

# Seventy-five Years of Breeding Dry Bean of the Western USA

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## ABSTRACT

A periodic comparison of cultivars is essential to assess selection gains, determine deficiencies, define objectives, and set breeding priorities. Our objective was to assess the progress, or lack thereof, achieved in improving yield, plant type, maturity, and resistance to major bacterial, fungal, and viral diseases of dry bean of the western USA from 1918 to 1998. Twenty-five great northern, pink, pinto, and red cultivars were evaluated for seed yield at three locations in Idaho and for anthracnose, *Bean common mosaic virus*, *Bean common mosaic necrosis virus*, common and halo bacterial blights, *Fusarium* and *Rhizoctonia* root rots, *Fusarium* wilt, and white mold in Colorado, Idaho, and Washington between 1999 and 2006. Yield ranged between 2904 kg ha<sup>-1</sup> for pinto 'UI 111' to 3921 kg ha<sup>-1</sup> for 'Bill Z', which represents a 35% gain in 54 yr. Yield gain in great northern was 587 kg ha<sup>-1</sup>, pink 136 kg ha<sup>-1</sup>, and red 687 kg ha<sup>-1</sup>. Stability indices ranged from 0.57 for 'Kodiak' to 1.86 for 'UI 3'. Maturity ranged from 90 d for 'UI 320' to 97 d for 'Frontier'. Seed weight ranged from 28 g for 'Viva' to 41 g for UI 320. An acceptable degree of resistance to *Rhizoctonia* root rot was achieved in most cultivars. All cultivars were susceptible to anthracnose, common bacterial blight, and white mold, and all except 'Chase' to halo blight. Only 'Matterhorn', 'Weihsing', and Kodiak combined an upright Type II growth habit with resistance to BCMV and rust. An integrated breeding strategy should be explored for simultaneous improvement of multiple traits in future cultivars.

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**Abbreviations:** BCMV, *Bean common mosaic virus*; BCMNV, *Bean common mosaic necrosis virus*; BCTV, *Beet curly top virus*.

**N**ATIVE AMERICANS grew rain-fed or dryland dry bean (*Phaseolus vulgaris* L.) before Europeans arrived on the American continents, and dry bean was found in Anasazi and other Native American dwellings in the western USA (Kaplan, 1956; Gentry, 1969; Kaplan and Lynch, 1999). Dryland subsistence dry bean production has been practiced on thousands of hectares in the western USA since time immemorial (Mimms and Zaumeyer, 1947). Popular bean market classes of the western USA include medium-seeded (25–40 g 100 seed weight<sup>-1</sup>) pinto, great northern, red Mexican, pink, and Anasazi. Most of these belong to the race Durango that was domesticated in the semiarid and arid central and northern highlands of Mexico (Singh et al., 1991). These dry bean germplasms are characterized by an indeterminate prostrate Type III growth habit (Singh, 1982). In the western USA, cool nights and long warm dry summer days characterize irrigated production systems. Race Durango Type III cultivars often out yield small-seeded (<25 g 100 seed weight<sup>-1</sup>) race Mesoamerica black and navy cultivars with predominately upright bush Type II growth habit in the USA (Singh and Powers, 2000). Further, both groups of cultivars out yield large-seeded (>40 g 100 seed weight<sup>-1</sup>) Andean light and dark red kidney, white kidney, cranberry, and other market classes with bush Type I growth habit.

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Presently, pinto is by far the most predominant market class in the USA and North America, whereas other market classes are grown more commonly in specific production regions.

Breeding and genetics of the western dry bean was initiated by the private sector in southern Idaho in 1918/1919 and at the University of Idaho in 1925 (Dean, 1994, 2000). Subsequently, the USDA started genetic improvement of the western dry bean at Greeley, Colorado, in 1930. In addition to the USDA and Idaho, California, Colorado, Michigan, Nebraska, New York, North Dakota, Oregon, and Washington have ongoing public dry bean breeding programs. Also, there are numerous private breeders dedicated to genetic improvement of several market classes of dry and green (garden, stringless, or snap) bean. Initially, selection for resistance to *Bean common mosaic virus* (BCMV) (a seed-borne and aphid-vectored potyvirus) within landraces was practiced at the University of Idaho resulting in great northern cultivars such as UI 1 (released in 1930) and UI 59 (released in 1932). Interested readers should refer to Dean (1994, 2000) for the history of breeding, year of release, and details regarding the UI cultivars. Resistance to *Beet curly top virus* (BCTV) (a leafhopper-vectored geminivirus) from Common Red Mexican landrace, BCMV, and Fusarium root rot [caused by *Fusarium solani* (Mart.) Sacc. f. sp. *phaseoli* (Burkholder) W. C. Snyder & H. N. Hans.] was combined subsequently using hybridization among landraces. Expansion of the western dry bean cultivars for production in the midwestern states has occurred since the 1970s. This expansion of production warranted further use of exotic germplasm to change plant growth habit to upright Type II, and resistance to rust [caused by *Uromyces appendiculatus* (Pers.) Ung.], white mold [caused by *Sclerotinia sclerotiorum* (Lib.) de Bary], common bacterial blight [(caused by *Xanthomonas campestris* pv. *phaseoli*) (Smith) Dye and *X. campestris* pv. *phaseoli* var. *fuscans*] and other diseases. Brick and Grafton (1999) and Miklas (2000) reviewed germplasm use and breeding of race Durango cultivars in the USA, and Singh et al. (1993) emphasized use of intergene pool and interracial hybridization for their improvement in the tropics and subtropics. In the USA alone, several dozen cultivars of race Durango have been developed during the last 80 yr.

Concerted efforts were made in 1998 to acquire as many private and public dry bean cultivars as possible. Based on the year of release, traits improved, availability of seed, and their popularity, 25 cultivars representing the four medium-seeded market classes of race Durango cultivated in the USA were selected for a comparative evaluation. Our objective was to assess the progress, or lack thereof, achieved in improving yield, plant type, maturity, and resistance to major bacterial, fungal, and viral diseases from 1918 to 1998.

## MATERIALS AND METHODS

Eight great northern, three pink, nine pinto, and five red cultivars of race Durango were evaluated at the University of Idaho Research and Extension Centers at Kimberly and Parma, and in on-farm trials at Hazelton, ID, from 1999 to 2001. The three sites represent the three major bean production regions in southern Idaho. Kimberly has a mean elevation of 1195 m with a Portneuf silt loam, mixed, mesic, Durixerollic Calciorthis soil, and pH of 7.6. Hazelton, less than 30 km east of Kimberly, is at 1341 m elevation, and soils are similar to those of Kimberly, but no actual data were available. Parma is at an elevation of 703 m with a Greenleaf silt loam (fine silty, mixed, superactive, mesic Zeric Calcicargids) soil, and pH of 7.6.

A randomized complete block design with four replications was used at each site. Each experimental unit consisted of four rows, each 6.7 m long. The spacing between rows was 0.56 m and an average of 23 seeds linear m<sup>-1</sup> was planted. The Hazelton trials were conducted on-farm and managed by the grower. Nonetheless, test plots at all three sites received fertilizers, pre-plant herbicides, and cultivation as recommended for commercial production in southern Idaho. Irrigation was applied, as needed to maintain optimum growth at all sites using flat beds and overhead sprinklers at Hazelton and raised beds and gravity flow at Kimberly and Parma. No pesticide for management of any disease or insect was needed. Data were recorded for growth habit during flowering and verified at maturity according to Singh (1982). Days to maturity was recorded when 90% of the pods changed color from green to yellow. The two central rows were harvested at maturity, threshed 10 to 12 d later, cleaned, dried, and seed yield recorded (kg ha<sup>-1</sup>) at 12% moisture by weight. Also, weight (g) of 100 seeds taken randomly was recorded. Reaction of 25 cultivars in separate nurseries in the field (on an average of 50 plants per cultivar) to BCTV was determined according to Larsen and Miklas (2004) and to white mold according to Miklas et al. (2001) in Washington. Also, seed yield was measured in a "purgatory field" at the Washington State University-Roza Agricultural Research Unit, where common bean has been planted every other year for the past 40 yr and *F. solani* predominates. However, *F. oxysporum*, *Pythium ultimum*, and *Rhizoctonia solani* are also present; the soil was purposely compacted to exacerbate the effect of root rots on plant health; nitrogen and phosphorus were limiting; and there was a 35% water deficit. Separate greenhouse evaluations on an average of six plants per cultivar were made in Idaho to determine the reaction of the 25 cultivars to BCMV strains NY15 and US 6 and *Bean common mosaic necrosis virus* (BCMNV, a potyvirus) strain NL-3K according to Strausbaugh et al. (2003). Also, in the greenhouse in Idaho, common bacterial blight (pathogen isolate obtained from Colorado) was evaluated according to Lema et al. (2006), halo blight (pathogen race 6) according to Taylor et al. (1978), anthracnose [caused by *Colletotrichum lindemuthianum* (Sacc. & Magn.) Bri. & Cav. race 73] according to Pastor-Corrales et al. (1995), and rust (*U. appendiculatus* race 53) according to Stavely (1983). Fusarium wilt and *Rhizoctonia* root rot were evaluated according to Abawi and Pastor-Corrales (1990), and white mold according to Petzoldt and Dickson (1996) in the greenhouse with an average of 24 plants per cultivar in Colorado. For diseases that were scored on a 1 to 9 scale, scores 1 to 3 were considered resistant, 4 to 6 intermediate

or moderately resistant, and 7 to 9 susceptible. Data for seed yield, seed weight, and days to maturity from each location and year were analyzed separately, homogeneity of variances was tested (Bartlett, 1947), and combined analysis was performed using a mixed model, whereby years and replications were random effects and locations and cultivars were considered fixed (McIntosh, 1983). Subsequently, simple correlation coefficients among the three locations were calculated using the mean seed yield of 25 cultivars over the 3 yr. Stability analysis for 25 cultivars was performed for seed yield according to Eberhart and Russell (1966). Statistical analyses of data were conducted using the SAS (SAS Institute, 2004).

## RESULTS AND DISCUSSION

Mean squares due to year, location, cultivar, and their interactions were highly significant ( $P \leq 0.01$ ) for seed yield, seed weight, and days to maturity in the combined analysis (Table 1). Because herbicide, fertilizer, and irrigation application at a particular site were relatively consistent over the 3 yr, differences in soil type, climatic factors, seed-bed preparation, and cultivation between the three sites and their interactions with cultivars most likely contributed to significant mean squares. These significant interactions between cultivars, locations, and years further indicated that the response of cultivars changed within and across locations from 1 yr to another. This three-way interaction included both crossover and noncrossover interactions among cultivars with or without changing the rank orders. For example, great northern 'UI 465' and 'UI 61' had similar yields at Kimberly but yielded differently at Parma when averaged over the 3 yr (Table 2). In contrast, 'UI 425' yielded higher than UI 61 at Kimberly, but its yield was comparatively lower at Hazelton. Thus, for maximizing yield within a production region selection of site-specific high-yielding cultivars would be justified. In contrast, identification of and establishing reliable yield estimates for broadly adapted cultivars will require the use of contrasting testing sites representative of the target environments, such as those used in this study for southern Idaho, over a period of three or more years.

Mean seed yield among cultivars over the 3 yr at Kimberly was positively correlated with that at Parma ( $r^2 = 0.60$  at  $P \leq 0.01$ ), approximately 300 km west of Kimberly. Yield at neither site was correlated with yield at Hazelton, which is less than 30 km east of Kimberly. These data suggest that dry bean cultivars respond differently to soil, environmental, and other factors. Grower practices at the trials at Hazelton could have contributed to differences from the Kimberly and Parma Research and Extension Centers. Nonetheless, as noted earlier Hazelton is at higher elevation compared to Kimberly, and Parma is at an even lower elevation and is warmer. Because yield of 25 cultivars at Parma tended to be higher in comparison to both Hazelton and Kimberly over the 3 yr (Table 3), it seems that warmer temperature favors higher yield

**Table 1. Mean squares from a combined analysis of variance for 25 dry bean cultivars evaluated for seed yield, seed weight, and days to maturity at Hazelton, Kimberly, and Parma, Idaho, from 1999 to 2001.**

Source	df	Mean square		
		Yield	Seed weight	Maturity†
Year (Y)	2	115268687**	60.0	264.0**
Location (L)	2	39776287**	1300.3**	720.0**
Y × L	4	19093568**	121.3**	1722.2**
Rep (Y × L)	27	539987	4.7	4.6
Cultivar (C)	24	2676423**	382.9**	74.2**
Y × C	48	1050075**	19.9**	23.6**
L × C	48	868173	8.8**	15.6**
Y × L × C	96	417760**	6.8**	12.7**
Error	647	160904	1.3	5.0

\*\*Significant at the 0.01 probability level.

†Evaluated in 2000 and 2001.

of medium-seeded cultivars in southern Idaho. Furthermore, because Hazelton and Parma were more contrasting and a positive correlation existed between Kimberly and Parma, future studies should emphasize Hazelton and Parma if resources become limiting. Mean seed yield across locations and years for great northern shows that UI 425 followed by 'Matterhorn' (Kelly et al., 1999b) had the highest, and 'Weihing' (Coyne et al., 2000) followed by 'UI 59' had the lowest yield (Table 2). The 549 kg ha<sup>-1</sup> difference in yield between UI 425 and UI 59 represents an 18% yield gain over 52 yr (Table 4). Although, as a group, pink cultivars had relatively higher yield, there were no significant differences among them and only 3% gains were realized between the oldest (Viva) and newest highest-yielding (UI 537) cultivars. There is not a ready explanation for the higher overall yield potential for pink cultivars compared to great northern, pinto, and older red cultivars that have similar seed size, growth habit, and evolutionary origin. The higher yield potential for pink and relatively recently bred red cultivars such as NW 63 (Burke, 1982b) and UI 239 (Myers et al., 1997) was also reported by Muñoz-Perea et al. (2006) in Idaho and has been a common observation in yield trials conducted elsewhere in the western USA. It is noteworthy that pink bean is prominent in the pedigree of Bill Z (Wood et al., 1989) and UI 239, the highest-yielding cultivars, respectively, for the pinto and red market classes. Among pinto cultivars, Bill Z had the highest and UI 111, released in 1944, the lowest yield. The approximately 1000 kg ha<sup>-1</sup> of difference between those cultivars represents a 35% yield increase over 43 yr. In the red market class, the 587 kg ha<sup>-1</sup> difference between UI 239 with the highest and 'UI 3' with the lowest yield represents 18% gain in yield in 55 yr. Interestingly, in the great northern class after the release of UI 425 in 1984, in the pink class after the release of UI 537 in 1990, in the pinto class after the release of

**Table 2. The year of release, growth habit, mean seed yield, stability index, seed weight, and days to maturity for 25 dry bean cultivars evaluated at Hazelton, Kimberly, and Parma, Idaho, from 1999 to 2001.**

Market class and cultivar	Year of release	Growth-habit <sup>†</sup>	Yield				Stability index	Seed weight	Maturity
			Kimberly	Hazelton	Parma	Mean			
			kg ha <sup>-1</sup>						
							g	d	
Great Northern									
UI 59	1932	III	2939	2669	3521	3043	1.07 ± 0.11	31	94
US 1140	1960	III	3345	3374	3601	3440	0.76 ± 0.19	33	92
UI 61	1966	III	3242	3375	3304	3307	0.79 ± 0.27	32	91
UI 425	1984	III	3820	2953	4002	3592	1.17 ± 0.28	35	96
Beryl	1986	III	3648	3180	3459	3429	0.63 ± 0.18	30	93
UI 465	1997	III	3208	3278	4056	3514	0.86 ± 0.16	36	94
Matterhorn	1998	II	3803	3048	3866	3572	1.27 ± 0.30	33	95
Weihing	1998	II	2817	2838	3361	3005	1.00 ± 0.12	34	92
Mean			3353	3089	3646	3363	0.95	33	93
Pink									
Viva	1974	III	3770	3688	3846	3768	0.78 ± 0.13	28	92
UI 537	1990	III	3949	3700	4020	3889	0.89 ± 0.10	35	91
Harold	1995	III	3762	3559	3939	3753	0.95 ± 0.11	33	93
Mean			3827	3649	3935	3803	0.87	32	92
Pinto									
UI 111	1944	III	2905	2517	3292	2904	1.24 ± 0.18	35	90
UI 114	1965	III	3367	2835	3888	3363	0.92 ± 0.19	38	93
UI 126	1983	III	3603	2760	4390	3584	1.22 ± 0.24	37	92
Bill Z	1987	III	3882	3300	4582	3921	1.14 ± 0.14	36	94
Chase	1993	III	3565	3131	3938	3545	0.75 ± 0.13	36	93
Frontier	1996	II	3765	2580	3406	3250	1.38 ± 0.30	38	97
UI 320	1997	III	3128	2972	3957	3352	0.82 ± 0.33	41	90
Burke	1998	III	3333	3212	3617	3387	0.73 <sup>‡</sup> ± 0.10	40	94
Kodiak	1998	II	3177	3104	3349	3210	0.57 <sup>‡</sup> ± 0.15	39	93
Mean			3414	2935	3824	3391	0.97	38	93
Red									
UI 3	1938	III	3631	2246	3799	3225	1.86 <sup>‡</sup> ± 0.31	29	94
UI 36	1963	III	3477	2824	3809	3370	1.34 <sup>‡</sup> ± 0.09	34	95
NW 63	1979	III	3445	3492	4009	3649	0.78 ± 0.14	33	93
UI 239	1993	III	3895	3236	4281	3812	1.14 ± 0.08	31	93
UI 259	1997	III	3799	3355	4114	3756	0.95 ± 0.12	34	94
Mean			3649	3031	4002	3562	1.21	32	94
Overall mean			3490	3089	3816	3465	1.00	34	93
LSD <sup>‡</sup> (0.05)			321	321	321	185		0.5	0.9
LSD <sup>§</sup> (0.05)			151	151	151	87		0.2	0.2

<sup>†</sup>II, indeterminate erect or upright; III, indeterminate, prostrate, semiclimber.

<sup>‡</sup>To compare means between cultivars.

<sup>§</sup>To compare means between market classes.

<sup>‡</sup>Significantly different from unity at  $P \leq 0.05$ .

Bill Z in 1987, and in the red market class after the release of UI 239 in 1993, there were no significant gains from subsequent cultivar releases.

Have we reached a yield plateau in the medium-seeded cultivars for the western states? In a 120-d favorable growing environment, the physiological yield potential is estimated to be 5000 kg ha<sup>-1</sup> for the race Durango (synonymous with Gene Pool 5, Singh, 1989) cultivars to which

these western dry bean belong (Singh et al., 1991). This could translate to approximately 4000 kg ha<sup>-1</sup> for an average 95-d frost-free period also free from other abiotic and biotic stresses in southern Idaho, and other parts of the western USA. Thus, expecting significantly higher yield than that of Bill Z in any of the four market classes in the western USA may not be realistic. Singh (2001) discussed general strategies for broadening the genetic base

and breeding for specific traits including yield potential, as well as simultaneous selection for multiple traits for cultivar development. Kelly et al. (1998) discussed in considerable detail alternative strategies for breeding for yield potential. Nonetheless, breeding dry bean cultivars significantly higher yielding than Bill Z, UI 425, UI 239, and UI 537 may require maximizing their harvest index by improving translocation efficiency of photosynthate from vegetative organs to developing seeds, at least, without losing overall dry matter yield (Wallace, 1985; Wallace et al., 1993). Alternatively, use of exceptionally high-yielding parents of somewhat diverse evolutionary origins (e.g., germplasm from races Jalisco and Mesoamerica) with positive general combining ability and favorable complementary genes could be pursued (Singh et al., 1989, 1993). Also, both approaches may require use of large population size and early generation yield testing (Singh et al., 1990), which may be very expensive and not feasible for resource-limited programs. Breeders with limited resources may attempt to conserve the yield potential of Bill Z and improve yield stability by improving resistance to abiotic (e.g., reduced fertilizer, water deficits, extreme temperatures) and biotic stresses. In fact, for more than 15 yr, breeding for disease resistance combined with increased emphasis on breeding for upright plant type to facilitate one-step direct harvest and minimize diseases, early maturity, and better seed quality (Brick and Grafton, 1999; Miklas, 2000) have likely contributed to the observed yield plateau. Continued genetic improvement for these traits is expected to reduce production costs, contribute to conservation of natural resources, and lessen adverse impacts from chemicals on human health, environment, and water streams. That breeding strategy may also facilitate sustainable organic and conventional dry bean production in the western USA and bring relatively larger returns to growers and the bean industry than breeding for increased yield potential per se. Furthermore, development of herbicide-resistant dry bean cultivars may eliminate the need for preplant incorporated herbicides in conventional production systems, thus minimizing herbicide inputs.

The yield data from three locations over 3 yr allowed us to examine the comparative stability of 25 dry bean cultivars (Table 2 and Fig. 1). Most cultivars had stability indices near 1.00, suggesting an average performance in both nonstressed and stressed environments. Cultivars Matterhorn, UI 126, UI 239, UI 425, and Bill Z, with values slightly higher than 1.00, placed in the top right quadrant in Fig. 1, suggest that, on average, they would be lower yielding under stressed conditions and would require favorable environments to realize their highest

**Table 3. Mean seed yield, seed weight, and days to maturity for 25 dry bean cultivars evaluated at Hazelton, Kimberly, and Parma, Idaho, from 1999 to 2001.**

Location	Yield				Seed weight				Maturity		
	1999	2000	2001	Mean	1999	2000	2001	Mean	2000	2001	Mean
	kg ha <sup>-1</sup>				g				d		
Kimberly	3025	4298	3146	3490	35	35	34	35	92	99	95
Hazelton	2664	3426	3178	3089	31	34	31	32	91	92	91
Parma	3685	4818	2945	3816	36	36	37	36	95	90	92
Mean	2577	3343	2710	2877	34	34	33	34	92	94	93
LSD (0.05)	213	213	213	123	0.6	0.6	0.6	0.4	0.6	0.6	0.5

**Table 4. Average gains for seed yield, seed weight, and days to maturity between the oldest and the highest-yielding improved dry bean cultivars of great northern, pink, pinto, and red market classes evaluated at Hazelton, Kimberly, and Parma, Idaho, from 1999 to 2001.**

Market class and cultivar	Year of release	Seed yield	Seed weight	Days to maturity
		kg ha <sup>-1</sup>	g	d
Great Northern				
UI 59	1932	3043	31	94
UI 425	1984	3592	35	96
Gains (%)		18	13	2
Pink				
Viva	1974	3768	28	92
UI 537	1990	3889	35	91
Gains (%)		3	25	-1
Pinto				
UI 111	1944	2904	35	90
Bill Z	1987	3921	36	94
Gains (%)		35	3	4
Red				
UI 3	1938	3225	29	94
UI 239	1993	3812	31	93
Gains (%)		18	7	-1

yield potential. In contrast, those cultivars in the lower right quadrant, comprising UI 537, Harold (Burke et al., 1995a), Viva (Burke, 1982a), and UI 259 (Myers et al., 2001b), would be higher yielding in relatively stressful environments. Nonetheless, although Bill Z, UI 239, and others in the upper right quadrant yielded relatively higher in favorable environments, their yield may not be significantly different from those of the latter group.

Hazelton had the lowest and Parma the highest mean seed weight (Table 3). Among the four market classes, pinto UI 320 (Myers et al., 2001a) followed by 'Burke' (Hang et al., 1998) and 'Kodiak' (Kelly et al., 1999a) had the largest seed (hence weight) among all cultivars (Table 2). In contrast, Viva pink followed by UI 3 red and 'Beryl' great northern possessed the smallest seed. Dry bean landraces of great northern, pink, pinto, and red market classes that were grown by Native Americans and early European settlers in the western USA, in general, have a relatively smaller seed weight

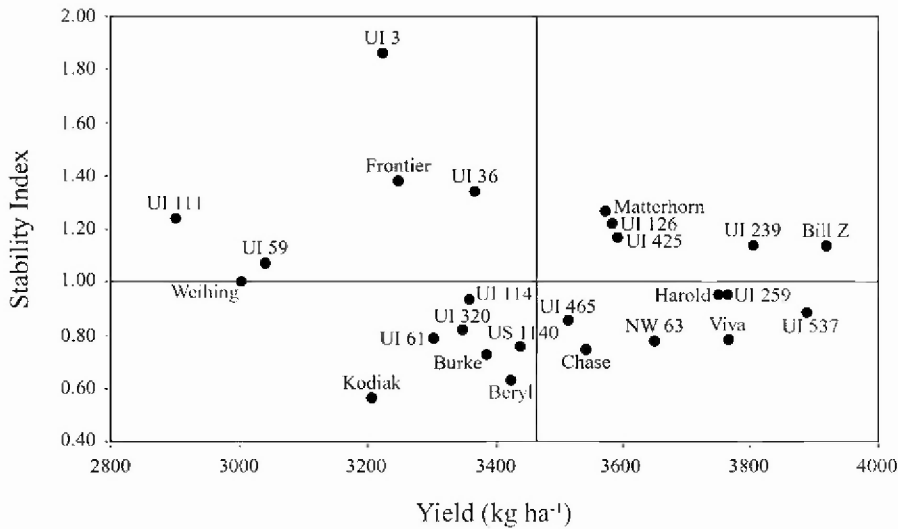


Figure 1. Plot of stability index according to Eberhart and Russell and mean seed yield for 25 dry bean cultivars evaluated at Hazelton, Kimberly, and Parma, Idaho, from 1999 to 2001.

(Muñoz-Perea et al., 2006). Because of market demand, increasing emphasis has been given to breeding for relatively larger seed size in race Durango cultivars. Because there is a negative association between seed weight and yield (White and Gonzáles, 1990; White et al., 1992), it may also have negatively contributed to the yield plateau in these medium-seeded cultivars as discussed above.

Mean maturity across sites and years ranged from 90 d for UI 320 and UI 111 to 97 d for 'Frontier' (Grafton et al., 1999). Great northern 'US 1140', UI 61, and Weihing, pink UI 537, and pinto UI 111 and UI 126 were also relatively early maturing. Breeding for early maturity was emphasized in the western USA to minimize risk from frost in early September and to provide some flexibility for late plantings in June and July. Thus, in addition to the above mentioned early-maturing cultivars, pinto 'Othello' (Burke et al., 1995b), red 'LeBaron' (Hang et al., 2000), and others have been developed in recent years. Native Americans had also realized the importance of early maturity for dryland production in the western USA, resulting in the Common Pinto landrace (Singh, 2003). Nonetheless, early maturity is often negatively correlated with seed yield in dry bean (White and Singh, 1991), thus further limiting yield potential of the western indeterminate cultivars.

Among the 25 cultivars, only the most recently released Matterhorn, Weihing, Frontier, and Kodiak had an indeterminate, upright Type II, growth habit (Table 2). All other cultivars had indeterminate, prostrate, semi-climbing Type III growth habit, typical of race Durango dry bean (Singh et al., 1991). Narrow-sense heritability for upright growth habit ranged from 0.42 to 0.62 (Brothers and Kelly, 1993). Using small-seeded tropical upright Type II dry bean and recurrent selection, Kelly and Adams (1987) developed the first group of upright Type II germplasm of race Durango that was subsequently

used for development of great northern 'Alpine' (Kelly et al., 1992a), Matterhorn, and Weihing, and pinto 'Aztec' (Kelly et al., 1992b), 'Sierra' (Kelly et al., 1990), Kodiak, and Frontier. Rust- and BCMV-resistant Type II cultivars such as great northern Matterhorn may yield similar to UI 425 or significantly less than pinto Bill Z in disease-free environments (Table 2), but they appear to outperform and exhibit broader adaptation and better stability across locations, especially in disease-prone humid midwestern production regions (Singh and Powers, 2000). High-yielding, high-quality, multiple disease resistant Type II cultivars of race Durango are therefore highly sought after in the midwestern states. Because such medium-seeded Type II cultivars

generally tend to produce smaller and fewer pods (Brothers and Kelly, 1993), breeding high-quality race Durango dry bean cultivars resistant to multiple biotic and abiotic stresses, without losing the yield potential of Type III growth habit in favorable or stress-free environments, is a daunting challenge indeed. Nonetheless, breeders may investigate usefulness of an integrated breeding approach for simultaneous selection for high seed yield, upright Type II growth habit, and resistance to multiple abiotic and biotic stresses (Singh, 1999; Singh et al., 1998). These integrated breeding approaches were probably not used by breeders early on. Instead, the developers of cultivars such as pinto Bill Z, red NW 63 and UI 239, pink UI 537, great northern UI 425, and others may have largely relied on repeated yield tests of advanced generation breeding lines that expanded over both stressful and favorable environments without intensive selection for resistance to diseases in early generations. The latter breeding strategy is still in use in some programs.

Breeding for resistance to viral diseases such as BCMV and BCTV was emphasized from the very beginning in the University of Idaho program (Dean, 1994, 2000). Selection in landraces against the locally prevalent BCMV strains resulted in cultivars such as UI 1 and UI 59, which were susceptible when challenged by more virulent strains of BCMV such as 'US 6' and BCMNV such as NL-3K (Table 5). Similarly, a great majority of cultivars were susceptible to these two viruses, anthracnose, common and halo bacterial blights, rust, Fusarium root rot, and white mold. Great northern (e.g., Matterhorn, Weihing) and pinto (e.g., 'Buster', UI 320) cultivars possessing the *I* allele imparting resistance to all known strains of BCMV, but resulting in necrotic reaction and plant death on inoculation with BCMNV strains such as NL-3K, have been available only within the last 10 yr. Similarly,

**Table 5.** Reaction of 25 dry bean cultivars to *Bean common mosaic necrosis virus* (BCMV), *Bean common mosaic virus* (BCMV), *Beet curly top virus* (BCTV), common and halo bacterial blight, anthracnose, Fusarium wilt and root rot, Rhizoctonia root rot, rust, and white mold evaluated in the greenhouse (GR) and/or field (FD) in Colorado, Idaho, and Washington between 1999 and 2006.

Market class and cultivar	BCMV(NL-3K) <sup>†</sup>		BCMV <sup>†</sup>	BCTV <sup>†‡</sup>	Common blight	Halo blight	Anthrac-nose (Race 73)	Fusarium		Rhizoctonia root rot <sup>†</sup>	Rust (Race 53)	White mold <sup>†</sup>				
	NY15	US 6		score				Wilt <sup>§</sup>	Yield <sup>§</sup>	score		GR	FD			
													score	kg ha <sup>-1</sup>	score	—score—
Great Northern																
Beryl	L	R	R	1.0	S	S	S	8.3	1156	5.3	S	6.2	8.2			
Matterhorn	N	R	R	3.3	S	S	S	7.1	1015	4.3	I	7.1	7.0			
UI 59	S	R	S	1.0	S	S	S	8.5	477	7.3	S	8.2	7.8			
UI 61	S	R	S	1.0	S	S	S	8.5	518	5.4	S	7.2	6.8			
UI 425	S	R	S	1.0	S	S	S	7.1	688	6.1	S	6.6	7.0			
UI 465	N	R	R	1.0	S	S	S	5.1	591	6.1	I	5.1	8.0			
US 1140	S	R	S	1.0	S	S	S	7.9	615	6.8	S	8.4	8.5			
Weihing	N	R	R	1.0	S	S	S	8.9	285	6.4	I	5.5	7.8			
Pink																
Harold	S	R	S	1.0	S	S	S	8.4	1613	7.2	S	7.1	7.8			
UI 537	S	R	S	1.0	S	S	S	7.5	1884	4.9	S	8.1	9.0			
Viva	S	R	S	1.0	S	S	S	8.7	1177	5.9	S	7.5	8.2			
Pinto																
Bill Z	S	S	S	1.0	S	S	S	8.2	862	5.9	S	8.1	9.0			
Burke	S	R	S	1.0	S	S	S	8.4	850	4.9	I	6.5	7.2			
Chase	S	S	S	1.0	S	I	S	8.1	647	6.3	I	4.3	8.8			
Frontier	S	S	S	1.0	S	S	S	5.5	123	6.7	I	6.4	6.5			
Kodiak	L	R	R	1.0	S	S	S	5.1	218	4.1	I	4.6	7.8			
UI 111	S	S	R	1.0	S	S	S	8.4	647	4.1	S	8.1	9.0			
UI 114	S	S	R	1.0	S	S	S	8.1	554	5.6	S	7.9	8.0			
UI 126	S	S	R	1.0	S	S	S	7.1	586	6.4	S	8.2	8.2			
UI 320	N	R	R	1.0	S	S	S	5.9	556	5.7	I	4.1	7.8			
Red																
NW 63	S	R	S	1.0	S	S	S	7.8	971	3.2	S	8.1	8.0			
UI 3	S	S	R	1.0	S	S	S	8.8	223	2.5	S	7.4	8.8			
UI 36	S	S	S	1.0	S	S	S	7.9	336	3.1	S	7.3	8.5			
UI 239	S	R	S	1.0	S	S	S	8.6	1439	7.1	S	8.1	8.0			
UI 259	S	R	S	1.0	S	S	S	7.1		4.9	S	6.9	7.8			

<sup>†</sup>Reaction to BCMV, BCMNV, BCTV, and other diseases: L, local lesion; N, top necrosis and plant death; I, intermediate reaction; R, resistant or symptomless; and S, severe disease symptoms.

<sup>‡</sup>Diseases scored on a 1 to 9 scale, where 1 = no visible symptoms and 9 = completely susceptible. Also, scores 1 to 3 were considered resistant, 4 to 6 moderately resistant, and 7 to 9 susceptible.

<sup>§</sup>Seed yield under Fusarium root rot in the field combined with other root rot pathogens, ~35% water deficit, nutritional deficiency, and compacted soil.

cultivars combining the *I* and recessive gene resistances to BCMV and BCMNV, such as Beryl and Kodiak, were also developed in the 1990s. Resistance or an intermediate reaction to the most widely distributed Middle American race 53 of the rust pathogen was present only in recently released cultivars, namely Matterhorn, UI 465 (Myers et al., 2001c), Weihing, Burke, 'Chase' (Coyne et al., 1994), Frontier, Kodiak, and UI 320. No pink or red cultivar was resistant to rust, reflecting the lack of importance of rust in the Pacific Northwest where these classes have been traditionally produced. Only pinto Chase was intermediate to halo blight, and although it possessed the SAP

6 marker linked with the common bacterial blight resistant QTL (Miklas et al., 1996) its reaction was susceptible under severe greenhouse pressure (Table 5). No cultivar of any of the four market classes released until the end of the 20th century was resistant to the most widely distributed race 73 of the anthracnose pathogen in the Americas. Most old and new cultivars had an intermediate level of resistance to Rhizoctonia root rot. In contrast, only UI 465, Frontier, Kodiak, and UI 320 were intermediate to Fusarium wilt. Similarly, only the three pink cultivars, red UI 239, and great northern Beryl and Matterhorn exhibited some resistance to Fusarium root rot. While

Beryl, UI 465, Weihing, Chase, Frontier, Kodiak, and UI 320 had a moderate level of resistance to white mold in the greenhouse straw-test in Colorado, all tended to be susceptible in the field at Paterson, Washington.

Introgression of resistance in race Durango cultivars to diseases such as rust, anthracnose, common and halo bacterial blights, and other disease not prevalent in the western states but problematic in the Midwest, Intermountain Regions, and Northern Plains, is a result of trying to expand the range of adaptation of the western dry bean cultivars into those regions. The question of benefit of these resistances for seed producers in the western states or for commercial growers in the midwestern states, or for both groups, could not be predicted at the moment because such broadly adapted cultivars may have lower yield potential in specific production regions. An integrated breeding strategy should be explored for simultaneous improvement of multiple traits in future cultivars.

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