OPTIONS FOR REDUCING ASCOCHYTA BLIGHT SEVERITY IN CHICKPEA (*CICER ARIETINUM* L.)

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ABSTRACT

Successful chickpea production in western Canada typically requires multiple applications of fungicides to minimize the severity of Ascochyta blight (AB) caused by *Ascochyta rabiei*. Although planting resistant cultivars could be economical and environmentally safer than fungicide usage, varieties with a high level of resistance are not available. The objectives of this research were i) to determine the effect of different seeding arrangement treatments on ascochyta blight severity and seed yield of two cultivars (moderately resistant and susceptible) of kabuli chickpea; ii) to compare one and four fungicide applications at recommended and reduced rates and their impact on disease severity and cost; and iii) to assess organ-specific reaction to AB in chickpea in leaves, stems and pods of 12 desi and 12 kabuli varieties that are of economic significance to western Canada.

Treatments significantly influenced AB severity on both moderately resistant and susceptible cultivars in a season with a severe epidemic. Seed yield was significantly influenced by treatments for both varieties in both years. Contrast analyses revealed that four fungicide applications significantly reduced the AB severity for both varieties in a season with a severe epidemic and for the susceptible variety in a season with a moderate epidemic. Seed yield of both varieties was significantly higher under four fungicide applications compared to a single application. Solid seeding and paired row arrangements did not differ in their effect on seed yield and AB severity for both varieties in both years, except that the susceptible variety benefited from paired row planting with respect to seed yield and reduced AB severity in the season with a severe epidemic. Reducing fungicide rates and seeding rate could reduce the cost of cultivation without significantly affecting disease control and yield. Economic assessment revealed that in a severe epidemic season, the gross returns were high for the moderately resistant variety under four fungicide applications than one fungicide application. Gross returns for the susceptible variety were higher under four fungicide applications in both years.

There were differences among varieties for AB severity on leaves, stems and pods, seed yield and 1000 seed weight at all site-years tested. The variation was greater in kabuli varieties than desi varieties. AB severity on leaves, stems and pods was lower under high fungicide regimes, with few exceptions. Varieties with a fern leaf type had lower AB severity than those with unifoliate leaves. There was a positive correlation among AB severity on leaves, stems and pods. No differences in organ-specific reaction were observed.

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For

Sri Mother Aurobindo

My parents and

My Supervisors

With deep gratitude!

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1.0 Introduction

Chickpea (*Cicer arietinum* L.) is an ancient grain legume crop grown since 7000 BC, mainly in semi-arid environments, and in some parts of the world as a cool-season legume (Saxena, 1990). Chickpea is a leguminous crop that is able to fix atmospheric nitrogen (N), resulting in a reduced requirement for N fertilizer. The seed is a major source of plant-based dietary protein for people in developing countries. The seeds are traditionally used in dhal and soups in the Indian sub-continent, salads in North America and hummus in the Middle East. Chickpea flour is used to make delicious and nutritional dishes for the vegetarian population. The excellent nutritional benefits and the good economic returns have made chickpea an attractive cash crop in many parts of the world.

Chickpea was introduced into western Canada in the 1990s and has shown economic benefits to producers and the pulse crop industry. Successful crops have produced economic returns of 2.5 to 4.5 times that of hard red spring wheat (*Triticum aestivum* L.) (Gan et al., 2003a). The area under cultivation of chickpea in western Canada increased from 800 ha in 1995 to 280,000 ha in 2000 (Statistics Canada, 2000). Canada's export of chickpea increased, generating more employment opportunities and revenues. Despite offering many benefits, the area under chickpea production in western Canada dropped significantly in 2002 and further in 2003, primarily due to the lack of management practices for ascochyta blight control (Gan et al., 2003b). The other major limiting factor for successful chickpea cultivation is the crop's requirement for a relatively long growing season.

Ascochyta blight (AB), a foliar disease caused by *Ascochyta rabiei* (Pass.) Labrousse is the major constraint limiting chickpea productivity worldwide. The disease occurs in the chickpea growing areas around the world. This devastating

disease reduces seed yield and quality, and yield losses in susceptible cultivars can be as high as 100% (Nene, 1982). AB can infect all above-ground plant parts. The symptoms appear as tan colored spots with pycnidia arranged in alternate concentric circles on leaves, stems and pods (Nene and Reddy, 1987). Lesions girdle and weaken the stem, leading to breakage. Seed size and quality are often reduced by the disease on pods.

Ascochyta rabiei is a heterothallic fungus that requires two compatible mating types to produce the sexual stage (Wilson and Kaiser, 1995). In Canada the presence of both mating types has contributed to pathogenic diversity (Chongo et al., 2004). Genetic diversity of *A. rabiei* is one of the reasons for the difficulties in managing this disease. The pathogen over-winters in crop residues and on seed. It is also spread through the air as ascospores during the spring to early summer (Armstrong et al. 2001). The seeds remain as a major source of primary inoculum. Under favourable conditions, this fungus can survive on crop debris for four years on the Canadian prairies (Gossen and Miller, 2004). Rain splashing is required for secondary spread of the pathogen within the field.

Successful cultivation of chickpea in western Canada is difficult without the use of fungicides. However foliar fungicides, even with multiple applications during a growing season, do not always provide adequate control of AB and yield losses can still be high (Reddy and Singh, 1990; Shtienberg et al. 2000). Repeated fungicide applications are expensive, and also not preferred due to environmental concerns. The appropriate fungicide application timing and correct rate not only result in reduced disease severity, but also reduce fungicide usage. Thus, it is necessary to determine the most effective system of fungicide application, which manage the disease and minimise the fungicide cost.

Microclimatic factors such as plant temperature, relative humidity and light interception can affect the sporulation of fungi. The conidia of *A. rabiei* are released only from wet pycnidia. At least 6 hrs of wetness is necessary for infection by the

pathogen at optimum temperature (Weltzien and Kaack, 1984). When the temperature is favourable and the moisture requirements of a pathogen on a susceptible host are fully met, an epidemic is likely to develop (Jhorar et al., 1998). Relative humidity (RH) directly affects sporulation of many fungi and germination of *A. rabiei* conidia occurs at 98-100% RH (Hassani, 1981). Humidity at plant level is highly influenced by the canopy. Alternative planting methods might change the canopy and the micro-climate, which may affect blight development.

Planting resistant varieties is the most economical and environmentally safe method to minimize the damage caused by AB. In Canada, chickpea production is only possible with partially resistant varieties (Saskatchewan Agriculture and Food, 2006a). Partially resistant varieties may also lose their resistance after the flowering stage (Chongo and Gossen, 2001). Components of partial resistance, such as resistance at leaves and stems, were regulated by different genes in faba bean (*Vicia fabae*) (Avila et al., 2004). Similar tissue-specific expression of genes was also reported in other crops. Organ-specific resistances, if found, could be useful in the selection of genotypes with improved field resistance. Knowledge of such resistances also helps in designing management strategies for AB control.

Relying exclusively on one control approach is unlikely to adequately protect chickpea crops from this disease (Chongo et al., 2003). In western Canada, the integrated disease management practices to control AB in chickpea included planting resistant varieties and 2-4 fungicide applications with chlorothalanil and strobilurins. There exists a need to develop integrated management approaches that include a combination of agronomic management, advanced disease control measures, and utilization of varieties with improved resistance. It is also important to assess the resistance to *A. rabiei* at different organs to determine if resistance in specific organs is available as a management option. Hence the objectives of this project were:

i) To determine the effect of seeding arrangements on ascochyta blight severity and seed yield of two cultivars of kabuli chickpea.

ii) To compare one and four fungicide applications at recommended and reduced fungicide rates and their impact on disease severity and cost.

iii) To assess organ-specific reaction to AB on chickpea in leaves, stems and pods of 12 desi and 12 kabuli varieties selected because they are of economic significance to western Canada.

iv) To assess organ-specific reaction to AB in chickpea leaves and stems of four kabuli varieties under controlled environments.

2.0 Literature Review

2.1 Chickpea production and challenges worldwide

Chickpea (*Cicer arietinum* L.) is a self pollinating, diploid (2n = 2x = 16), annual legume (Arumuganathan and Earle, 1991). It is a deep rooted crop belonging to the family Fabaceae. Chickpea is one of the first domesticated grain legume crops of the old world (Van der Maesen, 1972). The centre of origin for chickpea is Turkey and Syria (Singh, 1987). It is grown in ecologically diverse, semi-arid environments including India, the Mediterranean region, eastern Africa, the Americas and Europe (Saxena, 1990). The seed is a major source of plant-based dietary protein for many people in developing countries. The crude protein content of chickpea ranges from 17% to 24%. Chickpea seeds are also a good source of carbohydrates, and proteins and carbohydrates together constitute 80% of the total dry seed weight. The remaining 20% consists of 0.8-6.4 % fat, 2.1-11.7 % fiber, 0.2 % calcium and 0.3 % phosphorus. Chickpea is a good source of the essential amino acids including tryptophan (0.16 %), methionine (0.52 %), cysteine (1.45 %) lysine (1.45%) and threonine (0.16%) (Huisman and van der Poel, 1994; Williams and Singh, 1987). It is also used as fodder for cattle.

Production of chickpea contributed to agricultural sustainability through N_2-fixation and by being a rotation crop. The area harvested for chickpea in 2005 was 11,200,000 ha worldwide (Food and Agricultural Organization of the United Nations, 2005) with production of 9,172,000 MT. India is the major producer of chickpea, accounting for approximately 65% of the annual world production. India is also the largest importer of chickpea. Turkey is the largest exporter of chickpea followed by Australia. The average yield of chickpea worldwide is 818 kg/ha. There are two market classes of chickpea; kabuli type, having white flowers and cream

colored seed, and desi type, which have pigmented flowers and a relatively thicker seed coat that is usually tan to dark brown in color.

Chickpea production is limited by various biotic and abiotic stresses worldwide. Nene (1981) reported that there were about 41 pathogens infesting chickpea, which included 33 fungi, 7 viruses and 1 bacterium. The most important biotic stress limiting chickpea production worldwide is AB. Fusarium wilt is another important disease of chickpea. These diseases are more serious in temperate regions. Under favorable conditions, which are mostly cool and cloudy with higher humidity, the epidemic of AB may lead to complete yield loss (Nene, 1982; Chongo et al., 2000). Chickpea is less affected by insect pests than other pulse crops. However, the pod borer *Helicoverpa armigera* is an important problem for the production of chickpea in the tropics (Singh et al., 1994)

Among the abiotic stresses, early frost is an important concern, especially in the temperate regions with short growing season. Because of the crop's indeterminate growth, pod filling often coincides with the onset of winter leading to quality and yield loss. Although chickpea is a drought-tolerant crop, in some regions of the world where rainfall is scarce, drought is an important constraint to production.

2.2 Chickpea production and challenges in western Canada

Substantial changes in cropping systems have occurred throughout the northern Great Plains, resulting from strategies aimed at producing sound soil health, economic innovation and a quality environment (Gan et al., 2001; Miller et al., 2002). Pulse crop production expanded substantially in western Canada in the early 1990s and commercial production of chickpea started in 1995. Canada ranked sixth in the world in chickpea production, with an average yield of 1,509 kg/ha in 2005 (Food and Agricultural Organization of the United Nations, 2005). Canada was the fourth largest exporter of chickpea in 2003. Saskatchewan occupies a prime position in chickpea production in Canada. In 2004, Saskatchewan produced 87% of Canada's chickpea production. In

2005, the area seeded to chickpea in Saskatchewan was 66,800 ha (Saskatchewan Agriculture and Food, 2005). Successful crops have produced economic returns of 2.5 to 4.5 times that of hard red spring wheat (*Triticum aestivum* L.) (Gan et al., 2003a). Steady prices have raised interest into chickpea production and the area seeded to chickpea increased from <1000 ha in 1995 to > 400,000 ha in 2001, of which > 90% was concentrated in the dry regions of the Brown and Dark Brown soil zones (Gan and Noble, 2000). However, the area under chickpea production in western Canada dropped significantly in 2002 and further in 2003, partly due to the lack of management practices for AB control (Gan et al., 2003a). The other major limiting factor for successful chickpea cultivation is the long growing season requirement. Canadian production was 455 Kt in 2001, but declined to 179 Kt in 2003 (Food and Agricultural Organization of the United Nations, 2004). Under cool wet conditions such as those experienced in 1999 and 2000 in Saskatchewan, epidemics of AB are very severe (Chongo et al., 2000).

2.3 Ascochyta blight

2.3.1 Distribution of ascochyta blight

Ascochyta blight was first reported in Pakistan, and is found in at least 35 chickpea growing countries of the world (Kaiser et al., 2000a; Nene et al., 1996). In Western Asia, North Africa and southern European regions, chickpea production is limited by ascochyta blight (Nene 1982). Blight occurrence was also reported in Latin America and Bulgaria (Kaiser et al., 2000a). It was speculated that in North America, the disease was first introduced in Saskatchewan, Canada through the introduction of infected chickpea germplasm (Morrall and McKenzie, 1974). The first occurrence of ascochyta blight in South Australia was reported in 1973 (Khan et al., 1999).

2.3.2 Host range of Ascochyta rabiei

Ascochyta rabiei is pathogenic mainly on *Cicer arietinum* and other species of *Cicer*. Several host range studies under controlled environment conditions showed

A. rabiei to be pathogenic on lentil, field pea, vetch, common bean and cowpea (reviewed in Pande et al., 2005). Kaiser (1990) reported that *A. rabiei* is pathogenic on cowpea (*Vigna ungiculata),* common bean *(Phaseolus vulgaris),* prickly lettuce *(Lactuca serriola),* henbit deadnettle (*Lamium amplexicaule),* alfalfa (*Medicago sativa*), sweetclover *(Melilotus alba)* and field pennycress *(Thalapsi arvense).* In general, hosts other than *Cicer spp.* are rarely and weakly attacked and the infection remains latent, or mild disease symptoms occur. These alternate hosts are not required for the completion of the life cycle by the pathogen. However, such hosts could potentially serve as inoculum reservoirs.

2.3.3 Description of Ascochyta rabiei

The pathogen is heterothallic and requires two compatible mating types, MAT-1 and MAT-2, for production of the teleomorph (sexual stage) (Kaiser, 1997; Armstrong et al., 2001). The presence of two mating types ensures sexual recombination and leads to genetic diversity. The mycelium of the fungus is hyaline to brown and septate.

The anamorph (asexual stage) is characterized by the presence of dark brown, spherical to pear-shaped pycnidia (Sattar, 1934). When the pycndia are moistened, they swell and a slimy mass of conidia oozes out through the ostiole (Kovachevski, 1936). Conidia are formed from the inner cells of pycnidia and are hyaline, oval to oblong, slightly curved and slightly constricted. The conidia measure 6 - 12 × 4 - 6 µm and are generally 2- celled, with blunt ends (Nene, 1982).

The teleomorph (sexual stage) of *A. rabiei* (*Didymella rabiei* (Kovachevski) v. Arx) was first reported by Kovachevski (1936) in Bulgaria. It was later reported in Russia**,** Greece**,** Hungary, Spain, Syria**,** and the United States (reviewed in Wilson and Kaiser, 1995). *Didymella rabiei* was first reported in western Canada by Armstrong et al. (2001). The teleomorph is characterized by dark brown to black pseudothecia on over-wintering chickpea debris. Pseudothecia are sub-globose, 120-270 µm in diameter, and arranged in rows of the host tissue (Trapero-Casas and

Kaiser, 1992a). The asci are cylindrical, clavate and slightly curved. Once matured, pseudothecia become erumpent. Asci are bitunicate and ascocspores are irregularly distichous, hyaline, ellipsoidal to biconic and two celled; usually the upper cell is broader than the lower one.

2.3.4 Infection process of ascochyta blight

After coming into contact with host tissue, conidia of *A. rabiei* begin to germinate after 12 hrs (Pandey et al., 1987). The germ tubes elongate and secrete mucilaginous substances to remain in tight contact with the cuticle (Hohl et al., 1990). Penetration into the host tissue normally occurs 24 hours after inoculation, through the leaf cuticle, stem cuticle and through stomatal openings (Pandey et al., 1987). *Ascochyta rabiei* form typical appressoria associated with stomatal penetration (Ilarslan and Dolar, 2002). However, the appressoria of *A. rabiei* are not melanized, indicating that penetration is not only by mechanical force, but due to hydrolytic enzymes (Tenhaken, 1992). Tenhaken and Barz (1991) reported that *A. rabiei* secretes xylanases, exo-polygalacturanases and cutinases that are responsible for the infection.

Inter- and intra-cellular hyphae develop sub-cuticularly, mostly between the middle lamella and primary cell walls, along the epidermal cells (Ilarslan and Dolar, 2002). Without invading the protoplasm, hyphae invaded the cortex. Macroscopic symptoms were typically not observed until the third day after inoculation (Pandey et al., 1987). The fungal hyphae are surrounded by an extra-cellular electron-dense sheath, which is involved in recognition of susceptible and resistant host tissues by the pathogen. The recognition of susceptible tissue by the fungus in turn results in secretion of cell wall degrading enzymes for the infection of host tissue (Ilarslan and Dolar, 2002). Four days after inoculation, necrosis become visible and the hyphae in the cortical tissues fuse together to form aggregates. This darkened aggregate of hyphae differentiated into pycnidia (Pandey et al., 1987). The pycnidia are found largely in the vascular tissues, possibly due to the vascular tissue providing a

suitable matrix for pycnidial development when the surrounding tissues are destroyed (Kohler et al., 1995). Five or six days after inoculation, the pycnidia mature, arranged in a circular pattern on the infected host tissue. By the seventh day, most of the non-lignified cells are destroyed (Pandey et al, 1987; Ilarslan and Dolar, 2002).

Necrosis by *A. rabiei* is associated with the secretion of phytotoxins. *Ascochyta rabiei* produces three types of solanopyrones; A, B and C (Hohl et al., 1991), and cytochalsin (Latif et al., 1993). Solanopyrones A, B, C were first found to be products of *Alternaria solani*, the causal agent of late blight of potato (Ichihara et al., 1983; Jayakumar et al., 2006).. The aggressiveness of *A. rabiei* was positively correlated with phytotoxin production (Kaur, 1995).

2.3.5 Symptoms of ascochyta blight

Ascochyta rabiei infection may arise from seed-borne inoculum, conidia produced on infected debris or air-borne ascospores. Ascochyta blight symptoms occur on all above-ground plant parts at any growth stage of the crop, producing necrotic lesions that may result in the destruction of the plant (Nene, 1982; Shtienberg et al., 2000). The symptom on lower leaves start as pin-head spots, which are usually dark tan to black in color. These spots develop into water-soaked lesions. The centre of each lesion contains the small black fruiting bodies (pycnidia) arranged in concentric circles. On stems and petioles, the lesions expand and girdle. Girdled stems break and the foliage above the break point dies. On pods, lesions lead to seeds shriveling and discoloration of the seed. In the field, blight appears as small circular patches of dead plants. However, if the source of inoculum is seed-borne, disease symptoms are often scattered uniformly across the field. On resistant cultivars, although the lesions appear as small dark brown spots, they may not progress further (Chongo and Gossen, 2003). Under moist conditions, mature pycnidia swell and the conidia ooze out. Conidia are dispersed to neighboring plants through rain splashing (Armstrong e al., 2001). Under cool moist conditions, the disease spreads rapidly through the field.

2.3.6 Effect of environmental conditions on ascochyta blight

2.3.6.1 Temperature

Temperature has important effects on the lifecycle of *A. rabiei*, the infection process, and disease development. The optimum temperature for infection and development of *A. rabiei* is 20 °C (Trapero-Casas and Kaiser, 1992a). Asci and ascospores only develop at temperatures between 5 and 10 °C. Low temperature and a relatively long incubation period are required for sexual reproduction in most Ascomycetes. The lower and upper temperature limits for infection by *A. rabiei* are 5 and 30 °C, respectively (Trapero-Casas and Kaiser, 1992b). Disease severity increased with increasing temperatures to a maximum of 20 °C, then declined sharply at temperatures above 25-30 °C. At temperatures above 25 °C, spore production and mycelial growth decrease and cease at 32 °C. Temperature also affects latent period. Trapero-Casas and Kaiser (1992b) reported that the shortest incubation and latent period was found to be 4.5 days and 5.5 days, respectively, at 20 °C. A temperature higher or lower than 20 °C prolonged the latent period.

2.3.6.2 Leaf wetness period

Moisture is an important weather element for foliar pathogens. The effect of temperature on disease development is influenced by leaf wetness and the duration of the wetness period. Armstrong et al. (2004) found that ascochyta blight severity increased with increasing leaf wetness period (LWP). Disease severity was reduced by drying until 6 hrs post inoculation. Conidia showed swelling without germ tube formation, but many were able to survive intermittent dry periods. The minimum LWP for symptom development is 4-8 h (Jhorar et al., 1998). Germination of conidia increased with increasing LWP and germ tube penetration increased from 2% with 6 h of LWP to 11% with 24 h LWP (Jhorar et al., 1998). Disease severity plotted against LWP showed an exponential asymptote. The number of pycnidia that developed with continuous wet period was higher than with interrupted wetness periods. The maximum infection was observed with a wetness period of 18 h (Jhorar et al., 1998).

2.3.6.3 Relative humidity

Using long term weather data, Jhorar et al. (1997) correlated disease severity with maximum temperature and afternoon RH. The relationship between the disease and temperature was linear, and with RH was an exponential asymptote. The ratio between these two relationships, referred to as the humid thermal ratio (HTR) was calculated and found to be in a positive relationship with the disease severity. Use of HTR was suggested as a model to trigger fungicide applications. Jhorar et al. (1997) also reported that the afternoon RH was more influential than the morning RH.

2.4 Physiological and genetic basis of resistance

2.4.1. Genetic basis of resistance

Evaluation of chickpea germplasm has shown that there are very few accessions with resistance to AB (Reddy and Singh, 1984; 1990). However, wild species of *Cicer* such as *C. echinospermum* have some resistance (Collard et al., 2001). Both *C. reticulatum* and *C. echinospermum* are cross-compatible with *C. arietinum*, and could provide sources of resistance (Singh and Ocampo, 1993).

Several authors have reported on the inheritance of resistance. Ahmed et al. (1952) reported that disease resistance was controlled by two dominant complimentary genes. In desi cultivars, the resistance was governed by a single dominant gene (Vir et al., 1975; Eser, 1976; Hafiz and Ashraf, 1953). In kabuli, resistance to ascochyta blight was governed by a single recessive gene for one cultivar and one dominant gene in several cultivars (Singh and Reddy, 1983). Dey and Singh (1993) reported that two dominant complimentary genes were responsible for resistance in two chickpea genotypes, and one dominant and one recessive gene were controlling resistance in another. Tewari and Pandey (1986) reported that ascochyta blight resistance in chickpea was governed by two recessive genes through additive gene action. According to Kusmenoglu (1990), resistance to ascochyta in chickpea was

regulated by two recessive genes. Tekeoglu et al. (2000) reported that resistance was controlled by two quantitatively inherited major complimentary recessive genes and other minor genes. Santra et al. (2000) identified two quantitative trait loci (QTL), QTL1 and QTL 2 conferring resistance to ascochyta which together accounted for 50% and 45% of variation in blight reaction over two years, respectively. Flandez-Galvez et al. (2003) reported that resistance to AB under both field and controlled environments was associated with the genomic regions on LG1, LG2 and LG3. However, it was later found that the major QTL for AB resistance was located on LG4 (Udupa and Baum, 2003; Taran et al., 2006). Taran et al. (2006) also reported one QTL on each of LG3 (16%), LG4 (29%) and LG6 (12%). The QTL on LG3 region was unique to the population derived from a cross involving ICCV96029 and CDC Frontier.

A high degree of genetic diversity has been reported among isolates of *A. rabiei*. Three pathotypes, pathotype I (least aggressive), pathotype II (aggressive) and pathotype III (most aggressive) were reported in Syria (Udupa et al., 1998, Jamil et al., 2000). The more sexual recombination occurs in the pathogen's life cycle, the higher the chances are for the development of new pathotypes. Hence, attempts to attain durable resistance in chickpea have not been successful. The resistance to ascochyta blight, which is partial, tends to decline after flowering and further when the plant matures (Chongo and Gossen, 2001). Developing multilines and pyramiding many resistance genes from various sources have been attempted to breed varieties with durable resistance (van Rheenan and Haware, 1994).

2.4.2 Physiological basis of resistance

Resistant cultivars of chickpea differ from the susceptible cultivars in certain physiological aspects. The early disease cycle phases such as spore germination, germ tube elongation and appressorium formation were identical in both resistant and susceptible cultivars (Höhl et al., 1990; Ilarslan and Dolar 2002). In susceptible cultivars, the hyphae expanded sub-epidermally, and disrupted the host's cellular

structure (Höhl et al., 1990). However, even in susceptible cultivars, lignified cells were attacked less severely than cells that lacked lignin. In resistant cultivars, the plants showed hypersensitive reactions and the affected sites turned brown and necrotic which arrested the growth of pathogen (Höhl et al., 1990). Venora and Porta-Puglia (1993) reported that the thickness of the outer wall of epidermal and parenchyma cells of resistant genotypes were greater than in the susceptible genotypes. Chickpea also forms secondary metabolites with antimicrobial properties, such as biochanin A (5, 7-dihydroxy-42-methoxyisoflavone) and formononetin (7-hydroxy-42-methoxyisoflavone), to defend against invasive pathogens (Kessmann et al., 1988; Köster et al., 1983).

Glandular exudates from chickpea leaves promote conidial germination at a lower concentrations (0.012 and 0.006 mg/mL) and inhibit conidial germination at higher concentrations (0.3 and 1.5 mg/mL) (Armstrong-Cho and Gossen, 2005). The pH of the exudates from chickpea glandular trichomes ranges from 0.4 to 1.3 and exudates mainly consist of the organic acids malic acid (60%) and oxalic acid (30%) (Lauter and Munns, 1986; Rembold and Weigner, 1990). Sattar (1933) reported that the concentration of malic acid and oxalic acid in glandular exudates increased with increasing crop maturity. Hafiz (1952) found that conidia germination was greater in a medium of droplets of glandular exudates from young plants and germination ceased as the plants matured, and was arrested in droplets from 78-88 day old plants. In contrary to that, many studies could not correlate the AB resistance trichome density and acidity of the exudates (reviewed in Jayakumar et al., 2006).

Histo-chemical studies of *A. rabiei* on susceptible and resistant varieties indicated that hydrogen peroxide (H_2O_2) released apoplastically after infection was responsible for resistance. Although several classes of enzymes produce H_2O_2, copper amine oxidases (CuAOs), which are loosely associated enzymes in the plant cell walls especially in legume plants, produce considerable amount of H_2O_2. Also plant peroxidases use H_2O_2 in the process of suberin and lignin biosynthesis, which

act as barriers for infection. Inhibiting CuAO production also reduced AB resistance (reviewed in Jayakumar et al., 2006).

2.4.3 Status of chickpea cultivars available in western Canada

Most cultivars grown in western Canada were released from the Crop Development Centre (CDC) of the University of Saskatchewan and USDA, Pullman, Washington. Large-seeded kabuli, small-seeded kabuli, and desi are the three market classes of chickpea in western Canada (Gan et al., 2003a). Sanford, Dwelley and Evans are large seeded kabuli cultivars that were released by USDA and had moderate resistance to AB. However, the resistance in these cultivars appears to have declined due to the development of new pathotypes of *A. rabiei* (Chongo et al., 2004). CDC Xena, another large-seeded kabuli cultivar released by the CDC, was also moderately resistant at the time of release, but has become susceptible. CDC Xena, Sanford, Dwelley and Evans are classified as having 'very poor' resistance to AB in western Canada (Saskatchewan Agriculture and Food, 2006a). CDC Yuma and CDC ChiChi are also being grown in western Canada and are classified as having 'poor' resistance. CDC Frontier is a promising kabuli cultivar with medium seed size and fair resistance to AB. Amit (B-90) was introduced from Bulgaria into western Canada by Terramax, Regina, SK. This small-seeded kabuli also offers fair resistance to AB with consistent grain yield. Among the desi cultivars, CDC Anna, CDC Cabri, CDC Nika, CDC Desiray and Myles are being cultivated in western Canada. These cultivars have fair resistance to AB. Due to the development of new pathotypes within the *A. rabiei* population, cultivars once resistant may become susceptible over time.

2.5 Management of ascochyta blight

2.5.1. Cultural methods

Disease development depends on the interaction of host, pathogen and environmental conditions. Planting resistant cultivars is one of the economic and effective strategies to minimize the damage caused by blight (Akem et al., 1999, Nene and Reddy, 1987).

Seed lots for planting should be tested for AB infection in accredited laboratories (Pearse et al., 2000). Selection of disease-free seed will reduce the risk of seed-borne infection in new plantings (reviewed in Gan et al., 2006). Morrall (2001) suggested that planting large-sized seeds was more beneficial than small seeds, both in terms of yield and disease severity. Solar heating of seeds was used to reduce the damage caused by seed-borne pathogens in India. Chaube et al. (1987) reported that solarisation of infected seeds for 15 days resulted in reduced disease level of AB.

Ascochyta rabiei can survive on infected debris for several years (Navas-Cortes et al., 1995; Gossen and Miller, 2004). Infected plant debris is the most important source of primary infection in the field (Luthra et al., 1935). Field sanitation plays a vital role in any crop disease management program. As rain splash spreads ascochyta blight, infected debris in adjacent fields could be a source of inoculum. Planting chickpea in a field within 100 m of the adjacent field with ascochyta infected debris resulted in severe ascochyta blight (Trapero-Casas and Kaiser 1992a).

Burial of infected debris reduced the viability of ascospores and the survival of the pathogen (Kaiser, 1973). Navas-Cortes et al. (1995) reported that the fungus remained viable for 2 years in chickpea debris. However, the viability was reduced to 5-6 months when buried. Gossen and Miller (2004) reported that in the Canadian prairies where the air temperature varies widely from 40 °C to – 40 °C, the fungus survived for 4 years on the surface. Navas-Cortes et al. (1995) in Spain showed that

the debris on the surface had higher levels of colonization of *A. rabiei* than when buried, and the depth of burial had no significant impact. The study also found that pycnidia were formed when debris was buried. If pseudothecia formed at a depth of 10 cm, they were abnormal, making ascospore production scarce. Despite being an effective means of controlling AB, burial of debris is not being practiced in many arid regions such as western Canada, where reduced tillage is used to conserve soil moisture and organic matter.

Crop rotation with non-host crops helps to reduce the background level of AB inoculum. Effectiveness of crop rotations depends on the environmental conditions. In tropical regions, a break of 1-2 years between chickpea cultivation reduced the disease severity (Kaiser et al., 2000), whereas in temperate regions planting of non-host plants was recommended for four years between successive chickpea crops (Gossen and Miller, 2004).

Seeding late or early in order to avoid exposure of plants to ascospores, depending upon the time of epidemics, could minimize the damage caused by ascochyta (Gan et al., 2006). However, the cropping season is short in western Canada, so there are minimal options for adjusting planting dates.

2.5.2 Biological control

Antagonism among microorganisms can be utilized to control plant pathogens. *Ascochyta rabiei*, when buried in sterilized soil, formed pseudothecia and pycnidia more uniformly and rapidly than in natural soil, indicating that the fungus is affected by other saprophytic microorganisms (Navas-Cortez, 1992). Fungal antagonists such as *Trichoderma viridi* influenced the growth and survival of *A. rabiei* (Wang et al., 2003). Thal-8, a strain of *Rhizobium* native to Pakistan, produces an acid that is antifungal in nature and limits the growth of A. *rabiei* in soil (Khokhar et al., 2001). In a laboratory study, both *A. rabiei* and *D. rabiei* stages were inhibited by *Aureobasidium pullulans* and *Conostachya rosea* (Dugan et al., 2005). Botanical extracts are being used to control various insect pests and pathogens. Aqueous

extract of onion (*Allium cepa*) has shown antifungal activity against *A. rabiei* (Khan et al., 1998). Biological control is relatively less effective in combating pathogens than insect pests (Butt et al., 2001). However, biological control could be included as one of the components of the integrated disease management strategies for ascochyta blight of chickpea.

2. 5. 3 Fungicidal control

2. 5. 3. 1 Seed treatment

Ascochyta blight is seed-borne, and infested seed is an important source of primary inoculum in the field (Nene and Reddy, 1987; Dey and Singh, 1994). Seedlings emerging from infected seeds showed severe disease development (Maden et al., 1975). When disease-free seed is not available, seed treatment is advised to prevent spread of the disease. Seed treatment for controlling blight was in practice in India since the 1930s (Sattar 1933). In Saskatchewan, seed with ascochyta blight infection levels below 0.3% are required to qualify for crop insurance (Pearse et al., 2000). Thiabendazole applied with benomyl was more effective than when applied alone (Kaiser and Hannan, 1988). Disease transmission was reduced by more than 95% when the seeds were treated with benomyl (Demirci et al., 2003). Application of benomyl, thiram, carbendazim and chlorothalanil reduced the transmission by more than 90% (Demirici et al., 2003).

The performance of seed treatments in the field depended on environmental conditions (Demirci et al., 2003). Seed treatments did not completely eradicate the pathogen from seed and disease could still be transmitted from seed to seedlings (Kaiser and Hannan, 1987). Although seed treatment with systemic fungicides was effective in minimizing hyphal development and sporulation of *A. rabiei,* control of *D. rabiei* was not adequate (Shtienberg et al., 2000). In Saskatchewan, the seed treatment fungicides registered for chickpea ascochyta blight are Apron Maxx RTA® (fludioxonil, metalaxyl-M), and Crown® (carbathin, thiabendazole) (Pearse et al., 2000).

2.3.5.2. Foliar application of fungicide

Foliar application of fungicides is used in many chickpea growing regions. A one-time application of fungicide will control only one of the disease cycles, it will not prevent further infection by this polycyclic pathogen (Kaiser and Hannan, 1988). In regions where the environment is very conducive for the pathogen, multiple applications of fungicides are required during the growing season to manage the disease. In some cases, even multiple applications of fungicides were not sufficient to control the disease (Shtienberg et al., 2000). The timing and number of fungicide applications are critical to achieve effective control of the disease and to attain the maximum crop yield (Shtienberg et al., 2000; Chongo et al., 2003). The decision to apply fungicides before or after infection largely depends on the growing season. In regions where chickpea is grown in a short growing season, preventive applications can be beneficial, but in regions where chickpea is cultivated over a long growing period, a greater number of preventive applications are needed which is often not economical (reviewed in Gan et al., 2006). Similarly, the timing and number of applications depends upon the weather conditions. Rainy, windy and humid conditions increase the chances of epidemic outbreak, and thus influence the decision to spray. Many fungicides have been tested for their efficacy in ascochyta control. The fungicides registered for ascochyta blight control in chickpea differ among countries. Foliar application with protectant fungicides such as Bordeaux mixture (a.i. copper sulphate + hydrated lime), wettable sulphur (a.i. sulphur), maneb and captan could result in reduced disease levels (Nene, 1982). Chlorothalonil (Bravo®), a contact fungicide was effective against *A. rabiei* (Reddy and Singh, 1984) and is registered for this use in Canada. Mancozeb (Dithane®) was also tested to control chickpea ascochyta blight in Canada and was reported to be less effective (Chongo et al., 2003). Strobilurin fungicides, i.e., azoxystrobin and pyraclostrobin have been used in Canada in recent years. Azoxystrobin was found effective against *A. rabiei* (Demirici et al., 2003). Gossen (2004) found that some isolates of *A. rabiei* are resistant to strobilurin fungicides. Boscalid (Lance®) was also effectively controlling the disease (Chongo et al., 2000). The efficacy of foliar fungicide application depends on the longevity of the fungicide, foliage coverage,

and stage of growth of the crop. Field scouting can be used to identify the disease at the early stage and aids in deciding when to spray. In general, a combination of moderate host plant resistance, seed dressing, foliar application of fungicides, and cultural control methods comprising of field sanitation, crop rotation and burial of infected debris is used to minimize the disease severity and achieve economical yields (Reddy and Singh, 1990).

3.0 Alternative tools to manage ascochyta blight in chickpea

3.1 Introduction

Crop diversification is an important step to increase the profitability and sustainability of agriculture (Hatfield and Karlen, 1994). Chickpea, fits very well as a rotation crop in the semi-arid prairies especially under reduced tillage systems. Chickpea is an attractive cash crop in western Canada that generally provides more returns to growers than cereals. Production of chickpea in western Canada was at its peak in 2001, when 464,900 MT were produced on an area of 501,810 ha (Statistics Canada; Saskatchewan Agriculture and Food, 2005). Saskatchewan contributed more than 90% of the chickpea production and seeded area in western Canada. Despite these benefits, the area under cultivation of chickpea decreased significantly after 2001, primarily due to the devastating disease ascochyta blight caused by *Ascochyta rabiei*. Late crop maturity and lower market prices are other factors that reduced chickpea production in western Canada.

Ascochyta blight (AB) is a wide-spread foliar disease leading to extensive crop losses in most of the chickpea growing countries. Locally adapted chickpea cultivars which are partially resistant to AB became available to growers in western Canada in the mid 1990's. However, the resistance tended to decline after the flowering stage (Chongo and Gossen 2001).

The successful cultivation of chickpea in western Canada is currently difficult without the use of fungicides. The cost of fungicides is quite high and fungicide applications may not give adequate control under epidemic conditions and when planting highly susceptible cultivars. Fungicides such as chlorothalanil and pyraclostrobin are being used in western Canada to control AB in chickpea. Most of

the fungicides registered for use on chickpea are protectants. Post-infection fungicides need to be applied at a specific time. The correct timing and rate of fungicide applications reduce disease severity and ensure reduced usage of fungicides. Thus, it is necessary to determine the best possible frequency of fungicide application to effectively manage the disease and minimize fungicide cost.

AB is favoured by cool and moist conditions. Under favorable conditions such as cool and moist weather (>350 mm annual rainfall and 23–25 °C) the disease may cause 100% yield loss (Nene and Reddy, 1987). The microclimatic factors such as plant temperature, relative humidity and light interception are likely to affect the sporulation of *A. rabiei*. Any alteration in these factors would retard AB development. A paired row planting arrangement with a more open canopy could influence the pathogen because of changes in the micro-environment (Blad et al., 1978). The conidia of A. *rabiei* were reported to be released only from wet pycnidia. At least 6 hrs of wetness is necessary for infection by *A. rabiei* at optimum temperature (Weltzien and Kaack, 1984). Humidity at plant level is highly influenced by the canopy. Light intensity may affect spore germination, penetration, infection, release and viability (Colhoun, 1973).

Optimum plant population density is an important factor influencing crop productivity per unit area. The number of plants required per unit area to achieve profitable yields depends on the nature of the crop and its environment. The population cannot be too small as full potential will not be realized, and it cannot be too large as excessive plant competition will reduce the overall efficiency of plant growth. Doubling a kabuli chickpea population by reducing the row spacing from 60 cm to 30 cm resulted in a yield increase of 52% in Jordan (Kostrinski, 1974). The optimum plant population recommended for chickpea on the Canadian prairies is 44 plants m^2 (Gan et al., 2003c).

Air-borne ascospores play an important role in dispersal of the pathogen and make disease control difficult (Armstrong et al., 2001). Relying exclusively on one control

approach is unlikely to adequately protect chickpea crops from this disease (Chongo et al., 2003). An alternate planting method is proposed in this project aimed at improving microclimate conditions by altering plant canopy structures, creating less favorable conditions for disease development, increasing fungicide use efficiency, and achieving higher seed yield. Thus the objectives of this project were: i) To determine the effect of different seeding arrangements on ascochyta blight severity and seed yield of two cultivars of kabuli chickpea, and ii) To compare one and four fungicide applications at recommended and reduced fungicide rates and their impact on disease severity and cost.

3.2 Materials and Methods

3.2.1 Site description

Two field experiments were conducted on Orthic Brown Chernozemic soil with loam to silt loam texture at the Agriculture and Agri-Food Canada Research Centre in Swift Current, SK in 2004 and 2005. The saturated paste pH of the soil was 6.5 at 0-15 cm depth. The seedbed temperature at 5-cm depth on May 14, 2004 was 10 °C and on May 9, 2005 was 11 °C. In both years of the experiment, the seedbed was wheat stubble. The plot size dimensions were 8 m wide × 14 m long in 2004 and 4 m wide × 14 m long in 2005.

3.2.2. *Chickpea cultivars*

The two chickpea cultivars that were evaluated in this experiment were Amit and CDC Xena. Amit has fair resistance to AB, with fern leaves and a relatively small seed size
(265 mg seed^{-1}). CDC Xena has very poor resistance to AB, a unifoliate leaf type, and a larger seed size (490 mg seed^{-1}).

3.2.3. Crop management

For the 2004 trial, pre-seeding application of Edge ® (a.i. ethalfluralin) was applied at the rate of 22 kg ha^{-1} during late September 2003. For the 2005 trial, Edge ® was applied at 17 kg ha^{-1} as a pre-seeding herbicide in April 2005. In both years, Roundup Transorb® (a.i. glyphosate) was applied before seeding at 1.25 L ha^{-1} in late April. Pre-emergence applications of Roundup Weathermax® (a.i. glyphosate) were applied at the rates of 0.82 L ha^{-1} in 2004 and 1.24 L ha^{-1} in 2005. Pursuit (a. i. imazethapyr ammonium) at the rate of 30 ml ha^{-1} was also applied in both the years during the 3rd week of May.

In both years, Nitragin® soil implant + GC (Liphatech. Inc. Milwaukee, WI, USA.), a peat based granular inoculant, was applied with the seed at the rate of 5.6 kg ha^{-1}. This inoculant contained a minimum of 1 x 10^8 viable cells of *Rhizobium* spp. per gram. Fertilizer was applied at the rate of 0.82 g of 11-51-0 (N-P-K) per meter row.

Plots were seeded using a Noble Hoe ® drill with atom jet single shoot openers placed 25-cm apart. The seed of both cultivars had > 90% germination. Crown ® (a.i. carbathiin and thiabendazole) was used to treat Amit at the rate of 600 ml/100 kg of seed and for CDC Xena, 300 ml/100 kg of seed. Apron® (a. i. metalaxyl) was applied at the rate of 16 ml/ 100 kg of seed for both cultivars. The seeding rates used for Amit were 108 kg ha^{-1}, the recommended seeding rate and 75 kg ha^{-1} (70% seeding rate). CDC Xena was seeded at the rates of 236 kg ha^{-1}, the recommended seeding rate and 164 kg ha^{-1} (70% seeding rate). Solid seeded plots were sown in rows with 25 cm spacing. Paired row plots were sown in rows having a 25 cm wide spacing within the pair of rows and 75 cm wide spacing between the paired rows.

3.2.4. Description of treatments

The two numbers of fungicide applications, two fungicide rates, two different seeding patterns and two different seeding rates were used in combination which resulted in eight treatments as listed in Table 3.1.

Table 3.1 Components of the treatments

Treatments	Plant population m^{-2}	Seeding pattern	No. of fungicide applications	Fungicide rate
1	44	Solid	1	1 X
2	44	Paired	1	1X
3	44	Paired	1	0.67 X
4	31	Paired	1	0.67 X
5	44	Solid	4	1X
6	44	Paired	4	1X
7	44	Paired	4	0.67 X
8	31	Paired	4	0.67 X

Number of fungicide applications

a) One application of Headline® (pyraclostrobin) applied 45 days after planting.
b) Four fungicide applications - Alternating application of (Headline®, Bravo® {chlorathalanil}, Headline®, Bravo®) were made at 2 weeks interval, starting 45 days after planting

The recommended rate of application (1X rate) for Headline is 0.40 L/ ha and the 0.67 X rate is 0.27 L/ ha. The recommended rate of application for Bravo is 3 L / ha and the 0.67 X rate is 2 L/ ha. (Saskatchewan Agriculture and Food, 2006)

Seeding arrangements and fungicide rates

a) Solid seeded at 44 seeds/m^2 using the recommended fungicide rate (1X)
b) Paired row seeded at 44 seeds/m^2 using the recommended fungicide rate (1X)

c) Paired row seeded at 44 seeds/m^2 using the low fungicide rate (0.67X)

d) Paired row seeded at 31 seeds /m^2 using the low fungicide rate (0.67X)

Standard flat fan nozzles were used to spray the solid seeded plots. A three-nozzle (two on the sides and one above the canopy) application kit (Figure 3.1) was used to spray the paired row plots.

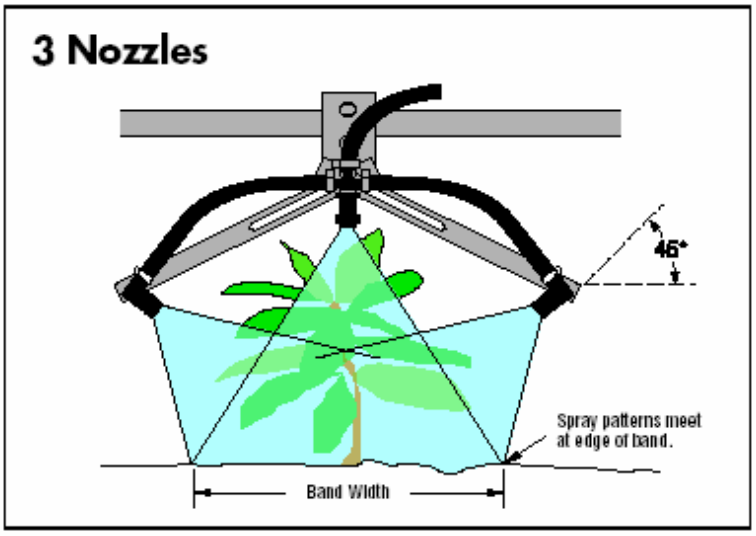

Figure 3.1 Three-nozzle application kit used in the experiment to spray paired row plots

3.2.6. Experimental design and data collection

The plots were arranged in a two factorial randomized complete block design (RCBD) with four replications. The two chickpea cultivars and eight treatments were the two factors. Based on previous experience of AB epidemics on chickpea in southern Saskatchewan, it was decided not to include control plots without any fungicide treatments, since these treatments would likely result in severe crop damage on the highly susceptible cultivar, resulting in little or no yield. AB ratings were conducted at 2 week intervals beginning one month after planting. At each rating session, five sites were selected at random in the middle rows of each plot. At each sampling site, 4 to 6 plants were rated for AB severity using the Horsfall –

Barratt scale (Horsfall and Barratt, 1945). Plant density was measured 2 weeks after emergence. Yield components including plant height, number of pods per five plants, number of seeds per pod, plant height and lowest pod height were measured.

3.2.7. Statistical analysis

Area Under the Disease Progress Curve (AUDPC) was calculated from the percent disease score values using the following equation.

$$AUDPC = \Sigma_i^{n-1} (y_i + y_{i+1})/2) (t_{i+1} - t_i) \qquad (Eq.\ 1)$$

Where y_i is the percent severity observed for the i_{th} observation, t_i is the date of the observation and observations were made on n dates (Shanner and Finney, 1977).

Data for AUDPC was not homogenous, so AUDPC data were log transformed to stabilize variance. Analysis of variance revealed that the data for disease severity, yield and plant growth parameters from the two years had significant differences and were analyzed separately for each year. Similarly, there was significant difference between the varieties and there was a significant treatment × cultivar interaction, and the data were analyzed separately for each cultivar. The General Linear Model procedure (PROC GLM) of SAS (SAS Institute. Inc, NY) was used to analyze the data. Linear contrast analyses were performed to compare the effect of individual components of the treatments, which were seeding pattern, seeding rate, number of fungicide applications and fungicide rate. Correlation analysis between AUDPC, yield, 1000 KWT and growth parameters was carried out through PROC CORR of SAS (SAS Institute Inc., NY).

3.2.7. Economic assessment of fungicide applications and seeding rate

The cost of fungicides per ha was calculated based on the current retail prices for the fungicides, and an average application cost of $ 7/ha given in the Saskatchewan Agriculture and Food's custom application rate guide (Saskatchewan Agriculture and Food, 2006b) was added to calculate the cost of fungicide application per ha. Mean fungicide application costs for treatments, which were similar with respect to

the number of fungicide applications and plant population, were used to calculate fungicide application cost for one application and four applications. Average yields from the respective group of treatments were used to arrive at gross returns. Seed cost of CDC Xena was $0.75 per kg and for Amit it was $ 0.54 per kg of seed. Chickpea grain prices (Amit = $ 0.32/kg; CDC Xena = $0.54/kg) were obtained from the Saskatchewan crop insurance program website (Saskatchewan Crop Insurance, 2006). Assuming the cost of all other inputs except seed and fungicide was the same for all the treatments, the difference in returns for each treatment was calculated.

3.3. Results

3.3.1 Weather conditions at Swift Current

Mean monthly air temperature and monthly precipitation of the 2004 and 2005 growing seasons are presented in Table 3.2. Mean air temperature for the growing season (May - Sep.) in 2004 was 13.3 °C, which was 2.4 °C less than the long-term average, and in 2005 was 14.4 °C, which was 1.3 °C less than the long term average. Precipitation during the growing season in 2004 was 311 mm, which was 50% more than the long-term average, whereas precipitation in 2005 (260 mm) was 30% more than the long-term average.

Table 3.2 Monthly precipitation and monthly mean temperature during the growing seasons of 2004 and 2005 at Swift Current

	Parameter	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Growing season**
2004	Precipitation (mm)	84	66	61	72	27	311
	Mean temperature (°C)	8.3	13.0	17.8	15.3	12.3	13.3
2005	Precipitation (mm)	22	123	21	52	41	260
	Mean temperature (°C)	9.9	14.7	18.6	16.5	12.5	14.4

Long-term mean precipitation of growing season (1961-2000) – 206 mm

Long-term mean air temperature of growing season (1961-2000) – 15.7 ° C

3.3.2. Severity of ascochyta blight in two chickpea cultivars in response to the treatments

Analysis of variance for AB severity (assessed as AUDPC), plant growth and development parameters, seed yield, and KWT are presented in the Appendices (Appendix tables A.1 to A.14).

3.3.2.1 Amit

Severity of AB on the partially resistant cultivar Amit was influenced by the treatments in 2004, but the influence was not significant in 2005 (Table 3.3). In 2004, treatments that received four fungicide applications had significantly lower mean AUDPC (477) than those treatments that received only one fungicide application (1135) (Tables 3.3 and 3.4, and Figure 3.2). The disease progressed more quickly for treatments with one fungicide application, compared to treatments which received four fungicide applications (Figure 3.2). However, in 2005, the mean AB severity in treatments that received four fungicide applications and one application did not differ (Tables 3. 3 and 3.4). Disease progress was similar for all treatments (Figure 3.3).

AB severity (AUDPC) under solid seeding was 852 in 2004 and 405 in 2005 (Table 3.4). AB severity under paired row planting was 771 in 2004 and 330 in 2005. Seeding pattern did not affect AUDPC in either year (Table 3.3).

The fungicide application rates (1X rate and 0.67X) did not differ in their effect on severity of AB (Tables 3. 3 and 3.4). In 2004, mean AUDPC for Amit at the 1X rate was 771 and for treatments at the 0.67 X rate was 795. In 2005, mean AUDPC under 1X rate was 330 and 0.67 X rate was 300.

Seeding rates for paired row planting (44 plants m^{-2} and 31 plants m^{-2}) did not affect AB severity in 2004 or 2005 (Tables 3. 3 and 3.4). Severity of AB under 44/m^2 was

771 and under 33 plants /m^2 was 795 in 2004. In 2005, severity of AB under 44/m^2 was 300 and under 33 plants /m^2 was 365.

Table 3.3 Linear contrasts of the effect of treatments on ascochyta blight severity on chickpea cultivar Amit evaluated at Swift Current in 2004 and 2005.

		2004		2005	
Source	**DF**	**F Value**	**Pr > F**	**F Value**	**Pr > F**
No. of fungicide applications: 1 vs. 4 applications	1	276.38	<.0001	1.33	0.2626
Fungicide rate: 1X vs. 0.67X with 4 applications	1	0.59	0.4519	0.21	0.6511
Seeding pattern: solid vs. paired with 1 X fungicide rate	1	2.02	0.1737	1.17	0.2922
Seeding rate : 44 vs. 31 seeds m^{-2} with 0.67X fungicide rate	1	0.00	0.9775	1.15	0.2948

Table 3.4 Effect of treatments on ascochyta blight severity measured as area under the disease progress curve (AUDPC) on two chickpea cultivars (CDC Xena and Amit) evaluated at Swift Current, 2004 and 2005.

Treatments	Plant population m^{-2}	Seeding pattern	No. of fungicide applications	Fungicide rate	Amit		CDC Xena	
					2004[Z]	2005[Z]	2004[Z]	2005[Z]
1	44	Solid	1	1 X	7.1 a (1212)	6.1 a (446)	7.9 a (2697)	7.3 a (1480)
2	44	Paired	1	1X	7.0 a (1097)	5.8 a (330)	7.9 a (2697)	6.8 bc (898)
3	44	Paired	1	0.67 X	7.0 a (1097)	5.8 a (330)	7.9 a (2697)	7.0 b (1097)
4	31	Paired	1	0.67 X	7.0 a (1097)	5.9 a (365)	7.9 a (2697)	6.9 bc (992)
5	44	Solid	4	1X	6.2 b (493)	5.9 a (365)	7.5 b (1808)	6.9 bc (992)
6	44	Paired	4	1X	6.1 b (446)	5.8 a (330)	7.4 b (1636)	6.7 dc (812)
7	44	Paired	4	0.67 X	6.2 b (493)	5.6 a (270)	7.4 b (1636)	6.5 d (665)
8	31	Paired	4	0.67 X	6.1 b (446)	5.9 a (365)	7.5 b (1808)	6.5 d (665)

Data were transformed using log transformation prior to analysis. Values in parenthesis are back-transformed to the original scale.

[Z] Means within a column followed by the same letters do not significantly differ at $P \leq 0.05$.

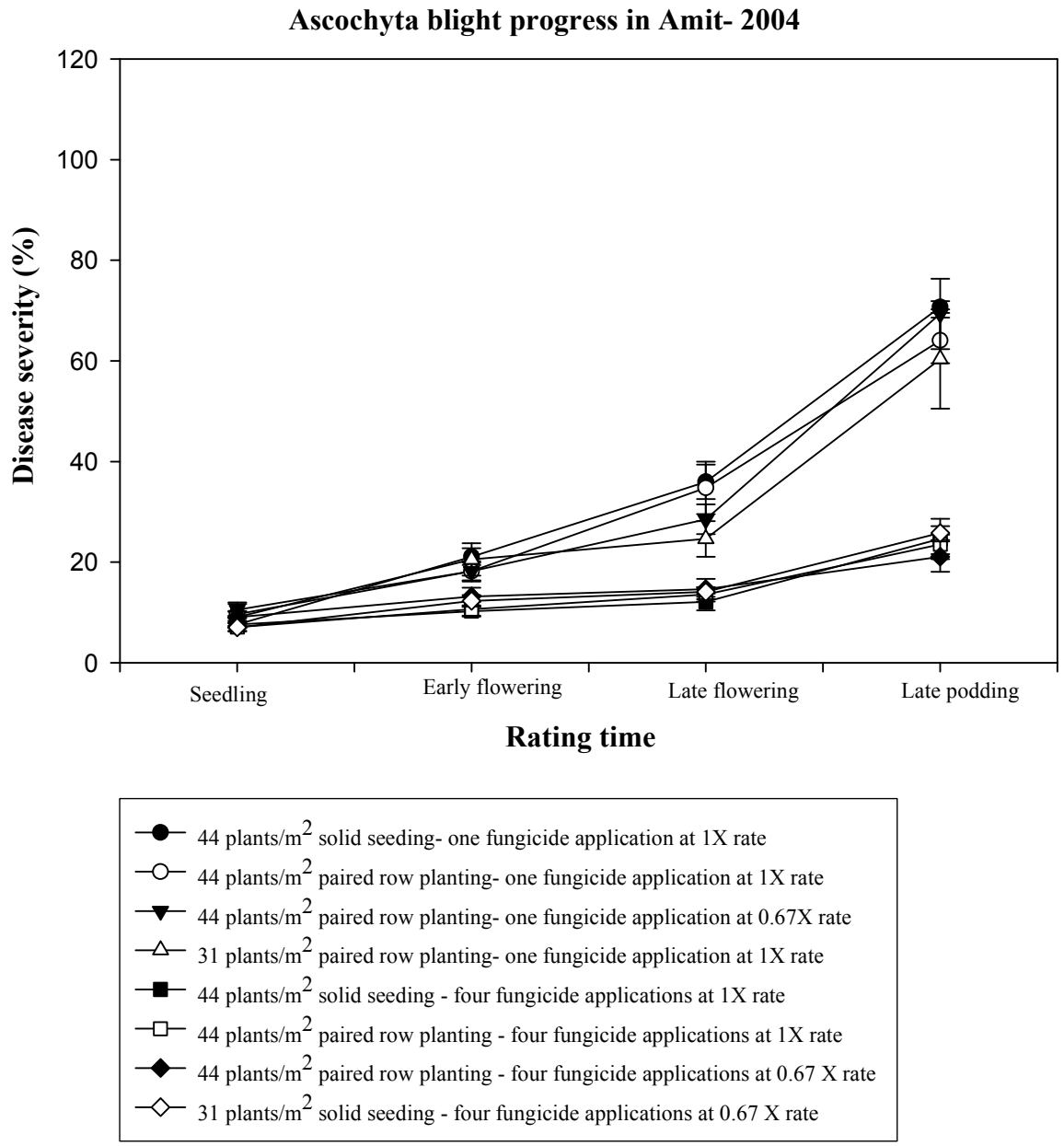

Figure 3.2 Ascochyta blight disease progress in chickpea cultivar Amit evaluated at Swift Current in 2004. Vertical bars are standard errors

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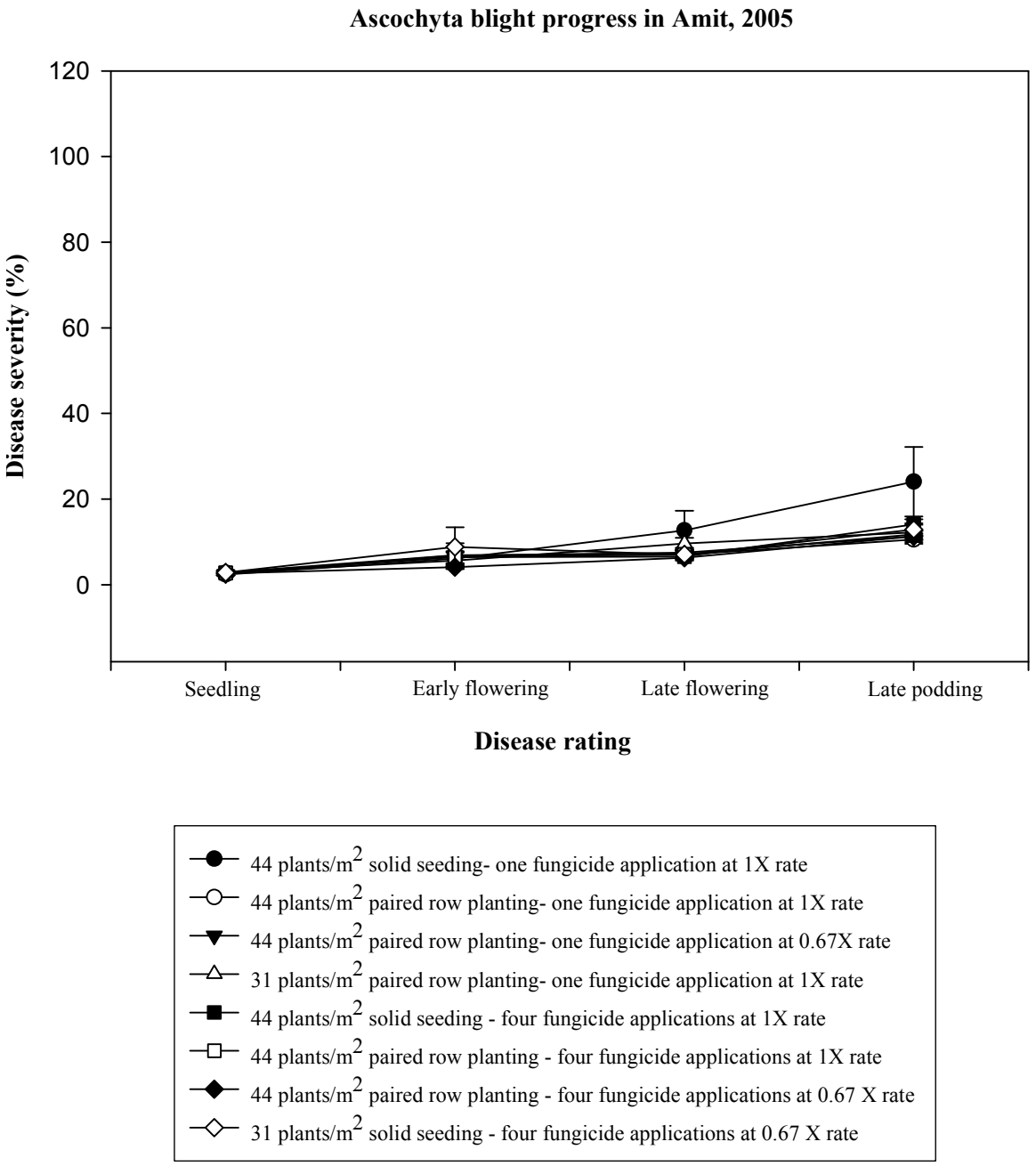

Figure 3.3 Ascochyta blight disease progress in chickpea cultivar Amit evaluated at Swift Current in 2005. Vertical bars are standard errors

3.3.2.2. CDC Xena

Treatments significantly influenced the severity of AB on the susceptible cultivar CDC Xena in both years. Severity of AB varied significantly in plots with one vs. four fungicide applications in both years (Tables 3.4 and 3.5). In 2004, AB severity (AUDPC) was significantly lower in treatments that received four applications of fungicide (1690), compared to a single application (2700). The disease progressed more quickly in treatments receiving one fungicide application than four applications (Figure 3.4). Similarly in 2005, treatments that received a single application had a mean AUDPC of 1160 which was generally higher than that of treatments with four applications (820) (Tables 3.4 and 3.5, Figure 3.5).

Mean AUDPC in solid seeding arrangement (2253) did not differ from paired row planting (2167) in 2004 (Table 3.5). In 2005, AUDPC under solid seeding (1236) was higher than under paired row planting (855). Seeding rates (44 plants m^{-2} and 31 plants m^{-2}) had no impact on the severity of AB in both years (Tables 3. 4 and 3.5). Mean AUDPC at 44 plants m^{-2} was 2167 in 2004 and 881 in 2005. Mean AUDPC of plots at 31 plants m^{-2} was 2253 in 2004 and 829 in 2005.

The rate of fungicide application (1X vs. 0.67X) did not affect the severity of AB in either year (Table 3.5). In 2004, mean AUDPC of Xena under 1X rate and 0.67X were both 2167. In 2005, mean AUDPC under 1X rate (855) was similar to the 0.67 X rate (881).

Table 3.5 Linear contrast of the effect of treatments on ascochyta blight severity on chickpea cultivar CDC Xena evaluated at Swift Current in 2004 and 2005

		2004		2005	
Source	**DF**	**F Value**	**Pr > F**	**F Value**	**Pr > F**
No. of fungicide applications: 1 vs. 4 applications	1	84.99	<.0001	17.69	<.0001
Fungicide rate: 1X vs. 0.67X with 4 applications	1	0.29	0.2503	0.01	0.7828
Seeding pattern: solid vs. paired with 1 X fungicide rate	1	2.12	0.0690	13.42	0.1288
Seeding rate : 44 vs. 31 seeds m^{-2} with 0.67X fungicide rate	1	0.52	0.3351	0.43	0.5460

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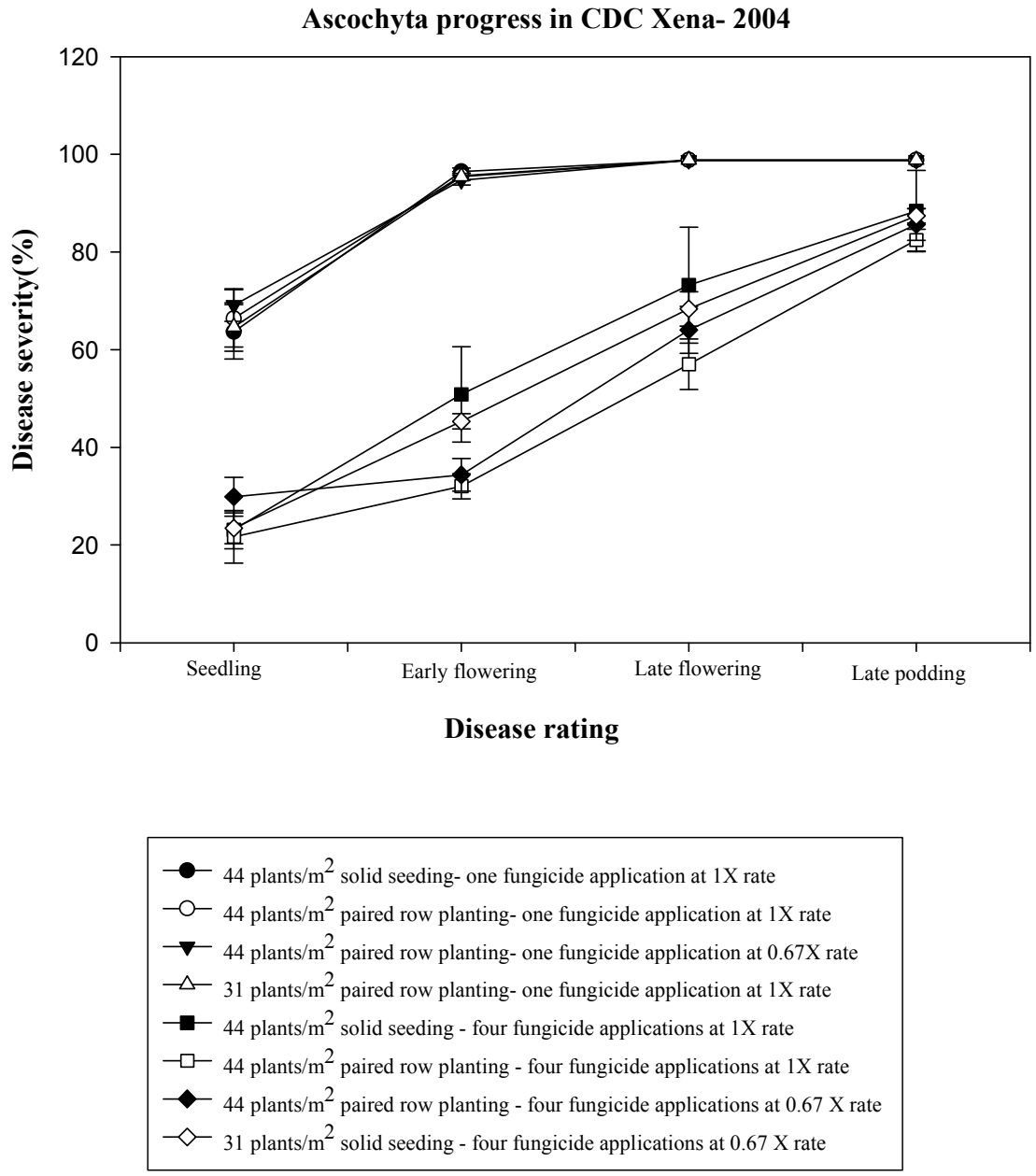

Figure 3.4 Ascochyta blight disease progress in chickpea cultivar CDC Xena evaluated at Swift Current in 2004. Veritical bars are standard errors

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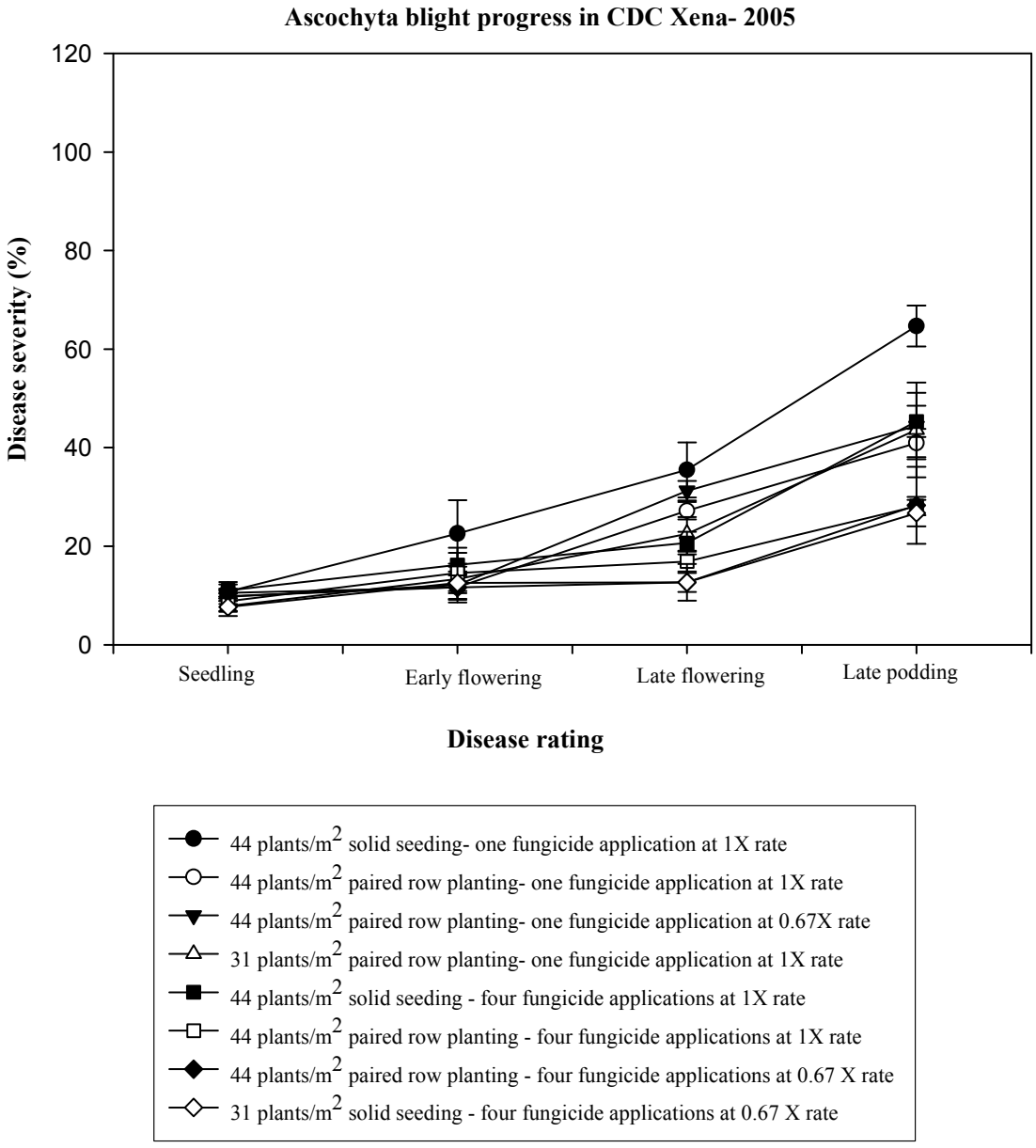

Figure 3.5 Ascochyta blight disease progress in chickpea cultivar CDC Xena evaluated at Swift Current in 2005. Veritical bars are standard errors

3.3.3. Effect of treatments on plant growth and development

3.3.3.1 Amit

Analysis of variance revealed that the treatments did not influence number of pods per plant, or number of seeds per plant of the moderately resistant cultivar Amit in either year. However, the average number of seeds per pod was significantly influenced by treatments in 2004.

Linear contrast analysis revealed that number of fungicide applications influenced plant height in 2005, but not in 2004 (Table 3.6). Plants that received four fungicide applications were slightly taller than the plants which received only one fungicide application (Table 3.7). None of the components of the treatments influenced the number of pods per plant in either 2004 or 2005 (Tables 3.8 and 3.9).

Seeding rate significantly influenced the number of seeds per plant in 2005, but not in 2004 (Table 3.10). Number of seeds per plants was slightly higher in treatments with 31 plants / m^2 rate, compared to treatments with 44 plants / m^2 (Table 3.11). Linear contrast analyses (Table 3.12) revealed that the average number of seeds per pod was significantly higher for treatments receiving four fungicide applications than one application (Table 3.13).

Table 3.6 Linear contrasts of effect of treatments on plant height of chickpea cultivar Amit at Swift Current in 2004 and 2005

		2004		2005	
Source	**DF**	**F Value**	**Pr > F**	**F Value**	**Pr > F**
No. of fungicide applications: 1 vs. 4 applications	1	0.18	0.6782	7.59	0.0119
Fungicide rate: 1X vs. 0.67X with 4 applications	1	0.10	0.7602	0.24	0.6277
Seeding pattern: solid vs. paired with 1 X fungicide rate	1	0.52	0.4785	0.02	0.8895
Seeding rate : 44 vs. 31 seeds m^{-2} with 0.67X fungicide rate	1	1.17	0.2914	0.71	0.4083

Table 3.7 Effect of treatments on the plant height (cm) of two chickpea cultivars (CDC Xena and Amit) at Swift Current, 2004 and 2005.

Treatments	Plant population m^{-2}	Seeding pattern	No. of fungicide applications	Fungicide rate	Amit		CDC Xena	
					2004[Z]	2005[Z]	2004[Z]	2005[Z]
1	44	Solid	1	1 X	48 a	52 b	43 a	50 abc
2	44	Paired	1	1X	54 a	54 ab	48 a	51 ab
3	44	Paired	1	0.67 X	50 a	51 b	46 a	51 ab
4	31	Paired	1	0.67 X	56 a	54 ab	47 a	53 a
5	44	Solid	4	1X	51 a	51 b	47 a	47 bc
6	44	Paired	4	1X	52 a	55 a	46 a	45 c
7	44	Paired	4	0.67 X	48 a	54 ab	46 a	47 bc
8	31	Paired	4	0.67 X	53 a	53 ab	50 a	48 abc

[Z] Means within a column followed by the same letters do not significantly differ at $P \leq 0.05$.

Table 3.8 Linear contrasts of effect of treatments on number of pods per plant of chickpea cultivar Amit at Swift Current in 2004 and 2005

		2004		2005	
Source	**DF**	**F Value**	**Pr > F**	**F Value**	**Pr > F**
No. of fungicide applications: 1 vs. 4 applications	1	0.16	0.5165	0.12	0.4048
Fungicide rate: 1X vs. 0.67X with 4 applications	1	0.72	0.9546	0.27	0.7529
Seeding pattern: solid vs. paired with 1 X fungicide rate	1	0.00	0.3596	1.3	0.7811
Seeding rate : 44 vs. 31 seeds m^{-2} with 0.67X fungicide rate	1	0.13	0.3008	0.81	0.0845

Table 3.9 Effect of treatments on the number of pods per plant of two chickpea cultivars (CDC Xena and Amit) at Swift Current, 2004 and 2005.

Treatments	Plant population m^{-2}	Seeding pattern	No. of fungicide applications	Fungicide rate	Amit		CDC Xena	
					2004[Z]	2005[Z]	2004[Z]	2005[Z]
1	44	Solid	1	1 X	42 ab	19 a	22 a	16 a
2	44	Paired	1	1X	45 ab	20 a	9 cd	19 a
3	44	Paired	1	0.67 X	32 b	19 a	18 a	24 a
4	31	Paired	1	0.67 X	38 ab	23 a	18 ab	22 a
5	44	Solid	4	1X	36 ab	25 a	8 d	21 a
6	44	Paired	4	1X	32 b	16 a	10 cd	25 a
7	44	Paired	4	0.67 X	41 ab	21 a	17 ab	21 a
8	31	Paired	4	0.67 X	48 ab	23 a	14 bc	21 a

[Z] Means within a column followed by the same letters do not significantly differ at $P \leq 0.05$.

Table 3.10 Linear contrasts of effect of treatments on number of seeds per plant of chickpea cultivar Amit at Swift Current in 2004 and 2005

		2004		2005	
Source	**DF**	**F Value**	**Pr > F**	**F Value**	**Pr > F**
No. of fungicide applications: 1 vs. 4 applications	1	0.09	0.7917	0.35	0.3628
Fungicide rate: 1X vs. 0.67X with 4 applications	1	2.15	0.8922	0.10	0.5851
Seeding pattern: solid vs. paired with 1 X fungicide rate	1	0.13	0.2404	0.61	0.6694
Seeding rate : 44 vs. 31 seeds m^{-2} with 0.67X fungicide rate	1	0.17	0.5001	0.73	0.0414

Table 3.11 Effect of treatments on the number of seeds per plant of two chickpea cultivars (CDC Xena and Amit) at Swift Current, 2004 and 2005.

Treatments	Plant population m^{-2}	Seeding pattern	No. of fungicide applications	Fungicide rate	Amit		CDC Xena	
					2004[Z]	2005[Z]	2004[Z]	2005[Z]
1	44	Solid	1	1 X	55 ab	20 a	16 a	15 b
2	44	Paired	1	1X	43 ab	25 a	1 b	22 ab
3	44	Paired	1	0.67 X	41 ab	18 a	16 a	28 ab
4	31	Paired	1	0.67 X	49 ab	28 a	15 a	24 ab
5	44	Solid	4	1X	36 b	29 a	0 b	24 ab
6	44	Paired	4	1X	38 b	15 a	1 b	30 a
7	44	Paired	4	0.67 X	73 a	26 a	11 a	26 ab
8	31	Paired	4	0.67 X	56 ab	25 a	4 b	19 ab

[Z] Means within a column followed by the same letters do not significantly differ at $P \leq 0.05$.

Table 3.12 Linear contrasts of effect of treatments on average number of seeds per pod of chickpea cultivar Amit at Swift Current in 2004 and 2005

		2004		2005	
Source	**DF**	**F Value**	**Pr > F**	**F Value**	**Pr > F**
No. of fungicide applications: 1 vs. 4 applications	1	12.78	0.0023	1.24	0.6843
Fungicide rate: 1X vs. 0.67X with 4 applications	1	0.90	0.3549	0.03	0.2459
Seeding pattern: solid vs. paired with 1 X fungicide rate	1	0.48	0.4989	0.07	0.557
Seeding rate : 44 vs. 31 seeds m^{-2} with 0.67X fungicide rate	1	2.70	0.1188	0.34	0.0957

Table 3.13 Effect of treatments on the average number of seeds per pod of two chickpea cultivars (CDC Xena and Amit) at Swift Current, 2004 and 2005.

Treatments	Plant population m^{-2}	Seeding pattern	No. of fungicide applications	Fungicide rate	Amit		CDC Xena	
					2004[Z]	2005[Z]	2004[Z]	2005[Z]
1	44	Solid	1	1 X	1.2 ab	0.9 ab	0.2 b	1.0 bc
2	44	Paired	1	1X	1.1 bc	1.2 ab	0.1 b	1.1 abc
3	44	Paired	1	0.67 X	1.2 ab	0.9 b	0.1 b	1.2 ab
4	31	Paired	1	0.67 X	1.0 c	1.2 ab	0.1 b	1.1 abc
5	44	Solid	4	1X	1.3 a	1.1 ab	0.6 a	1.1 abc
6	44	Paired	4	1X	1.3 a	0.9 ab	0.8 a	1.2 ab
7	44	Paired	4	0.67 X	1.3 a	1.2 a	0.8 a	1.2 a
8	31	Paired	4	0.67 X	1.3 a	1.0 ab	0.7 a	0.9 c

[Z] Means within a column followed by the same letters do not significantly differ at $P \leq 0.05$.

3.3.3.2 CDC Xena

Analysis of variance revealed that treatments had a significant impact on number of pods per plant, number of seeds per plant and average number of seeds per pod in either 2004 or 2005. In 2004, numbers of fungicide applications had a significant effect on number of pods per plant (Table 3.15), number of seeds per plant (Table 3.16) and average number of seeds per pod of CDC Xena (Table 3.17). The number of pods per plant under four fungicide applications (16) was greater than at one fungicide application (12) (Table 3.9). Number of seeds per plant under four fungicide applications (4) was lower than at one fungicide application (11) (Table 3.11). Average number of seeds per pod under four fungicide applications (0.7) was significantly higher than at one fungicide application (0.1) (Table 3.13).

In 2005, linear contrast analysis revealed that the number of fungicide applications significantly influenced the plant height of CDC Xena (Table 3.14). Plants were slightly taller in treatments that received one fungicide application (51 cm) than at four fungicide applications (47 cm) (Table 3.7). Number of fungicide applications significantly influenced the number of seeds per plant (Table 3.16) and average number of seeds per pod (Table 3.17). Number of seeds per plant (Table 3.11) and average number of seeds per pod (Table 3.13) were slightly greater for treatments that received four fungicide applications than at one fungicide application. Seeding rates had a significant effect on number of pods per plant (Table 3.15) and number of seeds per plant (Tables 3.16). Number of pods per plant for treatments with 44 plants / m^2 (Table 3.9) and number of seeds per plant for treatments with 44 plants / m^2 (Table 3.11) were greater than at treatments with 31 plants / $m^{2.}$ Linear contrast analysis revealed that fungicide rates had no effect on plant height, number of pods per plant, number of seeds per plant and average number of seeds per pod in either 2004 or 2005 (Tables 3.14, 3.15, 3.16 and 3.17).

Table 3.14 Linear contrasts of effect of treatments on plant height of chickpea cultivar CDC Xena at Swift Current in 2004 and 2005

		2004		2005	
Source	**DF**	**F Value**	**Pr > F**	**F Value**	**Pr > F**
No. of fungicide applications: 1 vs. 4 applications	1	0.18	0.6782	7.59	0.0119
Fungicide rate: 1X vs. 0.67X with 4 applications	1	0.1	0.7602	0.24	0.6277
Seeding pattern: solid vs. paired with 1 X fungicide rate	1	0.52	0.4785	0.02	0.8895
Seeding rate : 44 vs. 31 seeds m^{-2} with 0.67X fungicide rate	1	1.17	0.2914	0.71	0.4083

Table 3.15 Linear contrasts of effect of treatments on number of pods per plant of chickpea cultivar CDC Xena at Swift Current in 2004 and 2005

		2004		2005	
Source	**DF**	**F Value**	**Pr > F**	**F Value**	**Pr > F**
No. of fungicide applications: 1 vs. 4 applications	1	12.76	<.0001	1.13	0.1376
Fungicide rate: 1X vs. 0.67X with 4 applications	1	26.31	0.5359	0	0.6928
Seeding pattern: Solid vs. Paired with 1 X fungicide rate	1	9.9	0.138	1.52	0.5702
Seeding rate : 44 vs. 31 seeds m^{-2} with 0.67X fungicide rate	1	1.92	0.3718	0.11	0.0395

Table 3.16 Linear contrasts of effect of treatments on number of seeds per plant of chickpea cultivar CDC Xena at Swift Current in 2004 and 2005

		2004		2005	
Source	**DF**	**F Value**	**Pr > F**	**F Value**	**Pr > F**
No. of fungicide applications: 1 vs. 4 applications	1	16.56	<.0001	1.54	0.0021
Fungicide rate: 1X vs. 0.67X with 4 applications	1	44.93	0.9786	0.05	0.8604
Seeding pattern: solid vs. paired with 1 X fungicide rate	1	14.07	0.8306	1.81	0.9872
Seeding rate : 44 vs. 31 seeds m^{-2} with 0.67X fungicide rate	1	5.24	0.9786	1.44	0.01

Table 3.17 Linear contrasts of effect of treatments on average number of seeds per pod of chickpea cultivar CDC Xena at Swift Current in 2004 and 2005

		2004		2005	
Source	**DF**	**F Value**	**Pr > F**	**F Value**	**Pr > F**
No. of fungicide applications: 1 vs. 4 applications	1	66.59	<.0001	1.68	0.0009
Fungicide rate: 1X vs. 0.67X with 4 applications	1	0.09	0.769	0.55	0.2935
Seeding pattern: solid vs. paired with 1 X fungicide rate	1	0.15	0.7029	1.78	0.2755
Seeding rate : 44 vs. 31 seeds m^{-2} with 0.67X fungicide rate	1	0.77	0.3892	5.15	0.2935

3.3.4. Effect of treatments on seed yield and kernel weight

3.3.4.1. Amit

Analysis of variance revealed that seed yield of Amit was significantly influenced by the treatments in 2004. Linear contrast analysis revealed that the number of fungicide applications had a significant effect on yield in both years (Table 3.18). Mean seed yield of treatments with four fungicide applications in 2004 (2269 kg ha^{-1}) was significantly higher than at treatments with one fungicide application (1597 kg ha^{-1}). Treatments with four fungicide applications had mean yield of 2054 kg ha^{-1} in 2005, which was significantly higher than at one fungicide application (1969 kg ha^{-1}) (Table 3.19). Seeding patterns, seeding rate and fungicide rates did not affect the yield of Amit in 2004 and 2005 (Tables 3.18 and 3.19).

Analysis of variance indicated that 1000-kernel weight (1000 KWT) of Amit was significantly affected by the treatments in both years. The number of fungicide applications had a significant effect on 1000 KWT of Amit both in 2004 and 2005 (Table 3.20). In 2004, mean 1000 KWT for treatments that received four fungicide applications (221 g) was higher than at one fungicide application (191 g) and in 2005, mean 1000 KWT for treatments which received four fungicide applications (257 g) was higher than at one fungicide application (252 g) (Table 3.21). Fungicide rates and seeding rates did not affect 1000 KWT in either year (Tables.3.20 and 3.21). Seeding patterns had no effect on 1000 KWT in 2004, but in 2005 mean 1000 KWT under solid seeding (245 g) was significantly lower than under paired row planting (258 g) (Tables 3.20 and 3.21).

Table 3.18 Linear contrasts of effect of treatments on seed yield of chickpea cultivar Amit at Swift Current in 2004 and 2005

		2004		2005	
Source	**DF**	**F Value**	**Pr > F**	**F Value**	**Pr > F**
No. of fungicide applications: 1 vs. 4 applications	1	15.48	0.0011	8.51	0.0082
Fungicide rate: 1X vs. 0.67X with 4 applications	1	0.50	0.4904	0.00	0.9698
Seeding pattern: solid vs. paired with 1 X fungicide rate	1	1.35	0.2620	0.34	0.5674
Seeding rate: 44 vs. 31 seeds m^{-2} with 0.67X fungicide rate	1	1.36	0.2590	2.45	0.1324

Table 3.19 Effect of treatments on the yield (kg ha^{-1}) of two chickpea cultivars (CDC Xena and Amit) at two-site years (Swift Current, 2004 and 2005).

					Amit		CDC Xena	
Treatments	**Plant population m^{-2}**	**Seeding pattern**	**No. of fungicide applications**	**Fungicide rate**	**2004[Z]**	**2005[Z]**	**2004[Z]**	**2005[Z]**
1	44	Solid	1	1 X	1966 ab	1976 abc	51 c	446 b
2	44	Paired	1	1X	1303 c	1969 bc	21 c	265 c
3	44	Paired	1	0.67 X	1522 cb	1963 bc	47 c	285 c
4	31	Paired	1	0.67 X	1181 c	1959 bc	22 c	285 c
5	44	Solid	4	1X	2123 ab	2075 a	800 b	1060 a
6	44	Paired	4	1X	2301 a	2040 abc	1356 a	1077 a
7	44	Paired	4	0.67 X	2383 a	2049 ab	1005 ab	1086 a
8	31	Paired	4	0.67 X	2226 a	1941 c	760 b	1149 a

[Z] Means within a column followed by the same letters do not significantly differ at $P \leq 0.05$.

Table 3.20 Linear contrasts of effect of treatments on KWT of chickpea cultivar Amit at Swift Current in 2004 and 2005

		2004		2005	
Source	**DF**	**F Value**	**Pr > F**	**F Value**	**Pr > F**
No. of fungicide applications: 1 vs. 4 applications	1	9.46	0.0069	5.99	0.0233
Fungicide rate: 1X vs. 0.67X with 4 applications	1	0.81	0.3796	1.73	0.2022
Seeding pattern: solid vs. paired with 1 X fungicide rate	1	0.08	0.7842	23.6	<.0001
Seeding rate : 44 vs. 31 seeds m^{-2} with 0.67X fungicide rate	1	0.27	0.6115	2.82	0.1078

Table 3.21 Effect of treatments on the 1000 KWT (g) of two chickpea cultivars (CDC Xena and Amit) at two-site years (Swift Current, 2004 and 2005).

Treatments	Plant population m^{-2}	Seeding pattern	No. of fungicide applications	Fungicide rate	Amit		CDC Xena	
					2004[Z]	2005[Z]	2004[Z]	2005[Z]
1	44	Solid	1	1 X	196 abc	241 d	109 c	266 b
2	44	Paired	1	1X	183 c	254 bc	93 c	208 bc
3	44	Paired	1	0.67 X	195 bc	260 ab	107 c	182 c
4	31	Paired	1	0.67 X	183 c	264 a	90 c	192 c
5	44	Solid	4	1X	208 abc	248 cd	278 b	375 a
6	44	Paired	4	1X	222 ab	261 ab	370 a	389 a
7	44	Paired	4	0.67 X	232 a	263 a	327 ab	425 a
8	31	Paired	4	0.67 X	232 a	268 a	274 b	416 a

[Z] Means within a column followed by the same letters do not significantly differ at $P \leq 0.05$.

3.3.4.2 CDC Xena

Seed yield of CDC Xena was significantly influenced by the treatments in both 2004 and 2005 as revealed by analysis of variance. Linear contrast analysis indicated that number of fungicide applications had a significant effect on yield in both 2004 and 2005 (Table 3.22). In 2004, mean yield for treatments that received four fungicide applications (1054 kg ha^{-1}) was, significantly higher than at one fungicide application (40 kg ha^{-1}) (Tables 3.19). Similarly in 2005, mean yield for treatments that received four fungicide applications (1074 kg ha^{-1}) was significantly higher than at received one fungicide application (332 kg ha^{-1}) (Tables 3.19). Seeding patterns, seeding rate and fungicide rate did not influence the seed yield of CDC Xena in either 2004 or 2005 (Tables 3.19 and 3.22).

Treatments had a significant effect on kernel weight in both years. The number of fungicide applications had a significant effect on the 1000 KWT in both 2004 and 2005 (Tables 3.21 and 3.23). In 2004, mean 1000 KWT under four applications (325 g) was significantly greater than at one application (103 g). Similarly in 2005, mean 1000 KWT under four applications (396 g) was significantly greater than at one application (219 g) (Tables 3.21 and 3.23). Seeding pattern, seeding rate and fungicide rate had no effect on 1000 KWT in either years (Tables 3.21 and 3.23).

Table 3.22 Linear contrasts of effect of treatments on seed yield of chickpea cultivar CDC Xena at Swift Current in 2004 and 2005

		2004		2005	
Source	**DF**	**F Value**	**Pr > F**	**F Value**	**Pr > F**
No. of fungicide applications: 1 vs. 4 applications	1	81.91	<.0001	306.53	<.0001
Fungicide rate: 1X vs. 0.67X with 4 applications	1	1.40	0.6061	0.08	0.8235
Seeding pattern: solid vs. paired with 1 X fungicide rate	1	3.67	0.1845	2.50	0.3289
Seeding rate : 44 vs. 31 seeds m^{-2} with 0.67X fungicide rate	1	0.97	0.2154	0.38	0.9644

Table 3.23 Linear contrasts of effect of treatments on 1000 KWT (g) of chickpea cultivar CDC Xena at Swift Current in 2004 and 2005

		2004		2005	
Source	**DF**	**F Value**	**Pr > F**	**F Value**	**Pr > F**
No. of fungicide applications: 1 vs. 4 applications	1	96.02	<.0001	97.11	0.0004
Fungicide rate: 1X vs. 0.67X with 4 applications	1	0.27	0.5958	0.05	0.9259
Seeding pattern: solid vs. paired with 1 X fungicide rate	1	1.88	0.1604	1.00	0.0014
Seeding rate : 44 vs. 31 seeds m^{-2} with 0.67X fungicide rate	1	1.63	0.4796	0.00	0.5211

3.3.4. Economic assessment of fungicide usage and seeding rate

Fungicide rates and seeding rates did not influence AB severity on either cultivar in 2004 or 2005. The difference in the gross returns, after deducting the fungicide application cost and seeding cost, between the treatments was used to determine the economics (Table 3.24). The estimated unit price of each fungicide and seed price was taken from the Alberta Agriculture, Food and Rural Development website. Mean fungicide application cost for treatments that received one application of Headline was $ 44/ ha, and mean cost for four applications of fungicide (sequence: Headline, Bravo, Headline, Bravo) was $ 166/ha. Seed cost of CDC Xena was $0.75 per kg and for Amit it was $ 0.54 per kg of seed.

After subtracting the fungicide application cost and seed cost from the gross returns, the additional revenue associated with the three extra fungicide applications to Amit was
$ 143/ha in 2004 and $ - 23/ha in 2005 (Table 3.24). The additional revenue associated with the three extra fungicide applications to CDC Xena was $ 408/ha in 2004 and $ 376/ ha in 2005 (Table 3.24). The returns from the treatments with 44 plants m^{-2} were not higher than with 31 plants m^{-2}. Returns from Amit were higher than CDC Xena in both years and under both one and four fungicide applications. However, the returns due to additional fungicide applications were much more for CDC Xena.

Table 3.24 Economic assessments of fungicide application and seeding rate on returns from chickpea cultivars Amit and CDC Xena at Swift Current in 2004 and 2005.

	Seeding		Fungicide application				Amit-2004		Amit -2005		CDC Xena	CDC Xena-2004		CDC Xena-2005	
S. No	Plants /m^2	Pattern	No.	Rate	Fungicide Cost ($/ha)	Amit Seeding cost [b] ($/ha)	Yield [a] (Kg/ha)	Returns[1] ($/ha)	Yield [a] (Kg/ha)	Returns[1] ($/ha)	Seeding Cost [b] ($/ha)	Yield [a] (Kg/ha)	Returns[1] ($/ha)	Yield [a] (Kg/ha)	Returns[1] ($/ha)
1	44	Solid	1	1 X	48	58	1966	523	1976	555	177	51	-197	446	44
2	44	Paired	1	1X	34	58	1303	324	1969	558	177	21	-200	265	-48
3	44	Paired	1	0.67 X	34	58	1522	394	1963	556	177	47	-186	285	-37
4	31	Paired	1	0.67 X	34	39	1181	304	1959	574	123	22	-145	285	17
5	44	Solid	4	1X	177	58	2123	444	2075	534	177	800	78	1060	324
6	44	Paired	4	1X	128	58	2301	550	2040	543	177	1356	427	1077	353
7	44	Paired	4	0.67 X	128	58	2383	576	2049	546	177	1005	238	1086	358
8	31	Paired	4	0.67 X	128	39	2226	545	1941	530	123	760	160	1149	446

[1]. Returns = Gross returns − (fungicide + seed cost)
a) Grain cost of Amit = $ 0.32/ kg and cost of CDC Xena = $ 0.54/ kg ; Note: Grade of the grains was not taken into consideration for this assessment. b) Seed cost of Amit = $ 0.52/ kg and cost of CDC Xena = $0.75/ kg. Application cost of fungicide including machinery rental, fuel, labour charge and depreciation is $ 7.00 ha^{-1}

Headline application rate ($/ ha)

1X rate (0.40 L/ ha) = $ 41.00 (fungicide cost) + $ 7.00/ ha (application charges) = $ 48.00/ ha
0.67X rate (0.27 L / ha) = $ 28.00 (fungicide cost) + $ 7.00/ ha (application charges) = $ 34.00/ ha

Bravo application rate ($/ha)

1X rate 3 L/ ha = $ 34.00 (fungicide cost) + $ 7.00/ ha (application charges) = $ 41.00/ ha; 0.67 X rate 2 L/ ha = $ 29.00 (fungicide cost) + $ 7.00 (application charges) = $ 36.00/ ha.

3.3.5. Correlation analysis among ascochyta blight severity, yield and development parameters of chickpea

3.3.5.1. Amit

Correlation analysis revealed that in 2004, both AB severity and plant height were negatively correlated with yield, 1000 KWT and average number of seeds per pod (Table 3.25). Average number of seeds per pod was positively correlated with yield and 1000 KWT (Table 3.25).

In 2005, AB severity and average number of seeds per pod were negatively correlated (Table 3.25). Number of pods per plant and yield were negative correlated (Table 3.25). Number of pods per plant, number of seeds per plant and average number of seeds per pod were positively correlated with each other (Table 3.25).

3.3.5.2. CDC Xena

Disease severity was negatively correlated with yield and 1000 KWT in both 2004 and 2005 and with average number of seeds per pod in 2005 (Table 3.26). Yield and 1000 KWT were positively correlated in both years. Number of seeds per plant was negatively correlated with yield and 1000 KWT in 2004. Number of pods per plant had significantly positive correlation with number of seeds per plant in both years. Plant height, average number of seeds per pod, number of pods per plant and number of seeds per plant were positively correlated in 2005 (Table 3.26).

Table 3.25 Pearson's correlation coefficients(*r*) among various response variables of chickpea cv. Amit at Swift Current in 2004 and 2005

	Yield		1000 KWT		PTHT		Pod/pl		Seed/pl		Avseed	
Response variable	**2004**	**2005**	**2004**	**2005**	**2004**	**2005**	**2004**	**2005**	**2004**	**2005**	**2004**	**2005**
AUDPC	-0.68**	0	-0.59*	-0.16	0.59	-0.12	-0.02	-0.24	0.04	-0.30	-0.63*	-0.39*
Yield	-	-	0.75**	-0.045	-0.55*	0.14	0.03	-0.40*	0.05	-0.38*	0.78**	-0.23
1000 KWT			-	-	-0.54*	0.30	0.07	-0.04	0.10	-0.02	0.73**	0.01
PTHT (cm)					-	-	-0.15	-0.05	-0.18	0.02	-0.42*	0.15
Pod/pl							-	-	0.96**	0.98**	0.01	0.76**
Seed/pl									-	-	0.01	0.87**

*, ** Significant at $P < 0.05$ and $P < 0.01$, respectively;
Avseed - Average no. of seed(s) per pod
AUDPC - Area under disease progress curve
Yield - Seed yield (kg/ha)
1000 KWT - Thousand seed weight (g)
PTHT - Plant height (cm)
Pod/pl - No. of pods per plant
Seed/pl - No. of seeds per plant

Table 3.26 Pearson's correlation coefficients among various response variables of chickpea cv. CDC Xena at Swift Current in 2004 and 2005

	Yield		1000 KWT		PTHT		Pod/pl		Seed/pl		Avseed	
Response variables	**2004**	**2005**	**2004**	**2005**	**2004**	**2005**	**2004**	**2005**	**2004**	**2005**	**2004**	**2005**
AUDPC	-0.94**	-0.44*	-0.94**	-0.43*	0.05	0.32	0.35*	-0.01	0.46*	-0.01	-0.93**	-0.10
Yield	-	-	0.98**	0.94**	-0.21	-0.47*	-0.32	0.07	-0.43*	0.03	0.91**	-0.06
1000 KWT			-	-	-0.22	-0.39*	-0.31	-0.04	-0.40*	-0.01	0.95**	-0.05
PTHT (cm)					-	-	-0.19	-0.10	-0.22	-0.14	-0.21	-0.10
Pod/pl							-	-	0.86**	0.95**	-0.22	0.56*
Seed/pl									-	-	-0.35*	0.77**

*, ** Significant at $P < 0.05$ and $P < 0.01$, respectively;
Avseed - Average no. of seed(s) per pod
AUDPC - Area under disease progress curve
Yield - Seed yield (kg/ha)
1000 KWT - Thousand seed weight (g)
PTHT - Plant height (cm)
Pod/pl - No. of pods per plant
Seed/pl - No. of seeds per plant

3. 4. Discussion

Breeding efforts to develop cultivars with improved levels of resistance to AB, and with locally adapted agronomic traits have been in progress since the introduction of chickpea in western Canada in the 1990s. However, managing AB is dependent on fungicides regardless of the level of genetic resistance. Some of the alternative management options that were evaluated in this experiment were effective in reducing AB severity and improving fungicide efficacy, with some differential responses between the susceptible and moderately resistant varieties.

Weather conditions, including growing season rainfall and mean air temperature, influence the development of disease epidemics (Shtienberg et al., 2000, Trapero-Casas and Kaiser, 1992b). The results of this experiment supported these findings, in that ascochyta blight severity in 2004 was relatively higher than in 2005, associated with wetter, cooler conditions in 2004 compared to 2005 (Table 3.2). Mean air temperature for the growing season (May - Sep.) in 2004 was 13.3 °C and 2005 was 14.4 °C. Both Amit and CDC Xena had relatively higher disease severity in 2004 than in 2005. Conversely, both Amit and CDC Xena yielded more in 2005.

A change in the crop canopy micro-environment may affect disease development. A crop canopy that is open could allow the foliage and topsoil to dry, which is unfavourable for pathogen development. However, paired row planting, one of the components of the treatments, did not affect AB severity, yield, kernel weight, or plant growth parameters, with only a few exceptions.

In previous studies, under the semiarid growing conditions like those in this experiment, severity of AB was lower on chickpea with fern leaf type than chickpea with unifoliate leaf type (Gan et al., 2003b, Chongo et al., 2002). The response of the two cultivars Amit and CDC Xena to the treatments were significantly different, which is not unexpected as the resistance level of Amit was higher than that of CDC Xena. The response by CDC Xena to the paired row planting was greater in 2005

than in 2004. CDC Xena had significantly lower AB severity under paired row planting in 2005. Although paired row planting appeared advantageous in a moderate epidemic year like 2005, AB severity was greater in 2004 and the effect of paired row planting may have been overwhelmed.

In the paired row planting arrangement, the inter-row spacing was wide (75 cm) and intra row spacing was narrower (25 cm). The intra-row spacing in paired row planting was similar to that of solid seeding. Hence, even under paired row planting, rain splashing might have played a vital role in spreading the disease further. Amit being a fern leaf cultivar with relatively dense foliage, did not show a significant response to the alterations in planting arrangements in terms of AB severity, yield and growth parameters in either year, except 1000 KWT and plant height in 2005. Sweetingham et al. (1993) found that in lupins, wider intra-row spacing minimized the spread of spores through rain splash and also provided more light interception.

Plant population per unit area is an important factor affecting crop yield. Higher populations might increase the disease severity, increase competition among plants, and reduce yield. Also high relative humidity resulting from higher plant population and a favourable temperature can increase AB severity on chickpea (Jettner et al., 1999, Siddique et al., 1998). For both leaf types and over both years, severity of AB was not affected by the plant population density. Gan et al. (2003c) also found that plant population density did not affect the AB severity in chickpea. The recommended seeding rate for chickpea in the prairies is 44 plants m^{-2}, but the reduction in seeding rate to 70 % (31 plants m^{-2}) did not adversely affect AB severity, yield, and growth parameters for either cultivar in both years. The number of seeds per plant of Amit was higher when planted at the reduced seeding rate. The number of seeds per plant of CDC Xena was significantly lower when planted at the reduced seeding rate compared to 44 plants m^{-2}. In a previous study, AB severity of unifoliate cultivars was higher at low plant population densities (Gan et al., 2003c). This may reduce the seeds per plant of CDC Xena under lower plant density. In

summary, a reduction of 30 % of the seed could save 30 % of the seed cost to the growers.

Protectant application of fungicides and post-infection application of fungicides have been shown to reduce AB severity under epidemic conditions. Under high disease pressure, two sprays of chlorothalonil or strobilurins were required alone or in sequence to control AB in chickpea (Chongo et al., 2003). Time of application of fungicide and frequency of the fungicide application had a major impact on disease control. Applying fungicides not only reduced the AB severity, but also helped produce higher yields. In the current study under cool, moist conditions in 2004, four applications of fungicides starting before flowering reduced AB severity more than a single application prior to flowering. The response of the moderately resistant cultivar Amit to the four fungicide applications was less than the response of the highly susceptible cultivar CDC Xena in both years. In a moderate epidemic year like 2005, the effect of four applications on AB severity on Amit was not superior to one application. CDC Xena plots receiving only a single fungicide application had 1000-kernel weight only one third that of treatments receiving four fungicide applications. Also, treatments that received only one application produced seeds that were shriveled and reduced in size. The other plant growth and development parameters of CDC Xena such as number of pods per plant, number of seeds per pod and average seeds per seed were also affected by the additional fungicide applications.

Application of Headline (pyraclostrobin) before flowering coupled with genetic resistance of cultivars, could inhibit spore germination of *A. rabiei* and reduce disease spread. However, under severe epidemic conditions, multiple applications are needed even if the cultivar has moderate resistance. Decline of resistance after flowering in chickpea cultivars as observed by Chongo and Gossen (2001) could play an important role in deciding the time of fungicide application.

In the current study, the three additional fungicide applications after flowering reduced AB severity and yield loss in CDC Xena. Fungicide application during the pod filling stage could reduce seed borne infection and seed discoloration. This was evident from the results that average number of seeds per pod was higher when fungicides were applied four times during the season. It is also important to prevent the seed to seedling spread of ascochyta (Kaiser, 1972; Morrall and McKenzie 1974). Controlling a pathogen by arresting its growth at only one of the stages of the life cycle of the pathogen would be less efficient.

In the wet season (2004), the moderately resistant cultivar Amit produced greater returns with four applications. But the returns for Amit with one fungicide application was greater than with four applications in a moderate epidemic season (2005). With four applications, returns for CDC Xena were good in both seasons. With only one fungicide application, returns for CDC Xena were negative in 2004. It is important to note that the difference in the additional returns between Amit and CDC Xena are due to the prevailing market prices for the seed. CDC Xena, being a large-seeded kabuli, generally fetches a premium price in domestic and international markets compared to Amit.

Reducing fungicide rate to 2/3 (0.67 X) of the recommended (1X) rate did not affect efficacy in 2004 or 2005. Both cultivars developed similar levels of AB severity under 1X and 0.67X rates. Similarly, yield, 1000 KWT and plant growth and development parameters for the two cultivars were not affected by fungicide rates in either year. Even under severe epidemic conditions (2004), the two rates of fungicide application had similar effect on disease control. Cost of fungicides could be reduced by adopting the reduced rates without significant reduction in the yield.

From this study, it can be concluded that managing AB in chickpea and obtaining economical yield is possible through the integration of genetic resistance, cultural tools and fungicide applications. Timely application of fungicides at appropriate stages of growth, especially during pod filling, could minimize yield loss. In

addition, reduced fungicide rate and reduced seeding rate can be considered to reduce the cost of chickpea production.

4.0 Organ-specific reaction to ascochyta blight in chickpea under semi-arid conditions

4.1. Introduction

Chickpea (*Cicer arietinum* L) is well adapted to the Brown and Dark Brown soil zones of western Canada in rotation with cereal crops. Since the introduction of chickpea to western Canada in the mid 1990s, Saskatchewan reached a prime position in the chickpea export market, and more revenues were generated for growers and processors. The world export of chickpea over the period of 1996 - 2003 was 0.5 to 1.0 million MT, and Canadian exports of chickpea ranged from 6000 to 150,000 MT during the same period (Food and Agricultural Organization of the United Nations, 2005 and Saskatchewan Agriculture and Food, 2005). Ascochyta blight (AB) and late maturity are the two major constraints that reduced the chickpea seeded area and production in western Canada after 2001.

AB, a foliar disease caused by *Ascochyta rabiei* (Pass.) Labrousse, is the major constraint limiting chickpea productivity worldwide. This disease occurs in almost all the chickpea growing areas of the world. The build-up of inoculum in areas with intensive production of chickpea or with short crop rotations has contributed to the severity of epidemics. AB reduces chickpea seed yield and quality, and yield losses in susceptible cultivars can be as high as 100%.

Producers in western Canada rely heavily on fungicides to manage AB in chickpea. Normally 2-5 applications are needed during the growing season, which can make production uneconomical and cause environmental concerns. Planting resistant cultivars is an important alternative tool to manage AB and maintain sustainability of production. The disease reaction of current chickpea cultivars in western Canada

ranges from partially resistant to highly susceptible and no cultivar is totally resistant (Chongo et al., 2004). Airborne ascospores play an important role in dispersal of the pathogen and make disease control difficult (Armstrong et al., 2001). Chongo and Gossen (2001) reported that expression of partial resistance declines at flowering. Progress has been made by several breeding institutions including ICRISAT (India), ICARDA (Syria), USDA (USA) and Crop Development Centre, University of Saskatchewan (Canada) in developing chickpea cultivars that have improved levels of resistance to AB and that are adapted to the local growing conditions.

Defense responses in plants are expressed through a complex array of locally and systemically acquired events that are regulated depending upon the stress (Maleck and Dietrich, 1999). Chickpea cultivars resistant to AB show a hypersensitive reaction such as accumulation of auto-fluorescent spots on the leaflets (Hohl et al., 1990). Pre-formed structures such as trichomes, and the glandular exudates from the trichomes can have a small impact on AB resistance (Armstrong and Gossen, 2005). The formation of these resistant structures and other resistance associated processes are regulated by specific genes.

Organ-specific reaction to disease has been reported previously in many studies. *Arabidopsis thaliana* genes were expressed in a tissue-specific fashion genetically or expressed differentially in various plant organs (Somerville, 1989). Genes involved in defense-related processes such as leaf abscission and trichome development have shown leaf-specific expression. Similarly, some genes that encode for cell wall proteins are expressed predominantly in stems (reviewed in Edwards and Coruzzi, 1990). Genes encoding glycine-rich cell wall proteins (GRPs) were associated with defense against pathogens and were expressed specifically in cell walls in bean (Keller et al., 1989). Certain protease inhibitors protecting plants from insect attack were also expressed specifically in seeds (Hilder et al., 1987). Resistance to *Ascochyta fabae*, the causal agent of ascochyta blight on faba bean (*Vicia fabae*), is under different genetic control on leaves and stems (Rashid et al., 1991; Kohpina et al., 2000). Out of the six QTLs for resistance to AB detected in faba bean, four of

them were found to be effective in both leaves and stems; one of the two QTLs remaining was effective only in leaves, and the other was effective only in stems (Avila et al., 2004).

Organ-specific gene expression in response to *A. rabiei* in chickpea has not been reported. However, such organ-specific reactions, if present, would be of interest for breeders to identify sources of AB resistance for future crop improvement. Also, knowledge about organ-specific reaction will be useful for development of management strategies, such as selection of the best time to apply fungicides. Screening for organ- specific resistance in chickpea to AB at the field level is the primary step towards identifying sources of resistance in specific organs. However, in field screening trials, it is possible that the plants are simultaneously affected by other pathogens and pests. Environmental conditions influence development of ascochyta blight. Evaluation of plants in a controlled environment to observe organ-specific reaction to AB might reduce the environmental effects and infestation of other pathogens.

Thus, the objectives of this project were:

i) To assess organ-specific reaction to AB in chickpea on leaves, stems and pods of 12 desi and 12 kabuli varieties selected because they are of economic significance to western Canada, and

ii) To assess organ-specific reaction to AB in four kabuli chickpea varieties on leaves and stems in a controlled environment.

4.2 Materials and Methods

4.2.1 Field conditions

4.2.1.1 Chickpea varieties

Twelve desi and 12 kabuli chickpea cultivars and advanced breeding lines (all referred to as 'varieties' hereafter) of the 2004 Saskatchewan regional variety trials

were evaluated for their reaction to AB on leaves, stems and pods. The characteristics of the 12 desi and 12 kabuli varieties are presented (Tables 4.1).

Table 4.1 Kabuli and desi chickpea varieties evaluated for organ-specific reaction at Shaunavon and Swift Current in 2004 and 2005

Variety	Source	Leaf type	1000 Seed weight (g)
Kabuli Varieties			
242-1	CDC [1]	Unifoliate	340
97-Indian-112	CDC	Fern	380
Amit	Terramax Inc [2]	Fern	250
CDC Frontier	CDC	Fern	350
CDC Xena	CDC	Unifoliate	460
FLIP 97-133C	ICARDA [3]	Fern	370
FLIP 97-45C	ICARDA	Fern	370
FLIP 98-133C	ICARDA	Fern	320
FLIP 98-134C	ICARDA	Fern	400
FLIP 98-135C	ICARDA	Fern	430
FLIP 98-136C	ICARDA	Fern	290
Sanford	USDA[4]	Unifoliate	410
Desi varieties			
ICC-12512-9	ICRISAT[5]	Fern	260
CDC Anna	CDC	Fern	190
304T-7	CDC	Fern	230
363T-13	CDC	Fern	210
304-22	CDC	Fern	210
Myles	USDA	Fern	180
304-40	CDC	Fern	210
316B-42	CDC	Fern	200
296T-7	CDC	Fern	190
CDC Cabri	CDC	Fern	290
ICC 12512-1	ICRISAT	Fern	240
294T-16	CDC	Fern	200

[1] Crop Development Centre, University of Saskatchewan, Canada

[2] Terramax Inc- Regina, SK Canada

[3] International Center for Agricultural Research in the Dry Areas, Aleppo, Syria

[4] Unites States Department of Agriculture, United States of America

[5] International Crop Research Institute for the Semi-Arid Tropics, Patancheru, India

4.2.1.2 Trial establishment and design

Desi and kabuli chickpea varieties were evaluated in separate trials at four site-years in south-western Saskatchewan. The sites were Swift Current in 2004 and 2005, and Shaunavon in 2004 and 2005. At all of the site-years, the seed bed was fallow. The size of the plots was 1.2 m x 3.6 m. Fertilizer (11-51-0) was broadcast before seeding at 33 kg ha^{-1}, then incorporated and harrow packed at Swift Current based on soil test recommendations. Due to sufficient nutrients at Shaunavon, no fertilizers were applied. Nitragin ® GC culture, *Rhizobium* inoculant was applied in the seed row with the seed at the rate of 5.6 kg ha^{-1} at all four site- years. The dates of sowing were May 10 and May 13 at Shaunavon in 2004 and 2005 respectively. The dates of sowing were May 8 and May 9 at Swift Current in 2004 and 2005, respectively. Both desi and kabuli varieties were sown on the same dates. A split-plot design was used in each experiment with fungicide regimes as main plots and varieties as sub plots.

4.2.1.3 Crop management

Weed and disease management practices that were followed in this experiment were described in Table 4.2. Experiences from previous years of chickpea cultivation in Saskatchewan showed that ascochyta blight severity could be very high without fungicide application. Hence, it was decided not to include control treatments without fungicide. Two different fungicide application regimes were used. One application of Bravo® (a.i. chlorothalanil) was applied to both kabuli and desi trials as the "low fungicide regime" treatment at the late vegetative stage. For desi trials, Bravo® and Quadris® (a.i. azoxystrobin) fungicides applications were applied as the "high fungicide regime" treatment before flowering and early flowering, respectively. For kabuli trials, Bravo-® , Quadris® and Headline® (a.i.pyraclostrobin) fungicides were applied to kabuli trials as the "high fungicide regime" treatment before flowering, early flowering and late flowering, respectively.

Table 4.2 Crop management practices followed for both kabuli and desi trials

Crop Management	Shaunavon 2004		Shaunavon 2005		Swift Current 2004		Swift Current 2005	
	Date	Product and rate	Date	Product and rate	Date	Product and rate	Date	Product and rate
Weed management								
Pre-seeding herbicide	21-Apr	Edge at 17 kg/ha	4-May	Roundup Weathermax at 0.8 L/ha	26-Apr	Edge at 17 kg/ha	19-Apr	Edge at 17 kg/ha
			12-May	Edge at 17 kg/ha	20-May	Roundup Weathermax at 0.8 L/ ha		
					20-May	Pursuit at 30 ml/ha		
Post-emergence	4-Jun	Select at 198 ml/ha	20-May	Roundup	9-Jun	Sencor at 296 ml/ha	19-May	Roundup
	23-Jun	Poast Ultra at 469 ml/ha	27-Jun	Poast Ultra 469 ml/ha			22-Jun	Poast Ultra at 469 ml/ha
Disease management								
Low fungicide regime (Desi and kabuli)	12-Jul	Bravo at 4.0 L/ha	14-Jul	Bravo at 4.0 L/ha	16-Jul	Bravo at 4.0 L/ha	14-Jul	Bravo at 4.0 L/ha
High fungicide regime (Desi and kabuli)	22-Jul	Quadris at 0.5 L/ha	18-Jul	Quadris at 0.5 L/ha	24-Jul	Quadris at 0.5 L/ha	18-Jul	Quadris 0.5 L/ha
High fungicide regime (Kabuli only)	21-Apr	Headline 0.4 L /ha	4-Aug	Headline at 0.4 L/ha	5-Aug	Headline at 0.4 L/ha	5-Aug	Headline 0.4 L/ha

4.2.1.5 Disease evaluation and data collection

Ascochyta blight rating was carried out through visual observation using the Horsfall- Barratt scale (0-11) (Horsfall and Barratt, 1945) on leaves and stems. The Tivoli scale (0-5) (Tivoli, 1994) was used to rate disease on pods. Five plants in the middle two rows of each plot were randomly selected for disease ratings. Disease rating was initiated after the first appearance of disease symptoms. Four disease ratings were carried out at 15 day intervals. Yield and 1000 seed weight were also measured.

4.2.1.6 Statistical analyses

Disease ratings on leaves and stems were converted to percentage values as described by the Horsfall-Barratt scale. Pod ratings were used as score values. Leaf disease ratings were used to calculate the Leaf Area Under the Disease Progress Curve (LAUDPC) using the formula below.

$$AUDPC = \Sigma_i^{n-1} (y_i + y_{i+1})/2) (t_{i+1} - t_i) \qquad (Eq.\ 1)$$

where y_i is the percent severity observed for the i_{th} observation, t_i is the date of the observation and observations were made on n dates (Shanner and Finney, 1977).

Similarly, stem disease ratings were used to calculate the Stem Area Under the Disease Progress Curve (SAUDPC) using the same formula (Eq.1). Mean of the pod disease ratings (0-5 scale) were used as POD. LAUDPC, SAUDPC, POD, seed yield (YIELD) and 1000-seed weight (KWT) were transformed (logarithmic) to stabilize the variance. Some varieties were not included in the statistical analysis for KWT since there were missing values in KWT at Swift Current in 2004 and Shaunavon in 2004. Analysis of variance revealed significant differences between the years and locations for LAUDPC, SAUDPC, POD, YIELD and KWT. Hence, the data from the four site-years could not be pooled and instead were analysed separately for each site-year using the PROC Mixed program of SAS Institute. Variety, fungicide regime and variety × fungicide regime were fixed factors and year, replication and location were random factors. A macro developed by Saxton (1998) was used to

compare the means based on 't" test values at $P < 0.05$. Correlation analyses between LAUDPC, SAUDPC, POD, YIELD and KWT were carried out to investigate organ-specific reactions.

4.2.2. Controlled conditions

4.2.2.1 Kabuli varieties

Based on the results of the field evaluation in 2004, kabuli varieties with the most extreme reactions to AB on leaves and stems were identified. Varieties with widely divergent pod reactions were not detected. Similarly, the desi varieties did not show widely divergent reactions on any organ. Thus, the following four kabuli varieties were selected for evaluation under controlled conditions.

1. CDC Frontier: low LAUDPC
2. CDC Xena: high LAUDPC
3. FLIP 98-133C: low SAUDPC
4. Sanford: high SAUDPC

4.2.2.2 Plant establishment and artificial inoculation with *A. rabiei*

For each variety, six seeds were planted per 13-cm diameter pot. Seeds were treated with a mixture of Apron (317 g L^{-1} metalaxyl a.i) and Crown (92 g L^{-1} carbathiin and 58 g L^{-1} thiabendazole) to prevent seed to seedling transmission of AB and also other seed-borne pathogens. Pots were filled with a growing medium prepared using 107 litres each of Sunshine #1 and Sunshine # 3 peat moss (Sun Gro Horticulture Canada Ltd, BC, Canada), 40 litres of perlite, 20 litres of vermiculite and 60 ml of '0" grade fine ground calcium ($Ca CO_3$; 37 % calcium). Controlled release type granular fertilizer (N-P-K, 14-14-14) (Plant Products Co. Ltd, ON) was also added in the planting mixture at 20 g pot^{-1}. After emergence, pots were thinned to 3 plants per pot. Plants were watered every 5-7 days depending upon the crop growth. This experiment was conducted three times.

A spore suspension that contained 2 x 10^5 conidia per ml was prepared from a freshly grown fungal culture of a moderately aggressive isolate of *A. rabiei* (AR-296) obtained from the pulse pathology laboratory, University of Saskatchewan, Saskatoon. The suspension was sprayed to run off using an air sprayer on plants 21 days after seeding. Control plants were sprayed with water. All the pots were wrapped with polythene sheets, leaving the top portion open. Immediately after inoculation, the pots were transferred to a mist chamber for 48 h at 100% relative humidity, 20:16 °C day: night temperature and 16-h photoperiod. The light intensity was 200–250 mE m^{-2} s^{-1} supplied by incandescent bulbs. The experimental design was a completely randomized design with six replications. An uninoculated check was used as control.

4.2.2.3 Disease rating and statistical analysis

Disease ratings were conducted on leaves and stems, four times at 5-to-7- day intervals using the Horsfall-Barrat (0-11) scale (Horsfall and Barrat, 1945) starting from the time of disease initiation. Disease scores were converted into percentages. The percent disease values were used to calculate the AUDPC for leaves (LAUDPC) and stems (SAUDPC) using the equation described in section 4.2 (Eq.1). The data was checked for homogeneity of variance between the three repetitions and the data lacked homogeneity. Hence, the "REPEATED" statement was used in PROC MIXED program of SAS to model variances of LAUDPC and SAUDPC. A macro developed by Saxton (1997) was used to separate means based on "t" values. Correlation analysis was carried out using PROC CORR of SAS (SAS Institute Inc. NY).

4.3 Results

4.3.1 Weather conditions

Weather conditions during the cropping season (May-September) in 2004 and 2005 are summarized in Table 3.1 (Swift Current) and Table 4.3 (Shaunavon).

Table 4.3 Monthly precipitation and mean monthly temperature during the growing season at Shaunavon, SK in 2004 and 2005

	Parameter	May (19-31)	Jun	Jul	Aug	Sep	Growing season
2004	Precipitation (mm)	57	49	71	86	26	288
	Mean temperature (°C)	9.1	13.6	17.9	15.2	11.4	13.4
2005	Precipitation (mm)	33	82	12	42	21	190
	Mean temperature (°C)	11.1	14.7	18.7	16.3	11.9	14.6

4.3.2. Organ-specific reaction of kabuli varieties to ascochyta blight

4.3.2.1 Field trial

Analysis of variance for the ascochyta blight severity on leaves (LAUDPC), stem (SAUDPC), pods (POD) and seed yield and KWT are presented in Appendix B (Tables B.1 to B.12).

4.3.2.1.1 Severity on leaves

The kabuli varieties differed significantly in AB severity on leaves at all four-site years (Table 4.4). Significant differences were also observed between high and low fungicide regimes at all the site-years except Shaunavon in 2005 (Table 4.9). The variety × fungicide interaction was not significant except at Swift Current in 2005.

The LAUDPC was higher in 2004 than in 2005 at both locations. The varieties CDC Xena and Sanford had the highest LAUDPC in all four site-years. CDC Xena and Sanford had almost double the LAUDPC compared to the rest of the varieties (Table

4.4). Variety 242-1 had the next highest LAUDPC. Variety 97-Indian-112 also had relatively high LAUDPC, similar to 242-1 at Shaunavon-2004 and Swift Current-2004. The FLIP varieties had relatively low LAUDPC in all four site-years. The FLIP varieties were similar to each other in LAUDPC except at Shaunavon-2005 where there were significant differences among them. The varieties Amit and CDC Frontier were similar to the FLIP varieties in LAUDPC in all four site-years.

Table 4.4 Ascochyta blight severity on leaves measured as leaf area under the disease progress curve (LAUDPC) of 12 kabuli chickpea varieties evaluated at Shaunavon and Swift Current in 2004 and 2005 (mean of high and low fungicide regimes).

	Shaunavon						Swift Current					
Variety	**2004[Z]**			**2005[Z]**			**2004[Z]**			**2005[Z]**		
242-1	6.6	b	(761)	6.4	b	(587)	6.6	b	(724)	6.4	b	(627)
Amit	6.2	c	(506)	5.7	de	(291)	6.2	c	(495)	5.7	fg	(302)
FLIP 97-133C	6.0	cd	(423)	5.8	cd	(343)	6.2	c	(494)	5.8	def	(336)
FLIP 97-45C	6.0	cd	(407)	5.7	de	(288)	6.2	c	(484)	5.9	de	(373)
FLIP 98-133C	5.8	d	(317)	5.5	ef	(235)	6.2	c	(479)	5.7	efg	(307)
FLIP 98-134C	6.2	c	(509)	5.8	cd	(319)	6.4	bc	(602)	5.9	d	(380)
FLIP 98-135C	6.2	c	(495)	5.7	d	(306)	6.1	c	(442)	5.9	d	(379)
FLIP 98-136C	5.9	cd	(373)	5.4	f	(225)	6.3	bc	(537)	5.6	g	(271)
CDC Frontier	5.9	cd	(369)	5.6	def	(279)	6.1	c	(454)	5.6	fg	(276)
97-Indian-112	6.7	b	(784)	6.0	c	(395)	6.3	bc	(536)	6.2	c	(502)
Sanford	7.2	a	(1323)	6.7	a	(812)	6.7	ab	(777)	6.9	a	(963)
CDC Xena	7.4	a	(1637)	6.8	a	(909)	7.0	a	(1056)	6.9	a	(992)

Data were log transformed prior to analysis. Values in parenthesis are back-transformed to the original scale.

[Z] Means within a column followed by the same letters are not significantly different at $P < 0.05$

4.3.2.1.2 Severity on stems

Differences were observed among the varieties in their reaction to AB on stems at all four site-years, and between the high and low fungicide regimes at all site-years except Shaunavon in 2004 (Table 4.9). However, the variety × fungicide interaction was not significant at any site-years. The SAUDPC values were lower in 2005 when compared to 2004. CDC Xena and Sanford had the highest SAUDPC at all four site-years (Table 4.5). CDC Xena and Sanford had almost double the SAUDPC compared to the rest of the varieties. Varieties 97-Indian-112 and 242-1 formed a group of varieties with the next highest SAUDPC at all four site-years. FLIP varieties had relatively low SAUDPC. Varieties CDC Frontier and Amit did not differ from FLIP varieties in SAUDPC at all site-years. FLIP-97-45 C had relatively low SAUDPC at all the four-site years (Table 4.5).

Table 4.5 Ascochyta blight severity on stems, measured as stem area under the disease progress curve (SAUDPC) of 12 kabuli chickpea varieties evaluated at Shaunavon and Swift Current in 2004 and 2005 (mean of high and low fungicide regimes).

	Shaunavon						Swift Current					
Variety	**2004[Z]**			**2005[Z]**			**2004[Z]**			**2005[Z]**		
242-1	5.8	cd	(328)	6.0	b	(403)	5.6	cd	(267)	6.1	b	(461)
Amit	5.4	def	(224)	5.3	def	(204)	5.8	cd	(331)	5.6	cd	(265)
FLIP 97-133C	5.6	cdef	(282)	5.5	d	(235)	5.9	cd	(364)	5.6	cd	(266)
FLIP 97-45C	5.2	f	(185)	5.3	def	(194)	5.8	cd	(326)	5.6	cd	(263)
FLIP 98-133C	5.3	ef	(210)	5.1	f	(170)	5.5	d	(243)	5.4	d	(232)
FLIP 98-134C	5.7	cde	(293)	5.5	d	(233)	5.8	cd	(347)	5.7	c	(308)
FLIP 98-135C	5.5	def	(253)	5.4	de	(226)	6.3	bc	(520)	5.7	c	(312)
FLIP 98-136C	5.4	def	(219)	5.2	f	(174)	5.6	cd	(262)	5.4	d	(231)
CDC Frontier	5.5	def	(248)	5.2	ef	(190)	5.6	cd	(262)	5.5	cd	(243)
97-Indian-112	6.1	bc	(438)	5.7	c	(291)	6.6	ab	(772)	6.1	b	(454)
Sanford	6.4	ab	(612)	6.4	a	(615)	7.0	a	(1103)	6.8	a	(883)
CDC Xena	6.7	a	(826)	6.4	a	(613)	6.7	ab	(820)	6.7	a	(795)

Data were log transformed prior to analysis. Values in parenthesis are back-transformed to the original scale.

[Z] Means within a column followed by the same letters are not significantly different at $P < 0.05$

4.3.2.1.3. Severity on pods

The varieties differed in severity of AB on pods at all site-years except Swift Current in 2005. AB severity on pods was less under high fungicide regime than under low fungicide regime at Swift Current in 2004 and 2005 (Table 4.9). There was no variety × fungicide interaction except at Shaunavon-2004. POD ratings were generally low in 2005 and moderate in 2004. CDC Xena had the highest POD ratings at all four site-years followed by Sanford (Table 4.6). The varieties 97-Indian-112 and 242-1 formed a group of varieties showing next highest POD ratings. FLIP varieties had intermediate POD ratings at all four site-years. CDC Frontier and Amit had significantly lower POD ratings than CDC Xena and Sanford at all the four site-years. However, this group of varieties did not differ from the FLIP varieties.

Table 4.6 Ascochyta blight severity on pods (POD) of 12 kabuli chickpea varieties evaluated at Shaunavon and Swift Current in 2004 and 2005 (mean of high and low fungicide regimes).

	Shaunavon						Swift Current					
Variety	**2004[Z]**			**2005[Z]**			**2004[Z]**			**2005[Z]**		
242-1	0.8	b	(2.1)	0.1	ab	(1.2)	0.8	ab	(2.1)	-0.1	abc	(0.9)
Amit	0.7	b	(2.0)	-0.1	bc	(0.9)	0.4	de	(1.4)	-0.3	c	(0.8)
FLIP 97-133C	0.7	b	(2.1)	-0.1	bc	(0.9)	0.5	bcd	(1.6)	-0.1	ab	(0.9)
FLIP 97-45C	0.8	b	(2.3)	-0.1	abc	(0.9)	0.3	de	(1.4)	-0.1	abc	(0.9)
FLIP 98-133C	0.8	b	(2.3)	-0.1	bc	(0.9)	0.4	cde	(1.5)	-0.2	abc	(0.8)
FLIP 98-134C	0.8	b	(2.1)	-0.1	abc	(0.9)	0.7	abc	(2.0)	-0.2	abc	(0.8)
FLIP 98-135C	0.7	b	(2.1)	0.0	abc	(1.0)	0.5	bcd	(1.7)	-0.1	abc	(0.9)
FLIP 98-136C	0.8	b	(2.3)	-0.3	c	(0.7)	0.3	de	(1.3)	-0.1	abc	(0.9)
CDC Frontier	0.7	b	(2.1)	-0.3	c	(0.7)	0.1	e	(1.1)	-0.3	bc	(0.8)
97-Indian-112	0.7	b	(2.1)	0.0	ab	(1.1)	0.5	bcd	(1.6)	0.0	a	(1.0)
Sanford	1.1	a	(3.0)	0.2	ab	(1.2)	0.9	a	(2.3)	0.0	a	(1.0)
CDC Xena	1.2	a	(3.4)	0.2	a	(1.3)	0.9	a	(2.5)	0.0	a	(1.0)

Data were log transformed prior to analysis. Values in parenthesis are back-transformed to the original scale.

[Z] Means within a column followed by the same letters are not significantly different at $P < 0.05$

4.3.2.1.4. Yield and 1000 seed weight

Varieties differed significantly in yield at all four site-years. The varieties yielded significantly more when they received the high fungicide regime than the low fungicide regime at all the four site-years (Tables 4.7 and 4.9). The variety × fungicide interaction was significant at Shaunavon-2004 and Swift Current-2005. Yield was relatively higher in 2005 than in 2004 at both locations. Varieties CDC Frontier, Amit, FLIP-97-45, FLIP-98-136-C and FLIP-98-133-C had high yield at all site-years, with few exceptions (Table 4.7). FLIP-98-134-C and FLIP-98-135-C were intermediate in yield. Yield of Sanford and CDC Xena was lower than the other varieties. The difference between the highest yield and lowest yield was highly significant in all four site-years.

Analysis of variance revealed significant differences among the varieties in 1000 seed weight (KWT) at all four site-years. The high fungicide regime significantly increased KWT at three of four site-years (Table 4.9). The variety × fungicide interaction was significant at Shaunavon-2004 and Swift Current-2005. Seed weight was higher in 2005 than in 2004. Varieties FLIP-98-134-C and FLIP-98-135-C consistently had high KWT at all site-years (Table 4.8). Seed weight of CDC Xena was greater than the other varieties, However, KWT of FLIP-97-45-C was not significantly different from the KWT of CDC Xena at all site-years except Shaunavon in 2005, where KWT of CDC Xena was significantly higher than FLIP-97-45-C. The KWT of Sanford was also high in Shaunavon-2005. Seed weight of CDC Frontier was high in Swift Current in both years.
Varieties Amit and 242-1 had consistently low KWT at all the site-years. Under low fungicide regime, because of the high disease pressure there were missing observations for KWT of some varieties.

Table 4.7 Yield (kg ha^{-1}) of 12 kabuli chickpea varieties evaluated at Shaunavon and Swift Current in 2004 and 2005 (mean of high and low fungicide regimes).

	Shaunavon						Swift Current					
Variety	**2004[Z]**			**2005[Z]**			**2004[Z]**			**2005[Z]**		
242-1	6.6	e	(750)	8.2	a	(3504)	4.7	c	(106)	7.4	e	(1669)
Amit	7.8	ab	(2420)	8.1	a	(3159)	6.5	ab	(655)	7.8	abc	(2564)
FLIP 97-133C	6.8	de	(920)	8.1	a	(3438)	6.5	ab	(676)	7.8	bcd	(2350)
FLIP 97-45C	8.1	a	(3257)	8.1	a	(3190)	7.3	a	(1519)	7.8	bcd	(2462)
FLIP 98-133C	7.8	ab	(2461)	8.1	a	(3421)	6.8	ab	(899)	7.8	abc	(2541)
FLIP 98-134C	7.4	bcd	(1637)	8.1	a	(3345)	6.3	b	(562)	7.6	d	(2065)
FLIP 98-135C	7.0	cde	(1047)	8.1	a	(31890	6.2	b	(488)	7.7	cd	(2102)
FLIP 98-136C	8.0	ab	(2972)	8.2	a	(3706)	6.8	ab	(923)	7.9	ab	(2622)
CDC Frontier	7.6	abc	(1904)	8.1	a	(3175)	6.8	ab	(928)	8.0	a	(3031)
97-Indian-112	6.5	e	(639)	8.1	a	(3144)	6.1	b	(454)	7.7	cd	(2114)
Sanford	2.8	f	(16)	7.6	c	(1936)	2.8	d	(15)	6.0	g	(388)
CDC Xena	3.2	f	(23)	7.9	b	(2570)	2.6	d	(13)	6.3	f	(539)

Data were log transformed prior to analysis. Values in parenthesis are back-transformed to the original scale.

[Z] Means within a column followed by the same letters are not significantly different at $P < 0.05$

Table 4.8 One thousand seed weight (KWT) of 12 kabuli chickpea varieties evaluated at Shaunavon and Swift Current in 2004 and 2005 (mean of high and low fungicide regimes).

	Shaunavon						Swift Current					
Variety	**2004[Z]**			**2005[Z]**			**2004[Z]**			**2005[Z]**		
242-1	5.2	e	(180)	5.9	d	(367)			239*	5.9	cd	(353)
Amit	5.3	de	(194)	5.7	e	(292)	5.1	d	(158)	5.6	f	(270)
FLIP 97-133C	5.3	cde	(206)	6.0	bc	(408)			300*	6.0	abc	(391)
FLIP 97-45C	5.6	a	(269)	6.0	c	(402)	5.5	a	(251)	6.0	abc	(387)
FLIP 98-133C	5.5	abcd	(234)	5.9	d	(367)	5.2	c	(188)	5.8	de	(333)
FLIP 98-134C	5.5	abc	(242)	6.1	b	(436)	5.3	bc	(210)	6.0	ab	(403)
FLIP 98-135C	5.5	ab	(251)	6.1	b	(440)	5.3	c	(196)	6.0	a	(423)
FLIP 98-136C	5.3	de	(193)	5.7	e	(313)	5.0	d	(153)	5.7	ef	(296)
CDC Frontier	5.4	bcde	(216)	6.0	cd	(397)	5.4	ab	(229)	5.9	abc	(383)
97-Indian-112	5.4	abcde	(226)	6.1	b	(436)			282*	6.0	abc	(396)
Sanford			179*	6.0	bc	(410)			202*	5.6	f	(272)
CDC Xena			243*	6.2	a	(483)			225*	5.9	bcd	(368)

Data were log transformed prior to analysis. Values in parenthesis are back-transformed to the original scale.

[Z] Means within a column followed by the same letters are not significantly different at $P < 0.05$

* Mean 1000 seed weight under high fungicide regime only and not included in the statistical analysis.

Table 4.9 Effect of fungicide regime on ascochyta blight severity measured as leaf area under the disease progress curve (LAUDPC) on leaves, stem area under the disease progress curve (SAUDPC) on stems, disease ratings on pods (POD), seed yield (YIELD) and 1000-seed weight (KWT) of 12 kabuli chickpea varieties evaluated at Shaunavon and Swift Current in 2004 and 2005

	LAUDPC				SAUDPC				POD				YIELD				KWT			
Shaunavon	2004[Z]		2005[Z]		2004[Z]		2005[Z]		2004[Z]		2005[Z]		2004[Z]		2005[Z]		2004[Z]		2005[Z]	
Low	6.5 a	(677)	5.9 a	(383)	5.8 a	(327)	5.6 a	(277)	0.8 a	(2)	0.0 a	(1)	5.7 b	(290)	8.1 a	(3230)	5.2 b	(185)	6.0 a	(393)
High	6.2 b	(484)	5.9 a	(363)	5.7 a	(289)	5.5 b	(254)	0.8 a	(2)	0.1 a	(1)	7.6 a	(1947)	8.0 b	(2993)	5.5 a	(253)	6.0 a	(391)
Swift Current																				
Low	6.5 a	(675)	6.1 a	(467)	6.3 a	(522)	5.9 a	(378)	0.8 a	(2)	0.0 a	(1)	3.9 b	(51)	7.4 b	(1691)	5.0 b	(145)	5.8 b	(343)
High	6.2 b	(481)	6.0 b	(392)	5.8 b	(321)	5.8 b	(328)	0.2 b	(1)	0.2 b	(1)	7.7 a	(2112)	7.5 a	(1856)	5.6 a	(257)	5.9 a	(363)

Data were log transformed prior to analysis. Values in parenthesis are back-transformed to the original scale.

[Z] Means within a column followed by the same letters are not significantly different at $P < 0.05$

4.3.2.1.6. Correlation analyses

Correlation analysis of LAUDPC, SAUDPC, POD, YIELD and KWT was carried out across all the site years. LAUDPC, SAUDPC and POD were positively correlated with each other (Table 4.10). Negative correlations occurred between the disease components (LAUDPC, SAUDPC, POD) and yield components (YIELD, KWT), except between SAUDPC and KWT. There was no correlation between KWT and yield.

Table 4.10 Pearson's correlation coefficients among various response variables assessed on 12 kabuli chickpea varieties evaluated at Shaunavon and Swift Current in 2004 and 2005

Response variable	SAUDPC	POD	Yield	KWT
LAUDPC	**0.67****	**0.57 ****	**-0.61****	**-0.16***
SAUDPC	**-**	**0.35****	**-0.55****	**-0.02**
POD	**-**	**-**	**-0.39****	**-0.52****
Yield	**-**	**-**	**-**	**0.35**

*, ** Significant at $P < 0.05$ and $P < 0.01$, respectively;

LAUDPC - Leaf area under disease progress curve

SAUDPC - Stem area under disease progress curve

POD - Disease rating on pods

Yield – Seed yield (kg/ha)

KWT - 1000 seed weight (g)

4.3.2.2 Organ-specific reaction of desi varieties to ascochyta blight

4.3.2.2.1 Severity on leaves

Effect of varieties on AB severity on leaves was significant only at Swift Current in both years. The high fungicide regime reduced the LAUDPC in comparison to the low fungicide regime at all the site-years except Shaunavon-2005 (Table 4.16). There was no variety × fungicide interaction at any site. AB severity on leaves was lower in 2005 than 2004. The varieties CDC Anna, Myles and 363-T-13 had high LAUDPC at all site-years (Table 4.11). Varieties 296T-7 and 304-40 had low LAUDPC at all site-years. The other varieties were intermediate.

Table 4.11 Ascochyta blight severity on leaves, measured as leaf area under the disease progress curve (LAUDPC) of 12 desi chickpea varieties evaluated at Shaunavon and Swift Current in 2004 and 2005 (mean of high and low fungicide regimes).

	Shaunavon						Swift Current					
Variety	**2004[Z]**			**2005[Z]**			**2004[Z]**			**2005[Z]**		
304-22	5.7	cd	(290)	5.8	ab	(315)	6.0	bcd	(403)	5.6	bcd	(265)
304-40	5.8	abcd	(341)	5.8	ab	(326)	5.9	d	(365)	5.5	cd	(241)
294T-16	5.9	abcd	(371)	5.8	ab	(335)	6.1	abcd	(465)	5.6	bc	(272)
296T-7	5.6	d	(276)	5.7	b	(285)	6.0	bcd	(407)	5.4	d	(225)
304T-7	5.9	abcd	(358)	5.9	ab	(379)	6.0	bcd	(396)	5.7	ab	(292)
316B-42	5.8	bcd	(328)	5.8	ab	(314)	6.4	a	(576)	5.7	ab	(291)
363T-13	6.2	a	(477)	5.9	ab	(348)	6.2	abcd	(482)	5.6	bcd	(261)
CDC Anna	6.0	abcd	(386)	6.0	a	(384)	6.2	ab	(509)	5.8	a	(335)
CDC Cabri	6.1	ab	(450)	5.9	ab	(362)	5.9	cd	(371)	5.6	abc	(279)
ICC 12512-1	5.9	abcd	(347)	5.8	ab	(336)	6.2	abc	(488)	5.6	bcd	(259)
ICC-12512-9	6.0	abc	(397)	5.8	ab	(321)	5.9	bcd	(383)	5.6	abc	(279)
Myles	5.8	abcd	(340)	6.0	a	(390)	6.0	bcd	(408)	5.6	bcd	(268)

Data were log transformed prior to analysis. Values in parenthesis are back-transformed to the original scale.

[Z] Means within a column followed by the same letters are not significantly different at $P < 0.05$

4.3.2.2.2 Severity on stems

Varieties differed in SAUDPC at three of four site-years (Table 4.12). Fungicide regimes differed significantly in their effect on SAUDPC at Swift Current in 2004 and 2005, but not at Shaunavon 2004 and 2005 (Table 4.16). There was no variety × fungicide interaction at all site-years. Varieties CDC Anna, 363T-13 and Myles had high SAUDPC at all site-years (Table 4.12). Varieties 296T-7, 304-22 and 304-40 consistently had low SAUDPC at all the four site-years, while 294T-16, 316B-42, 363T-7, CDC Cabri, ICC 12512-1 and ICC 12512-9 did not differ from each other, and were intermediate in SAUDPC at all site-years.

Table 4.12 Ascochyta blight severity on stems, measured as stem area under the disease progress curve (SAUDPC), of 12 desi chickpea varieties evaluated at Shaunavon and Swift Current in 2004 and 2005 (mean of high and low fungicide regimes).

	Shaunavon						Swift Current					
Variety	**2004[Z]**			**2005[Z]**			**2004[Z]**			**2005[Z]**		
304-22	5.5	bcd	(250)	5.4	cd	(220)	5.7	bcd	(295)	5.4	cde	(224)
304-40	5.4	cd	(215)	5.5	bcd	(236)	5.5	cd	(235)	5.4	cde	(226)
294T-16	5.6	bcd	(260)	5.5	abcd	(244)	6.1	abc	(447)	5.6	abc	(259)
296T-7	5.2	d	(188)	5.3	d	(208)	5.4	d	(223)	5.3	e	(198)
304T-7	5.6	bcd	(270)	5.7	abc	(295)	5.5	cd	(235)	5.5	bcd	(248)
316B-42	5.8	ab	(324)	5.5	abcd	(251)	5.8	bcd	(316)	5.6	ab	(273)
363T-13	5.8	ab	(324)	5.6	abcd	(267)	5.4	d	(217)	5.5	bcd	(242)
CDC Anna	6.0	a	(404)	5.8	a	(334)	6.2	ab	(512)	5.7	a	(304)
CDC Cabri	5.7	abc	(297)	5.6	abcd	(273)	5.6	bcd	(277)	5.4	cde	(220)
ICC 12512-1	5.7	abc	(286)	5.7	abc	(304)	6.4	a	(631)	5.4	de	(216)
ICC-12512-9	5.8	ab	(328)	5.5	abcd	(238)	5.7	bcd	(301)	5.5	bcd	(235)
Myles	5.8	ab	(329)	5.8	ab	(321)	5.7	bcd	(313)	5.6	abc	(259)

Data were log transformed prior to analysis. Values in parenthesis are back-transformed to the original scale

[Z] Means within a column followed by the same letters are not significantly different at $P < 0.05$

4.3.2.2.3 Severity on pods

Varieties did not differ in AB severity on pods (POD) in any site-years. The high fungicide regime reduced POD ratings at all the site-years except Shaunavon-2004 (Table 4.16). The variety × fungicide interaction was not significant at three of four site-years. Swift Current had relatively higher POD ratings than Shaunavon in both years (Table 4.13).

Table 4.13 Ascochyta blight severity on pods (POD) of 12 desi chickpea varieties evaluated at Shaunavon and Swift Current in 2004 and 2005 (mean of high and low fungicide regimes).

	Shaunavon						Swift Current					
Variety	**2004[Z]**			**2005[Z]**			**2004[Z]**			**2005[Z]**		
304-22	0.7	a	(2.0)	0.0	a	(1.0)	0.0	c	(1.0)	-0.2	abcd	(0.8)
304-40	0.7	a	(1.9)	-0.1	a	(0.9)	0.1	bc	(1.1)	-0.3	d	(0.8)
294T-16	0.6	a	(1.8)	0.0	a	(1.0)	0.4	ab	(1.5)	0.0	ab	(1.0)
296T-7	0.7	a	(2.0)	0.1	a	(1.1)	0.3	abc	(1.3)	-0.2	cd	(0.8)
304T-7	0.7	a	(2.0)	0.0	a	(1.0)	0.2	abc	(1.3)	-0.2	cd	(0.8)
316B-42	0.8	a	(2.1)	0.0	a	(1.0)	0.2	abc	(1.3)	-0.2	abcd	(0.8)
363T-13	0.6	a	(1.9)	0.0	a	(1.0)	0.1	bc	(1.1)	-0.2	cd	(0.8)
CDC Anna	0.7	a	(1.9)	0.1	a	(1.1)	0.2	abc	(1.2)	-0.1	abc	(0.9)
CDC Cabri	0.7	a	(2.0)	0.1	a	(1.1)	0.5	a	(1.6)	0.0	a	(1.0)
ICC 12512-1	0.6	a	(1.8)	0.0	a	(1.0)	0.5	a	(1.6)	-0.2	bcd	(0.8)
ICC-12512-9	0.7	a	(2.0)	-0.1	a	(0.9)	0.1	bc	(1.1)	-0.2	cd	(0.8)
Myles	0.7	a	(1.9)	0.0	a	(1.0)	0.1	bc	(1.1)	-0.3	d	(0.8)

Data were log transformed prior to analysis. Values in parenthesis are back-transformed to the original scale.

[Z] Means within a column followed by the same letters are not significantly different at $P < 0.05$

4.3.2.2.4 Yield and 1000 seed weight

Varieties differed in YIELD at all four site-years. Fungicide regime did not affect YIELD at Shaunavon-2005 or Swift Current-2005 (Table 4.16), but the YIELD was higher under the high fungicide regime than under the low fungicide regime in Shaunavon-2004 and Swift Current-2004 (Table 4.16). There was no variety × fungicide interaction (Table 4.14). YIELD was higher in 2005 than in 2004. Varieties ICC 12512-9, ICC 12512-1 and 304-22 had high YIELD at all four site-years (Table 4.14). Myles, CDC Anna and 363T-13 had the lowest YIELD at all four site-years. The YIELD of CDC Cabri, 296-T, 304-T7, 316-B and 304-40 was intermediate.

Varieties differed significantly in KWT at the four-site years. Fungicide regimes differed in their effect on KWT in 2004 at both locations, but not in 2005 (Tables 4.16). The variety × fungicide regime interaction was not significant. In 2005, KWT was higher than in 2004. CDC Cabri had the highest KWT at all four site-years (Table 4.15). Varieties ICC-12512-9 and ICC-12512-1 had the next highest KWT. CDC Anna and Myles had the lowest KWT at all the four site-years. The other varieties were generally intermediate with respect to KWT.

Table 4.14 Yield (kg ha^{-1}) of 12 desi chickpea varieties evaluated at Shaunavon and Swift Current in 2004 and 2005 (mean of high and low fungicide regimes).

	Shaunavon						Swift Current					
Variety	**2004[Z]**			**2005[Z]**			**2004[Z]**			**2005[Z]**		
304-22	8.0	abc	(2854)	8.0	abcd	(3106)	7.0	ab	(1067)	7.9	a	(2589)
304-40	7.7	bcd	(2200)	8.1	a	(3400)	6.3	cd	(570)	7.9	a	(2621)
294T-16	7.3	def	(1536)	8.1	abc	(3249)	5.1	e	(171)	7.8	abc	(2378)
296T-7	7.7	abcd	(2232)	8.1	abcd	(3174)	6.0	d	(412)	7.9	a	(2613)
304T-7	7.6	bcd	(2034)	8.1	abcd	(3197)	5.9	d	(375)	7.8	ab	(2455)
316B-42	7.6	cde	(1939)	8.0	de	(2872)	6.4	bcd	(622)	7.8	abc	(2378)
363T-13	7.1	ef	(1225)	8.0	abcde	(3072)	5.2	e	(180)	7.7	bcd	(2112)
CDC Anna	6.9	f	(1011)	8.0	cde	(2942)	4.5	e	(94)	7.6	cd	(2053)
CDC Cabri	7.7	bcd	(2136)	8.0	bcde	(3000)	6.9	abc	(1029)	7.8	a	(2546)
ICC 12512-1	8.1	ab	(3235)	8.0	bcde	(3033)	6.8	abc	(933)	7.9	a	(2697)
ICC-12512-9	8.2	a	(3542)	8.1	ab	(3321)	7.2	a	(1352)	7.8	a	(2564)
Myles	6.9	f	(978)	7.9	e	(2766)	5.2	e	(178)	7.6	d	(1974)

Data were log transformed prior to analysis. Values in parenthesis are back-transformed to the original scale (Kg/ ha)

[Z] Means within a column followed by the same letters are not significantly different at $P < 0.05$

Table 4.15 One thousand seed weight (KWT) of 12 desi chickpea varieties evaluated at Shaunavon and Swift Current in 2004 and 2005 (mean of high and low fungicide regimes).

	Shaunavon						Swift Current					
Variety	**2004[Z]**			**2005[Z]**			**2004[Z]**			**2005[Z]**		
304-22	5.0	b	(142)	5.4	e	(227)	4.8	cd	(119)	5.4	de	(229)
304-40	4.9	bcd	(130)	5.5	de	(233)	4.8	cd	(121)	5.5	d	(235)
294T-16	4.9	bcd	(131)	5.4	de	(230)	4.7	de	(111)	5.4	de	(227)
296T-7	4.9	bcd	(128)	5.3	g	(199)	4.6	e	(100)	5.3	fg	(205)
304T-7	4.9	bc	(135)	5.5	d	(236)	4.7	de	(111)	5.5	d	(238)
316B-42	4.9	bc	(135)	5.3	g	(205)	4.7	de	(109)	5.4	f	(213)
363T-13	4.8	bcd	(128)	5.4	de	(229)	4.6	ef	(95)	5.4	e	(224)
CDC Anna	4.8	d	(116)	5.4	f	(217)			107*	5.3	fg	(205)
CDC Cabri	5.2	a	(178)	5.7	a	(303)	5.1	a	(167)	5.8	a	(320)
ICC 12512-1	5.1	a	(169)	5.6	c	(267)	4.9	bc	(137)	5.5	c	(256)
ICC-12512-9	5.2	a	(175)	5.7	b	(285)	5.0	ab	(153)	5.6	b	(273)
Myles	4.8	cd	(121)	5.3	g	(205)	4.4	f	(80)	5.3	g	(201)

Data were log transformed prior to analysis. Values in parenthesis are back-transformed to the original scale (g)

Means within a column followed by the same letters are not significantly different at $P < 0.05$

* Mean 1000 seed weight under high fungicide regime only and not included in the statistical analysis.

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Table 4.16 Effect of fungicide regimes on ascochyta blight measured as leaf area under the disease progress curve (LAUDPC) on leaves, stem area under the disease progress curve (SAUDPC) on stems, pod disease ratings (POD) on pods, seed yield (YIELD) and 1000 seed weight (KWT) of 12 desi chickpea varieties evaluated at Shaunavon and Swift Current in 2004 and 2005

	LAUDPC				SAUDPC				POD				YIELD				KWT			
Shaunavon	2004[Z]		2005[Z]		2004[Z]		2005[Z]		2004[Z]		2005[Z]		2004[Z]		2005[Z]		2004[Z]		2005[Z]	
Low	6.1 a	(452)	5.9 a	(353)	5.6 a	(283)	5.5 a	(254)	0.7 a	(2)	0.6 a	(2)	7.3 b	(1539)	5.4 b	(218)	4.8 b	(122)	5.5 a	(233)
High	5.7 b	(286)	5.7 a	(286)	5.7 a	(285)	5.5 a	(254)	0.6 a	(2)	-0.1 b	(1)	7.8 a	(2397)	6.7 a	(844)	5.1 a	(159)	5.5 a	234
Swift Current																				
Low	6.3 a	(551)	5.7 a	(300)	5.9 a	(375)	5.5 a	(254)	0.8 a	(2)	0.1 b	(1)	8.0 a	(3075)	7.8 a	(2395)	4.6 b	(97)	5.5 a	(234)
High	5.8 b	(341)	5.5 b	(245)	5.6 b	(264)	5.4 b	(231)	0.2 b	(1)	0.3 a	(1)	8.0 a	(3100)	7.8 a	(2372)	4.9 a	(136)	5.5 a	(234)

Data were log transformed prior to analysis. Values in parenthesis are back-transformed to the original scale.

[Z] Means within a column followed by the same letters are not significantly different at $P < 0.05$

4.3.2.2.5. Correlation analysis

Correlation analysis of LAUDPC, SAUDPC, POD, YIELD and KWT of 12 desi varieties was carried out across all site-years (Table 4.17). LAUDPC, SAUDPC and POD were positively correlated with each other. The yield components (YIELD, KWT) were negatively correlated with all of the disease components (LAUDPC, SAUDPC, POD). However, only the relationship between YIELD and the disease components was highly significant. KWT did not show significant relationship with any other response variable.

Table 4.17 Pearson's correlation coefficients among various response variables of desi chickpea varieties evaluated at Shaunavon and Swift Current in 2004 and 2005

Response variables	**SAUDPC**	**POD**	**Yield**	**KWT**
LAUDPC	**0.95****	**0.46****	**-0.88****	**-0.15**
SAUDPC	**-**	**0.41****	**-0.87****	**-0.18**
POD	**-**	**-**	**-0.32****	**-0.04**
Yield	**-**	**-**	**-**	**0.16**

*, ** Significant at $P < 0.05$ and $P < 0.01$, respectively;

LAUDPC - Leaf area under disease progress curve

SAUDPC - Stem area under disease progress curve

POD - Disease rating on pods

Yield – Seed yield (kg/ha)

KWT - 1000 seed weight (g)

4.3.3 Controlled conditions

4.3.3.1 Severity on leaves and stems

Analysis of variance revealed that varieties significantly influenced LAUDPC and SAUDPC. Significant differences among the three experimental runs were also observed for LAUDPC and SAUDPC. However, the relative rank of the four varieties for LAUDPC and SAUDPC was same across the three repetitions. The means of the four varieties for LAUDPC and SAUDPC calculated across the three repetitions were presented (Table 4.18). Sanford and CDC Xena had significantly higher LAUDPC and SAUDPC than CDC Frontier and FLIP-98-133C. However, there were no significant differences among the varieties within a group. Correlation analysis revealed a significantly positive correlation ($R^2 = 0.66$, $P \leq 0.01$) between LAUDPC and SAUDPC.

Table 4.18 Varietal differences in ascochyta blight severity on leaves, measured as leaf area under disease progress curve (LAUDPC) and stems, measured as stem area under disease progress curve (SAUDPC) of four kabuli chickpea varieties grown under controlled environment (mean of three experimental runs).

Variety	LAUDPC	SAUDPC
CDC Xena	213 a	157 a
Sanford	185 a	140 a
FLIP-98-133-C	67 b	43 b
CDC Frontier	61 b	48 b

Means within a column followed by the same letter are not significantly different from each other at $P \leq 0.05$.

4. 4 Discussion

4.4.1 Field conditions

AB severity is greatly influenced by environment, presence of inocula, virulence of the pathogen and the resistance structures and mechanisms present in the host plant. Monthly rainfall of 40 mm and monthly mean temperature of at least 8 °C were needed before an epidemic of AB occurred (Ketelaer et al., 1988). Rain splashing may accelerate the disease spread and keep the leaf surface wet. Increasing leaf wetness periods increase the disease severity (Armstrong et al., 2004). In this experiment, significant differences were observed between the two locations (Shaunavon and Swift Current) and between the two years (2004 and 2005) with respect to reaction to AB on leaves, stems and pods, as well as seed yield and kernel weight. LAUDPC, SAUDPC and POD values of both kabuli and desi varieties were high at Swift Current in 2004, followed by Shaunavon in 2004, Swift Current in 2005 and Shaunavon in 2005. Similarly the mean growing season precipitation at Swift Current-2004 (311mm) was higher than the other three site-years. The mean growing season precipitation at Swift Current-2004 was 50% more than the long term (1961-2000) average at Swift Current (204 mm). The growing season precipitation at Shaunavon-2004 (288 mm) was 50 % more than Shaunavon-2005 (190 mm). The mean air temperature during the 2004 growing season was 1 °C lower than the mean air temperature during the 2005 growing season at both locations. Thus, 2004 was a relatively cool, wet year, which resulted in higher disease severity levels on all three organs studied at both locations. Variation in isolates isolated from the same field might cause variation in disease infection (Morjane et al., 1994).

LAUDPC was consistently higher than SAUDPC for both kabuli and desi varieties. It was previously reported that AB symptoms are initiated later on stems than leaves, due to the thicker cell walls of stem (Ilarslan and Dolar, 2002). Results of this experiment differ from Chongo et al. (2004), who found lower levels of AB on leaves than stems. However, the rating scale used to assess the disease was different

than the one used in this experiment. The organs of a plant such as leaves, stems, and pods, differ in their cellular structure mostly with respect to cellulose, hemi-cellulose and some polysaccharides composition.

LAUDPC, SAUDPC and POD values of both desi and kabuli varieties evaluated in this experiment were positively correlated. This is an indication that resistance to AB on leaves, stems and pods is governed by the same genes. In a similar study to assess partial resistance to AB in pea, Xue and Warkentin (2001) found no correlation between disease severity on leaves and stems, and reported that the resistance at leaves and stems could be governed by different genes. Other studies support the conclusion that the resistance to mycosphaerella blight of pea on leaves and stems was governed by different genes (Clulow et al., 1991). However, in chickpea, of the five markers associated with stem resistance four of them were also associated with seedling resistance, indicating that common QTLs control the resistance in both leaves and stems (Collard et al., 2003).

The correlation between LAUDPC, SAUDPC and POD in this experiment may indicate that AB resistance on these organs is under the control of the same genes. In this experiment, there was a strong environmental influence on the AB severity. This might have masked the expression of organ-specific genes for AB resistance, if present. Biochemical evaluation for the presence of specific pathogenesis related proteins or other defense related structures among the tissue types of each of these organs could answer whether or not there are organ-specific genes regulating the resistance.

The reaction of varieties to AB showed differences in severity levels across the station-years. Significant genotype and environment interaction (G × E) was expected as chickpea is largely affected by environment (Lichtenzveig et al., 2002). However, the relative ranks of varieties at all site-years for LAUDPC, SAUDPC and POD did not vary significantly, i.e., there were no cross-over interactions. Resistance to AB in chickpea is a quantitatively inherited trait and the results of this

experiment which showed continuous variation among varieties support that observation. Classifying the varieties evaluated in this experiment as susceptible or resistant based on certain arbitrary numbers resulting from the disease scale could generate inconsistent classification due to the quantitative nature of the disease and environmental variability affecting the pathogenecity assays (Chen et al., 2004).

Sanford and CDC Xena, the unifoliate leaf varieties, had consistently higher disease severity than the fern leaf type kabuli varieties at all site-years. These varieties were considered partially resistant in North America in the early 1990s. The break-down of resistance in Sanford and CDC Xena could have been due to the development of new races of *A. rabiei*. For example, Chongo et al. (2003) observed that Sanford was susceptible to almost all the isolates when tested for resistance against 14 isolates of *A. rabiei*.

Kabuli varieties from the Food Legume Improvement Programme (FLIP) of ICARDA, Syria were moderately resistant to AB in all site years. The FLIP varieties that were evaluated in this test all had a fern leaf type. CDC Frontier is one of the varieties of western Canada that has shown considerable resistance to AB. CDC Anna and Myles were relatively susceptible at all site-years. Like Sanford, the breakdown of resistance in these varieties could also be due to the development of aggressive pathotypes of *A. rabiei.* ICC-12512-9, ICC-12512-1 and 296-T were moderately resistant across
site-years.

The high fungicide regime reduced disease levels (LAUDPC, SAUDPC), especially during severe epidemic conditions in 2004. The benefit of the high fungicide regime was more pronounced in a cool, moist year like 2004 than 2005 at both locations. The disease control achieved by the high fungicide regime also resulted in higher seed yield. Under high disease pressure, two sprays of chlorothalonil or strobilurins were required alone or in sequence to control AB in chickpea (Chongo et al., 2003). Two application of chlorothalanil reduced the disease from 45% to 8% and doubled

the yield (Chongo et al., 2003). The seed yield of a variety depends upon the genetic nature of the variety, the expression of genes responsible for yield, and the interaction with environment. However, it is clear that the high fungicide regime helped, attain higher yield.

Yield and KWT were negative correlated with LAUDPC, SAUDPC and POD. This supports previous finding that AB resistance and chickpea seed yield were negatively correlated (Chongo et al., 2003). The impact of disease severity on KWT was strong especially at Swift Current-2004 which received high precipitation during the growing period and the harvest was delayed until October, 2004. Under the low fungicide regime and because of the high disease pressure there was no seed produced by Sanford and CDC Xena. These varieties would have had the highest KWT among the varieties under disease free or minor epidemic conditions. This was evident at Shaunavon-2005 where CDC Xena had the highest KWT.

4.4.2 Controlled conditions

Under controlled environmental conditions, significant differences between the repetitions were detected. The age of the fungal culture influences the disease cycle. Differences in the age of the *A. rabiei* isolate used in the three repetitions and the difference in the position of handling the atomizer could have caused this variation. However, the varieties had relatively similar ranks for LAUDPC and SAUDPC across the three repetitions.

Varieties resistant and susceptible to diseases differ from each other in terms of cell structure and other resistance-associated structures as discussed in section 4.4. It was observed in the current study that the appearance of symptoms on resistant varieties was delayed by 1-2 days compared to the susceptible varieties. Pre-infection processes of AB such as spore germination, appressorium formation and germ tube penetration are all similar in both resistant and susceptible varieties.

However, the difference during disease development, between resistant and susceptible varieties was observed (Hohl et al., 1990; Ilarslan and Dolar, 2002).

Pedersen and Morrall (1994) reported that in lentil (*Lens culinaris* Medik) expression of resistance to ascochyta blight caused by *A. lentis* in leaflets and stems differed among cultivars. AB severity on leaves of resistant chickpea varieties was less than on stems and Chongo and Gossen (2003) suggested that it could be due to the regulation of resistance by different genes at these organs. The positive correlation ($R^2 = 0.66$) observed between LAUDPC and SAUDPC in the current study indicates the possibility of the same genes regulating resistance in both organs. Such correlations were also observed under field conditions.

The relative performance of desi and kabuli varieties evaluated across the four site-years in this experiment will help breeders identify promising sources of resistance in varieties that are also well adapted to the Canadian growing conditions. Fungicide regime comparisons will help designing AB management strategies. Components of partial resistance on leaves, stems and pods appear to be controlled by the same genes. Further biochemical and genetic analysis of the tissue types and inheritance of resistance at these organs would clearly answer the question of whether or not resistances at different organs are regulated by different genes.

5.0 General discussion and conclusions

Ascochyta blight (AB) is an important constraint to the chickpea production in western Canada. Reducing the losses caused by AB is dependant to some extent on fungicide applications; however, repeated fungicide applications are generally not efficient and economical. Alternative management options and use of varieties with genetic resistance were found to be promising control strategies.

There were differences between site-years in disease severity and yield (Chapter 3 and Chapter 4). Weather significantly influences AB disease development. At all of the site-years studied, the mean temperature was in the range of 15-20 °C and rainfall was greater than 150 mm. AB is more severe under conditions of cool temperature (15-25 °C) and high rainfall (>150 mm rainfall) during the growing season, and can cause complete loss in susceptible varieties (Nene, 1982). Inocula present in the soil and infected debris, and air-borne ascospores significantly influence the disease severity. Differences in the level and age of inocula and aggressiveness of *A. rabiei* between the two locations might also have caused the difference between locations.

Varieties with fern leaf type had lower AB severity than those with unifoliate leaf type. Significant differences in AB severity were observed between Amit (fern leaf type) and CDC Xena (unifoliate leaf type).

Treatments influenced the AB severity and seed yield of both susceptible and resistant varieties (Chapter 3). The influence was more pronounced in 2004, which was relatively cooler and wetter than 2005. Paired row planting was expected to create a change in the micro-environment around the phyllosphere. The wider

spacing between the paired rows might have provided open canopies that allow more sunlight to enter and keep the topsoil surface and canopy drier. However, in both years, paired row planting did not substantially affect AB severity and seed yield in Amit and CDC Xena.

Reducing the recommended seeding rate by one third did not affect AB severity or seed yield for either cultivar. Since reducing seeding rate did not have any significant impact in AB severity and seed yield, 33% of the seed cost could be saved. This supports the conclusion of a previous study which showed that, AB severity was not affected by plant population density (Gan et al., 2003b).

Generally two to four fungicide applications are required for successful cultivation of chickpea in western Canada. The timing and number of fungicide applications are very important in controlling AB. In this study, four applications of fungicide reduced the AB severity of both resistant and susceptible cultivars in a severe epidemic year. However, the susceptible cultivar benefited more than the moderately resistant cultivar. When only one fungicide application was applied to CDC Xena, yield was very low. The KWT of CDC Xena was also very low under a single application regime. The benefit of four applications of fungicide applied at appropriate crop growth stages was clearly evident for CDC Xena. Under lower disease pressure in 2005, the moderately resistant variety Amit had an acceptable yield even with only one fungicide application. Similarly, the moderately resistant variety ILC 482 treated with 2 applications of chlorothalanil at pre-flowering and post –flowering stages provided economical chickpea production in Syria (Reddy and Singh, 1990). This indicates that the combination of a genetically resistant variety and a minimal number of fungicide applications is efficient in terms of AB control and yield.

A reduction to 2/3 of the recommended fungicide rate did not significantly affected AB severity, seed yield and KWT for both resistant and susceptible varieties in both years. Reducing the fungicide rate to 2/3 of the recommended rate would provide a

substantial cost saving. However, reducing the fungicide rate may increase the likelihood of *A. rabiei* developing resistance against the fungcide.

Among the chickpea types tested in the experiment, desi varieties and fern leaf type kabuli varieties generally showed higher resistance to AB than the unifoliate kabuli varieties (Chapter 4). Significant positive correlations occurred among the components of partial resistance including LAUDPC, SAUDPC and POD in desi and kabuli varieties. This may indicate that resistance components in these organs are regulated by the same genes.

Variation in the environmental conditions and difference in the *A. rabiei* population may have led to significant differences between site-years in terms of AB severity, yield and KWT. Hence, conclusion about organ-specific reaction to AB in chickpea may be more reliable if based on controlled environment studies. Contrasting kabuli varieties with respect to LAUDPC and SAUDPC were evaluated in controlled growing conditions. LAUDPC and SAUDPC were positively correlated with each other. This may indicate that resistance in leaves and stems were under the control of the same genes. Previous work involving detection of QTLs for resistance to AB in chickpea also reported that some of the QTLs associated with resistance in stems were also associated with resistance in seedlings (Santra et al., 2000).

Varieties differed significantly in LAUDPC, SAUDPC and POD. The relative rankings of varieties across the four site-years were similar. LAUDPC of varieties was higher than SAUDPC. The possible reason could be later disease initiation on stems. Attempts to identify promising sources of resistance among the varieties that are agronomically adapted to the western Canadian conditions were successful. Among kabuli varieties tested in this experiment, FLIP-98-136C and FLIP 97-133C were relatively resistant to AB. Among desi varieties evaluated in this test 296T-7 and ICC 12512-9 showed relatively high resistance to AB. The varieties that were relatively resistant to AB were also relatively high yielding.

LAUDPC, SAUDPC and POD were negatively correlated with yield and KWT of both desi and kabuli chickpea varieties, but KWT and yield were not correlated. The KWT and yield of the highly susceptible varieties CDC Xena and Sanford were very low or nil due to the severe epidemics of AB.

Fungicide applications before and after flowering were effective in reducing LAUDPC, SAUDPC and POD and yield loss in both desi and kabuli varieties. The AB resistance level in desi varieties was generally greater than kabuli varieties, and a single application might be sufficient to manage AB. There was no variety × fungicide interaction for LAUDPC, SAUDPC and POD.

Several studies have examined the genetic diversity of *A. rabiei* from chickpea growing countries. Developing varieties with durable resistance to AB is the current challenge for breeders. Identifying sources of resistance should include screening of varieties at different growth stages. Multi- location and multi- year evaluations are needed to identify lines that are resistant to most pathotypes and in different environments. Wild relatives of chickpea such as *C. bijugum* and *C. echinospermum* were found to be good sources of resistance to AB (Collard et al., 2001). However, solutions to some of the problems associated with the embryo development resulting from such inter-specific crosses are yet to be found. Several embryo rescue techniques overcoming the species barrier are currently being developed at the Crop Development Centre, University of Saskatchewan. Pyramiding the genes responsible for resistance to AB is required to develop varieties with durable resistance. This can be achieved through international collaborations.

Fungicide applications are effective in minimizing the damage caused by AB. To minimize the cost of cultivation and environmental effects of fungicides, fungicide usage can be reduced by supplementing with genetic resistance. Adoption of cultural management options such as crop rotation and alternative management options such as those evaluated in this experiment can minimize damage due to AB. An integrated disease management strategy involving crop rotation for at least 4 years,

selection of resistant varieties, planting disease-free seed, seed treatment and foliar spray with fungicides would likely be the most economical and reliable approach to minimize AB severity and yield and quality losses.

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Appendix A

Table A.1 Analysis of variance for the effect of treatments on ascochyta blight severity measured as area under the disease progress curve (AUDPC) of chickpea cultivar Amit at Swift Current in 2004 and 2005

Year	Source of variation	DF	Sum of squares	Mean square	F Value	Pr > F
2004	Treatment	7	5.13	0.73	52.71	<.0001
	Rep	3	0.18	0.06	4.40	0.0183
	Error	21	0.24	0.01		
	Corrected total	31	5.71			
2005	Treatment	7	0.50	0.07	0.67	0.6957
	Rep	3	0.48	0.16	1.50	0.2443
	Error	21	2.25	0.10		
	Corrected	31	3.23			

Table A.2 Analysis of variance for the effect of treatments on plant height of chickpea cultivar Amit at Swift Current in 2004 and 2005

Year	Source of variation	DF	Sum of squares	Mean square	F Value	Pr > F
2004	Treatment	7	182.49	26.07	0.86	0.5532
	Rep	3	19.32	6.44	0.21	0.8857
	Error	17	513.02	30.17		
	Corrected total	27	708.94			
2005	Treatment	7	61.00	8.71	1.87	0.1257
	Rep	3	45.25	15.08	3.24	0.04
	Error	21	97.75	4.65		
	Corrected total	31	204.00			

Table A.3 Analysis of variance for the effect of treatments on number of pods per plant of chickpea cultivar Amit at Swift Current in 2004 and 2005

Year	Source of variation	DF	Sum of squares	Mean square	F Value	Pr > F
2004	Treatment	7	21903.80	3129.12	0.70	0.6711
	Rep	3	17245.30	5748.42	1.29	0.3105
	Error	17	5638.11	331.654		
	Corrected total	27	8166.51			
2005	Treatment	7	5990.47	855.78	1.21	0.3429
	Rep	3	1109.09	369.70	0.52	0.6727
	Error	21	1073.51	51.11		
	Corrected total	31	1523.44			

Table A.4 Analysis of variance for the effect of treatments on number of seeds per plant of chickpea cultivar Amit at Swift Current in 2004 and 2005

Year	Source of variation	DF	Sum of squares	Mean square	F Value	Pr > F
2004	Treatment	7	29850.90	4264.42	0.76	0.6307
	Rep	3	19307.80	6435.92	1.14	0.3612
	Error	17	7549.77	444.104		
	Corrected total	27	11374.50			
2005	Treatment	7	12185.00	1740.71	1.61	0.1881
	Rep	3	1764.34	588.11	0.54	0.6582
	Error	21	2772.59	132.02		
	Corrected total	31	3928.62			

Table A.5 Analysis of variance for the effect of treatments on average number of seeds per pod of chickpea cultivar Amit at Swift Current in 2004 and 2005

Year	Source of variation	DF	Sum of squares	Mean square	F Value	Pr > F
2004	Treatment	7	0.26	0.04	4.62	0.0047
	Rep	3	0.08	0.03	3.15	0.0523
	Error	17	0.13	0.01		
	Corrected total	27	0.48			
2005	Treatment	7	0.02	0.01	1.08	0.4107
	Rep	3	0.01	0.01	1.40	0.2720
	Error	21	1.00	0.05		
	Corrected total	31	1.61			

Table A.6 Analysis of variance for the effect of treatments on yield of chickpea cultivar Amit at Swift Current in 2004 and 2005

Year	Source of variation	DF	Sum of squares	Mean square	F Value	Pr > F
2004	Treatment	7	4952247.00	707464.00	4.53	0.0051
	Rep	3	620581.00	206860.00	1.33	0.2988
	Error	17	2652485.00	156029.00		
	Corrected total	27	8398908.00			
2005	Treatment	7	70866.70	10123.80	1.96	0.1099
	Rep	3	69619.80	23206.60	4.49	0.0138
	Error	21	108423.00	5163.02		
	Corrected total	31	248910.00			

Table A.7 Analysis of variance for the effect of treatments on 1000 KWT of chickpea cultivar Amit at Swift Current in 2004 and 2005

Year	Source of variation	DF	Sum of squares	Mean square	F Value	Pr > F
2004	Treatment	7	10441.30	1491.62	2.90	0.0343
	Rep	3	3232.33	1077.44	2.10	0.1385
	Error	17	8733.18	513.72		
	Corrected total	27	21868.11			
2005	Treatment	7	2305.00	329.28	10.86	<.0001
	Rep	3	21.75	7.25	0.24	0.8681
	Error	21	636.75	30.32		
	Corrected total	31	2963.50			

Table A.8 Analysis of variance for the effect of treatments on ascochyta blight severity measured as area under the disease progress curve (AUDPC) of chickpea cultivar CDC Xena at Swift Current in 2004 and 2005

Year	Source of variation	DF	Sum of squares	Mean square	F Value	Pr > F
2004	Treatment	7	1.59	0.22	15.65	<.0001
	Rep	3	0.03	0.01	0.65	0.5936
	Error	21	0.30	0.01		
	Corrected total	31	1.92			
2005	Treatment	7	2.13	0.30	7.52	0.0001
	Rep	3	1.28	0.42	10.52	0.0002
	Error	21	0.85	0.04		
	Corrected total	31	4.25			

Table A.9 Analysis of variance for the effect of treatments on plant height of chickpea cultivar CDC Xena at Swift Current in 2004 and 2005

Year	Source of variation	DF	Sum of squares	Mean square	F Value	Pr > F
2004	Treatment	7	106.97	15.28	0.65	0.7109
	Rep	3	58.09	19.36	0.82	0.4959
	Error	21	494.16	23.53		
	Corrected total	31	659.22			
2005	Treatment	7	173.50	24.79	1.96	0.11
	Rep	3	45.00	15.00	1.19	0.3389
	Error	21	265.50	12.64		
	Corrected total	31	484.00			

Table A.10 Analysis of variance for the effect of treatments on number of pods per plant of chickpea cultivar CDC Xena at Swift Current in 2004 and 2005

Year	Source of variation	DF	Sum of squares	Mean square	F Value	Pr > F
2004	Treatment	7	17939.50	2562.78	10.15	<.0001
	Rep	3	284.75	94.92	0.38	0.7712
	Error	21	212.05	10.09		
	Corrected total	31	941.02			
2005	Treatment	7	236.82	33.83	0.71	0.6619
	Rep	3	33.08	11.02	0.23	0.8727
	Error	21	996.42	47.44		
	Corrected total	31	1266.31			

Table A.11 Analysis of variance for the effect of treatments on number of seeds per plant of chickpea cultivar CDC Xena at Swift Current in 2004 and 2005

Year	Source of variation	DF	Sum of squares	Mean square	F Value	Pr > F
2004	Treatment	7	33878.90	4839.84	14.2	<.0001
	Rep	3	605.62	201.88	0.59	0.6269
	Error	21	286.29	13.63		
	Corrected total	31	1665.68			
2005	Treatment	7	13036.50	1862.36	7.81	0.0001
	Rep	3	2184.25	728.08	3.05	0.0510
	Error	21	2082.95	99.19		
	Corrected total	31	2860.27			

Table A.12 Analysis of variance for the effect of treatments on average number of seeds per pod of chickpea cultivar CDC Xena at Swift Current in 2004 and 2005

Year	Source of variation	DF	Sum of squares	Mean square	F Value	Pr > F
2004	Treatment	7	3.33	0.48	14.08	<.0001
	Rep	3	0.04	0.01	0.37	0.7768
	Error	21	0.71	0.03		
	Corrected total	31	4.07			
2005	Treatment	7	0.38	0.05	3.86	0.0075
	Rep	3	0.07	0.02	1.59	0.2214
	Error	21	0.60	0.03		
	Corrected total	31	0.97			

Table A.13 Analysis of variance for the effect of treatments on yield of chickpea cultivar CDC Xena at Swift Current in 2004 and 2005

Year	Source of variation	DF	Sum of squares	Mean square	F Value	Pr > F
2004	Treatment	7	8041372.00	1148767.00	15.25	<.0001
	Rep	3	193867.00	64622.30	0.86	0.4782
	Error	21	1581848.00	75326.10		
	Corrected total	31	9817087.00			
2005	Treatment	7	4882456.00	697494.00	64.63	<.0001
	Rep	3	54813.30	18271.10	1.69	0.1990
	Error	21	226619.00	10791.40		
	Corrected total	31	5163888.00			

Table A.14 Analysis of variance for the effect of treatments on 1000 KWT of chickpea cultivar CDC Xena at Swift Current in 2004 and 2005

Year	Source of variation	DF	Sum of squares	Mean square	F Value	Pr > F
2004	Treatment	7	386377.00	55196.80	17.99	<.0001
	Rep	3	5527.84	1842.62	0.60	0.6218
	Error	21	64428.40	3068.02		
	Corrected total	31	456333.00			
2005	Treatment	7	310634.00	44376.30	22.65	<.0001
	Rep	3	4235.59	1411.87	0.72	0.5509
	Error	21	41150.20	1959.53		
	Corrected total	31	356020.00			

Table A.15. Analysis of variance for the effect of fixed and random factors on ascochyta blight severity measured as area under the disease progress curve (AUDPC) on two chickpea cultivars at Swift Current in 2004 and 2005.

Source	DF	Sum of squares	Mean square	F value	Pr > F
Year	1	20.35	20.35	308.94	<.0001
Variety	1	32.09	32.09	487.13	<.0001
Treatment	7	6.64	0.95	14.40	<.0001
Rep	3	0.37	0.12	1.89	0.1361
Variety x Year	1	0.06	0.05	0.87	0.353
Treatment x Year	7	1.85	0.26	4.01	0.0007
Treatment x Variety	7	0.24	0.03	0.52	0.8179
Error	96	6.32	0.06		
Corrected total	123	69.88			

Table A.16. Analysis of variance for the effect of fixed and random factors on plant height of two chickpea cultivars at Swift Current in 2004 and 2005.

Source	DF	Sum of squares	Mean square	F value	Pr > F
Year	1	124.77	124.77	7.42	0.0077
Variety	1	660.79	660.79	39.31	<.0001
Treatment	7	223.60	31.94	1.90	0.0778
Rep	3	40.46	13.49	0.80	0.4956
Variety x Year	1	12.57	12.57	0.75	0.3893
Treatment x Year	7	104.68	14.95	0.89	0.5179
Treatment x Variety	7	78.01	11.14	0.66	0.7027
Error	96	1613.73	16.81		
Corrected total	123	2862.84			

Table A.17. Analysis of variance for the effect of fixed and random factors on number of pods per plant of two chickpea cultivars at Swift Current in 2004 and 2005.

Source	DF	Sum of squares	Mean square	F value	Pr > F
Year	1	1565.00	1565.00	16.78	<.0001
Variety	1	5565.31	5565.31	59.68	<.0001
Treatment	7	855.26	122.18	1.31	0.2538
Rep	3	89.32	29.77	0.32	0.8114
Variety x Year	1	5721.37	5721.37	61.35	<.0001
Treatment x Year	7	1145.04	163.58	1.75	0.1056
Treatment x Variety	7	1019.47	145.64	1.56	0.1561
Error	96	8952.20	93.25		
Corrected total	123	23677.36			

Table A.18. Analysis of variance for the effect of fixed and random factors on number of seeds per plant of two chickpea cultivars at Swift Current in 2004 and 2005.

Source	DF	Sum of squares	Mean square	F value	Pr > F
Year	1	803.23	803.23	5.38	0.0225
Variety	1	12808.24	12808.24	85.84	<.0001
Treatment	7	1786.78	255.25	1.71	0.1155
Rep	3	131.88	43.96	0.29	0.8292
Variety x Year	1	13052.35	13052.35	87.47	<.0001
Treatment x Year	7	2161.58	308.80	2.07	0.0542
Treatment x Variety	7	1733.87	247.70	1.66	0.1281
Error	96	14324.80	149.22		
Corrected total	123	44910.25			

Table A.19. Analysis of variance for the effect of fixed and random factors on average number of seed per pod of two chickpea cultivars at Swift Current in 2004 and 2005.

Source	DF	Sum of squares	Mean square	F value	Pr > F
Year	1	2.01	2.01	58.84	<.0001
Variety	1	4.04	4.04	118.55	<.0001
Treatment	7	1.66	0.24	6.95	<.0001
Rep	3	0.01	0.00	0.12	0.9464
Variety x Year	1	4.66	4.66	136.53	<.0001
Treatment x Year	7	1.59	0.23	6.68	<.0001
Treatment x Variety	7	0.55	0.08	2.31	0.0322
Error	96	3.27	0.03		
Corrected total	123	18.09			

Table A.20. Analysis of variance for the effect of fixed and random factors on yield of two chickpea cultivars at Swift Current in 2004 and 2005.

Source	DF	Sum of squares	Mean square	F value	Pr > F
Year	1	741295.59	741295.59	11.36	0.0011
Variety	1	54569579.00	54569579.00	835.90	<.0001
Treatment	7	12999711.00	1857101.60	28.45	<.0001
Rep	3	487471.54	162490.51	2.49	0.065
Variety x Year	1	58232.05	58232.05	0.89	0.3473
Treatment x Year	7	1912105.00	273157.86	4.18	0.0005
Treatment x Variety	7	1957278.90	279611.27	4.28	0.0004
Error	96	6267120.20	65282.50		
Corrected total	123	80137272.00			

Table A.21. Analysis of variance for the effect of fixed and random factors on KWT of two chickpea cultivars at Swift Current in 2004 and 2005.

Source	DF	Sum of squares	Mean square	F value	Pr > F
Year	1	177507.68	177507.68	123.09	<.0001
Variety	1	18355.98	18355.98	12.73	0.0006
Treatment	7	389969.95	55709.99	38.63	<.0001
Rep	3	4258.23	1419.41	0.98	0.4036
Variety x Year	1	18726.35	18726.35	12.99	0.0005
Treatment x Year	7	14793.38	2113.34	1.47	0.1888
Treatment x Variety	7	265268.32	37895.47	26.28	<.0001
Error	96	138443.32	1442.12		
Corrected total	123	1052492.02			

Appendix B

Table B.1 Analysis of variance for the effect of varieties and fungicide regimes on ascochyta blight severity on leaves measured as leaf area under the disease progress curve (LAUDPC) of 12 kabuli chickpea varieties evaluated at Shaunavon and Swift Current in 2004 and 2005

Site-Year	Effect	DF	F Value	Pr > F
Shaunavon -2004	Variety	11	16.5	<.0001
	Fungicide regime	1	20.68	<.0001
	Variety x Fungicide	11	0.64	0.7884
Shaunavon-2005	Variety	11	32.8	<.0001
	Fungicide regime	1	1.31	0.2584
	Variety x Fungicide	11	0.58	0.8357
Swift Current-2004	Variety	11	3.93	0.0004
	Fungicide regime	1	19.72	<.0001
	Variety x Fungicide	11	1.15	0.3444
Swift Current-2005	Variety	11	41.69	<.0001
	Fungicide regime	1	18.27	<.0001
	Variety x Fungicide	11	2.03	0.0464

Table B.2 Analysis of variance for the effect of varieties and fungicide regimes on ascochyta blight severity on stems measured as stem area under the disease progress curve (SAUDPC) of 12 kabuli chickpea varieties evaluated at Shaunavon and Swift Current in 2004 and 2005

Site-Year	Effect	DF	F Value	Pr > F
Shaunavon -2004	Variety	11	8.6	<.0001
	Fungicide regime	1	1.83	0.1827
	Variety x Fungicide	11	1.22	0.2987
Shaunavon-2005	Variety	11	41.11	<.0001
	Fungicide regime	1	4.44	0.0406
	Variety x Fungicide	11	1.36	0.2253
Swift Current-2004	Variety	11	4.54	0.0001
	Fungicide regime	1	12.22	0.001
	Variety x Fungicide	11	0.8	0.6363
Swift Current-2005	Variety	11	25.87	<.0001
	Fungicide regime	1	6.39	0.0149
	Variety x Fungicide	11	0.45	0.9247

Table B.3 Analysis of variance for the effect of varieties and fungicide regimes on ascochyta blight severity on pods measured as POD of 12 kabuli chickpea varieties evaluated at Shaunavon and Swift Current in 2004 and 2005

Site-Year	Effect	DF	F Value	Pr > F
Shaunavon -2004	Variety	11	4.56	0.0001
	Fungicide regime	1	0.23	0.6309
	Variety x Fungicide	11	4.16	0.0003
Shaunavon-2005	Variety	11	2.06	0.0431
	Fungicide regime	1	1.05	0.3114
	Variety x Fungicide	11	0.71	0.7190
Swift Current-2004	Variety	11	5.15	<.0001
	Fungicide regime	1	90.29	<.0001
	Variety x Fungicide	11	0.50	0.8937
Swift Current-2005	Variety	11	1.58	0.1360
	Fungicide regime	1	27.27	<.0001
	Variety x Fungicide	11	0.49	0.9005

Table B.4 Analysis of variance for the effect of varieties and fungicide regimes on yield of 12 kabuli chickpea varieties evaluated at Shaunavon and Swift Current in 2004 and 2005

Site-Year	Effect	DF	F Value	Pr > F
Shaunavon -2004	Variety	11	65.61	<.0001
	Fungicide regime	1	224.62	<.0001
	Variety x Fungicide	11	15.13	<.0001
Shaunavon-2005	Variety	11	7.91	<.0001
	Fungicide regime	1	4.53	0.0386
	Variety x Fungicide	11	0.91	0.5372
Swift Current-2004	Variety	11	25.37	<.0001
	Fungicide regime	1	422.56	<.0001
	Variety x Fungicide	11	3.72	0.0008
Swift Current-2005	Variety	11	86.32	<.0001
	Fungicide regime	1	5.24	0.0265
	Variety x Fungicide	11	3.32	0.0019

Table B.5 Analysis of variance for the effect of varieties and fungicide regimes on KWT of 12 kabuli chickpea varieties evaluated at Shaunavon and Swift Current in 2004 and 2005

Site-Year	Effect	DF	F Value	Pr > F
Shaunavon -2004	Variety	11	4.35	0.0006
	Fungicide regime	1	69.64	<.0001
	Variety x Fungicide	11	3.04	0.0104
Shaunavon-2005	Variety	11	27.34	<.0001
	Fungicide regime	1	0.07	0.7941
	Variety x Fungicide	11	1.04	0.4249
Swift Current-2004	Variety	11	11.69	<.0001
	Fungicide regime	1	253.05	<.0001
	Variety x Fungicide	11	4.86	0.0036
Swift Current-2005	Variety	11	13.23	<.0001
	Fungicide regime	1	5.46	0.0237
	Variety x Fungicide	11	0.48	0.9046

Table B.6 Analysis of variance for the effect of varieties and fungicide regimes on ascochyta blight severity on leaves measured as leaf area under the disease progress curve (LAUDPC) of 12 desi chickpea varieties evaluated at Shaunavon and Swift Current in 2004 and 2005

Site-Year	Effect	DF	F Value	Pr > F
Shaunavon -2004	Variety	11	1.61	0.1288
	Fungicide regime	1	40.40	<.0001
	Variety x Fungicide	11	0.42	0.9409
Shaunavon-2005	Variety	11	0.89	0.5610
	Fungicide regime	1	1.58	0.2149
	Variety x Fungicide	11	0.31	0.9795
Swift Current-2004	Variety	11	1.99	0.0517
	Fungicide regime	1	66.23	<.0001
	Variety x Fungicide	11	0.98	0.4806
Swift Current-2005	Variety	11	2.32	0.0230
	Fungicide regime	1	25.72	<.0001
	Variety x Fungicide	11	0.79	0.6442

Table B.7 Analysis of variance for the effect of varieties and fungicide regimes on ascochyta blight severity on stems measured as stem area under the disease progress curve (SAUDPC) of 12 desi chickpea varieties evaluated at Shaunavon and Swift Current in 2004 and 2005

Site-Year	Effect	DF	F Value	Pr > F
Shaunavon -2004	Variety	11	2.36	0.0201
	Fungicide regime	1	0.01	0.9251
	Variety x Fungicide	11	1.34	0.2349
Shaunavon-2005	Variety	11	1.59	0.135
	Fungicide regime	1	1.01	0.3207
	Variety x Fungicide	11	0.27	0.9886
Swift Current-2004	Variety	11	2.13	0.0354
	Fungicide regime	1	6.71	0.0126
	Variety x Fungicide	11	1.13	0.3599
Swift Current-2005	Variety	11	3.97	0.0004
	Fungicide regime	1	7.79	0.0076
	Variety x Fungicide	11	1.29	0.2609

Table B.8 Analysis of variance for the effect of varieties and fungicide regimes on ascochyta blight on pods measured as POD of 12 desi chickpea varieties evaluated at Shaunavon and Swift Current in 2004 and 2005.

Site-Year	Effect	DF	F Value	Pr > F
Shaunavon -2004	Variety	11	0.48	0.9053
	Fungicide regime	1	0.90	0.3463
	Variety x Fungicide	11	0.79	0.6504
Shaunavon-2005	Variety	11	0.38	0.9587
	Fungicide regime	1	7.23	0.0099
	Variety x Fungicide	11	0.56	0.8515
Swift Current-2004	Variety	11	1.71	0.1010
	Fungicide regime	1	112.25	<.0001
	Variety x Fungicide	11	1.10	0.3811
Swift Current-2005	Variety	11	1.90	0.0623
	Fungicide regime	1	14.36	0.0004
	Variety x Fungicide	11	2.10	0.0383

Table B.9 Analysis of variance for the effect of varieties and fungicide regimes on Yield of 12 desi chickpea varieties evaluated at Shaunavon and Swift Current in 2004 and 2005

Site-Year	Effect	DF	F Value	Pr > F
Shaunavon -2004	Variety	11	6.51	<.0001
	Fungicide regime	1	21.33	<.0001
	Variety x Fungicide	11	0.48	0.905
Shaunavon-2005	Variety	11	2.30	0.0244
	Fungicide regime	1	0.12	0.7343
	Variety x Fungicide	11	0.55	0.859
Swift Current-2004	Variety	11	15.14	<.0001
	Fungicide regime	1	112.73	<.0001
	Variety x Fungicide	11	0.65	0.7759
Swift Current-2005	Variety	11	3.80	0.0007
	Fungicide regime	1	0.31	0.5801
	Variety x Fungicide	11	1.06	0.41

Table B.10 Analysis of variance for the effect of varieties and fungicide regimes on KWT of 12 desi chickpea varieties evaluated at Shaunavon and Swift Current in 2004 and 2005

Site-Year	Effect	DF	F Value	Pr > F
Shaunavon -2004	Variety	11	8.94	<.0001
	Fungicide regime	1	96.04	<.0001
	Variety x Fungicide	11	0.53	0.8707
Shaunavon-2005	Variety	11	94.39	<.0001
	Fungicide regime	1	0.45	0.5065
	Variety x Fungicide	11	0.40	0.9498
Swift Current-2004	Variety	11	12.09	<.0001
	Fungicide regime	1	90.49	<.0001
	Variety x Fungicide	11	0.85	0.5869
Swift Current-2005	Variety	11	67.85	<.0001
	Fungicide regime	1	0.21	0.6491
	Variety x Fungicide	11	0.75	0.6854

Table B.11 Analysis of variance for ascochyta blight on leaves measured as leaf area under the disease progress curve (LAUDPC) of four kabuli chickpea varieties grown under controlled environmental conditions

Effect	DF	F Value	Pr > F
Experimental run	2	3.69	0.0409
Variety	3	75.83	<.0001

Table B.12 Analysis of variance for ascochyta blight on stems measured as stem area under the disease progress curve (SAUDPC) of four kabuli chickpea varieties grown under controlled environmental conditions

Effect	DF	F Value	Pr > F
Experimental run	2	20.26	<.0001
Variety	3	58.27	<.0001

Table B.13 Analysis of variance for the effect of fixed and random factors on the ascochyta blight reaction to leaves measured as leaf area under the disease progress curve (LAUDPC) of 12 kabuli chickpea at Swift current and Shaunavon in 2004 and 2005.

Source	DF	Sum of squares	Mean Square	F Value	Pr > F
Year	1	7.15	7.15	104.36	<.0001
Location	1	0.86	0.86	12.55	0.0005
Variety	11	28.21	2.56	37.42	<.0001
Fungicide	1	3.76	3.76	54.90	<.0001
Variety x Fungicide	11	0.33	0.03	0.44	0.9361
Year x Location	1	0.01	0.01	0.01	0.9123
Variety x Year	9	0.84	0.09	1.36	0.2069
Fungicide x Year	1	1.23	1.23	17.96	<.0001
Variety x Location	11	0.67	0.06	0.89	0.5518
Fungicide x Location	1	0.29	0.29	4.19	0.0419
Error	197	13.50	0.07		
Corrected total	245	54.00			

Table B.14 Analysis of variance for the effect of fixed and random factors on the ascochyta blight reaction to stems measured as stem area under the disease progress curve (SAUDPC) of 12 kabuli chickpea at Swift current and Shaunavon in 2004 and 2005.

Source	DF	Sum of squares	Mean Square	F Value	Pr > F
Year	1	1.126	1.13	8.48	0.004
Location	1	3.62	3.62	27.23	<.0001
Variety	11	29.32	2.66	20.06	<.0001
Fungicide	1	3.099	3.10	23.32	<.0001
Variety x Fungicide	11	1.29	0.12	0.89	0.5551
Year x Location	1	0.01	0.01	0.08	0.7816
Variety x Year	9	0.75	0.08	0.63	0.7694
Fungicide x Year	1	0.90	0.91	6.82	0.0097
Variety x Location	11	0.87	0.08	0.60	0.8299
Fungicide x Location	1	0.89	0.89	6.71	0.0103
Error	197	26.18	0.13		
Corrected total	245	69.50			

Table B.15 Analysis of variance for the effect of fixed and random factors on the ascochyta blight reaction to pods measured as pod disease rating (POD) of 12 kabuli chickpea at Swift current and Shaunavon in 2004 and 2005.

Source	DF	Sum of squares	Mean Square	F Value	Pr > F
Year	1	19.14	19.14	291.67	<.0001
Location	1	2.59	2.59	39.39	<.0001
Variety	11	1.95	0.18	2.70	0.0029
Fungicide	1	1.42	1.42	21.61	<.0001
Variety x Fungicide	11	0.36	0.03	0.50	0.9025
Year x Location	1	1.43	1.43	21.74	<.0001
Variety x Year	9	0.51	0.05	0.86	0.5585
Fungicide x Year	1	0.38	0.38	5.79	0.0171
Variety x Location	11	0.57	0.05	0.78	0.6549
Fungicide x Location	1	3.24	3.24	49.44	<.0001
Error	197	12.93	0.06		
Corrected total	245	52.43			

Table B.16 Analysis of variance for the effect of fixed and random factors on the yield of 12 kabuli chickpea at Swift current and Shaunavon in 2004 and 2005.

Source	DF	Sum of squares	Mean Square	F Value	Pr > F
Year	1	50.79	50.79	214.10	<.0001
Location	1	34.22	34.22	144.23	<.0001
Variety	11	37.30	3.39	14.29	<.0001
Fungicide	1	62.84	62.84	264.91	<.0001
Variety x Fungicide	11	3.83	0.35	1.47	0.1453
Year x Location	1	4.87	4.86	20.51	<.0001
Variety x Year	9	10.82	1.20	5.07	<.0001
Fungicide x Year	1	61.86	61.86	260.74	<.0001
Variety x Location	11	8.87	0.81	3.40	0.0002
Fungicide x Location	1	11.01	11.01	46.39	<.0001
Error	197	46.74	0.24		
Corrected total	245	266.48			

Table B. 17 Analysis of variance for the effect of fixed and random factors on the 1000-seed weight (KWT) of 12 kabuli chickpea at Swift current and Shaunavon in 2004 and 2005.

Source	DF	Sum of squares	Mean Square	F Value	Pr > F
Year	1	11.18	11.18	890.60	<.0001
Location	1	0.67	0.67	53.92	<.0001
Variety	11	3.21	0.29	23.26	<.0001
Fungicide	1	2.46	2.45	195.76	<.0001
Variety x Fungicide	11	0.30	0.03	2.21	0.016
Year x Location	1	0.04	0.04	3.06	0.082
Variety x Year	9	0.44	0.05	3.89	0.0002
Fungicide x Year	1	1.94	1.94	154.82	<.0001
Variety x Location	11	0.49	0.04	3.61	0.0001
Fungicide x Location	1	0.18	0.18	14.89	0.0002
Error	174	2.18	0.01		
Corrected total	222	24.52			

Table B.18 Analysis of variance for the effect of fixed and random factors on the ascochyta blight reaction to leaves measured as leaf area under the disease progress curve (LAUDPC) of 12 desi chickpea at Swift current and Shaunavon in 2004 and 2005.

Source	DF	Sum of squares	Mean Square	F Value	Pr > F
Year	1	4.96	4.96	77.33	<.0001
Location	1	0.03	0.03	0.41	0.5229
Variety	11	1.96	0.18	2.77	0.0021
Fungicide	1	6.49	6.49	101.23	<.0001
Variety x Fungicide	11	0.79	0.07	1.12	0.343
Year x Location	1	3.08	3.08	48.08	<.0001
Variety x Year	11	0.64	0.06	0.90	0.5397
Fungicide x Year	1	2.03	2.03	31.72	<.0001
Variety x Location	11	1.08	0.10	1.53	0.1212
Fungicide x Location	1	0.09	0.09	1.34	0.2483
Error	237	15.19	0.06		
Corrected total	287	36.31			

Table B.19 Analysis of variance for the effect of fixed and random factors on the ascochyta blight reaction to leaves measured as stem area under the disease progress curve (SAUDPC) of 12 desi chickpea at Swift current and Shaunavon in 2004 and 2005.

Source	DF	Sum of squares	Mean Square	F Value	Pr > F
Year	1	2.14	2.14	14.72	0.0002
Location	1	0.00	0.00	0.02	0.8846
Variety	11	7.22	0.66	4.51	<.0001
Fungicide	1	1.16	1.16	7.95	0.0052
Variety x Fungicide	11	1.13	0.10	0.71	0.7309
Year x Location	1	0.66	0.66	4.55	0.0339
Variety x Year	11	1.93	0.18	1.21	0.2822
Fungicide x Year	1	0.15	0.15	1.00	0.3187
Variety x Location	11	1.73	0.16	1.08	0.3797
Fungicide x Location	1	0.66	0.66	4.54	0.0342
Error	237	34.51	0.15		
Corrected total	287	51.30			

Table B.20. Analysis of variance for the effect of fixed and random factors on the ascochyta blight reaction to pods measured as pod disease rating (POD) of 12 desi chickpea at Swift current and Shaunavon in 2004 and 2005.

Source	DF	Sum of squares	Mean Square	F Value	Pr > F
Year	1	20.63	20.63	336.72	<.0001
Location	1	6.52	6.52	106.45	<.0001
Variety	11	0.97	0.09	1.44	0.1566
Fungicide	1	4.89	4.89	79.82	<.0001
Variety x Fungicide	11	0.47	0.04	0.69	0.7466
Year x Location	1	1.16	1.16	18.96	<.0001
Variety x Year	11	0.32	0.03	0.47	0.921
Fungicide x Year	1	0.68	0.68	11.13	0.001
Variety x Location	11	0.92	0.08	1.36	0.1927
Fungicide x Location	1	1.92	1.92	31.29	<.0001
Error	237	14.52	0.06		
Corrected total	287	53.00			

Table B. 21. Analysis of variance for the effect of fixed and random factors on the yield of 12 desi chickpea at Swift current and Shaunavon in 2004 and 2005.

Source	DF	Sum of squares	Mean Square	F Value	Pr > F
Year	1	86.90	86.90	470.42	<.0001
Location	1	55.11	55.11	298.31	<.0001
Variety	11	31.98	2.91	15.74	<.0001
Fungicide	1	14.18	14.18	76.76	<.0001
Variety x Fungicide	11	0.80	0.07	0.40	0.9569
Year x Location	1	28.06	28.06	151.91	<.0001
Variety x Year	11	22.41	2.04	11.03	<.0001
Fungicide x Year	1	15.00	15.00	81.18	<.0001
Variety x Location	11	5.59	0.51	2.75	0.0023
Fungicide x Location	1	3.70	3.70	20.01	<.0001
Error	236	43.60	0.18		
Corrected total	286	298.06			

Table B. 22. Analysis of variance for the effect of fixed and random factors on the 1000-seed weight (KWT) of 12 desi chickpea at Swift current and Shaunavon in 2004 and 2005.

Source	DF	Sum of squares	Mean Square	F Value	Pr > F
Year	1	24.87	24.87	2761.45	<.0001
Location	1	0.64	0.64	70.72	<.0001
Variety	11	5.63	0.51	56.84	<.0001
Fungicide	1	1.55	1.55	171.96	<.0001
Variety x Fungicide	11	0.02	0.00	0.16	0.9992
Year x Location	1	0.59	0.59	65.33	<.0001
Variety x Year	11	0.30	0.03	3.06	0.0008
Fungicide x Year	1	1.54	1.54	170.91	<.0001
Variety x Location	11	0.17	0.02	1.68	0.0793
Fungicide x Location	1	0.01	0.01	1.37	0.2424
Error	223	2.01	0.01		
Corrected total	273	33.74			