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GERMPLASM

Registration of #STRKR Barley Germplasm

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Abstract

#STRKR (Reg. No. GP-208, PI 674325) is a hulless, six-row barley (*Hordeum vulgare* L.) germplasm composed of the bulk of three full-sib lines, two of which have winter growth habit and one of which has facultative growth habit. The germplasm was released by the Oregon Agricultural Experiment Station in 2014. The three sister lines from the Oregon State University Barley Breeding Program that were bulked to form #STRKR were derived from the cross of F_1('Maja'/'Legacy')/Maja/3/'Doyce'. #STRKR was tested under the experimental designation Streaker. The #STRKR germplasm is uniform for spike type, rachilla hair length, resistance to stripe rust (incited by by *Puccinia striiformis* f. sp. *hordei*), and grain quality parameters. It is relatively uniform in terms of height and heading date. #STRKR is phenotypically heterogeneous for awn texture, grain color, and tolerance to scald (incited by *Rhynchosporium commune*). As a blend, #STRKR has shown winter survival comparable to Maja in environments where there was differential winter injury. #STRKR germplasm provides a resource for reselection and a parental source for disease resistance and quality parameters.

#STRKR (Reg. No. GP-208, PI 674325) is a hulless, six-row barley (*Hordeum vulgare* L.) germplasm comprising the bulk of three full-sib lines, two of which have winter growth habit and one of which has facultative growth habit. The germplasm was released by the Oregon Agricultural Experiment Station in 2014. #STRKR was derived from the pedigree F_1('Maja'/'Legacy')/Maja/3/'Doyce'. Maja is a six-row, hulled malting barley with facultative growth habit, released by the Oregon Agricultural Experiment Station in 2006. Legacy is a six-row, hulled malting barley with spring growth habit, developed by Busch Agricultural Resources Inc. Doyce is a six-row, hulless feed barley with winter growth habit, released by the Virginia Agricultural Experiment Station (Brooks et al., 2005a) (Fig. 1).

The three full-sib components of #STRKR were all advanced lines from the Oregon State University Barley Breeding Program that were phenotypically similar in terms of resistance to stripe rust (incited by *Puccinia striiformis* f. sp. *hordei*), spike type, plant height, and maturity. However, each of the lines had advantages in terms of yield in specific environments (e.g., dryland, high rainfall, and irrigated; data not shown), and the three components differed in tolerance to scald (incited by *Rhynchosporium commune*). Each of the component sibs was segregating for grain color at the bulking generation. Therefore, in 2011 the three lines were mixed in equal proportions. Key considerations behind making the bulk were (i) the demonstrated advantages of a mixture in terms of reducing the effects of disease, in this case scald (Mundt et al., 1994), (ii) the delay in cultivar release that would be incurred by achieving

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Abbreviations: OFOOD, Oregon Food Barley; SNP, single nucleotide polymorphism.

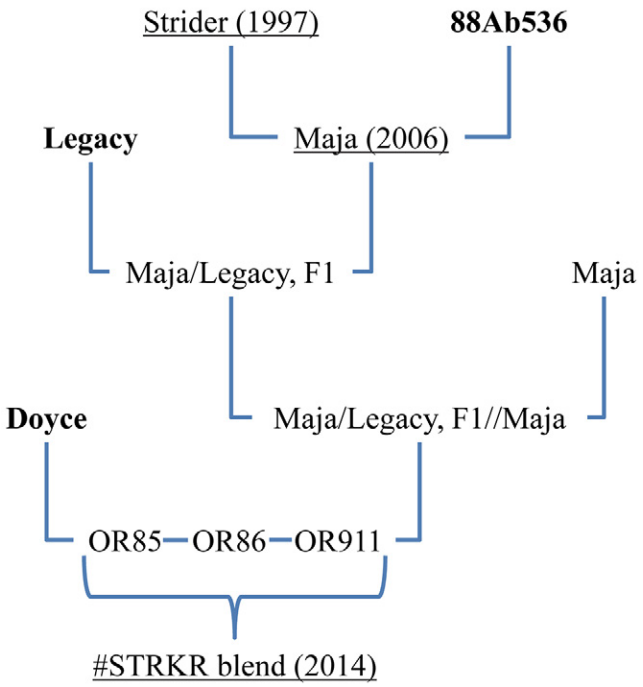

Fig. 1. Pedigree contributing to #STRKR. Lines in bold were developed by other breeding programs. Underlined lines were released from the Oregon Agricultural Experiment Station with the year of release in parentheses.

uniformity in grain color for each component line, and (iii) the interest of local growers in quickly assessing the commercial potential of food barley with diversity in seed color. The three-component bulk was intended as a vehicle for implementing an evolutionary/participatory plant breeding strategy that would result in a cultivar for the whole grain natural foods market, where heterogeneity and phenotypic diversity may be positive attributes. However, seed certification and cultivar release are potentially problematic for barley when the three component lines, although full-sibs, are not released and maintained separately so as to allow for resynthesis at future dates. We are, therefore, releasing #STRKR as a germplasm rather than as a cultivar. The germplasm provides a resource for researchers interested in selecting pure lines and studying the effects of selection on a heterogeneous mixture relative to specific traits and a crop alternative for growers interested in producing an uncertified heterogeneous mixture of hulless food barley with multicolored grain, agronomic potential, resistance to barley stripe rust, and potential for winter survival in environments similar to those where the germplasm has been tested.

#STRKR was tested under the experimental designation Streaker in the Oregon Food Barley (OFOOD) trial. The OFOOD trial was grown for 2 yr (2011–2012 and 2012–2013) at eight locations, with five of the locations replicated over the 2 yr for a total of 13 environments. In the 2013 crop year, there was limited commercial production leading to the commercialization of "Streaker Barley Flakes" by Camas County Mill of Junction City, Oregon. These flakes have served as the basis for extensive product development (Anonymous, 2014).

Methods

Generation Development and Line Selection

The cross between F_1(Maja/Legacy)/Maja and Doyce was made in 2003. Selections were made using a modified bulk-pedigree method. All generations from the F_1 through F_4 were grown under fall-planted conditions at the Oregon State University Hyslop Research Farm near Corvallis, OR. The F_2 populations were planted in bulk, from which individual heads were selected, threshed, bulked, and planted as an F_3 population. From the F_3 population, heads were selected and planted in F_4 head rows. Selected F_4 head rows were harvested in bulk and advanced to a preliminary yield trial. Selections were subsequently grown in replicated, multi-environment yield trials in Oregon for multiple years. In 2008–2009, two F_5 progenies were designated as OR85 and OR86 and grown in the Oregon Barley Elite Trial (OBELT). This trial was grown again in 2009–2010, and an F_6 progeny row was selected and designated OR911. OR85, OR86, and OR911 were phenotypically similar in terms of resistance to stripe rust, spike type, plant height, and maturity. However, as previously noted, each of the full-sib lines had advantages in terms of specific attributes and all were segregating for grain color. Therefore in 2011 equal amounts of seed from OR85, OR86, and OR911 were bulked and identified with the experimental designation Streaker and evaluated in the OFOOD trial for 2 yr across eight locations in the Pacific Northwest: Corvallis, OR (2011–2012 and 2012–2013); Hermiston, OR (2011–2012 and 2012–2013); Lewis-Brown, OR (2011–2012); Pendleton, OR (2011–2012 and 2012–2013); Mount Vernon, WA (2011–2012); Pullman, WA (2011–2012 and 2012–2013); Aberdeen, ID (2011–2012 and 2012–2013); and Parma, ID (2011–2012). Final selection for this germplasm occurred in summer 2013 when 2100 heads of Streaker were selected from three local farmer's fields (700 per field). The heads were threshed individually, and only hulless heads were selected. In fall 2013, 600 head rows from each farm were planted in separate blocks at the Oregon State University Lewis-Brown Research Farm near Corvallis. Seed from each block was bulked in equal weights to produce the #STRKR germplasm.

Genotypic Comparison

Single head selections from each of the three full-sibs (OR85, OR86, and OR911) were used to grow a single plant for DNA extraction and genotyping using single nucleotide polymorphisms (SNPs) under the auspices of the USDA National Institute of Food and Agriculture Triticeae Coordinated Agricultural Project (http://www.triticeaecap.org/), and these data are available at the T3 database (USDA–NIFA, 2014). In the T3 database, the three components of #STRKR can be found in the "LTT_TCFW6" panel of Trial Code "TCFW6_LTT_9K" under the genotype experiment list. Two of the three components (OR85 and OR86) were homozygous at 99.9% of the 6895 SNP loci analyzed by the Infinium iSelect 9K genotyping chip, whereas OR911 was homozygous at 92.7% of the loci. Pairwise genetic differences for the three components range from 12 to 20% (Table 1). Therefore, the #STRKR germplasm will capitalize on the heterogeneity present among the three genotypes, which are

Table 1. Pairwise genetic differences between each of the three components of #STRKR based on 6895 molecular markers on the Infinium iSelect 9K genotyping chip.

	OR85	OR86	OR911
OR85	–	18%	20%
OR86		–	12%
OR911			–

phenotypically very similar. All three components are similar in plant height and maturity, and all have a soft kernel texture. Accordingly, the #STRKR germplasm is sufficiently uniform for production and processing.

Statistical Analysis

All statistical analyses were conducted with Microsoft Excel (Microsoft Inc.) and SAS for Windows version 9.3 (SAS Institute). Thirteen environments (location-years) from the OFOOD trial were included in the comparison of Streaker and checks Maja and 'Alba' (Graebner et al., 2015) in the analysis of agronomic and food quality traits, although not all traits were measured at all locations. Plot size, nutrient management, weed control, and irrigation (if applied) were in accordance with sound agronomic practice at each location. Entries were replicated two, three, or four times at each location. Analysis of yield trial data were based on the trial means and were conducted both within and across locations. Mean separation tests were based on LSD ($P = 0.05$).

Characteristics

Botanical Description

#STRKR is a six-row barley germplasm in which all plants have semicompact spikes and long rachilla hairs. There are rough- and smooth-awned plants. OR86 is facultative, as measured by timely flowering under spring-sown conditions whereas OR85 and OR911 require vernalization to flower in an agronomically acceptable time frame. Under spring-planted conditions, OR86 flowered at 184 Julian days, comparable to 88Ab536 (facultative), which flowered at 182 Julian days, and 'Full Pint' (spring) (Verhoeven et al., 2011), which flowered at 178 Julian days. OR85 and OR911 never flowered under spring-planted conditions. Under fall-sown conditions, the three components of #STRKR flowered within approximately 1 wk of each other and were of similar plant height (data not shown). Grain color varies from blue to brown to white. In a random sample of 500 seeds, the percentages of blue, brown, and white seed coats were 50%, 17%, and 33%, respectively.

Agronomic Performance

In the remaining narrative, the experimental designation *Streaker* is retained since this appears in published annual reports of agronomic performance for 2011 to 2013. Across all 13 environments, Streaker was lower yielding than Alba and Maja but the differences were not significant (Table 2). Reduced yield is expected from hulless cultivars as compared to hulled cultivars due to the weight of the hull. On average, the barley hull accounts for 11 to 13% of total grain yield (Rey et al., 2009). Streaker was significantly shorter than Alba. Grain from Streaker had a significantly heavier test weight than Alba and Maja under all growing conditions, as would be expected for hulless versus hulled cultivars. Streaker flowered significantly earlier than Alba under all growing conditions (Table 3).

Pendleton, OR, and Pullman, WA, are classified as dryland locations with annual rainfall averages of 420 and 540 mm yr^{-1}, respectively (Western Regional Climate Center, 2014), and no supplemental irrigation. Under these conditions, Streaker was significantly lower yielding than Alba (Table 4). Corvallis, OR,

Table 2. ANOVA table for the yield of #STRKR (tested as Streaker) and check cultivars across 9 location-years (2 high rainfall, 3 dryland, 4 irrigated).†

Component of variance	df	Sum of squares	Mean square	F	*P* value
Line	2	5064866	2532433	1.5	0.24
Location-year	8	53888531	6736066	4.1	0.01
Error	16	26180796	1636300		
Total	26	85134193			

† Corvallis, OR (2011–2012 and 2012–2013); Hermiston, OR (2012–2013); Pendleton, OR (2011–2012); Pullman, WA (2011–2012 and 2012–2013); Aberdeen, ID (2011–2012 and 2012–2013); and Parma, ID (2011–2012).

Table 3. Agronomic performance and food quality of #STRKR (tested as Streaker) and check cultivars across 13 location-years (4 high rainfall, 4 dryland, 5 irrigated).†

	Agronomic traits				Food quality traits			
	Yield	Heading date	Plant height	Test weight	β-glucan	Protein	Solvent retention capacity (water)	Kernel hardness
	kg ha^{-1}	d after 1 Jan.	cm	kg hL^{-1}	% (w/w)	%	%	SKCS units‡
Streaker	6238	134	90.7	74.3	4.1	12.2	100.8	46.1
Alba	7299	142	99.3	65.9	4.3	11.0	107.4	69.1
Maja	6746	136	90.6	65.0	3.9	11.2	100.5	52.4
No. of environments	9	7	13	9	11	11	10	13
LSD (0.05)	1278	4	4.9	2.8	0.3	0.7	6.1	5.5

† Corvallis, OR (2011–2012 and 2012–2013); Hermiston, OR (2011–2012 and 2012–2013); Lewis-Brown, OR (2011–2012); Pendleton, OR (2011–2012 and 2012–2013); Mount Vernon, WA (2011–2012); Pullman, WA (2011–2012 and 2012–2013); Aberdeen, ID (2011–2012 and 2012–2013); and Parma, ID (2011–2012).

‡ SKCS, single-kernel characterization system.

and Mount Vernon, WA, are considered high rainfall, with average rainfall greater than 800 mm yr^{-1} (Western Regional Climate Center, 2014). Under these conditions, Streaker yielded significantly less than Alba and was significantly shorter than Alba (Table 5). In Hermiston, OR, and Aberdeen and Parma, ID, supplemental irrigation was applied in accordance with local practice because the average annual rainfall is below 400 mm yr^{-1}. Under irrigated conditions, Streaker did not have a significantly different yield from Alba or Maja (Table 6).

Disease Resistance

Disease was measured in 2012, 2013, and 2014 under high-rainfall conditions: no diseases were observed at the dryland or irrigated locations. Streaker was resistant to stripe rust at both high-rainfall locations. The intensity of the stripe rust epidemics at these locations is apparent from the stripe rust severity of 'Thoroughbred', a cultivar released by the Virginia Agricultural Experiment Station (Brooks et al., 2005b), which averaged 82.5% severity over the 2 yr. Streaker was significantly more susceptible to scald than Alba and comparable to Maja (Table 7).

Seedling inoculation with five leaf rust (incited by *Puccinia hordei*) isolates at the USDA–ARS Cereal Disease Laboratory revealed that Streaker was susceptible to all isolates. Leaf rust was observed under field conditions at Mount Vernon, WA in 2013; Streaker was rated as susceptible. Powdery mildew (incited by *Blumeria graminis* f. sp. *hordei*) is observed occasionally in the US Pacific Northwest. Intense epidemics occurred at Mount Vernon in 2012 and 2013 and in Corvallis in 2014. In Mount

Table 4. Agronomic performance and food quality of #STRKR (tested as Streaker) and check cultivars across four dryland location-years.†

	Agronomic traits				Food quality traits			
	Yield	Heading date	Plant height	Test weight	β-glucan	Protein	Solvent retention capacity (water)	Kernel hardness
	kg ha^{-1}	d after 1 Jan.	cm	kg hL^{-1}	% (w/w)	%	%	SKCS units‡
Streaker	5860	144	89.6	74.6	4.3	14.2	108.2	45.5
Alba	7512	147	95.6	66.8	4.3	12.2	111.6	70.4
Maja	6023	146	87.0	68.1	4.0	12.7	99.7	48.8
No. of environments	3	2	4	3	4	4	4	4
LSD (0.05)	1172	0	11.4	2.0	0.3	1.5	12.0	5.7

† Pendleton, OR (2011–2012 and 2012–2013) and Pullman, WA (2011–2012 and 2012–2013).

‡ SKCS, single-kernel characterization system.

Table 5. Agronomic performance and food quality of #STRKR (tested as Streaker) and check cultivars across four high-rainfall location-years. †

	Agronomic traits				Food quality traits			
	Yield	Heading date	Plant height	Test weight	β-glucan	Protein	Solvent retention capacity (water)	Kernel hardness
	kg ha^{-1}	d after 1 Jan.	cm	kg hL^{-1}	% (w/w)	%	%	SKCS units‡
Streaker	4635	123	92.8	75.7	4.4	12.0	94.2	50.6
Alba	8243	136	111.0	67.0	4.2	9.7	104.5	74.9
Maja	4927	125	96.2	62.4	3.7	10.7	100.9	56.9
No. of environments	2	3	4	3	3	3	2	4
LSD (0.05)	2163	4	5.1	8.5	0.8	1.6	17.9	11.0

† Corvallis, OR (2011–2012 and 2012–2013); Lewis-Brown, OR (2011–2012); and Mount Vernon, WA (2011–2012).

‡ SKCS, single-kernel characterization system.

Table 6. Agronomic performance and food quality of #STRKR (tested as Streaker) and check cultivars across five irrigated location-years. †

	Agronomic traits				Food quality traits			
	Yield	Heading date	Plant height	Test weight	β-glucan	Protein	Solvent retention capacity (water)	Kernel hardness
	kg ha^{-1}	d after 1 Jan.	cm	kg hL^{-1}	% (w/w)	%	%	SKCS units‡
Streaker	7323	141	89.9	73.0	3.9	10.8	96.8	43.0
Alba	6667	145	93.0	64.7	4.3	10.4	104.5	63.4
Maja	8198	143	89.0	64.8	3.9	10.1	101.1	51.7
No. of environments	4	2	5	4	5	5	4	5
LSD (0.05)	1398	4	8.4	3.0	0.6	1.2	9.9	13.7

† Hermiston, OR (2011–2012 and 2012–2013); Aberdeen, ID (2011–2012 and 2012–2013); and Parma, ID (2011–2012).

‡ SKCS, single-kernel characterization system.

Table 7. Reaction of #STRKR (tested as Streaker) and check cultivars to barley stripe rust (rated at Corvallis, OR, in 2011–2012 and 2012–2013 and Lewis-Brown, OR, in 2011–2012) and scald (rated at Corvallis, OR, in 2011–2012 and 2012–2013 and Lewis-Brown, OR, and Mount Vernon, WA, in 2011–2012), and winter survival (rated at Pullman, WA, and Aberdeen, ID, in 2011–2012 and 2012–2013 and Parma, ID, in 2011–2012).

	Barley stripe rust	Scald	Winter survival
	%	1–9 †	%
Streaker	6.7	7.1	92.0
Alba	3.3	0.9	97.9
Maja	0.0	6.8	93.0
No. of environments	3	4	5
LSD (0.05)	13.1	2.7	4.2

† Based on a 1–9 scale, where 1 = most resistant and 9 = most susceptible.

Vernon in 2012 and 2013, no mildew was observed on Streaker, but adjacent plots of the cultivar Full Pint were rated up to 53% leaf coverage. In Corvallis in 2014, Streaker had 10% mildew severity, Alba had 30%, and Maja had 20%.

Food Quality

Streaker had significantly greater percentage protein than Alba and Maja across all growing conditions (Table 3). Streaker had similar levels of grain β-glucan (AACC International Method 32-23.01 [AACC International, 1999]) to Alba and Maja across all growing conditions (Table 3 and Table 8). Streaker had a significantly lower solvent retention capacity (AACC International Approved Method 56-11.02 [AACC International, 2009) for water than Alba across all growing conditions (Table 3). Across all growing conditions, Streaker had significantly softer kernels than Alba and Maja (Table 3). Additional data on other nutritional traits, processing characteristics, and food products are available under the heading "Food Barley Data," link to "Standard Reference Panel" at Anonymous (2014). In 2006, the US Food and Drug Administration approved a health claim for barley that allows: "foods containing barley to claim that they reduce the risk of coronary heart disease. Specifically, whole grain barley and dry milled barley products such as flakes, grits, flour, and pearled barley, which provide at least 0.75 g of soluble fiber per serving" (21 CFR 101.81) (Ames and Rhymer, 2008; National Barley Foods Council, 2003). Based on the average β-glucan content of #STRKR, to receive the daily recommended soluble fiber, a person would have to eat at least 17 g of steamed grain or 44 g of bread (approximately two slices) made with 40% barley flour.

Table 8. ANOVA table for the grain β-glucan content of #STRKR (tested as Streaker) and check cultivars across 11 location-years (2 high rainfall, 4 dryland, 5 irrigated).†

Component of variance	df	Sum of squares	Mean square	F	*P* value
Line	2	1.05	0.53	4.3	0.03
Location-year	10	4.60	0.46	3.8	0.01
Error	20	2.43	0.12		
Total	32	8.08			

† Corvallis, OR (2011–2012 and 2012–2013); Hermiston, OR (2011–2012 and 2012–2013); Pendleton, OR (2011–2012 and 2012–2013); Pullman, WA (2011–2012 and 2012–2013); Aberdeen, ID (2011–2012 and 2012–2013); and Parma, ID (2011–2012).

Winter Survival

Differential winter survival was observed in 5 of the 13 environments. In these environments (Pullman and Aberdeen in 2011–2012 and 2012–2013 and Parma in 2011–2012), the winter survival of Streaker was significantly lower than that of Alba but was still greater than 90% (Table 7).

Availability

Seed from individual head selection for the hulless trait, are maintained by the Barley Breeding Program at Oregon State University, Corvallis, OR 97331. Seed for research purposes will be available on request from the corresponding author for at least five years. #STRKR has been deposited in the National Plant Germplasm System and will be available for distribution one year from the date of this publication. It is requested that an appropriate recognition of source be given when any component of the #STRKR blend contributes to the development of new germplasm or cultivars.

Acknowledgments

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