2010

Evaluating the Agronomic Potential of Chickpea Germplasm for Western Nebraska

Carlos A. Urrea
University of Nebraska-Lincoln, currea2@unl.edu

Evaluating the Agronomic Potential of Chickpea Germplasm for Western Nebraska

Carlos A. Urrea,* Robert M. Harveson, Ann E. Koehler, Paul Burgener, and David D. Baltensperger

Alternative Crops

ABSTRACT

The chickpea or garbanzo bean (*Cicer arietinum* L.) shows promise as an alternative crop for Nebraska because it fits well with existing equipment, processors, and infrastructure. Initially chickpea production grew rapidly in Nebraska, but it declined in recent years because of Ascochyta blight [*Ascochyta rabiei* (Pass.) Labr.] and concern about the variability in yield, seed size, pest resistance, and quality of current varieties. Therefore, we evaluated existing chickpea germplasm (Western Regional Chickpea Trial provided by USDA-ARS, Pullman, WA) under irrigated and dryland conditions at 11 environments in western Nebraska during 2005 to 2007 to identify lines that are well adapted to this region, have desirable yield and quality characteristics, and are resistant to Ascochyta blight. This paper reports findings of the agronomic characteristic portion of the study. CA0090B347C and W6 17256 were the top yielding entries under both irrigated and dryland conditions and showed some resistance to Ascochyta blight however, their seed size did not meet commercial standards. Nevertheless, these lines show promise as parental germplasm for ongoing breeding efforts. 'Sierra', a commercial cultivar, may be an acceptable alternative, though fungicides treatments will likely be needed to control blight. During these trials, only irrigated production was economically viable. Returns from the higher yielding entries were competitive and if achieved on a consistent basis would make chickpea a viable crop for this region. For dryland production to be feasible, the cost of production needs to be reduced and/or varieties need to be developed with improved yield and seed size under limited moisture conditions.

The chickpea or garbanzo bean was one of the first grain legumes or pulse crops domesticated in the Old World and probably originated in present-day Turkey and Syria (van der Maesen, 1987). There are two types of chickpeas, the larger, light-colored kabuli and the smaller, dark-colored desi. Chickpeas are primarily used for human consumption and are a good source of protein. Long a staple in many parts of the world, chickpeas are becoming increasingly popular in North America where they are primarily used as a salad bean (Pushpamma and Geervani, 1987; van der Maesen, 1987) and increasingly in hummus (Lucier et al., 2000).

Historically chickpea has been a minor crop in the United States, though acreage has increased markedly since the late 1980s (Price, 2002) with 81,900 ha planted in 2008 (USDA-ERS, 2009). The majority of the 2008 crop (87.7% kabuli) was produced in Washington (36.6%), Idaho (32.6%), North Dakota (11.4%), and California (7.8%) (USDA-ERS, 2009).

United States exports have grown from 1,643,846 kg in 1989 to 23,411,477 kg in 2008 (USDA-ERS, 2009). During that same period, imports increased from 11,822,177 to 16,503,171 kg (USDA-ERS, 2009). Domestic consumption has grown as well, from 0.06 kg person^{-1} in 1980 to 0.15 kg person^{-1} in 2008 (USDA-ERS, 2009).

Long grown in California and the Palouse region (eastern Washington, northern Idaho, and northeast Oregon), production of chickpea has expanded to the northern Great Plains, particularly North Dakota, since the mid-1990s (Price, 2002). Pulse crop production has grown in this region because of the availability of affordable, relatively flat land and because standard equipment used for cereal crops can be used to harvest these crops (Price, 2002). Chickpea is primarily grown in arid and semiarid areas (Millan et al., 2006) and recently there has been renewed interest in chickpea as an alternative crop for the High Plains region because it can be grown under dryland or limited irrigation production systems (Margheim et al., 2004).

One of the major factors limiting chickpea production is Ascochyta blight, a fungal disease that can affect all aboveground plant parts (Nene and Reddy, 1987; Kaiser, 1992). Economic losses result from reduced yields and quality (Harveson, 2007). It is spread by infected seeds and residue from diseased plants (Nene and Reddy, 1987; Kaiser, 1992; Akem, 1999). Cool, moist, and windy conditions favor the development and spread of the disease (Nene and Reddy, 1987; Kaiser, 1992; Akem, 1999). In the United States, the presence of Ascochyta blight in chickpea has been reported in Washington (Kaiser and Muehlbauer, 1984), Idaho (Derie et al., 1985; Kaiser and Muehlbauer, 1988), California (Guzman et al., 1995), Montana and North Dakota (Miller et al., 2002), and Nebraska (Harveson, 2002).

C.A. Urrea, R.M. Harveson, A.E. Koehler, and P. Burgener, Univ. of Nebraska, Panhandle Research & Extension Center, 4502 Ave. I, Scottsbluff, NE 69361; D.D. Baltensperger, Texas A&M Univ., 370 Olsen Blvd., College Station, TX 77843-2472. Received 14 Jan. 2010. *Corresponding author (currea2@unl.edu).

Published in Agron. J. 102:1179–1185 (2010)
Published online 12 May 2010
doi:10.2134/agronj2010.0018

Abbreviations: SI, stability index.

Table 1. Chickpea genotypes obtained through the Western Regional Chickpea Trial, Pullman, WA, that were evaluated in six irrigated and five dryland environments in western Nebraska from 2005 to 2007.

Genotypes	Type	Source
Dwelley	commercial cultivar	Muehlbauer et al., 1998
Dylan	commercial cultivar	Muehlbauer et al., 2006
Sierra	commercial cultivar	Muehlbauer et al., 2004
CA9783163C	advanced line	USDA-ARS
CA9990B1579C	advanced line	USDA-ARS
CA0090B347C	advanced line	USDA-ARS
CA9890233W	advanced line	USDA-ARS
CA99901875C	advanced line	USDA-ARS
W6 17256	advanced line	USDA Plant Introduction

Control strategies typically involve integrating the use of pathogen-free seed, burying or burning residue, rotating chickpeas with nonhost crops, and judiciously using fungicides (Nene and Reddy, 1987; Kaiser, 1992; Akem, 1999; Gan et al., 2006; Harveson, 2007). Development of resistant cultivars is the preferred approach to controlling Ascochyta blight, however, this has proven elusive as resistance has not always been effective under high disease pressure or across locations, and shifts in levels of resistance have been observed over time or as plants mature (Singh and Reddy, 1996; Akem, 1999; Jayakumar et al., 2005). Developing cultivars with high levels of resistance that is effective over multiple locations and stable over time is challenging because of the complexity of both the pathogen and the patterns of inheritance of resistance. Ascochyta blight outbreaks are influenced by environmental conditions and the genetic background of both the cultivar and the pathogen population (Jayakumar et al., 2005). To be commercially viable, cultivars must also possess desirable agronomic characteristics and some sources of resistance lack preferred yield and quality traits (Singh and Reddy, 1996).

Nebraska producers need the flexibility to take advantage of emerging market opportunities and chickpeas have this potential. Chickpeas fit well with existing equipment, dry bean processors, and regional infrastructure. Initially chickpea production in Nebraska grew rapidly (from 607 ha in 2000 to almost 4047 ha in 2006). However, planted hectares declined to fewer than 121 ha in 2007 largely because of the threat for Ascochyta blight. Also of concern is the variability of yield, seed size, pest resistance, and quality of currently available varieties. Thus it is essential that well-adapted cultivars with desirable agronomic characteristics be developed.

Therefore, we evaluated existing chickpea germplasm (Western Regional Chickpea Trial provided by USDA-ARS, Pullman, WA) in field trials during 2005 to 2007 to identify lines that are well adapted to this region, have desirable yield and quality characteristics, and are resistant to Ascochyta blight. Promising lines will be included in our ongoing breeding efforts to develop economically viable chickpea cultivars for this region. Here we report the results of the agronomic characteristics portion of the study. Results of the Ascochyta blight resistance portion of the study were reported in Harveson et al. (2009).

MATERIALS AND METHODS

Locations

This study was conducted from 2005 to 2007 at two research sites associated with the University of Nebraska (Scottsbluff and Sidney) and in a grower's field located near Alliance, NE. Soil at the Scottsbluff site (41°53′36″ N, 103°40′42″ W, 1200 m elevation) is a Tripp very fine sandy loam soil (coarse-silty, mixed, superactive, mesic Aridic Haplustoll). Soil at the Sidney site (41°12′ N, 103°0′ W, 1315 m elevation) is a silt loam (fine-silty, mixed, superactive, mesic Aridic Argiustoll). Soil at the Alliance site (42°25′ N, 102°96′ W, 1279 m elevation) is a fine-silty, mixed, superactive, mesic Aridic Argiustoll.

Germplasm

Fourteen entries were evaluated at each location during each of the 3 yr. Only the nine entries that were common to all sites and years are included in this paper. These entries consisted of six advanced lines and three commercial cultivars obtained from the chickpea breeding program at USDA-ARS, Pullman, WA through the Western Regional Chickpea Trial and the National Plant Germplasm System (Table 1).

Experimental Design

We evaluated the adaptation of chickpea germplasm under irrigated and dryland conditions in the Nebraska Panhandle. These included five dryland trials: Scottsbluff (2006), Sidney (2005 and 2006), and Alliance (2005 and 2006); and six irrigated trials: Scottsbluff (2005, 2006, and 2007), Sidney (2006), and Alliance (2005 and 2006). Within each environment, genotypes were assigned to experimental units using a randomized complete block design with four replications at each location. All plots were 1.7 m wide and consisted of eight rows. Row length varied by location: Alliance (6 m), Scottsbluff irrigated (3 m) and dryland (6 m), Sidney irrigated (7.4 m) and dryland (10 m). Seed was planted at a density of 44.7 seeds m^{-2}. Before planting, seeds were inoculated with N-Dure (Microbials, LLC, Kentland, IN) at a rate of 2.2 kg inoculum 682 kg $seed^{-1}$.

Trials were planted in early May when soil temperature at a depth of 5 cm were 7.2°C and rising as recommended by Margheim et al. (2004). All trials were planted in fields where corn (*Zea mays* L.) had been grown the preceding year.

Phosphorus was applied at a rate of 4.8 kg ha^{-1} by broadcasting an 11–15–0 starter fertilizer. Plots were treated with 85 g ha^{-1} sulfentrazone (Spartan, FMC Corp., Philadelphia, PA) preplant and 170 g ha^{-1} of quizalofop-P ethyl (Assure II, Dupont, Wilmington, DE) postplant to control broadleaf and grass weeds, respectively. Because the purpose of this study was to evaluate the inherent agronomic and resistance characteristics of the germplasm, no fungicide treatments were applied at the University of Nebraska sites (Scottsbluff and Sidney). However, the cooperating grower (Alliance) followed his customary production practices and applied 658 mL ha^{-1} pyraclostrobin (Headline, BASF Crop Protection) at flowering to control Ascochyta blight. After emergence and throughout the growing season irrigated plots were watered approximately once a week with 1.3 cm of water using sprinkler irrigation systems. Plots were harvested with a plot combine (Wintersteiger Classic, Salt Lake City, UT).

Response Variables

Environmental data, including daily rainfall (mm), and minimum and maximum temperatures (°C) were obtained from data recorded by automated weather stations near each

Table 2. Planting dates, amount of rainfall, and number of days with temperature above 35°C after flowering in irrigated and dryland environments at three locations in Nebraska from 2005 to 2007.

Climate variables	2005			2006			2007
	Scottsbluff	Alliance	Sidney	Scottsbluff	Alliance	Sidney	Scottsbluff
Planting dates	5 May	6 May	4 May	8 May	2 May	3 May	1 May
Rainfall, mm	195	241	322	116	145	172	49
No. days max. T > 35°C	12	16	9	21	20	20	20

research site and reported by the High Plains Regional Climate Center (http://www.hprcc.unl.edu) (Table 2).

To evaluate plant response to environments, we determined yield (kg ha^{-1}), 100-seed weight (g), and the number of days to harvest (when plants were dry enough to be harvested with a combine). We calculated Eberhart and Russell's (1966) stability index (SI)to evaluate the yield performance of the genotypes across environments. The prevalence of Ascochyta blight in each plot was rated each year in mid-July. These data were reported in Harveson et al. (2009).

Statistical Analysis

Data were analyzed using PROC MIXED (SAS Institute, 2004). Each environment (location-year combination) was analyzed separately. Location and replication were treated as random effects and genotype was treated as a fixed effect. Homogeneity of the variances was evaluated using Barlett's χ^2 test (Steel and Torrie, 1980). When appropriate the data were pooled. In the pooled analyses, year × location and replication were random effects and genotypes were fixed effects. Means were separated using an *F*-protected LSD. All tests were considered significant at $P \leq 0.05$. The Eberhart and Russell (1966) SI was plotted against mean seed yield across irrigated environments to further evaluate the comparative performance of the nine chickpea genotypes.

Economic Analysis

Chickpea production data were used to develop an economic analysis using a partial budgeting approach based on individual observations. All site years were used in the dryland analysis, while only 4 of the 6 yr were used for the irrigated analysis to evaluate the economic potential of irrigated chickpeas both with (Alliance 2005 and 2006) and without (Scottsbluff 2005 and 2006) fungicide protection. Each observation was evaluated for gross and net return. The gross return was derived using the moisture adjusted weight multiplied by a 3-yr average of the grower price as reported by the USDA Agricultural Market Service. Net return was determined by subtracting the cost of production, either dryland or irrigated, from the gross return. All costs were assumed to be constant except for hauling, which was based on crop yield, and fungicide treatments for the Alliance site. Cost of dryland and irrigated chickpea production was obtained from "Chickpea Production in the High Plains" (Margheim et al., 2004). An ANOVA was performed on these data using PROC GLM (SAS Institute, 2004).

RESULTS AND DISCUSSION

Seed yield, 100-seed weight, and days to harvest varied ($P \leq 0.01$) with genotype, environment, and their first order interaction in both irrigated and dryland environments (Table 3). Most of the variance is attributed to environments followed by genotypes.

Yield

Seed yield varied widely among environments and entries. On average, each entry performed better under irrigated than under dryland conditions. Overall, seed yield averaged 53% lower under dryland than under irrigated conditions, ranging from 48 to 57% lower for individual entries (Table 4).

Among irrigated environments, yield was greatest at Scottsbluff 2006 and least at Scottsbluff 2007 followed by Sidney 2006 (Table 4). The lower yields in the latter two environments may be due in part to the relatively high incidence of Ascochyta blight, during these trials. Ascochyta blight ratings averaged 2.7 and 3.2 (1–5 scale where 1 = no disease and 3 = 50% stand with 50% of plants showing symptoms) at Scottsbluff and Sidney, respectively (Harveson et al., 2009). Additional factors include a high incidence of root rot (*Rhizoctonia solani*) (data not shown) in Scottsbluff 2007, and early season hail in Sidney 2006.

Among dryland environments, yield was greatest at Alliance 2005 and least at Scottsbluff and Alliance 2006 (Table 4). These results may, in part, reflect early growing season weather conditions as high temperatures can reduce flowering and seed set (Auckland and van der Maesen, 1980). Alliance 2005 experienced below average temperatures and above average precipitation during May and June, whereas Scottsbluff and Alliance 2006 had above average temperatures from May through July and below average precipitation during May (Fig. 1). However, Sidney 2006 experienced similar temperature and precipitation patterns (Fig. 1), yet on average yielded about 2.7 times more than Alliance or Scottsbluff. Sidney received the greatest amount

Table 3. Mean squares from combined analysis of variance for three chickpea cultivars and six genotypes evaluated in six irrigated and five dryland environments in western Nebraska from 2005 to 2007.

Source	Seed yield		100-seed weight		Days to harvest	
	DF	Mean squares	DF	Mean squares	DF	Mean squares
			Irrigated			
Environment (E)	5	20018545**	5	1792.7**	3	1635.4**
Blocks/E	18	65908	18	12.4	12	19.6
Genotype (G)	8	1049311**	8	249.8**	8	83.3**
G × E	40	480664**	38	79.1**	24	44.2**
Error	140	44520	129	6.4	96	11.9
			Dryland			
Environment (E)	4	1301794**	3	492.6**	3	238.7**
Blocks/E	14	29945**	12	56.1	12	22.9
Genotype (G)	8	170929**	8	254.8**	8	43.4**
G × E	32	44871**	23	40.0**	24	48.2**
Error	112	10170	79	9.0	96	5.9

** Significant at $P < 0.01$.

Table 4. Mean yield of three chickpea cultivars and six genotypes evaluated in six irrigated and five dryland environments in western Nebraska from 2005 to 2007.

Genotype	2005 Scottsbluff	2005 Alliance	2005 Sidney	2006 Scottsbluff	2006 Alliance	2006 Sidney	2007 Scottsbluff	Average
	kg ha^{-1}							
				Irrigated				
CA0090B347C	1954	2105		2289	1795	874	327	1557
W6 17256	1661	1846		1048	1574	1456	341	1321
Sierra	1509	1526		2354	1738	215	358	1283
CA9990B1579C	1645	1721		2332	1503	390	69	1276
Dwelley	851	1704		2190	1387	71	138	1057
Dylan	871	1348		2319	1403	18	188	1024
CA9783163C	716	1579		2134	1471	41	104	1008
CA9890233W	484	1330		2445	1523	138	126	1008
CA99901875W	329	1140		2134	1236	44	261	857
Mean	1113	1589		2138	1514	360	213	1155
LSD (0.05)†	366	352		380	352	198	103	
				Dryland				
CA0090B347C		1681	796	421	285	845		806
W6 17256		1228	228	214	332	936		588
CA9990B1579C		1255	409	178	265	745		570
Sierra		1240	319	373	216	686		567
CA9783163C		1425	318	160	198	521		524
CA9890233W		1268	409	96	250	584		521
Dwelley		1160	319	136	130	525		454
CA99901875W		1123	387	131	147	441		446
Dylan		1049	205	322	272	361		442
Mean		1270	377	226	223	627		547
LSD (0.05)†		256	127	150	140	172		

† To compare means among genotypes.

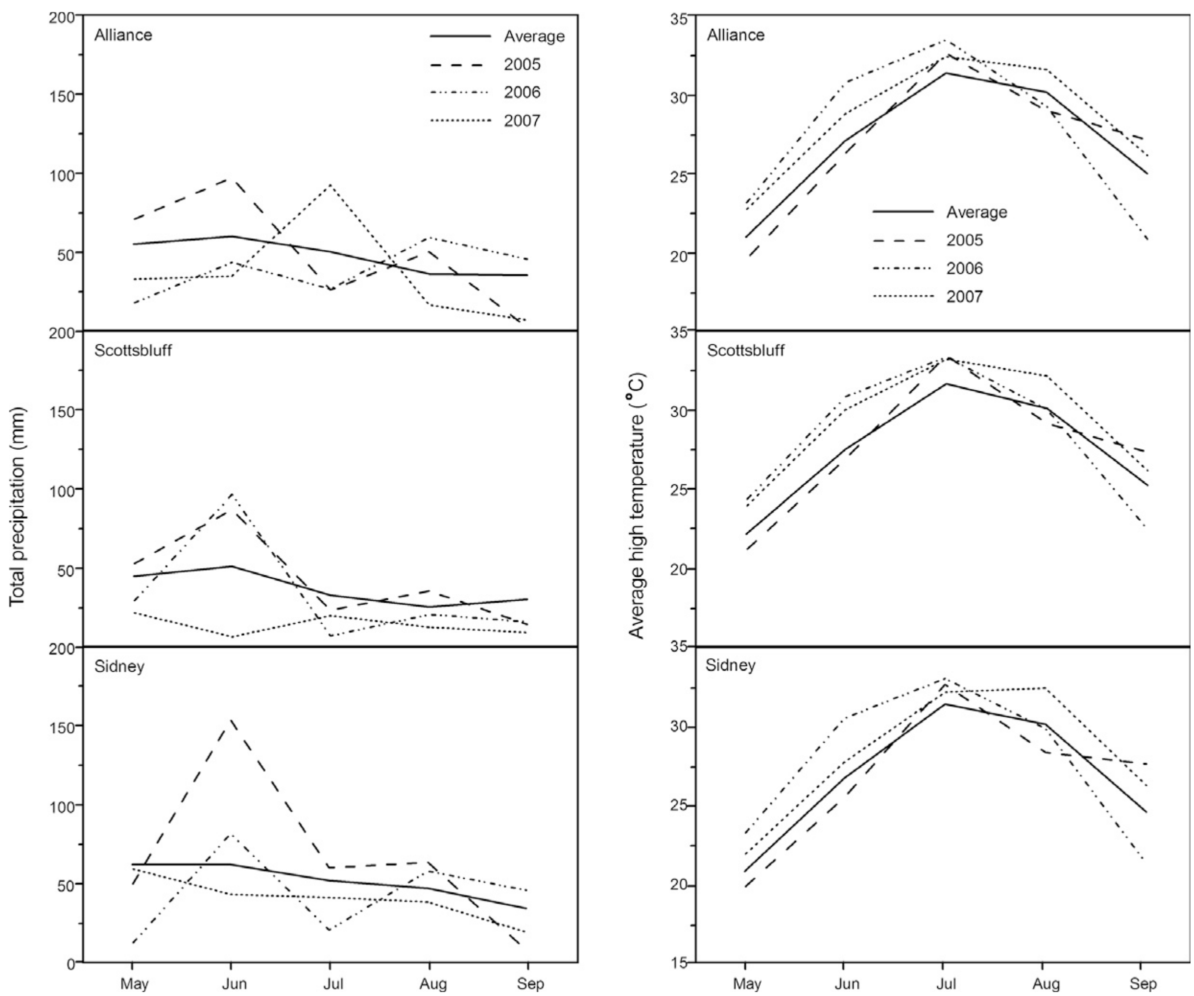

Fig. 1. Monthly total and long-term average (Alliance 21, Scottsbluff 18, and Sidney 27 yr) precipitation (mm) and maximum temperatures (°C) for each of three research sites in western Nebraska from 2005 to 2007.

of precipitation during 2005 (Table 2) which may have permitted more carryover soil moisture during the early 2006 growing season.

CA0090B347C and W6 17256 were the top yielding entries, ranking first and second, respectively, averaged across all irrigated and all dryland environments. CA0090B347C ranked first in three and second in one of the six irrigated environments and first in three and second in two of the five dryland environments (Table 4). W6 17256 was one the top three performers in all but one of the irrigated environments, ranking first in one and second in three of the six irrigated environments. Although the yield response of W6 17256 was more variable under dryland conditions, it ranked first in two of the five dryland environments (Table 4). In 2006, W6 17256 had lower germination in part because of poor seed quality. It is noteworthy that W6 17256 had the highest dryland yield at Sidney 2006 (Table 4) where the incidence of Ascochyta blight was greatest. At Sidney 2006 the average Ascochyta blight rating for W6 17256 was 1.5 under both irrigated and dryland conditions whereas the site average for the genotypes was 3.2 (Harveson et al., 2009). Of the commercial cultivars, 'Sierra' had the greatest yield when averaged across environments, ranking third among irrigated and fourth among dryland environments (Table 4).

To further evaluate the yield performance of the entries, we plotted mean seed yield across all irrigated environments against the Eberhart and Russell (1966) SI (Fig. 2). According to Eberhart and Russell (1966), desirable varieties are those which are high yielding and stable (index value of 1.0 and little deviation) across environments. Thus, the most promising entries are those in the upper right quadrant of Fig. 2. These include the previously mentioned CA0090B347C, W6 17256, and Sierra, as well as CA9990B1579C which was ranked fourth (irrigated) and third (dryland) in seed yield when averaged across environments (Table 4). Other than Sierra, currently available commercial cultivars ('Dwelley' and 'Dylan') did not perform as well in terms of yield. Although, SI values were acceptable for most entries, the variation across environments during these trials was more than desired.

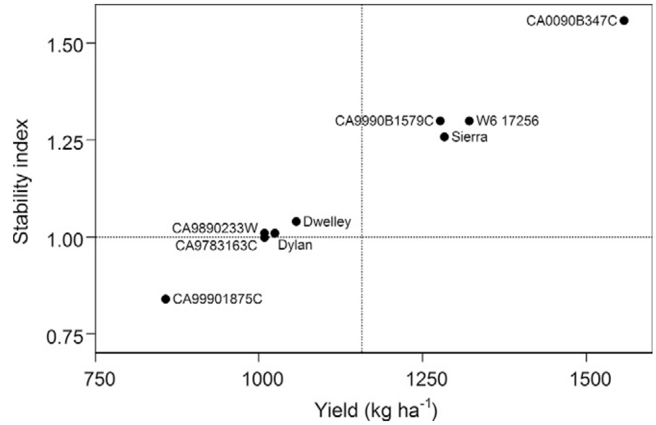

Fig. 2. Classification of three chickpeas cultvars and six genotypes evaluated in six irrigated environments in western Nebraska from 2005 to 2007 based on mean seed yield and stability index. Dotted lines represent the overall mean seed yield (vertical) and stability index (horizontal).

100-Seed Weight

100-seed weight, an indicator of seed quality, varied among environments and entries and was generally greater under irrigated than under dryland conditions. Overall, 100-seed weight averaged 4.5% lower under dryland than under irrigated conditions and ranged from 3.4% heavier to 13.9% lighter for individual entries (Table 5).

100-seed weight was greatest at Alliance 2005 under both irrigated and dryland conditions and least at Sidney 2006 (irrigated) and Alliance 2006 (dryland) (Table 5). This response may, in part, reflect the greater amount of precipitation at Alliance 2005

Table 5. 100-seed weight of three chickpea cultivars and six genotypes evaluated in six irrigated and four dryland environments in western Nebraska from 2005 to 2007.

Genotype	2005 Scottsbluff	2005 Alliance	2006 Scottsbluff	2006 Alliance	2006 Sidney	2007 Scottsbluff	Average
	g						
			Irrigated				
Dylan	34.3	56.9	53.2	52.8	.	42.6	48.0
CA9783163C	31.8	54.0	48.2	49.2	.	41.9	45.0
CA9990B1579C	41.3	55.1	43.9	49.3	39.0	38.4	44.5
CA9890233W	32.0	57.2	50.3	53.1	34.5	38.4	44.3
Sierra	39.1	54.2	45.4	50.2	30.9	39.8	43.3
Dwelley	34.2	52.3	50.2	49.7	33.2	37.5	42.9
CA99901875W	28.4	57.8	45.6	50.8	27.2	33.9	40.6
CA0090B347C	38.3	47.1	38.7	43.2	38.2	37.8	40.5
W6 17256	35.3	40.4	24.4	38.2	36.6	33.0	34.6
Mean	35.0	52.8	44.4	48.5	34.2	38.1	42.2
LSD (0.05)†	3.0	1.8	3.8	3.5	3.3	5.5	
			Dryland				
Dylan		52.6	53.5	39.1	42.1		46.8
CA9783163C		45.1	48.6	36.1	42.6		43.1
CA99901875W		47.8	41.4	36.3	42.3		42.0
Dwelley		46.3	42.3	35.5	41.2		41.3
Sierra		45.5	42.4	34.2	40.9		40.8
CA9990B1579C		47.8	39.7	34.7	40.4		40.7
CA9890233W		48.2	.	34.5	38.1		40.3
CA0090B347C		41.1	39.5	31.8	36.2		37.2
W6 17256		37.2	23.4	26.1	32.5		29.8
Mean		45.7	41.4	34.3	39.6		40.3
LSD (0.05)†		4.9	3.4	4.1	3.7		

† To compare means among genotypes.

Table 6. Mean days to harvest of three chickpea cultivars and six genotypes evaluated in four irrigated and four dryland environments in western Nebraska from 2005 to 2007.

Genotype	2005 Alliance	2006 Scottsbluff	2006 Alliance	2006 Sidney	2007 Scottsbluff	Average
	days					
			Irrigated			
CA0090B347C	120	115		111	101	112
Dylan	128	104		116	105	113
CA9990B1579C	125	115		114	107	115
W6 17256	123	119		109	107	115
Sierra	123	115		115	105	115
Dwelley	128	115		116	110	117
CA9783163C	128	115		116	113	118
CA9890233W	125	115		118	114	118
CA99901875W	125	115		116	115	118
Mean	125	114		115	109	116
LSD (0.05)†	4	4.3		3.7	7.3	
			Dryland			
CA0090B347C	113	115	114	105		112
W6 17256	113	122	110	106		113
CA9890233W	120	115	110	105		113
CA9990B1579C	120	115	110	114		115
Sierra	120	115	110	113		115
CA9783163C	120	116	110	114		115
CA99901875W	120	115	110	114		115
Dwelley	120	116	110	115		115
Dylan	120	118	110	114		116
Mean	118	116	110	112		114
LSD (0.05)†	3.2	3	1.2	3.6		

† To compare means among genotypes.

and the more moderate amount of precipitation at Alliance and Sidney 2006 (Table 2). As with yield, the larger seed size at Alliance 2005 may in part reflect below average temperatures and above average precipitation during the early growing season (May through June) at Alliance 2005 contrasted with above average temperatures (May through July) and below average precipitation (May) at all locations during 2006 (Fig. 1).

Dylan had the greatest average 100-seed weight across all irrigated and all dryland conditions, whereas top yielding CA0090B347C and W6 17256 had the smallest seed size (Table 5). Sierra had intermediate seed size (Table 5).

Days to Harvest

Days to harvest varied among environments and entries, and were generally less under dryland than under irrigated conditions. On average, chickpeas were ready for harvest approximately 2 d earlier under dryland than under irrigated conditions. Days to harvest occurred 3 d later to 5 d earlier under dryland conditions for individual entries (Table 6).

Days to harvest were least at Scottsbluff 2007 among irrigated environments and at Alliance 2006 among dryland environments (Table 6). Days to harvest were later at Alliance 2005 under both irrigated and dryland conditions (Table 6). Perhaps the higher levels of precipitation at these locations during 2005 contributed to the delays in readiness for harvest (Table 2).

On average, CA0090B347C was ready for harvest earliest under both irrigated and dryland conditions (Table 6). W6 17256 and Sierra were ready an average of 3 d later under irrigated conditions, and 1 to 3 d later, respectively, under dryland conditions. Dylan was among the earliest harvest ready entries under irrigated conditions, but was the latest under dryland conditions. This suggests that Dylan may be more sensitive to soil moisture levels than many of the other entries.

Economic Analysis

Production of chickpeas under fungicide protected irrigated conditions (Alliance 2005 and 2006) resulted in positive net returns for eight of the nine entries (Table 7). Sierra and CA9990B1579C had the largest net return; near $400.00 ha^{-1} (Table 7). Although CA0090B347C and W6 17256 were the highest yielding entries (Table 4), their net return values were lowest, with W6 17256 being negative (Table 7). Because of their small seed size (able to pass through a 9-mm screen), the price for these chickpeas was reduced almost 30% which substantially reduced their gross return values. When little or no Ascochyta blight is present, the potential for chickpea in the region is significant and positive.

Production of chickpeas without the application of fungicide was economically successful at Scottsbluff (2005 and 2006). Returns were positive for eight of the entries, with both CA9900B1579C and Sierra having a net return exceeding $750.00 ha^{-1} (Table 7). Only W6 17256 showed a net return less than zero (Table 7). The net return value for the unprotected trials

Table 7. Economic analysis of dryland and irrigated chickpea production in western Nebraska from 2005 to 2007.

Genotype	Irrigated, Protected, Gross return	Irrigated, Protected, Net return	Irrigated, Unprotected, Gross return	Irrigated, Unprotected, Net return	Dryland, Gross return	Dryland, Net return
	$ ha^{-1}					
Sierra	1294.41a	404.92a	1532.09a	764.83a	347.26a	–100.59a
CA9990B1579C	1278.54ab	389.14ab	1577.11a	809.60a	359.65a	–88.29a
Dwelley	1225.89ab	336.78ab	1206.26ab	440.81ab	268.87a	–177.63a
CA9783163C	1209.83ab	320.81ab	1130.20ab	365.18ab	303.42a	–144.15a
CA9890233W	1131.69abc	243.11abc	1161.84ab	396.63ab	302.27a	–145.29a
Dylan	1091.23bc	202.87bc	1265.36a	499.58a	269.72a	–177.63a
CA99901875W	946.03cd	58.47cd	976.81ab	212.63ab	252.01a	–195.23a
CA0090B347C	891.15d	0.35d	980.52ab	212.43ab	287.73a	–160.92a
W6 17256	776.38d	–113.32d	603.71b	–160.79b	228.80a	–219.22a
Overall mean	1103.60	214.50	1167.20	401.20	291.10	–156.6
LSD (0.05)†	179.60	178.60	569.90	566.60	183.40	182.1

† To compare means among genotypes.

is adequately high to allow producers to apply treatments of fungicide at a cost of \$69.00 ha^{-1} as a risk of management strategy.

None of the entries produced positive net returns under dryland conditions (Table 7). Gross and net return values varied little among entries ($P \leq 0.05$) and losses averaged approximately \$157 ha^{-1} (Table 7). These results suggest that dryland production of chickpeas may not be a viable option in the Nebraska Panhandle. This study was conducted during a prolonged regional drought. It is unknown how these entries might perform under dryland conditions during years with average or above average precipitation. However, drought is a normal though unpredictable occurrence in the High Plains. Therefore, even if dryland chickpea production can be profitable under non-drought moisture regimes, it would still be a risky venture given the unpredictability of drought. Producers in this region have historically been focused on low input, low risk dryland crop production. Dryland chickpea production may have additional rotation benefits in terms of crop diversity and nitrogen fixation, but this is offset by poor yields and high cost of production. Under present market and production constraints, this crop does not meet the goals of dryland crop producers in this region.

CONCLUSIONS

For western Nebraska and the High Plains region to become a competitive chickpea production area, varieties are needed that are well adapted to this region, have desirable yield and quality characteristics, and are resistant to Ascochyta blight. In these trials, CA0090B347C and W6 17256 were the top yielding entries under both irrigated and dryland conditions and showed some resistance to Ascochyta blight (particularly W6 17256). Both were ready to harvest within an acceptable time frame. Unfortunately, their seed size does not meet commercial standards which reduces the price for these chickpeas and their economic viability. Nevertheless, CA0090B347C and W6 17256 show promise as parental germplasm sources for ongoing breeding efforts to develop well adapted, high yielding, disease resistant cultivars for this region. In the interim, the commercial cultivar, Sierra, may be an acceptable alternative, though fungicides treatments will likely be needed to control Ascochyta blight.

Chickpeas have potential as an alternative crop for this region. Because of their ability to fix N and thus improve soil fertility, chickpeas could be a valuable addition to crop rotation systems. However, under the conditions of these trials, only irrigated production was economically viable. Returns from the majority of the entries were competitive and if they could be achieved with cost effective fungicide treatment(s) on a consistent basis, it would make chickpeas a viable crop for this region.

For dryland production to be feasible, the cost of production needs to be reduced and/or varieties need to be developed with improved yield and seed size under limited moisture conditions. If successful, chickpea would be a valuable alternative in dryland areas dominated by winter wheat and proso millet and would fit well in summer fallow rotations.

ACKNOWLEDGMENTS

Financial support received from the Nebraska Dry Bean Commission (Project no. WBS 26-6243-0204-005) from 2005 to 2008 is greatly appreciated. We also thank Clay Carlson and Dong-Man Khu for technical support. Germplasm provided by Dr. Kevin McPhee through the Western Regional Chickpea Trial from USDA-ARS Pullman, WA, is greatly appreciated. We also appreciate Mark Watson's contribution to this research.

REFERENCES

Akem, C. 1999. Ascochyta blight of chickpea: Present status and future priorities. Int. J. Pest Manage. 45:131–137.

Auckland, A.K., and L.J.G. van der Maesen. 1980. Chickpea. p. 249–259. *In* W.R. Fehr and H.H. Hadley (ed.) Hybridization of crop plants. ASA and SSSA, Madison, WI.

Derie, M.L., R.L. Bowden, K.D. Kephart, and W.J. Kaiser. 1985. *Ascochyta rabiei* on chickpeas in Idaho. Plant Dis. 69:268.

Eberhart, S.A., and W.A. Russell. 1966. Stability parameters for comparing varieties. Crop Sci. 6:36–40.

Gan, Y.T., K.H.M. Siddique, W.J. MacLeod, and P. Jayakumar. 2006. Management options for minimizing the damage by ascochyta blight (*Ascochyta rabiei*) in chickpea (*Cicer arietinum* L.). Field Crops Res. 97:121–134.

Guzman, P., R.M. Davis, R.L. Gilbertson, N. Smith, and S. Temple. 1995. First report of *Ascochyta rabiei* causing ascochyta blight of garbanzo in California. Plant Dis. 79:82.

Harveson, R.M. 2002. A severe outbreak of ascochyta blight of chickpeas in western Nebraska. Plant Dis. 86:698.

Harveson, R.M. 2007. Ascochyta blight of chickpeas in Nebraska. NebGuide G1676. Univ. of Nebraska–Lincoln Ext., Inst. of Agric. and Natural Resources, Univ. of Nebraska, Lincoln.

Harveson, R.M., C.A. Urrea, and D.D. Baltensperger. 2009. Evaluating chickpea genotypes for resistance to ascochyta blight in Nebraska. Available at http://www.plantmanagementnetwork/org/sub/php/research/2009/chickpea/ (verified 15 Apr. 2010). Plant Health Prog. doi:10.1094/PHP-2009-0720-01-RS.

Jayakumar, P., B.D. Gossen, Y.T. Gan, T.D. Warkentin, and S. Banniza. 2005. Ascochyta blight of chickpea: Infection and host resistance mechanisms. Can. J. Plant Pathol. 27:499–509.

Kaiser, W.J. 1992. Epidemiology of *Ascochyta rabiei*. p. 117–131. *In* K.B. Singh and M.C. Saxena (ed.) Disease resistance breeding in chickpea. Proc. of the Consultative Meet. on Breeding for Disease Resistance in Kabuli Chickpea, Aleppo, Syria. 6–8 Mar. 1989. ICARDA, Aleppo, Syria.

Kaiser, W.J., and F.J. Muehlbauer. 1984. Occurrence of *Ascochyta rabiei* on imported chickpeas in eastern Washington. Phytopathology 74:1139.

Kaiser, W.J., and F.J. Muehlbauer. 1988. An outbreak of ascochyta blight of chickpea in the Pacific Northwest, USA, in 1987. Int. Chickpea Newsl. 18:16–17.

Lucier, G., B. Lin, J. Allshouse, and L.S. Kantor. 2000. Factors affecting dry bean consumption in the United States. p. 26–34. *In* Vegetables and Specialties S&O/VGS-280/April 2000. Available at http://www.ers.usda.gov/briefing/drybeans/PDFs/DryBeanConsumption.pdf (verified 13 Apr. 2010). Economic Res. Serv., USDA, Washington, DC.

Margheim, J.F., D.D. Baltensperger, R.G. Wilson, D.J. Lyon, G.L. Hein, R.M. Harveson, P. Burgener, J.M. Krall, J.T. Cecil, J.R. Rickertsen, A.P. Merrigan, M.H. Watson, and B.J. Hansen. 2004. Chickpea production in the High Plains. EC04–183. Univ. of Nebraska Coop. Ext., Univ. of Nebraska, Lincoln.

Millan, T., H.J. Clarke, K.H.M. Siddique, H.K. Buhariwalla, P.M. Gaur, J. Kumar, J. Gil, G. Kahl, and P. Winter. 2006. Chickpea molecular breeding: New tools and concepts. Euphytica 147:81–103.

Miller, P., P. McKay, B. Jenks, J. Riesselman, K. Neill, D. Buschena, and A.J. Bussan. 2002. Growing chickpeas in the northern Great Plains. MT200204 AG 3/2002. Montana State Univ. Ext. Serv., Bozeman.

Muehlbauer, F.J., W.J. Kaiser, and I. Kusmenoglu. 1998. Registration of 'Dwelley' chickpea. Crop Sci. 38:283.

Muehlbauer, F.J., S.R. Temple, and W. Chen. 2004. Registration of 'Sierra' chickpea. Crop Sci. 44:1864.

Muehlbauer, F.J., S.R. Temple, and W. Chen. 2006. Registration of 'Dylan' chickpea cultivar. Crop Sci. 46:2705.

Nene, Y.L., and M.V. Reddy. 1987. Chickpea diseases and their control. p. 233–270. *In* M.C. Saxena and K.B. Singh (ed.) The chickpea. CAB Int., Wallingford, Oxon, England.

Price, G.K. 2002. Will the Farm Act get pulses racing? p. 18–21. *In* Agricultural Outlook/November 2002. Available at http://www.ers.usda.gov/publications/agoutlook/Nov2002/ao296f.pdf (verified 13 Apr. 2010). Economic Res. Serv., USDA, Washington, DC.

Pushpamma, P., and P. Geervani. 1987. Utilization of chickpea. p. 357–368. *In* M.C. Saxena and K.B. Singh (ed.) The chickpea. CAB Int., Wallingford, Oxon, England.

SAS Institute. 2004. User's guide: Statistics. SAS Inst., Cary, NC.

Singh, K.V., and M.V. Reddy. 1996. Improving chickpea yield by incorporating resistance to ascochyta blight. Theor. Appl. Genet. 92:509–515.

Steel, R.G.D., and J.H. Torrie. 1980. Principles and procedures of statistics. A biometrical approach. McGraw-Hill, New York.

USDA-ERS. 2009. Dry beans. *In* Vegetables and Melons Outlook/VGS-324/August 27, 2009. Available at http://www.ers.usda.gov/briefing/drybeans/ (verified 13 Apr. 2010). Economic Res. Serv., USDA, Washington, DC.

van der Maesen, L.J.G. 1987. Origin, history, and taxonomy of chickpea. p. 11–34. *In* M.C. Saxena and K.B. Singh (ed.) The chickpea. C.A.B. Int., Wallingford, Oxon, England.