‘BeltGlade RR-1’, ‘BeltGlade RR-2’, and ‘BeltGlade RR-3’: Rust-resistant Snap Bean Breeding Lines with the Ur-4 and Ur-11 Genes

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Bean rust, incited by the fungus Uromyces appendiculatus (Pers.) Unger var. appendiculatus [formerly U. phaseoli (Ruben) Wint.] is a common disease of Phaseolus vulgaris L. It has the potential to cause serious crop losses, and is particularly troublesome in warm, humid production regions such as Florida (Stavely, 1999a, 1999b; Stavely and Pastor-Corrales, 1989). Currently, the Florida snap bean industry is valued at over $100 million annually, and generally relies on just over a half-dozen cultivars. The major source of rust resistance in these popular cultivars is the Ur-4 gene (Kelly et al., 1996), previously identified in ‘Early Gallatin’ as Up-2 (Christ and Groth, 1982). Unfortunately, this gene is not completely effective against the races that now infect snap beans in Florida, and growers must routinely apply fungicides to control bean rust and a number of other foliar diseases. In the past few years, 90 of the estimated 150 worldwide bean rust races have been identified and are curated at Beltsville, Md. (Stavely, 1998a, 1999b). To date, 11 dominant resistant genes have been identified and controlled these pathogenic races. They confer various host plant resistance reactions, including immunity, hypersensitivity, and/or reduced uredinia size (Stavely, 1998a). The Ur-4 gene confers a hypersensitive type resistance, with necrotic lesions of 0.3–1.0 mm in diameter, to 30 of these races (Stavely, 1998a). Another gene, the dominant Ur-11 allele, confers hypersensitive or reduced uredinium (≤0.3 mm) type resistance to 89 of these races (Stavely, 1998a). The Ur-11 gene was previously identified as Ur-32 and later found to be linked in repulsion phase with the Ur-3 locus (Stavely, 1998b). The Ur-11 allele is not protective against Race 108 from Honduras (= H951, Steadman, pers. comm.), but Ur-4 is effective. When combined, the Ur-4 and Ur-11 genes concurrently provide either immunity, chlorotic or necrotic hypersensitive, or tiny uredinium resistance to all of the 90 races, with duplicate resistance to 29 of these races (Stavely, 1998b). Given the dynamic epidemiology of bean rust, more races will likely arise in the United States, Central America, and the Caribbean basin. A prudent strategy for the management of this disease is the deployment of different genes that confer resistance to a wide array of races, thereby diversifying the genetic basis of resistance.

The primary objective of this breeding effort was to generate broad-spectrum bean rust resistance in subtropically adapted, fresh market, snap bean germplasm. To accomplish this objective, the Ur-11 gene was introgressed into snap bean germplasm with existing resistance based on the Ur-4 gene. Additional emphasis was placed on the retention of resistance to bean common mosaic virus as conferred by the I gene (Drijfhout, 1978) and presently deployed in many of the important cultivars grown in Florida. These breeding lines are intended for use as a combined source of rust resistance based on Ur-11 and Ur-4 genes.

Origin
‘BeltGlade RR-1’ (BG-RR-1), ‘BeltGlade RR-2’ (BG-RR-2), and ‘BeltGlade RR-3’ (BG-RR-3), previously coded as 5-1815, 5-1853, and 5-1858, respectively, were developed using a modified backcross and pedigree method. In this crossing scheme, PI 181996 was the male donor of the Ur-11 gene (Stavely, 1988). PI 181996 was introduced from Guatemala in 1949 and is a typical Mesoamerican accession with an indeterminate growth habit, photoperiod sensitivity and black seeds (Stavely, 1990). A series of snap beans with bush growth habits were used as female parents recurrently, but not sequentially (Fig. 1). These included ‘Eagle’ and ‘Opus’, each used in one cross, ‘Sprite’ and ‘Podsquad’, each used twice and three times, respectively. ‘Eagle’, a processor snap bean, was the primary source of the Ur-4 gene and the unprotected I gene. ‘Opus’, ‘Podsquad’, and ‘Sprite’ are fresh-market snap bean cultivars, which have been commonly grown in Florida. All of these cultivars also carry the Ur-4 gene, as well as the I gene without any recessive modifiers.

From the first cross between ‘Eagle’ and PI 181996, an F1 individual was selected for snap bean horticultural quality, along with Ur-4 and Ur-11 based resistance to bean rust, and BCMV resistance as conferred by the I gene. This plant was subsequently crossed as a male to ‘Sprite’ with the F1 again tested for rust resistance. The progeny were subsequently crossed and backcrossed to ‘Podsquad’, with a rust resistant BC1 individual crossed again to ‘Sprite’. After this last cross with ‘Sprite’, ‘Podsquad’ was used as a female parent in the sixth cross. An F2 progeny set was generated and tested for rust resistance, with a desirable individual used in the last cross to ‘Opus’. Progeny from each of the seven crosses were selected for rust resistance following the inoculation technique of Stavely (1983), where 12 indicator races and Race 108 (Stavely, 1998a), were used to differentiate Ur-4 and Ur-11 based resistance (Stavely et al., 1983). Because each of the named snap bean cultivars and the F1 individual in the first cross were homozygous for the I gene, testing for BCMV resistance was delayed until near the end of the breeding program. With completion of the final cross, progeny were increased and the F2 selected for rust resistance and snap bean quality in Beltsville, Md. Subsequent selection for yield, plant type, pod, and seed formation was conducted at three sites in Belle Glade and Homestead, Fla., from the F2 to F6 generations. Individual field selections in the F2 generation were bulk increased in the greenhouse to produce the F3 progeny.
which were tested for resistance to rust and BCMV. The I gene was identified using the systemic necrosis-inducing strain NL-3 and confirmed by the presence of the linked RAPD marker OW13690 (Haley et al., 1994). Bulk increases of the F7 in the greenhouse were again challenged for rust resistance and rated according to Stavely et al. (1983) and Stavely and Pastor-Corrales (1989) (Table 1). Selection was also practiced for BCMV resistance and against off-types. Selected progeny were bulked and released.

**Description**

In general, the leaf morphology of these breeding lines is similar to that of ‘Opus’, but the leaf is smaller. The floral morphology of these lines is nearly identical to that of ‘Opus’. Flowers are first set and visible on the fourth or fifth node, but the sixth to eight node is commonly the first to have open flowers. All flower petals are white to off-white and light green at the base. Flowers are borne on green pedicels, ≥1.0 cm long, with pointed green stipules. In Florida, crop phenology is nearly equivalent for ‘BeltGlade RR-1’, ‘BeltGlade RR-2’, and ‘Opus’, with first flowers opening ≈34 d and mid-bloom at 40 d. On average, ‘Pod Squad’ and ‘BeltGlade RR-3’ reach anthesis in 37 d, and mid-bloom in 45 d, but ‘BeltGlade RR-3 produces the fewest flowers and tends to split set. Fruit set is relatively high on Centro Internacional de Agricultura Tropical (C.I.A.T.) Type Ib plants (van Schoonhoven and Pastor-Corrales, 1987), and pods are suitable for mechanical harvest. Plant height in the three breeding lines and the standard cultivars averages between 30–40 cm; that of ‘BeltGlade RR-2’ averages ≤40 cm while ‘BeltGlade RR-3 is shortest (30–35 cm). Plants are generally ready for harvest in 60–65 d.

Pod color for these breeding lines at snap bean stage is a solid and uniform light to medium green, drying to light to medium tan. Pod morphology of ‘BeltGlade RR-1’ and ‘BeltGlade RR-2’ is similar to that of ‘Opus’. Pods tend to be straight to slightly curved, with a round transect and minimal interlocular constriction. In Florida, pod length is generally 10–12 cm, with sieve sizes mostly in the “3” and “4” range. Apicules are also similar to those of ‘Opus’. ‘Opus’ generally has four to eight seeds per pod, and differs from the first two breeding lines, which usually have five and six seeds per pod. ‘BeltGlade RR-3’ has a pod morphology similar to that of ‘Pod Squad’, but pods are smaller. Sieve sizes for this breeding line fit in the “2” and “3” range, with three to four seeds per pod and pod lengths of 9.5–11.5 cm. ‘Pod Squad’ commonly has five to seven seeds per pod; most pods are sieve size “3” with lengths of 10–11 cm.

Seed of these three breeding lines are monochrome, off-white to ivory, semi-shiny to semi-dull, with a small yellow hilar ring. Seed shape is cuboid to reniform with a mostly round to off-round transect shape and a distinctive “flat spot” 0.5–1.0 mm in diameter on the distal end. Seed test weights

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**Table 1. Reaction of 'Beltglade RR-1', (BG-RR-1), 'Beltglade RR-2' (BG-RR-2), 'Beltglade RR-3' (BG-RR-3), 'Opus', 'Pod Squad', and 'Sprite' snap bean to foliar inoculation with 13 races of bean rust**

| Bean rust race | BG-RR-1 | BG-RR-2 | BG-RR-3 | Opus | Pod Squad | Sprite |
|----------------|--------|--------|--------|------|-----------|--------|
| 38             | 2 or 2.3 | 2 or 2.3 | 2 or 2.3 | 4.3  | 4,3 or 6.5 | 5.6    |
| 41             | 3.2    | 3.2    | 3.2    | 4,5  | 4.5       | 4.5    |
| 45             | 3.2    | 3.2    | 3.2    | 4,5  | 4.5       | 4.5    |
| 46             | 3.2    | 3.2    | 3.2    | 4,5  | 4.5       | 4.5    |
| 47             | 3.2    | 3.2    | 3.2    | 4,5  | 4.5       | 4.5    |
| 44             | 1.2    | 1.2    | 1.2    | 2+,2 | 2+,2      | 2+,2   |
| 49             | 2 or 2.3 | 2 or 2.3 | 2 or 2.3 | 2+,2 | 2+,2      | 2+,2   |
| 53             | 3.2    | 3.2    | 3.2    | 4    | 4.5       | 4.5    |
| 58             | 3.2    | 3.2    | 3.2    | 4    | 4.5       | 4.5    |
| 63             | 3.2    | 3.2    | 3.2    | 4    | 4.5       | 4.5    |
| 67             | 3.2    | 3.2    | 3.2    | 4    | 4.5       | 4.5    |
| 78             | 2.3    | 2.3    | 2.3    | 2+   | 2+        | 2+     |
| 108            | 2 or 2.3 | 2 or 2.3 | 2 or 2.3 | 2+   | 2+        | 2+     |

*Reaction ratings are based on grades 1–6 devised by Stavely et al. (1983) and Stavely and Pastor-Corrales (1989), where: 1 = immunity, no visible symptoms; 2 = necrotic hypersensitivity, without sporulation and necrotic spots ≤300 µm in diameter; 2+ = necrotic spots 300–100 µm in diameter; 2++ = necrotic spots 1.0–3.0 mm; 2+++ = necrotic spots ≥3.0 mm; 3 = sporulating pustules ≤300 µm in diameter; 4 = sporulating pustules 300–500 µm in diameter; 5 = sporulating pustules 500–800 µm in diameter; 6 = sporulating pustules ≥800 µm in diameter. When grade varied, the most prevalent is listed first.
for ‘Opus’, ‘Pod Squad’, and the three breeding lines averaged 28.5–30 g/100 seed.

**Availability**

These three breeding lines are released without restriction. Small samples of seed may be obtained either from BTS or JRS. Seed has also been deposited in the U.S. Dept. of Agriculture (USDA) germplasm repository at Pullman, Wash.

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