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Erect Small-red Dry Bean Germplasm Lines: ARS-R93344, ARS-R93346, ARS-R93349

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An upright plant architecture is preferred for dry bean production in the Midwest because this architecture maximizes production under monoculture (Kelly and Adams, 1987). Upright plants are at much lower risk than prostrate ones of losing yield and culinary quality to disease (Blad et al., 1978) and weather damage (Kelly and Adams, 1987) under humid growing conditions. All small-red market-class cultivars in commercial production have prostrate growth habits and, thus, sprawl over the ground.

ARS-R93344, ARS-R93346, and ARS-R93349 are three new small-red dry bean (*Phaseolus vulgaris* L.) germplasm lines developed cooperatively by the U.S. Dept. of Agriculture, Agricultural Research Service (USDA/ARS), and the Michigan Agricultural Experiment Station. These germplasm lines (hereafter referred to as new releases) combine a narrow profile plant architecture and upright, indeterminant, and short-vine growth habit with the seed size, shape, and pigmentation characteristic of the small-red (formerly Red Mexican) market class (Figs. 1 and 2).

Origin

The new releases originated from the following crosses: X90108/X90131 (ARS-R93344), X90108/X90123 (ARS-R93346), and X90112/X90116 (ARS-R93349). X90108, X90112, X90116, X90123, and X90131 are USDA/ARS recurrent selections with complex pedigrees. The C_0 population resulted from a series of crosses involving upright, indeterminant, short-vine pinto breeding lines with the commercial small-red cultivars: ‘Ember’ (Syngenta, Nampa, Idaho) and ‘U136’ (released in 1964 by the Idaho Experiment Station); XPB-197 (small-red breeding line, Asgrow Seed Co., Twin Falls, Idaho); ‘Dessarural’ (Central American origin); and ‘Revolucion-79’ (Nicaraguan National Program). The upright pinto beans were derived by complex recurrent crossing among nine commercial pinto bean cultivars and 16 upright navy and tropical black breeding lines (Kelly and Adams, 1987).

Single-plant F_2 selections were made for upright architecture and seed traits of the small-red market class. The F_3 progenies were advanced to the F_6 generation as single-plant rows, alternately in Puerto Rico and Michigan. The $F_{2:6}$ progenies were assigned permanent accession numbers ARS-R93344, ARS-

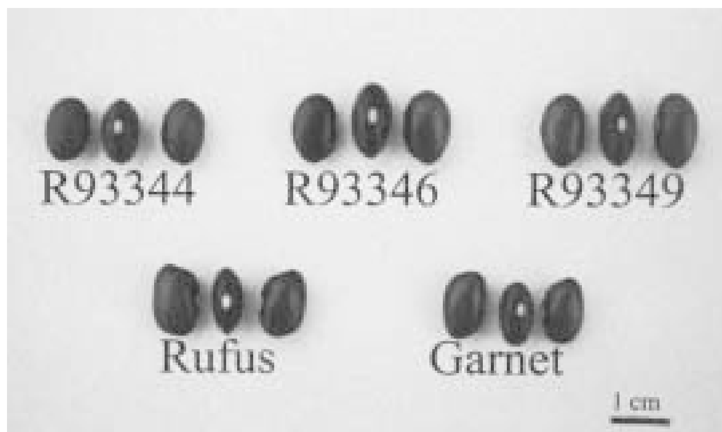

Fig. 1. Seed of ARS-R93344, ARS-R93346, and ARS-R93324, and the commercial cultivars Rufus and Garnet.

Fig. 2. Mature plant architecture of small-red germplasm ARS-R93344, ARS-R93346, and ARS-R93349, and the commercial cultivar Rufus. Note the acutely upward angled branches and erect architecture (Type IIa growth habit) of the new germplasm lines compared to the weak branching Type III growth habit of ‘Rufus’.

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R93346, and ARS-R93349 and entered into replicated yield trials in 1993. Seeds were harvested in bulk from the 1993 yield trials and used in subsequent yield trials. Greenhouse- (East Lansing, Mich.) grown seedlings (16-h day length at 25 ± 3 °C) from the bulked $F_{2:6}$ seed lots were rub-inoculated with viral homogenates of bean common mosaic virus (BCMV) (NL3 strain) at the primary leaf stage (8 to 10 d after planting; Kelly et al., 1995). Plants grown from the same seed lot as those screened for BCMV were inoculated in the greenhouse at Beltsville, Md., with known races of *Uromyces appendiculatus* (Pers.:Pers.) Unger, the causal organism of bean rust disease (Stavely, 1983).

Description

The new releases possess Type IIa growth habit (Singh, 1982) for *P. vulgaris* and resemble the ideotype for beans proposed by Adams (1973), i.e., an erect plant with strong main stem and three to five basal branches angled acutely (Fig. 1). This ideotype gives improved lodging resistance as compared to commercial small-red cultivars.

Dry bean seed color, shape, and mass (g/100) are important to consumers and processors and serve as criteria for market class standards (Adams and Bedford, 1973). The seed characteristics of the new releases meet the requirements and expectations of commerce for beans of the small-red market class. The new releases have an attractive garnet brown seed (Bassett, 1998) with a noticeable black hilum ring (Table 1, Fig. 1). Individual seeds are oval, ≈1.2 × 0.8 cm in length, plump at the surface, tangential to hilum, and gently rounded at the apices, giving them a more attractive appearance than 'Rufus' and 'Garnet', which have rhomboid-shaped seeds (Fig. 1). The surface color hue angles (Hosfield et al., 1995; Ruengsakulrach et al., 1994) (data not shown) of dry seed were determined with a Hunter Lab Color and Color Difference meter and indicated that the new releases have a more intense red than 'Rufus' or 'Garnet'. Seed masses between 28 and 40 g/100 seed for small-red beans are preferred for this market class.

The new releases average ≈50 cm in height (data not shown), have white flowers, and they bloom between 40 and 50 d after planting (Table 2). They are midseason in maturity and mature 90–95 d after planting (Table 2) with exceptional "dry down" (100% of pods have uniformly changed from green to mature color), and pods and stems are a straw-yellow at harvest.

ARS-R93344 and ARS-R93349 possess the *I* and *bc-1²* genes for resistance to BCMV. ARS-R93346 is susceptible to BCMV. ARS-R93349 also carries the *Ur-6* gene for resistance to bean rust disease; however, ARS-R93349 is still segregating for rust resistance because of the bulk breeding procedure. ARS-R93344 and ARS-R93346 are susceptible to rust. All three releases are susceptible to bean anthracnose, caused by *Colletotrichum lindemuthianum* (Sacc. & Magnus) Lams.-Scrib.

Performance

Yield and seed mass of the new releases were measured in replicated field experiments from 1993 to 1999 (Table 1). Horticultural and canning quality were measured in particular experiments (Tables 2 and 3). Except for two experiments, 'Rufus' and 'Garnet' were used as control cultivars. These controls are small-red commercial cultivars that have a viney Type III growth habit (Singh, 1984). 'Rufus' is late maturing (>95 d) and high yielding; 'Garnet' is early maturing (<90 d) and yields less than 'Rufus' (Table 1). In the 1996 experiment, 'NW-63', a commercial small-red cultivar with Type III growth habit, was used as the control.

Yields of the new releases ranged from 1528 to 3214 $kg \cdot ha^{-1}$; ARS-R93344 and ARS-R93346 were significantly lower yielding than ARS-R93349 in 1997, and ARS-R93344 was lower yielding than ARS-R93346 in 1996 (Table 1). As a group, the new releases had their highest yield in Washington (1998B) and lowest yield in Michigan (1998A). The yield of 'Rufus' was significantly higher than the new releases in 1993, ARS-R93344 and ARS-R93346 in 1997, and ARS-R93344 in 1999. The yields of the new releases were not significantly different from 'Garnet' except in 1994 ARS-R93344 significantly outyielded 'Garnet' (Table 1). In general, the seed mass trait of the new releases was similar to 'Rufus' but greater than 'Garnet' (Table 1). Differences in seed mass among the new releases were significant in 1996, 1998B, and 1999. Data aver-

Table 1. Yield and seed mass of ARS-R93344, ARS-R93346, and ARS-R93349 and commercial control cultivars from 1993 to 1999.[z, y]

	Yield and **seed mass**															
	Year															
Entry	1993[z]		1994[z]		1995[z]		1996[z]		1997[z]		1998A[z]		1998B[y]		1999[z]	
	$kg \cdot ha^{-1}$; **g/100 seed**															
ARS-R93344	2261	**34.1**	3214	**27.6**	1955	---	2778	**35.4**	2191	**35.0**	1717	**30.7**	3062	**38.0**	1652	**30.6**
ARS-R93346	2377	**32.7**	2713	**29.5**	1909	---	3114	**34.9**	1937	**36.0**	1528	**29.0**	2997	**41.0**	1907	**32.5**
ARS-R93349	2313	**33.5**	2902	**30.4**	1976	---	2901	**37.3**	2692	**37.5**	1747	**28.8**	3114	**40.0**	1995	**36.6**
Rufus[x]	2902	**33.8**	2626	**34.4**	2023	---	---	---	2984	**36.4**	1962	**28.6**	2897	**40.0**	2387	**35.5**
Garnet[x]	1937	**27.0**	2295	**25.5**	1867	---	---	---	2217	**30.2**	1741	**29.3**	---	---	2015	**30.1**
NW 63[x]	---	---	---	---	---	---	2901	**37.0**	---	---	---	---	---	---	---	---
$LSD_{0.05}$	446	**4.0**	695	**4.5**	391	---	302	**1.5**	493	**3.6**	238	**2.5**	800	**2.0**	491	**2.5**
cv (%)	13.6	**7.1**	16.1	**8.2**	12.0	---	7.1	**2.7**	13.0	**5.8**	9.1	**4.8**	21.0	**3.0**	5.3	**4.4**

[z]Replicated small-red yield trials grown in lattice designs at the Saginaw Valley Sugarbeet and Bean Research Farm near Saginaw, Mich.
[y]Replicated small-red and pink yield trial grown in a randomized complete-block design at Othello, Wash.
[x]Commercial cultivars used as experimental controls.

Table 2. Days to flower, maturity, and lodging of ARS-R93344, ARS-R93346, and ARS-R93349 and commercial control cultivars.[z]

	Year										
Entry	1994[y]	1995[y]	1998A[y]	1999[y]	1994[y]	1995[y]	1998B[x]	1995[y]	1996[y]	1998A[y]	1999[y]
	Days to flower (no.)				Maturity (days)			Lodging (scale)			
ARS-R93344	47	48	45	39	92	88	96	1	1	2	2
ARS-R93346	47	51	48	43	92	88	99	2	1	1	3
ARS-R93349	47	49	49	40	92	88	93	4	3	2	5
Rufus[w]	47	50	46	45	92	88	100	5	5	5	5
Garnet[w]	42	47	---	36	87	83	---	5	5	---	5
$LSD_{0.05}$	3	---	2	2	---	---	3	---	---	1	1
CV (%)	3	---	3	3	---	---	2	---	---	21	12

[z]Days to flower = number of days from planting until 50% of plants in plot have one open flower; maturity = number of days from planting until plots can be harvested; lodging, scale from 1 to 5 where 1 = upright and 5 = prostrate (100% lodged).
[y]Replicated small-red yield trial grown at the Saginaw Valley Sugarbeet and Bean Research Farm near Saginaw, Mich.
[x]Replicated small-red and pink yield trial grown at Othello, Wash. Commercial cultivars used as experimental controls.
[w]Commercial cultivars used as experimental controls.

Table 3. Thermal processing (canning) traits for ARS-R93344, ARS-R93346, and ARS-R93349 and commercial control cultivars.[z]

Entry	Washed-drained weight[y]				Shear resistance[x]				PQI[w]			
	Year				Year				Year			
	1993	1994	1997	1998	1993	1994	1997	1998	1993[v]	1994	1995	1997
	g				N/kg				Index			
ARS-R93344	290	283	---	278	81	81	---	81	27	36	40	---
ARS-R93346	287	287	---	282	74	62	---	76	24	38	39	---
ARS-R93349	283	274	296	276	73	82	72	79	26	41	41	35
Rufus[u]	278	271	285	271	85	82	80	75	30	42	41	42
Garnet[u]	288	269	290	268	83	74	78	70	26	36	43	37
$LSD_{0.05}$	19	8	8	11	2	2	15	6	4	4	3	2
CV (%)	4	13	3	2	14	10	17	4	9	10	4	6

[z]Data from replicated lattice experiments grown at the Saginaw Valley Sugarbeet and Bean Research Farm near Saginaw, Mich.
[y]Washed-drained weight = the rinsed weight (g) of canned beans after draining for 2 min on a standard no. 8 screen (mesh 0.24 cm) positioned at a 15° angle.
[x]Determined with an Allo-Kramer Shear Press and is the force required to bring 1 kg of cooked beans to a point of rupture and catastrophic breakdown of individual beans.
[w]PQI = Processing Quality Index: constructed as a linear function of subjectively determined scores on a 1–7 scale and measured on several attributes of processed beans, namely, the amount of clumping and splitting of individual canned beans, overall visual appeal of the canned sample; cooking broth characteristics of viscosity, color, and the amount of starch exudation (leakage) into the broth; and cooked seed characteristics of color, size, and shape for the market class; the 1–7 scale represents undesirable and desirable expressions of the traits, respectively.
[v]A 1–5 scale was used to represent the undesirable and desirable expressions of the components of PQI, respectively.
[u]Commercial cultivars are used as experimental controls.

aged over five tests indicated that the seed mass of ARS-R93349 was significantly greater than 'Garnet'.

The new releases were tested for their aggregate canning quality (Table 3), which reflects consumer and processor preferences. Canning quality was evaluated with a team of trained judges on the basis of a processing quality index (PQI) (Walters et al., 1997), and for hydrophilic and textural properties of cooked seeds (Hosfield and Uebersax, 1980; Hosfield et al., 1984a, 1984b). The PQI is a linear function of the amount of clumping, splitting, and overall visual appeal; canning broth characteristics of viscosity, color, and amount of exuded starch; and cooked seed characteristics of color, size, and shape for the market class. Index values are averages of five judges and higher values indicate better quality. 'Rufus' had higher PQI scores than 'Garnet', but the differences were significant only in 1994 and 1997. Both 'Rufus' and 'Garnet' showed acceptable canning qualities. Differences in PQI scores among the new releases were not significant except in 1994. 'Rufus' had a significantly higher PQI than ARS-R93346 in 1993, and a higher PQI than ARS-R93349 in 1997.

Shear resistance measures the rheology of a food (Kramer, 1964). Rheology is involved in the masticatory process of eating. The ideal range of shear resistance values for small-red beans is 65 to 75 N/kg and the acceptable range is 55 to 85 N/kg (Hosfield, unpublished data). 'Rufus had a higher shear resistance than 'Garnet', although the difference was only significant in 1994 (Table 3). Data averaged over the tests indicated that ARS-R93344 had the highest and ARS-R93346 the lowest shear resistance of the new releases. The average (over the tests) shear resistance of ARS-R93349 was similar (77 N/kg) to ARS-R93344 (81 N/kg).

The hydrophilic properties (water entrainment) of canned beans were determined gravimetrically (Hosfield and Uebersax, 1980; Hosfield et al., 1984a, 1984b) and expressed as g washed-drained weight (WDWT). This trait measures the rinsed weight of canned beans after draining for 2 min on a 0.24-cm mesh screen. The WDWT is important to processors to maximize the number of units of canned product per unit of fresh weight (processor yield). The WDWTs of the new releases and controls were acceptable, but <300 g optimum for canned beans (Hosfield and Uebersax, 1980; Hosfield et al., 1984a, 1984b).

Availability

A limited quantity of seed is available from G.L.S. (hosfiel2@msu.edu). The Michigan Agricultural Experiment Station has no seed of these lines for distribution.

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