Development of Large-Seeded High-Quality, High-Yielding Great Northern Dry Bean 'Hungerford' and 'Sawtooth'

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ABSTRACT

Large-seeded (45 g 100 seed weight^{-1}), high-yielding, and high-quality Hungerford (Reg. No. CV-285, PI 653258) and Sawtooth (Reg. No. CV-286, PI 653259) great northern dry bean (*Phaseolus vulgaris* L.) cultivars were developed at the University of Idaho-Kimberly Agricultural Research and Extension Center. The Idaho Agricultural Experiment Station released Hungerford and Sawtooth on 12 Apr. 2007. Hungerford and Sawtooth are full-season (95–100 d maturity) cultivars adapted to the western United States that have resistance to *Bean common mosaic virus* (an aphid-vectored potyvirus) and rust [caused by *Uromyces appendiculatus* (Pers.) Ung.]. Both also have moderate to high levels of resistance to heat, drought, and soil zinc deficiency and manganese toxicity.

Great northern dry bean (*Phaseolus vulgaris* L.) is an important market class in Nebraska, Idaho, and other western U.S. states. However, there is very little consumption of great northern bean in North America. Most of the North American production is exported to Europe, Middle East, and North Africa. In countries such as Bulgaria, France, Greece, Spain, and Turkey, there is demand for large-seeded (≥40 g 100 seed weight^{-1}) whiter bean of this market class. For example, in Spain and France, 100 seeds of some great northern types (e.g., Xanget) may weigh >75 g (Rodiño et al., 2006). These types usually command three or four times the price of regular great northern bean from the United States. These are local landraces that evolved in Europe after the introduction of common bean from the Americas approximately 500 yr ago (Rodiño et al., 2006; Zeven, 1997). These landraces from Europe have an indeterminate climbing growth habit Type IV (Singh, 1982), are grown on small hectarage using trellises or crops such as corn (*Zea mays* L.) for support, and may take >120 d from planting to harvest maturity. Moreover, despite coming from similar latitudes, these landraces may not flower or be excessively late when grown in the field in the western United States. Great northern landraces (e.g., Montana 5) and selections thereof, such as 'UI 59', from the United States have an indeterminate prostrate growth habit Type III. One hundred seeds of the great northern cultivars produced in the United States often weigh <40 g. These take a full season (>95 d) to mature in the western United States. Like medium-seeded pinto, pink, and red market classes, great northern belongs to the common bean race Durango that originated in the highlands of Mexico (Singh, 1989; Singh et al., 1991).

Among the major production problems of great northern and other market classes of race Durango bean in the western United States are drought, high temperatures during the reproductive phase, and low soil fertility, including deficiency of iron and zinc. Similarly, diseases such as *Bean common mosaic virus* (BCMV, an aphid-vectored potyvirus), *Beet curly top virus* (BCTV, a leafhopper-vectored curtovirus), root rots (mostly caused by *Fusarium solani* and *Rhizoctonia solani*), and white mold [caused by *Sclerotinia sclerotiorum* (Lib.) de Bary] are endemic and widespread problems in the region.

Breeding and genetics of great northern bean were initiated at the University of Idaho in 1925 (Dean, 1994, 2000). Initially, selection for resistance to BCMV within

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Abbreviations: AREC, Agricultural Research and Extension Center; BCMV, *Bean common mosaic necrosis virus*; BCMNV, *Bean common mosaic necrosis virus*; BCTV, *Beet curly top virus*; CDBN, Cooperative Dry Bean Nursery; CIAT, Centro Internacional de Agricultura Tropical; IDBT, Idaho Dry Bean Trial; WRBT, Western Regional Bean Trial.

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landraces was practiced, resulting in great northern cultivars such as UI 1 (released in 1930) and UI 59 (released in 1932). Subsequently, resistance to BCTV from the Common Red Mexican landrace was combined with BCMV resistance through hybridization among landraces. Subsequently, breeding for early maturity (e.g., 'US 1140'), upright growth habit Type II, rust [caused by *Uromyces appendiculatus* (Pers.) Ung.] resistance, and broad adaptation was emphasized. Thus, cultivars such as 'Matterhorn' (Kelly et al., 1999) and 'Weihing' (Coyne et al., 2000) were developed. Brick and Grafton (1999) reviewed the strategies used and progress achieved in improving cultivars of race Durango. Miklas (2000) further reviewed the use of germplasm for improving cultivars of race Durango. However, in Idaho and elsewhere, great northern cultivars developed thus far either have lacked desired seed quality and/or resistance to BCMV, rust, and other diseases (Singh et al., 2007). The objective of this research was to develop large-seeded ($\geq$40 g 100 seed weight^{-1}), high-yielding, and high-quality great northern cultivars Hungerford (Reg. No. CV-285, PI 653258) and Sawtooth (Reg. No. CV-286, PI 653259) with resistance to BCMV and rust.

Materials and Methods

Hungerford and Sawtooth were derived from a double-cross population, UIG4 = Matterhorn/Starlight//Beryl/Weihing, that was made in 1999–2000. The Michigan Agricultural Experiment Station released great northern Matterhorn (Kelly et al., 1999). High-yielding, broadly adapted Matterhorn has an indeterminate upright or erect growth habit Type II (Singh, 1982) with small to medium length vine in southern Idaho. Matterhorn carries the *I* gene resistance to the US-6 and all other strains of the BCMV. However, when inoculated with the strains of *Bean common mosaic necrosis virus* (BCMNV, an aphid-vectored potyvirus) Matterhorn exhibits top or systemic necrosis including black root and eventual plant death. Matterhorn is resistant (no disease symptoms) to the race 38 (Andean) of *U. appendiculatus* but exhibits an intermediate reaction or small pustules when inoculated with race 53 (Middle American) of the pathogen. The Nebraska Agricultural Experiment Station released high-quality great northern 'Starlight' (Coyne et al., 1991) and Weihing (Coyne et al., 2000). Starlight has good great northern seed type and an indeterminate semiprostrate growth habit Type III, and is susceptible to BCMV and BCMNV. However, Weihing has a similar growth habit and resistance to BCMV and rust as Matterhorn. Beryl is a Rogers/Syngenta great northern cultivar with growth habit Type III. In addition to the *I* gene, Beryl carries a recessive resistance gene such that it exhibits local necrosis or pinpoint lesions when inoculated with the NL-3K and other strains of the BCMNV. The rust reaction of Beryl is similar to that of Matterhorn and Weihing. Seed quality of Beryl and Matterhorn is not as good as Starlight and Weihing.

Hungerford was a single plant selection made for extra-large white great northern seed in the F_2 of a double-cross population in the field at Parma, ID. The F_2–derived F_3 ($F_{2:3}$) progeny-row was grown in the field at Kimberly, ID, where all plants selected for extra-large great northern seed were harvested in bulk followed by a single plant selection in the field at Parma. The $F_{4:5}$ plant-to-progeny row was grown in the greenhouse at Kimberly, selection was made for resistance to the US-6 strain of BCMV and extra-large white great northern seed, and all selected plants were harvested in bulk. Subsequently, seed was increased in the field at Kimberly. Hungerford was tested in the Idaho Dry Bean Trial (IDBT) and/or the Western Regional Bean Trial (WRBT) as UIG4-6P-3P, ABL 2, and/or 06I6 from 2004 to 2006.

Sawtooth was a single plant selection made in the double-cross F_2 population that exhibited large white great northern seed in the field at Parma, ID. The $F_{2:3}$ progeny-row was grown in the greenhouse where a single-plant selection was made for resistance to the US-6 strain of BCMV and large white great northern seed. The $F_{3:4}$ plant-to-progeny row was grown in the field at Kimberly and plants selected for large white great northern seed were harvested in bulk. A single plant selection for large white great northern seed was made in the F_5 in the field at Parma. The F_6 progeny row was screened in the greenhouse for BCMV resistance and large white great northern seed. All plants were harvested in bulk, followed by seed increase in the field at Kimberly. Six F_6 plants were screened for resistance to races 38 and 53 of *U. appendiculatus* in a separate greenhouse at Filer, ID. Sawtooth was tested in the IDBT, WRBT, and/or Cooperative Dry Bean Nursery (CDBN) as UIG4-53P-2P, ABL 6, and/or 06I1 from 2004 to 2006.

In the IDBT, WRBT, and CDBN, data were recorded for growth habit, number of days to maturity, seed yield, and 100-seed weight, among other traits. Additionally, the two cultivars were tested for reaction to Fusarium root rot [caused by *Fusarium solani* f. sp. *phaseoli* (Burkh.) Snyd. & Hansen] and BCTV in the field at Prosser, WA, for soil zinc deficiency in the field at Kimberly, and for anthracnose [caused by *Colletotrichum lindemuthianum* (Sacc. & Magn.) Lams.-Scrib. races 23 and 73], common bacterial blight [*Xanthomonas campestris* pv. *phaseoli* and *Xanthomonas campestris* pv. *phaseoli* var. *fuscans*], halo blight [caused by *Pseudomonas syringae* pv. *phaseolicola* (Burkh.) race 2], and white mold in separate greenhouse nurseries at Filer or Kimberly. All data were analyzed using the SAS (v 9.1) PROC GLM statistical package (SAS Institute, 2004).

Results and Discussion

Plant Characteristics

Hungerford has an indeterminate semiprostrate growth habit Type III with medium to large vine (Table 1). The central leaflet of the fully developed trifoliolate leaf is ovate with average length of 9.5 cm and width of 7.5 cm. The flower bracteoles are chordate and medium size. Flower color is white with the absence of stripes at the outer base of the standard. Sawtooth also has an indeterminate semiprostrate growth habit Type III with medium to large vine. The central leaflet of the fully developed trifoliolate leaf is ovate with average length of 10 cm and width of 8 cm. The flower bracteoles are large chordate. Flower color is white with the absence of stripes at the outer base of the standard.

The Type III growth habit of Hungerford and Sawtooth was similar to the growth habit of the parents (Beryl and Starlight) used in the double-cross (UIG4). Nonetheless, Matterhorn and Weihing with 25% genetic contribution each had growth habit Type II in the double-cross UIG4 from which Hungerford and Sawtooth were derived. Despite that genetic contribution, neither Hungerford nor Sawtooth had Type II growth habit. In common bean, increasing indeterminacy (i.e., from determinate Type I to indeterminate Types II to IV) and the weakness of stem and branches are dominant traits. Moreover, while the determinate growth habit is controlled by a single recessive gene *fin* (Bliss, 1971) located on the linkage group B1 or chromosome 2 (Miklas and Singh, 2007), the expression and inheritance of stem strength or erectness seem to be more complex, affected by growing conditions and agronomic management, and are quantitatively inherited (Brothers and Kelly, 1993; Kelly, 2001). Furthermore, in our study, selection for growth habit was not practiced in any generation.

Because the western United States has a semiarid environment and bean is largely produced for seed under gravity irrigation, producers of great northern and other market classes of race Durango cultivars thus far have capitalized on the comparatively higher yield potential of the prostrate viny Type III over erect Type I and Type II cultivars. However, in the midwestern United States (e.g., North Dakota, Michigan) and in Manitoba, Alberta, Ontario, and Saskatchewan, Canada, upright Type II growth habit cultivars are sought after to minimize seed yield and quality losses from foliar diseases such as white mold, rust, anthracnose, and common bacterial blight because of higher humidity. Furthermore, in addition to disease avoidance mechanisms of the open upright plant canopy and consequently better seed quality than Type III cultivars because of reduced contact of pods with the soil, Type II cultivars would be more suitable for the one-step direct harvest, thus reducing production costs and dependence on farm labor and energy. Breeders interested in Type II cultivars should simultaneously select for upright growth habit and high-quality large great northern seed from the early generations. However, the early-generation simultaneous selection for both traits would require much larger plant population in the F_1, F_2, and F_3 because the frequency of such genotypes would be low. Alternatively, the selection for these two and other recessive traits could be delayed until later generations (e.g., F_5 and F_6), especially when advancing considerably larger genetic variability through early generations using the single-seed-descent method or its modifications.

Pod Characteristics

Pods of Hungerford are distributed along the stem length and branches. At maturity, pods are tan or yellowish-brown with light purple stripes. Dry pods are flat and slightly curved, with straight to curved-down beak. Also, pods have slight constrictions with an average of four to five seeds. Pods of Sawtooth also are distributed along the stem length and branches. At maturity, pods are smooth tan or yellowish-brown without stripes. Dry pods are flat and slightly curved, with straight to curved-down beak. Pods may have slight constrictions with an average of five to six seeds.

Maturity

Hungerford is a full-season cultivar, taking 92 to 102 d with a mean of 95 d, compared with a range of 90 to 105 d and mean of 97 d for 'UI 425', across 15 environments comprising seven stressed and nonstressed organic and conventional production systems in the IDBT in southern Idaho in 2005 and 2006 (Table 1). Hungerford's maturity ranged from 90 to 103 d with a mean of 97 d compared with a range of 86 to 97 d and mean of 91 d for 'Orion' across four environments in Colorado, Idaho, Nebraska, and Washington in the WRBT in 2006 (Table 1; P. Miklas, unpublished, 2007).

Sawtooth also is a full-season cultivar, taking 91 to 103 d with mean of 96 d in the IDBT in southern Idaho in 2005 and 2006, compared with a range of 90 to 105 d and a mean of 97 d for UI 425 (Table 1). Sawtooth's maturity ranged from 92 to 102 d with a mean of 99 d, compared with a range of 86 to 97 d and mean of 91 d for Orion across four locations in the WRBT in 2006 (Table 2; P. Miklas, unpublished, 2007). In the CDBN, maturity

Table 1. Mean days to maturity for great northern dry bean cultivars Hungerford and Sawtooth and check cultivars evaluated in the Idaho Dry Bean Trial (IDBT) and the Western Regional Bean Trial (WRBT) in 2005 and 2006, and in the Cooperative Dry Bean Nursery (CDBN) in 2006.†

Cultivar	2005		2006		Overall mean
	Range	Mean	Range	Mean	
	d				
			IDBT		
Sawtooth	93–103	98	91–98	94	96
Hungerford	92–102	96	92–97	94	95
UI 425	92–105	99	90–98	94	97
$LSD_{0.05}$		2.3		3.4	2.4
			WRBT		
Sawtooth	95–100	98	92–102	99	99
Hungerford	–	–	90–103	97	97
Orion	–	–	86–97	91	91
$LSD_{0.05}$				6.5	6.9
			CDBN		
	West		East		
Sawtooth	90–104	96	84–116	99	98
Matterhorn	87–94	91	79–94	86	89
$LSD_{0.05}$		5.9		3.8	4.2

†IDBT, six environments in 2005 and nine in 2006; WRBT, in Colorado, Idaho, and Washington in 2005 and in Colorado, Idaho, Nebraska, and Washington 2006; and CDBN, evaluated in seven states in the West and four in the East in 2006. The LSD values were determined using all genotypes tested in experiment.

of Sawtooth across 11 locations ranged from 84 to 116 d with a mean of 98 d, compared with the respective values of 79 to 94 and 89 d for Matterhorn (Table 1; Hang, 2006).

Biomass Yield and Harvest Index

Sawtooth had a mean biomass yield of 5541 kg ha^{-1} with harvest index of 0.45 compared with the respective values of 5554 kg ha^{-1} and 0.53 for Matterhorn in the CDBN in 2006 (Hang, 2006). Among all dry bean, the race Durango cultivars have the highest (~0.60) harvest index (Singh, 1989; Singh et al., 1991). Maximizing seed yield through simultaneously increasing biomass yield and harvest index is a worthwhile strategy (Wallace, 1985; Wallace et al., 1993), especially for production regions such as southern Idaho that have only one crop per year. However, for full-season growing environments, the upper limits of biomass production for the race Durango cultivars in the northwestern United States are not known. Moreover, breeders interested in improving harvest index of cultivars such as Hungerford and Sawtooth using the early maturity gene from US 1140 and similar cultivars would face a daunting challenge because of a negative association between early maturity and seed yield (White and Singh, 1991).

Canning Quality

Although the major portion of great northern bean is sold as a dry pack, some canning is done for domestic consumption and export. The consumption of canned great northern bean may increase with or without mixing other ingredients whereby the wholesome appearance of intact seed coat of canned bean continues to be important for consumers. We therefore need to know the canning characteristics of new cultivars. In the CDBN canning test conducted in Michigan and New York, the variation in size, color, acceptance or freedom from splits, and overall canning score for Sawtooth were within the acceptable limits and relatively similar to Matterhorn (Table 2, Hang, 2006).

Table 2. Variation in size, color, and freedom from splits from canning and overall canning score for great northern Sawtooth and Matterhorn evaluated in the Cooperative Dry Bean Nursery in Michigan and New York in 2006.

Cultivar	Variation in size†	Uniformity of color†	Appearance (freedom from splits)†	Canning test score‡
Sawtooth	1.50	1.75	1.13	2.7
Matterhorn	1.25	1.50	0.63	3.9

†New York canning test scored on a 0 to 2 scale, where 0 = very poor, 1 = acceptable, and 2 = near perfect.

‡Michigan canning test scored on a 1 to 7 scale, where 1 = unacceptable, 4 = acceptable, and 7 = highly desirable.

Seed Weight

Hungerford, Sawtooth, and UI 425 had a similar mean 100-seed weight of 40 g in the IDBT across 15 environments in Idaho in 2005 and 2006 (Table 3). In the WRBT in 2006, the weight of Hungerford was 44 g and Sawtooth was 45 g, compared with 36 g for Orion (Table 3). In the CDBN across 11 environments in 2006, 100 seeds of Sawtooth weighed 43 g compared with 34 g for Matterhorn (Table 3). The weight of 100 seeds of the other three parents, namely Beryl, Starlight, and Weihing of the double-cross population UIG4 that produced Hungerford and Sawtooth, respectively, were 27, 37, and 34 g in southern Idaho. Thus, Hungerford and Sawtooth were results of transgressive segregation, suggesting that the four parents possessed complementary and additive genes for seed weight. Furthermore, because Hungerford and Sawtooth have more chalky whiter smooth seed coat color without veins, similar transgressive segregation also seemed to have occurred for these seed traits.

Seed Yield

Average yield of Sawtooth was 2471 kg ha^{-1} and that of Hungerford was 2246 kg ha^{-1} compared with 2443 kg ha^{-1} for UI 425 across 15 environments in the IDBT in southern Idaho in 2005 and 2006 (Table 4). In the WRBT, the average yield of Sawtooth was 2615 kg ha^{-1} and that of Hungerford was 2603 kg ha^{-1} compared with 2338 kg ha^{-1} for Orion (Table 4). In the CDBN across seven western states, Sawtooth yielded 3357 kg ha^{-1} compared with 3384 kg ha^{-1} for Matterhorn in 2006 (Table 4, Hang, 2006). However, across all 11 locations in the United States and Canada, the respective yields were 2510 kg ha^{-1} and 3128 kg ha^{-1}.

Table 3. Mean 100-seed weight for great northern cultivars Hungerford and Sawtooth and check cultivars evaluated in the Idaho Dry Bean Trial (IDBT) and the Western Regional Bean Trial (WRBT) in 2005 and 2006, and in the Cooperative Dry Bean Nursery (CDBN) in 2006. †

Cultivar	2005 Range	2005 Mean	2006 Range	2006 Mean	Overall mean
			g		
IDBT					
Sawtooth	39–45	42	34–44	37	40
Hungerford	38–45	42	36–43	38	40
UI 425	39–47	43	35–42	37	40
$LSD_{0.05}$		2.9		3.0	2.5
WRBT					
Sawtooth	37–47	44	42–49	45	45
Hungerford	–	–	39–50	44	44
Orion	–	–	31–39	36	36
$LSD_{0.05}$				3.1	4.4
CDBN					
	West		East		
Sawtooth	39–47	43	32–49	42	43
Matterhorn	31–37	35	30–35	32	34
$LSD_{0.05}$		2.6		3.4	2.2

†IDBT, six environments in 2005 and nine in 2006; WRBT, in Colorado, Idaho, and Washington in 2005 and in Colorado, Idaho, Nebraska, and Washington 2006; and CDBN, evaluated in seven states in the West and four in the East in 2006. The LSD values were determined using all genotypes tested in experiment.

Disease Resistance

Hungerford and Sawtooth have the dominant *I* gene resistance to BCMV strains NY-15 and US-6. However, when inoculated with the BCMNV strain NL-3K, similar to Matterhorn, Hungerford and Sawtooth exhibit top or systemic necrosis including black root (Table 5). The presence of the SCAR marker SW 13 in Hungerford and Sawtooth further supported the fact that both carried the dominant *I* gene imparting resistance to all known strains of BCMV (Haley et al., 1994). Hungerford and Sawtooth are resistant to race 38 of *U. appendiculatus*. However, Hungerford and Sawtooth exhibit an intermediate reaction or small pustules when exposed to the rust pathogen race 53. Hungerford and Sawtooth are susceptible to anthracnose, common bacterial blight, Fusarium root rot, halo blight, and white mold. Similar to Matterhorn, Hungerford and Sawtooth are moderately susceptible to BCTV.

Abiotic Stress Resistance

Hungerford and Sawtooth have moderate to high levels of resistance to heat and intermittent drought (data not shown). Both also have high levels of resistance to soil zinc deficiency and manganese toxicity in southern Idaho.

Area of Adaptation

Hungerford and Sawtooth were developed for 95- to 100-d frost-free bean production regions of southern Idaho. However, they have exhibited a broad adaptation in relatively warmer bean growing environments in the western United States. Because of their semi-prostrate growth habit Type III and lack of resistance to anthracnose, common bacterial blight, and white mold, Hungerford and Sawtooth may have limited adaptation in or be unsuited to the relatively cool and wet production environments in the midwestern United States and Canada.

Seed Status

Breeder and Foundation seed of Hungerford and Sawtooth will be maintained by the Idaho Foundation Seed Program under the direction of the Idaho Agricultural Experiment Station, University of Idaho, Moscow, ID 83844. Moreover, Hungerford and Sawtooth will have Foundation, Registered, and Certified classes of seed. An application will be filed for cultivar protection under Title V of the U.S. Plant Variety Protection Act. A small quantity of seed of Hungerford and Sawtooth for research purposes is available from the corresponding author for the first five years. Appropriate acknowledgment of its developers and the University of Idaho for the use of Hungerford and Sawtooth as germplasm would be highly appreciated.

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Table 4. Mean seed yield for great northern cultivars Sawtooth and Hungerford and check cultivars evaluated in the Idaho Dry Bean Trial (IDBT) and the Western Regional Bean Trial (WRBT) in 2005 and 2006, and in the Cooperative Dry Bean Nursery (CDBN) in 2006.†

Cultivar	2005		2006		Overall mean
	Range	Mean	Range	Mean	
	kg ha^{-1}				
IDBT					
Sawtooth	1593–3582	2556	1087–3588	2385	2471
Hungerford	1215–3942	2334	1108–3571	2157	2246
UI 425	1229–4280	2553	1263–3540	2332	2443
$LSD_{0.05}$		209		372	197
WRBT					
Sawtooth	851–4319	2695	1241–5019	2535	2615
Hungerford	–	–	910–5151	2603	2603
Orion	–	–	817–5246	2338	2338
$LSD_{0.05}$				742	643
CDBN					
	West		East		
Sawtooth	1292–4233	3357	818–2096	1662	2510
Matterhorn	1244–4607	3384	2421–3329	2872	3128
$LSD_{0.05}$		507		607	455

†IDBT, six environments in 2005 and nine in 2006; WRBT, in Colorado, Idaho, and Washington in 2005 and in Colorado, Idaho, Nebraska, and Washington in 2006; CDBN, evaluated in seven states in the West and four in the East in 2006. The LSD values were determined using all genotypes tested in experiment.

Table 5. Reaction of great northern bean cultivars Sawtooth and Hungerford and check cultivar UI 425 to *bean common mosaic virus* (BCMV), bean common mosaic necrosis virus (BCMNV), and rust evaluated in the greenhouse in Idaho from 2003 to 2007.

Cultivar	BCMV		BCMNV	Rust pathogen	
	NY-15	US-6	NL3-K	Race 38	Race 53
Sawtooth	Resistant	Resistant	Systemic necrosis	Resistant	Intermediate
Hungerford	Resistant	Resistant	Systemic necrosis	Resistant	Intermediate
UI 425	Resistant	Resistant	Susceptible	Susceptible	Susceptible

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