | 42.9bcd | 15.2b | 46.2bcd | 46.2bc | 12.8cd | 26.2ab | 11.5b |
| 3. Taylor | 38.4de | 38.4cd | 10.4b | 39.2d | 39.2cd | 9.0d | 18.0b | 8.1b |
| 4. Cardinal | 43.0b-e | 43.0bcd | 11.5b | 48.8bc | 48.8bc | 16.5c | 32.7a | 18.7a |
| Varieties in Mixtures | | | | | | | | |
| 6. Montcalm | 40.3cde | 40.3bcd | 12.2b | 47.1bcd | 47.5bc | 9.1d | 21.1b | 8.9b |
| Taylor | 37.7e | 37.7d | 10.0b | 42.1cd | 42.0bc | 10.8d | 20.9b | 10.7b |
| 7. C-20 | 47.8ab | 113.3a | 15.6b | 65.8a | 119.0a | 37.2a | 32.0a | 12.9ab |
| Montcalm | 44.8bcd | 44.8bc | 14.4b | 45.3bcd | 45.4bc | 8.2d | 20.9b | 8.8b |
| Taylor | 40.7cde | 40.7bcd | 12.1b | 42.2cd | 28.9d | 9.3d | 18.7b | 14.0ab |
| Cardinal | 45.5abc | 45.5b | 12.0b | 53.3b | 53.3b | 11.1d | 21.2b | 11.4b |
| Means | 43.3 | 56.4 | 14.0 | 49.3 | 58.3 | 15.5 | 23.7 | 11.7 |
| CV% | 9.1 | 6.9 | 29.9 | 9.5 | 12.1 | 20.1 | 24.6 | 30.1 |

* can = canopy

Numbers within columns followed by the same letter are not significantly different at P = .05.

Table 52. Means of plant traits, per plant, of varieties in pure stand and in mixtures at full bloom and at physiological maturity in an experiment inoculated with <u>P.</u> <u>s.</u> pv <u>phaseolicola</u> for the 1987 and 1988 seasons combined.

| Varieties | Full Bloom: Plant ht (can) (cm) | Full Bloom: Plant wt (g) | Physiological Maturity: Plant ht (can) (cm) | Physiological Maturity: Pod No. | Physiological Maturity: Pod wt wt (g) | Physiological Maturity: Plant wt (g) |
|---|---|---|---|---|---|---|
| Pure Stand | | | | | | |
| 1. C-20 | 58.2a | 22.6a | 63.3b | 26.1b | 23.7abc | 12.4b-e |
| 2. Montcalm | 44.3c | 16.6b | 46.0c | 14.8cd | 29.7a | 14.6abc |
| 3. Taylor | 36.9d | 10.3d | 37.9d | 9.7ef | 19.7cd | 9.2e |
| 4. MIC/Cardinal | 51.0b | 14.2bcd | 69.1a | 15.9c | 24.1abc | 17.9a |
| Varieties in Mixtures | | | | | | |
| 6. Montcalm | 43.7c | 14.4bcd | 48.6c | 10.6ef | 23.9abc | 10.0e |
| Taylor | 36.6d | 12.1cd | 39.0d | 11.4def | 21.7bcd | 10.7de |
| 7. C-20 | 50.8b | 16.2bc | 64.7ab | 32.5a | 27.6ab | 14.7ab |
| Montcalm | 44.2c | 14.1bcd | 47.3c | 10.4ef | 24.5abc | 10.7cde |
| Taylor | 36.6d | 11.3d | 38.8d | 8.5f | 16.4d | 10.3e |
| MIC/Cardinal | 54.3ab | 17.1b | 70.0a | 13.2cde | 19.1cd | 14.5a-d |
| Means | 45.7 | 14.9 | 52.5 | 15.3 | 23.0 | 12.5 |
| CV% | 9.1 | 24.7 | 8.7 | 21.5 | 23.3 | 26.6 |

* can = canopy

Numbers within columns followed by the same letter are not significantly different at P = .05.

# CHAPTER 5

# 5.0 DISCUSSION

## 5.1 The Reactions of the Parents, $F_1$ and $F_2$ Plants to the Pathogens

### 5.1.1 Anthracnose

The parents, B83302 and C-20, were confirmed as resistant and susceptible, respectively, to the Á-race of *C. lindemuthianum*. The single dominant gene that confers resistance to the Á-race in B83302 is the "Are" gene first reported by Mastenbroek 1960 (BIC 1989). The information obtained from the segregation ratio of 3R:1S was used to formulate the mechanical mixture of 3 Montcalm : 1 Domino for 1987 and 3 Montcalm : 1 Black Magic for 1988 seasons.

### 5.1.2 Angular leaf spot

In the Montcalm (S) x GO 5686 (R) cross, the gene in GO 5686 conferring resistance to the Michigan-5 isolate of *P. griseola* is a single recessive gene. This was confirmed by a susceptible reaction observed in $F_1$, and the 1R:3S segregation of the $F_2$ population to the isolate. Acquaah (1988), using the same cross, also observed that the $F_1$ was susceptible to the Michigan-5 isolate and the $F_2$ population segregated in a 1R:3S ratio.

5.1.3 Halo blight

In the cross involving Montcalm (R) x Taylor (S), the resistance in Montcalm seemed to be conferred by two genes acting in recessive espistasis. The $F_1$ susceptible reaction and the segregation ratio of 7R:9S in the $F_2$ population to Michigan-1 isolate of P. s. pv phaseolicola indicated that the resistance is conferred by two interacting recessive genes.

There seems to be a variation in the number of genes and their mode(s) of action in Montcalm conferring resistance to halo blight, as studied by Msuku (1984). However, he crossed different Malawian bean lines with Montcalm and tested the progenies against a Malawian halo blight isolate, HB39 (pathotype 2). Other researchers, as reviewed by Msuku (1984), also found that different genes with different gene actions conferred resistance to different races, isolates and pathotypes of P. s. pv phaseolicola. The different observations could be accounted for by the use of different parents, races, pathotypes or isolates, strength of inoculum used, the method of inoculation and the environmental variations. There are two types of foliar symptoms, the water-soaked reaction and the systemic chlorosis (Zaumeyer and Meiners, 1956). These symptoms may influence the classification of plants into resistant or susceptible categories.

## 5.2 Disease Progress in the Mixtures

### 5.2.1 Anthracnose

The incidence of anthracnose was very high in the 1987 season when compared to 1988. Disease levels and the rate of disease progress were similar for the two seasons, although the initial disease levels were similar for only the first season. The disease levels at all scoring times on the foliage and the pods were not significantly different for Domino(S) and C-20(S) in the pure stands, and in the mixtures with the R varieties in the 1987 season.

Under the high disease incidence obtained in 1987, these experimental mixtures were not effective in disease reduction. Alexander *et al.* (1986), working with stem rust of wheat, found that under heavy infection, disease levels on the susceptible component in the mixture was high when the percentage of the resistant component was low. The severity in the mixture was not reduced until the resistant proportion was increased to above sixty percent.

In this experiment the proportions of the resistant : susceptible (R:S) were 3R : 1S, 1R : 1S and 2R : 2S. It is possible that the proportions of the R components in the mixtures were not high enough to reduce disease levels on the S component. It is also possible that the incoming inoculum was so high that the trapping effect of the R component was not effective. Since the source of the inoculum was the two spreader rows on all sides of the plots, the source of inoculum was more of a general than focal type.

For the 1987 season, the initial infection levels were similar and low on Domino and C-20 in all the combinations. Other reports on the mixtures and disease development have indicated low initial levels (Sitch and Whittington 1983, Alexander *et al.* 1986 and Parry 1985 and Priestley *et al.* 1988). Control in the mixture appeared later during the epidemic.

Although the disease levels were not significantly different, there was variation in the levels between the S components in pure stand and in the mixtures. Disease levels on S components remained low in the mixed stand throughout the season. Domino and C-20 in a mixed stand with the R component had lower disease levels than in pure stand. The four-component mixture with 2R:2S showed more reduction in disease than the 3R:1S mixture (3 Montcalm:1 Domino) or 1R:1S (1 Seafarer:1 Domino).

The mixtures with Montcalm and Seafarer were not as effective as the four-component mixture although they had a high or equal ratio of R plants to the other mixtures. There could have been a microenvironmental effect due to shading from Montcalm and Seafarer which had higher biomass at full bloom in the mixture as compared to pure stand, whereas Domino had a lower biomass in the mixture than in pure stand (Table 43). The interaction between the two genotypes may have resulted in the formation of a dense canopy as compared to the 4-component mixture.

Disease levels in Domino in the four-component mixture continued to increase while the disease in other combinations was levelling off. Wolfe and Barrett (1980) and Mastenbroek (1984) also observed that the disease in the healthy mixture can continue to increase because of the green tissue still remaining.

In the mixtures consisting of Domino : C-20, both the components had more disease than in the pure stand in the 1987 season. The explanation for this reaction could be that there was a special plant interaction between the two components which formed a compact canopy with interwoven leaves and branches. This interaction could have created a microenvironment favorable for disease development. Sitch and Whittington (1983) and Karjaleinen (1986) suggested that microclimate in the canopy may be an important factor in disease development or disease escape in mixtures. The S cultivar C-20, had lower disease levels in pure stand than in mixture in 1987. This may have resulted from the plots bordering the C-20 plot influenced its disease levels. Parry (1985) and Priestley et al. (1988) discussed the importance of interplot interference.

In 1988, the initial anthracnose levels were different for all the combinations, being high when the S components were in pure stand and low when in mixed stand with R components. Luthra and Rao (1979) and Malik et al. (1988)

observed that the initial levels of leaf rust in wheat multilines were significantly lower than in their pure lines. Since the disease level in 1988 was not as high as that in the previous year, the R components may have effectively trapped the spores, thus reducing the initial infection in the mixtures.

The rate of anthracnose development as well as the final stages of the disease in S components in the mixtures were lower than in the pure stands. These observations were similar to those of Malik et al. (1988) that heterogeneous populations of wheat showed minimal coefficients of leaf infection at the initial as well as the final stages. Reduction of disease in the mixtures has been found by other workers (Wolfe 1978, Wolfe and Barrett 1980, Chin and Wolfe 1984, Alexander et al. 1986, Ayanru and Browning 1977, Parry 1985 and Priestley et al. 1988, Berger 1973 and Sitch and Whittington 1983). Reduced disease spread in the mixtures probably resulted from the low initial infection per plot due to small numbers of S plants and the lower probability that subsequently produced spores would alight upon spatially isolated S tissue as suggested by Burdon (1978).

The disease levels on S cultivars in pure stand and their S mixtures were significantly higher than those in the mixtures with R components. Disease increased faster in pure stands of S cultivars because of high initial infection per plot due to a large number of S plants compared to those in the mixtures with R plants. The amount of subsequent infection was high, thus, a greater chance of self-infection, which is the infection from the spores produced on same plants or within the same population.

The infection in the mixture of Black Magic (S) and C-20, unlike Domino and C-20, had the same levels as their pure stands, possibly because the two components are similar morphologically. There probably was no interaction between them which could have created a condition favorable for more disease development.

The disease levels in the mixtures remained lower than in the pure stand for the whole epidemic period for the two seasons. There may have been less self infection in the mixtures than in the pure stand. Disease development under monoculture did not reach the maximum level of 5 on the 0-5 scale. Epidemic development was discontinuous due to hot and dry weather. The S cultivars were producing a new, healthy flush of leaves as soon as conditions became less favorable for epidemic development.

### 5.2.2 Angular leaf spot

The angular leaf spot levels and the rate of disease development were high for the 1987 season. There were no differences in the disease reaction in pure stand of S varieties nor in the mixtures with R varieties. There was no protection of the S varieties by the R varieties in 1987.

The composition of the mixtures used in this study was 1R:3S and 2R:2S. The proportions of the R varieties may not have been high enough to be effective in reducing the disease. Karjalainen (1986) observed that when the incidence of Septoria nodorum in spring wheat was high its progress in the mixture was very rapid. Likewise, Alexander et al. (1986) found that only the mixtures with high proportions of the R component were highly effective in reducing stem rust in wheat mixtures. In this experiment, mixtures did not reduce the disease in the S components, possibly because the two spreader rows on both sides of the plots acted like a general source of inoculum rather than a focal source. In this case, the frequencies of the R cultivar in the mixture may have had less effect on disease spread. The amount of exogeneous spores and number of pathogen generations during active development of the epidemics may have influenced the effectiveness of mixtures as suggested by Wolfe (1985).

Pod infection of S varieties was lower in pure stand than in the mixtures. Changes in the microenvironment around the plants may have contributed to this disease "escape." The S plants were defoliated by the disease, which exposed the pods to aeration and light penetration. Thus the microenvironment around the plants was not conducive to disease development. On the other hand, plants in the mixtures were covered by the foliage of the R plants which were type II, full season varieties. This condition formed shading and less aeration that may have contributed to disease development. Modification of microclimate was suggested by Burdon (1978) as one of the limitations of epidemic development within the mixture.

The initial disease level for Montcalm in pure stand was higher than in the other combinations in 1988. Disease progress was slow in the mixtures at the beginning of the epidemic period but later increased at a faster rate. Towards the end, mixtures lost their ability to control the disease. Earlier control of the disease is important because plants can produce higher biomass which can contribute eventually to yield advantage. Lyimo and Teri (1984) observed that the initial levels of angular leaf spot and rust of beans were similar for the mixtures and the pure stand. Later, as the disease progressed, the severity was higher in the pure stand than in the mixtures. In their case, mixtures maintained lower disease levels throughout the season once the protection was manifest.

The two mixtures used, 1R:3S and 2R:2S, were similar in their effect on disease development on Montcalm and Taylor (S components of the 2R:2S mixture). In this case even the 25% of the R variety was similar to 50% R insofar as modifying disease progression was concerned. White (1982) also observed that barley mildew was effectively controlled in a mixture with 25% R variety. Higher proportions of the R varieties could have given better control as observed by Berger (1973), Sitch and Whittington (1983), Alexander et al. (1986) and Karjalainen (1986). This could have been more important particularly in 1987 when the epidemic was severe. Unlike 1987, there was no advantage of mixture on the reduction of disease on the pods in 1988. This was probably due to wet and cool weather during pod development and pod maturity.

5.2.3 Halo blight

Halo blight incidence was not at epidemic levels for either the 1987 or 1988 seasons. The initial disease levels were similar for Taylor and MIC (Michigan Improved Cranberry) in 1987 except that Taylor in pure stand had a higher level which was rated 0.33 on a 0-5 scale (Table 13). An external source of inoculum possibly contributed to the infection as explained earlier for anthracnose and angular leaf spot. For the 1988 season, the initial disease levels were variable and higher than that of the previous season (Table 14). Since the first disease score was taken over three weeks after the inoculation date, the internal infection could have already started. As proposed by Burdon (1978), the initial infection is mainly from the external source while the subsequent infection is from both external and internal sources. In this experiment, the initial disease reduction achieved by mixtures was not lost because the disease never reached the maximum levels.

There were significant differences in reaction for the S components in pure stand and in the mixtures with the R components. Infection levels and the rate of disease progress were high for Taylor (S) in pure stand and low in the mixtures throughout the epidemic period for both seasons. The two-component mixtures (7R:9S) had effects similar to the four-component mixtures (2R:2S) for the two season.

MIC and Cardinal, which are only moderately resistant, had low disease levels and low infection rate as compared to Taylor. MIC had slightly higher disease in the mixed stand than in the pure stand at the final reading. This could have been due to shading imposed by the other varieties because MIC is a type III viny variety. Any other interplant interaction which could have created a microenvironment conducive for disease development may have been involved, as suggested by Sitch and Whittington (1983). There was no difference between Cardinal in pure stand and in the mixtures in terms of disease infection. It is possible that disease level was not high enough to cause infection or for the pathogen to multiply rapidly on Cardinal.

There was some mixture effect on pod infection. The disease levels on the pods of Taylor and MIC were lower than in the pure stand. Taylor mixed with Montcalm had slightly higher disease than that in the four-component mixture. This data may not be very reliable because it was taken before physiological maturity because of the presence of bacterial blight which could have confused the symptoms at the later stage.

## 5.3 Mixture Yields Under Control and Disease Experiments

In the control experiment, mixtures were intermediate in yield, but a four-component mixture, of C-20 : Montcalm : Taylor : Black Magic was the highest yielder in 1988 and C-20 : Montcalm : Seafarer : Domino was the third highest yielder in 1987. The yielding ability of the mixture was low in 1987 because C-20 and Domino which were the mixture components, were high yielding showing that yield of the mixtures was below that of the high yield varieties. The yielding ability for the mixtures in 1988 was high because C-20 and Black Magic had low yields possibly due to frost damage. The highest yielding varieties in pure stand were the early maturing and generally lower yielding than C-20 and Black Magic under normal conditions. Therefore, the yielding ability of the mixture is a good indicator of mixture performance when compared to its highest yielding component.

On the average, the mean relative yield of the mixtures was between 102.7% and 105.2% for the two seasons. These data are comparable to findings of Mumaw and Weber (1957) who observed that on average, soybean blends yielded 2.0% higher than the mean of their components. In this study the mixture of C-20 : Montcalm : Domino : Seafarer significantly outyielded the mean yield yield of its components by 15.1% in 1987. In 1988, C-20 : Montcalm : Taylor : Black Magic also significantly outyielded the mean of its components by 19.5%. The mixtures had two high yielding, Type II varieties which were able to competed well with less vigorous Montcalm, Seafarer and Taylor, the type 1 varieties. Gubbles and Kenaschuk (1987) found that the yield response of blends of flax in a 1:1 ratio averaged 110% of the mean of the components but the average yield of all the blends was 102.5%. They suggested that the higher the yield of the components in pure stand, the higher the yield of the blend. Shorter and Frey (1979) and Alexander *et al.* (1986) suggested that mixture can be affected by inherent yielding ability of the varieties in the mixtures and specific combinations of genotypes in the mixture.

The observations of this experiment were also in agreement with Simmonds (1962) who observed that in eight out of nine experiments on cereal mixtures, yield of the mixtures were 3% to 5% more than mean yield of their components. Frey and Maldonado (1967) showed that under moisture stress, oat mixtures on average yielded 4% above the mean yield of their components.

Yields of varieties in pure stand, mixtures and the $F_2$ populations were variable in two seasons. C-20 and Black Magic yielded low and the $F_2$ population of Montcalm X G05686 was killed by frost in 1988. Montcalm tended to suppress C-20 and Domino in 1987 but the latter were aggressive competitors in 1988. Taylor in 1988 had different competitive patterns depending on the mixture in which it was involved. Seafarer was an unsatisfactory competitor for the two season and yielded poorly in the two seasons, thus it should not be considered as a component in the mixture.

In these mixtures, the competitive patterns of genotypes fitted the patterns described by Schutz and Brim (1967). The patterns observed were complementary, overcomplementary and undercomplementary. The patterns of competition in the mixtures from the yield and yield components and plant traits data changed between the seasons. The yield of the mixtures also changed between the seasons.

It would seem that mixtures of genotypes of different maturity would be less competitive because they have different peaks for growth, but this was not the case. For example, Montcalm with C-20, Domino or Black Magic, which have different maturity periods, showed competitive effects. Seafarer and Taylor, the early maturing varieties, were weak competitors in the mixtures. Rao and Prasad (1984) observed that a dwarf variety of wheat in the mixture, though a weak competitor, supported the tall variety from lodging and in turn the tall variety compensated it for the yield.

Yield stability for the mixtures and varieties in pure stand was not analyzed because some varieties were replaced in the second season. However, on the basis of the yield difference between the two season for the mixtures and pure stand, there seem to be fluctuations for both mixtures and for varieties in pure stand. It is important to test the yield stability of the mixtures over different sites and seasons because yield stability is one of the important characteristics for mixtures to be judged successful. Hoeckstra _et al._ (1985a) observed that mixtures were more consistent across environment than were pure stands. Shorter and Frey (1979), in yield tests on 28 spring oat cultivars and breeding lines, found that mixtures had lower genotype x environment interaction variances and thus were more stable than the components sown alone. White (1982) and Priestley _et al._ (1988), however, did not see any significantly greater yield stability of mixtures, as compared to pure stands.

Yields of the susceptible varieties were reduced under anthracnose conditions compared to the control experiment, as expected. The yield abilities of the mixtures were high in the anthracnose experiment compared to control in 1987 because C-20 and Domino had lower yield due to the disease.

In the 1987 season there was no protection of the susceptible varieties by the resistant ones. Mixtures yielded about the same as the mean yield of their components except for the C-20 : Domino mixture which was significantly low. Components of these mixtures showed a complementary interaction with almost no net gain except for C-20 : Domino which exhibited undercompensation. Alexander _et al._ (1986), observed that mixtures of susceptible and moderately resistant wheat varieties did not yield more than the mean of their components in pure stand, in the presence of stem rust. Karjalainen (1986) also observed that under high mildew, mixtures of susceptible and moderately resistant varieties of barley could only buffer high yield reduction. Parry (1985), Karjalainen (1986) and Priestley *et al.* (1988) concluded that yield benefits of the mixtures over the pure lines were not always remarkable. However, Parry (1985) and Priestley *et al.* (1988) observed that one mixture of spring barley had constantly higher yield than the mean of its component which was directly associated with the disease reduction in the mixture.

The mixtures on average yielded 6.8% above the mean of the components in 1988 ranging from 0.6% to 10.1% in 1988. C-20 : Montcalm : Black Magic : Seafarer had significally yielded 10.1% above the mean of the components. From the disease data Montcalm and Seafarer protected C-20 and Black Magic in the two- and four-component mixtures. However, the mixture of Montcalm : Black Magic yielded the same as the mean yield of the components and Black Magic : Seafarer yielded 6.1% higher than the mean of the components but was not significant. These data show that disease reduction may not necessarily result in yield increase. There was also a mixing response of 3.4% for Montcalm : Black Magic whose components are all resistant.

Yield of the mixtures can be affected by several factors including inherent yield of each genotype, mixture composition, effect of disease levels and the effect of plant competition among and within the varieties. Plant competition can be an important factor in the yield of the mixture other than disease control by itself. Yield components and plant traits data supports this point.

The yield of mixtures under both angular leaf spot and halo blight disease increased over the mean of their components. For the angular leaf spot, there was a significant average increase of 32.3% in 1987 and 16.4% for 1988. There was yield reduction for Montcalm in 1988 in the mixtures and the yield remained the same in 1987 in the mixtures compared to the pure stand. Most of the components of yield were the same as in pure stand in 1987 but in 1988 the components of yield were either below or the same as pure stand. Taylor, in the mixture, maintained the same yield as expected for both seasons and its components of yield followed the same pattern. These results suggest that yield increase in the mixtures was not directly from disease reduction but rather from plant interactions as suggested by Burdon and Chilvers (1977).

For halo blight, the average yield advantage for the mixtures was 18% and 5.4% for the two seasons although disease data showed that the incidence of halo blight was low for both seasons. Therefore, the yield increase observed could be the result of other mechanisms such as plant interaction or buffering against other environmental factors. Wolfe (1978) suggested that one advantage of mixtures was to buffer against non-target diseases and other environmental factors.

Even when there was no apparent protection of angular leaf spot by resistant varieties both of the mixtures had yield increase over the mean yield of the components. Mixtures also showed yield advantage even when halo blight was not serious for both seasons. The yield increase in these situations does not seem to be related to disease reductions but rather contribution from plant interaction or from other mechanisms. Burdon and Chilvers (1977) concluded that the yield benefits were not from disease reduction but rather from plant competitive ability. Yield and yield components and plant traits of individual genotypes in the mixtures compared to pure stand seem to suggest that plant interaction contribute to yield increase.

The response of yield and yield components and plant traits were variable between genotypes in different mixtures and under different seasons and conditions such as diseases compared to the pure stand. Even Seafarer which had lower yields in all the mixtures in the two seasons showed variations in yield components and plant traits. Yield of some genotypes and their yield components and plant traits were either increased or decreased or remained unchanged in the mixtures when compared to the expected values in the pure stand under different conditions. This suggests that there were different interaction mechanisms in the mixtures under different conditions. These interactions or competitions may be acting at different times as indicated by the components of yield affected.

In the present work there were no patterns of yield advantage between two-component or four-component mixtures but rather there were differences between the seasons. Parry (1985), also observed that yield increase between the two-way and the three-way mixtures were similar.

# CHAPTER 6

## 6.0 SUMMARY AND CONCLUSIONS

Disease progress for anthracnose, angular leaf spot and halo blight was assessed on susceptible varieties in pure stand in different mixtures with resistant varieties, and in $F_2$ populations from resistant by susceptible crosses. Disease levels in the pure stand of susceptible varieties were compared to the disease levels in susceptible varieties in the mixtures. The disease levels for anthracnose and angular leaf spot were high in 1987 and the resistant plants in the mixtures were unable to effectively protect the susceptible ones. When the disease infection was moderate in 1988, resistant plants effectively reduced disease on the susceptible plants.

Halo blight infection was moderate in both seasons, and the disease on Taylor cranberry, the susceptible variety, was reduced in the mixtures. There were no differences between the levels of halo blight on MIC, Michigan Improved Cranberry, and Cardinal cranberry, the moderately resistant varieties, in pure stand and in the mixtures. This means there was less inoculum produced within MIC and Cardinal populations as compared to Taylor, because pathogen development and multiplication is restricted by the semi-resistant nature of these varieties.

In this study it was, therefore, observed that mixtures were not effective in reducing disease levels on susceptible varieties under heavy disease infections but effective under moderate disease levels. Possibly, under heavy disease infestation, higher proportions of resistant varieties would give some protection. However, a mixture with 75% of a resistant variety was not effective under anthracnose infestation. Unless the resistant variety has other favorable qualities, its higher proportion in the mixtures may not be desirable.

There was no difference between the two- or four-component mixtures in terms of disease progress. Disease progress was slow in all three $F_2$ populations. There were more uninfected plants than expected even when the disease levels were high in 1987. This is consistent with the hypothesis of resistant segregants providing protection to susceptibles.

Yields of the varieties in pure stand and the mixtures were compared during the two seasons for different experiments. Mixtures were generally intermediate in yield, although a four-component mixture in 1988 exhibited the highest yield under the control experiment. Mixtures also yielded below their high yielding components except that one mixture was 9.3% above its high yielding component. On the average, mixture yields of 2.7% to 5.2% above the mean yield of their components for the two seasons were observed in the control experiment.

Mixtures under anthracnose infection on the average yielded 4.2% below the expected value in 1987 when disease levels were high and 6.8% above the means of the components when disease was moderate. Under angular leaf spot infection the mixtures had 18.0% and 5.4% above the mean yield of the components in 1987 and 1988. Under halo blight infection the average yield of the mixture was 32.3% and 16.4% above the means of their components. The performance of the mixtures affected by halo blight or angular leaf spot may be atypical because there were only two mixtures for each disease.

The general trend of the yield data suggests that yields in the mixtures may not necessarily be directly associated with disease reduction. Positive interaction between genotypes and efficient utilization of environmental resources may have contributed to yield increases.

Yield and yield components data showed that there was intergenotypic competition within the mixtures. The type II varieties were highly competitive and since they were high yielding they contributed to yield increases in the mixtures. Performance of Montcalm was variable in the mixtures between the two seasons while Seafarer was a weak competitor. Because of differential competition abilities in mixtures, mixture seed-stocks will have to be reconstituted frequently.

Mixtures can provide practical means of disease control in low-input farming where farmers do not use fungicides. Mixtures could also be used as an insurance against total yield loss should adverse biotic or abiotic stresses occur. Farmers can also benefit from high yield of the mixtures and the stability of the mixture, as documented in other studies. Mixture could be used in Western agriculture to avoid risks of genetic uniformity particularly when uniformity is not critical. Mixtures may be useful in the future should the prices of fungicide become prohibitive or should the problems of fungicide tolerance and environmental pollution become critical.

Mixtures have the advantage that they can be easily formulated as compared to the development of superior pure lines and multilines, because components of mixtures can be picked from the existing varieties or lines. Mixtures can also buffer against non-target disease as suggested by Wolfe (1978).

It would be desirable to have more mixtures evaluated over more locations and seasons so that more comprehensive and reliable results can be obtained. With more observations, yield stability of the mixtures could be determined and compared to that of the varieties in pure stand.

The number of mixtures that was used in the angular leaf spot and halo blight experiments was small, therefore, results can be atypical. In order to get a more complete and representative picture of the performance of mixtures under disease conditions, it would be desirable to evaluate more mixtures of differing components. Different mixture components should be tested to design mixtures with positive synergism so as to increase their performance.

For practical purposes, improved varieties should be tested in farmers' mixtures (land races) to see if they can be used to improve farmers' mixtures or see what varieties are compatible with the land races. More complex mixtures, that is, mixtures with more components should be included in the evaluations because such mixtures are close to what farmers grow.

Control plots, that is, fungicide treated plots, should be included in experiments designed to evaluate performance of mixtures under disease conditions. This is important in order to determine whether any increase in yield by mixing varieties is associated with disease reduction. Also, for proper experimental evaluations of the mixtures, it would be desirable to have a uniform field, plump and viable seeds, and to minimize other biotic and abiotic hazards. But under farmers' conditions, mixtures are widely believed to perform to greater advantage under stressful environments than the pure line varieties.

Mixtures can be made from distinctly different varieties or lines when phenotypic uniformity is not required or can be made from closely related lines when phenotypic uniformity is considered (Fehr 1988). Breeding for improving mixtures should focus on improving the components in terms of yield and disease resistance and adaptation to the environment, depending on the limitations of growing conditions. Varieties and lines for mixture components can be selected from on-going breeding programs or can be developed. Components of mixtures of different varieties can be developed by using any method suitable for the species. For example, for a self-pollinated crop like beans, pedigree, bulk breeding or single seed descent can be used. Lines developed will have to be evaluated for their performance over different locations, seasons and in different mixture components and ratios. The newly developed lines or varieties can be used to replace mixture component. In a disease-prone area mixtures should have resistant components.

Excessive diversity such as wide ranges of maturity periods and seed variability particularity in cooking times may not be acceptable in some areas. In this case, mixtures can be formulated from related lines. Mixtures of related lines can be derived from populations that have a common parent and lines that are genetically different from each other can be selected. Parents differing in pest resistance can be used to develop lines with differing genes for pest resistance. Mixtures formulated from these lines should be evaluated for their performance and stability over different locations, seasons and in different mixtures.

The number of components used in the mixture would depend on the local preference, purpose of the mixture, variability and the productivity of the components. Subsistence farmers use greater number of components to provide food diversity and a risk measure against biotic and abiotic factors.

Once suitable mixtures components are identified, they can be produced in pure stand and made available to farmers. Under subsistence farming where mixture used is well established, the new, improved mixture components should be used to complement their mixture components. The new materials can be made available to farmers continuously so that they can include them in their mixtures. Different lines should be made available so that farmers can have a flexibility in formulating their own mixtures and preserve variability. Breeders or agronomists can assess the rate of loss of the new lines or how competitive they are and thus advise farmers how frequent they can reconstitute their mixtures. Breeders should formulate a way of assessing farmers seeds to ensure that the new components are not being lost or they are not aggressively competing with the farmers' components.

# APPENDICES

## APPENDIX 1

Reaction of 18 *Phaseolus vulgaris* genotypes, tested in the greehouse, to Á-race of *Colletotrichum lindemuthianum*.

| | Genotypes | Reaction to Á-race |
|---|---|---|
| 1. | Charlevoix | R |
| 2. | Montcalm | R |
| 3. | Isabella | MS |
| 4. | Ruddy | S |
| 5. | Domino | S |
| 6. | B83302 | R |
| 7. | Olathe | S |
| 8. | Ouray | S |
| 9. | Laker | R |
| 10. | C-20 | S |
| 11. | Seafarer | R |
| 12. | Taylor | S |
| 13. | Cran 425 | S |
| 14. | MIC | R |
| 15. | Rufus | S |
| 16. | Viva Pink | S |
| 17. | Black Magic | S |
| 18. | N.Y. Marrow | S |

R = Resitant; MS = Moderately Susceptible; S = Susceptible

## APPENDIX 3

Reaction of 18 *Phaseolus vulgaris* genotypes tested in the greenhouse, to Michigan-1 isolate of *Pseudomonas syringae* pv *phaseolicola*.

| Genotypes | Reaction to Michigan-1 isolate |
|---|---|
| 1. Charlevoix | S |
| 2. Montcalm | R |
| 3. Isabella | MR |
| 4. Ruddy | S |
| 5. Domino | R |
| 6. B83302 | R |
| 7. Olathe | R |
| 8. Ouray | R |
| 9. Laker | S |
| 10. C-20 | R |
| 11. Seafarer | R |
| 12. Taylor | S |
| 13. Cran 425 | MR |
| 14. MIC | MR |
| 15. Rufus | R |
| 16. Viva Pink | R |
| 17. Black Magic | R |
| 18. N.Y. Marrow | S |

R = Resitant; MR = Moderately Resistant; S = Susceptible

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