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REGISTRATION

Cultivar

Registration of 'Sockeye CL+' soft white winter wheat

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Abstract

Soft white winter (SWW) wheat (*Triticum aestivum* L.) is the main market class produced in Washington State. With consistent production of winter wheat, winter annual weeds have been a constant concern of producers. For over 20 years, growers have used the Clearfield Production System to control grassy weeds in commercial production. The persistent use of group 2 (amino acid/acetolactate synthase inhibitors) Beyond (brand) herbicide (imazamox) tolerant wheat has resulted in many soils with residual herbicide contamination. The objective of this research was to develop a two-gene, Beyond-tolerant SWW cultivar that could be used in the Clearfield Production System. 'Sockeye CL+' (Reg. no. CV-1215, PI 699243) is a SWW wheat cultivar developed and released in March 2020 by the Agricultural Research Center of Washington State University. Sockeye CL+ was tested under the experimental designations MAS11295-1-1-0-4 and WA8306 CL+, assigned through progressive generations of advancement. This cultivar is a two-gene Beyond tolerant semi-dwarf cultivar broadly adapted across the wheat production regions of Washington. Sockeye CL+ has improved resistance to the stripe rust pathogen (caused by *Puccinia striiformis* Westend. f. sp. *tritici* Erikss.), tolerance to snow mold, improved end-use quality, and maintains high grain yield across production regions as compared to other commercially available herbicide tolerant cultivars. Sockeye CL+ has intermediate plant height with mid-season maturity and has high grain volume weight. This line has maintained high grain yield across multiple years and locations of testing in Washington. The end-use quality properties of Sockeye CL+ meet both domestic and export market standards.

Plain Language Summary

Soft white winter (SWW) wheat is the main market class produced in Washington State. With consistent production of winter wheat, winter annual weeds have been a constant concern of producers. The objective of this research was to develop a wheat

Abbreviations: BASF, Baden Aniline and Soda Factory; IT, infection type; SRC, solvent retention capacity; SWW, soft white winter.

cultivar capable of surviving application of the herbicide Beyond in order to control weeds. Sockeye CL+ was developed and released in March 2020 by the Agricultural Research Center of Washington State University. This cultivar is a two-gene Beyond tolerant semi-dwarf cultivar broadly adapted across Washington. Sockeye CL+ has improved high-temperature adult-plant resistance to the stripe rust pathogen over commercially grown Clearfield cultivars, is tolerant to snow mold, has intermediate plant height with mid-season maturity, and high grain volume weight. This line maintains high grain yield across multiple years and locations of testing in Washington. The end-use quality of Sockeye CL+ exceed both domestic and export market standards.

1 | INTRODUCTION

The state of Washington is known for its production of high end-use quality and high yielding soft white winter (SWW) wheat (*Triticum aestivum* L.). The state is also characterized by its diverse production regions, with most production occurring under rain-fed conditions, which can range from 150 mm to over 600 mm of annual precipitation. Accumulation of precipitation in the soil profile typically occurs during the months of October through April (through both rainfall and snowmelt), with little precipitation occurring during the summer months. In these regions, diverse cropping systems are employed, ranging from a winter wheat–summer fallow system in the lower rainfall regions to continuous cropping with 3-year rotations in the higher rainfall areas. Over the decades of winter wheat production, many commercial production fields have seen the increase of winter annual weeds like downy brome (*Bromus tectorum* L.) and jointed goat grass (*Aegilops cylindrica* Host.). These weeds have been difficult to control due to their similar growth pattern to winter wheat. To combat this, many growers are using the Clearfield Production System and planting cultivars which are tolerant to the herbicide Beyond.

Due to the diversity of production regions, wheat production across Washington is prone to many different disease pressures. Stripe rust (caused by *Puccinia striiformis* West-end. f. sp. *tritici* Erikss.), is an annual concern in wheat fields, and is a common concern for growers. While the disease can be controlled by fungicides, this application often results in yield losses and their use incurs significant costs. Other diseases, such as snow mold (caused by *Microdochium nivale*, *Typhula idahoensis*, *T. ishikariensis*, and *T. incarnata*), have no economical fungicides to control them. Reliance on genetic resistance and/or tolerance to the disease in commercial cultivars is the best option for growers to maintain high grain yield.

'Sockeye CL+' (Reg. no. CV-1215, PI 699243), a SWW wheat, was developed and released in March 2020 by the Agricultural Research Center of Washington State University. Sockeye CL+ was released as a replacement for 'UI Magic CL+' (PI 678629; registered as 'UI Magic' but marketed as UI Magic CL+ to indicate Clearfield herbicide tolerance) in rainfed wheat production systems with over 300 mm of annual precipitation and in rotations typically experiencing a longer crop production cycle. UI Magic CL+ has been a dominant cultivar in commercial production in this region but is limited by moderate susceptibility to stripe rust. Sockeye CL+ has shown broad adaptation across these production regions and across years which have had dramatically differing environments. The release of Sockeye CL+ is based on (i) the presence of two mutations for enhanced tolerance to Beyond, (ii) high-temperature adult-plant resistance to stripe rust, (iii) tolerance to snow mold, (iv) improved end-use quality, and (v) high grain yield across target production regions.

2 | METHODS

2.1 | Breeding design

Sockeye CL+, having experimental designations MAS11295-1-1-0-4 and WA8306 CL+, was derived from $F_{3:4}$ head row selections from the cross OR2070011/'Curiosity CL+'. OR2070011 is an unreleased soft white winter wheat breeding line from Oregon State University. Curiosity CL+ (Gill et al., 2020a) is a Beyond tolerant cultivar released from Washington State University in 2013 with the pedigree 'Eltan'*3/CL0618. Eltan (PI 536994; Peterson et al., 1991) is a SWW wheat cultivar that was previously grown in the state of Washington for multiple years and ranked No. 1 in production in low rainfall cropping systems due to its excellent emergence, cold tolerance, and tolerance to snow mold, which Curiosity CL+ inherited. 'CL0618' is an Australian hard red spring two-gene mutant line that is a Baden Aniline and Soda Factory (BASF)-approved, two-gene donor parent for the mutant alleles *Als1* (D genome) and *Als2* (B genome) which confer tolerance to

imazamox. OR2070011 is a broadly adapted experimental breeding line from Oregon State University with the pedigree 'Tubbs'/'Bitterroot' (PI 655042). Tubbs (PI 629114) is a line developed and released by Oregon State University in 2002 and is known for its high agronomic characteristics in Oregon. Bitterroot (PVP 200800411) is a cultivar developed and released by the University of Idaho in 2008 and is known for its high grain yield under Northern Idaho production, along with very good end-use quality attributes. The cross for developing Sockeye CL+ was completed in the Plant Growth Facility (greenhouse) in Pullman, WA, in 2011.

Upon completion of the cross, the F_1 seed were hand harvested and replanted. Two weeks after planting, F_1 seedlings were placed in a growth chamber (Conviron), set at 4°C to satisfy vernalization requirements with an 8-h daylength photoperiod, for 8 weeks. After vernalization, seedlings were placed in a greenhouse bay set at 22–24°C and a 16-h daylength photoperiod. At maturity, F_1 plants were harvested, and F_2 seed were bulked (52 g) to establish a population designated as MAS11295. From the F_2 bulked seed, a 1.5- by 4.5-m plot was established in the field in the fall of 2012 using 40 g of seed. In the spring of 2013, when the plants were at the early tillering stage (Feekes 3; Large, 1954) seedlings were sprayed with Beyond herbicide (imazamox [2-(4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl)-5-(methoxymethyl)-3-pyridinecarboxylic acid]) at the rate of 105 g ai ha^{-1}, with 2.0% (v/v) methylated seed oil and 5.0% (v/v) urea ammonium nitrate. Herbicide application utilized a CO_2 backpack sprayer with TeeJet 8002E flat-fan nozzles (TeeJet Spraying Systems) set to deliver 112 L ha^{-1} at 290 kPa at a walking speed of 4.5 kph. This method of application was used for all subsequent field trials. Four weeks after spraying, plants were evaluated for visual injury, and those which appeared not to be injured were tagged for further evaluation. After further selection for heading date, plant height, and disease resistance, 20 plants were remaining, and left to grow until maturity, with one head per plant harvested to generate F_3 seed.

These 20 F_3 selections were planted in non-replicated 1-m-long rows in the fall of 2013 at the Cook Agronomy Farm, Pullman, WA, along with selections from other populations that were also herbicide tolerant. The tolerant (Curiosity CL+) and susceptible ('Brundage 96'; Zemetra et al., 2003) checks were planted every 40 rows. In the spring of 2014, at the Feekes 3 growth stage, plants were sprayed with Beyond at the rate of 105 g ai ha^{-1}, with 2.0% (v/v) methylated seed oil and 5.0% (v/v) urea ammonium nitrate. The lines were visually evaluated for tolerance to Beyond herbicide, disease resistance, heading date, plant height, and other general agronomic characteristics. From this population, two F_3 rows were identified as meeting agronomic standards, and four heads were snapped from each row and eight rows were planted in the fall of 2014, advancing to a non-replicated $F_{3:4}$ head row field trial in Pullman in 2015. The lines were once again sprayed and evaluated for tolerance to Beyond herbicide (as described previously), disease resistance, heading date, plant height, and other general agronomic characteristics.

Four lines were selected from this population with visual characteristics meeting Washington cropping systems and harvested during the summer of 2015. A subsample of 20 g was sent to the USDA-ARS Western Wheat Quality Laboratory (WWQL), Pullman, and analyzed for Single Kernel Characterization System (SKCS) hardness, milling characteristics, and flour properties (Solvent Retention Capacity [SRC] Water). Of these, all four lines were identified as having acceptable end-use quality properties and were advanced to a $F_{3:5}$ non-replicated field trial at Pullman in 2016. This trial and subsequent herbicide tolerance qualification trials were sprayed with Beyond as previously described and per BASF protocols. All trial locations were evaluated for plant height, grain yield (Zürn 150 Combine, Zürn Harvesting GmbH & Co.), grain volume weight, disease resistance (when present), and end-use quality. Using seed generated from the non-replicated field trial, MAS11295-1-1-0-4 was evaluated in replicated BASF approved spray and field breeding trials for 49 location-years between 2017 and 2022 in all precipitation zones in Washington state. A general α-lattice design (three replications; Mason et al., 2003) was used for general breeding trials whereas a strip-plot (split-block) design (three replications; Steele & Torrie, 1980) was used for spray trials to easily compare sprayed versus unsprayed plots. Based on breeding and spray trial data from 2017 and 2018, MAS11295-1-1-0-4 was selected for testing on a regional basis and assigned the new identification number WA8306 CL+. This line was entered into the Washington State University Extension Uniform Cereal Variety Testing Program in 2019. In 2020, along with being in Washington trials, it was also entered into the Oregon State University Extension Uniform Cereal Variety Testing Program. The line was subsequently tested in these programs in 2021 and 2022. Sockeye CL+ was evaluated for Beyond herbicide tolerance from 2017 to 2020 in BASF approved field trials using the SWW varieties Curiosity CL+ as the two-gene resistant check and Brundage 96 as the susceptible check.

2.2 | Disease resistance evaluation

In 2019 and 2020, WA8306 CL+ was evaluated for stripe rust resistance in naturally and artificially inoculated and unreplicated field trials by the USDA-ARS Wheat Health, Genetics, and Quality Research Unit. Field screening locations included the Palouse Conservation and Spillman Farms near Pullman in 2019, and the Plant Pathology, Palouse Conservation, and Spillman Farms near Pullman, the Lind Dryland Research Station near Lind, WA, the Mount Vernon Research and

Extension Center in Mt. Vernon, WA, and a grower's field in Walla Walla, WA, in 2020. Weather conditions at these locations can be accessed through the AgWeatherNet system of weather stations (https://weather.wsu.edu/; accessed March 5, 2025). Replicated seedling resistance tests for stripe rust were conducted in 2019 and 2020 in the Plant Growth Facility under low temperature cycles (diurnal temperature cycle gradually changing from 4°C to 20°C; Chen & Line, 1992) with races PSTv-4, 14, 37, 40, 51, and 198. The selection of these races was determined by virulence and the most commonly found races of the previous years. Adult-plant tests in the greenhouse were also conducted at high temperatures (diurnal temperature cycle gradually changing from 10°C to 30°C; Chen & Line, 1995) using PSTv-14, 37, and 40. Infection type (IT) data were collected on a scale of 0 to 9 (Line & Qayoum, 1992; McNeal et al., 1971), and disease severity on a scale of 0% to 100% (Peterson et al., 1948).

Snow mold (caused by *Microdochium nivale*, *Typhula idahoensis*, *T. ishikariensis*, and *T. incarnate*) evaluation was conducted at two locations near Waterville and Mansfield, WA, between 2019 and 2022, for a total of eight location-years. Single rows, replicated twice, were planted under field conditions with natural inoculation, with a score of 0 indicating highly susceptible plants, and a score of 9 for highly tolerant plants. Ratings were done on field locations with a minimum of 90 days of snow cover. Tolerance to low pH soils was evaluated in fields near Rockford, WA, in 2019 and 2020 and was conducted on single rows, replicated three times, in a randomized complete block design. The field location where testing took place has a soil pH of 5.2 in the top 15 cm, 4.8 in the next 15 cm, and was >6.1 below 30 cm. Observations resulted in ratings which were taken on a 1 to 5 scale, with 1 indicating severely stunted and discolored plants with no tillers, whereas 5 indicated green, healthy plants of normal growth, and multiple tillers, similar to the protocols of Froese and Carter (2016). The first rating took place as soon as the field was accessible in the spring, usually at Feekes 2, and continued every 2 weeks for 2 months until Feekes 6 (Large, 1954).

WA8306 CL+ was tested for strawbreaker foot rot (caused by *Oculimacula acuformis* and *O. yallundae*) resistance during the 2020 field season in three-replicate inoculated field plots near Pullman as described by Murray and Sheng (2017) using 'Madsen' (PI 511673; Allan et al., 1989) as the resistant control and Eltan as the susceptible control. Disease incidence (0% to 100%) and severity (scale of 0 to 4, where 0 = no lesion and 4 = lesion girdling the stem) were determined by visual observation of stem bases. A disease index (0% to 100%) was calculated by multiplying the percentage of infected stems (disease incidence) by the disease severity of infected stems and dividing by four. WA8306 CL+ was also tested for Cephalosporium stripe (caused by *Cephalosporium gramineum*) tolerance during the 2020 field season in three-replicate inoculated field plots near Pullman as described in Murray and Sheng (2020). In these trials, Eltan was the tolerant check and 'Stephens' (CItr 17596; Kronstad et al., 1978) was the susceptible check. Lines in the trial were given a disease index (0% to 100%) score by multiplying the percentage of infected stems (disease incidence) by the disease severity (scale of 0 to 4, where 4 = symptoms detected in the flag leaf, 3, 2, or 1 = symptoms detected on the respective leaves fellow the flag leaf, and 0 = no visual symptoms) and dividing by five.

2.3 | End-use quality testing

Since 2016, Sockeye CL+ has been evaluated for end-use quality, using seed from field trials, by the USDA-ARS Western Wheat Quality Laboratory (WWQL), Pullman, according to the Cereals and Grains Association Approved Methods of Analysis (Cereals & Grains Association, 2021). At each location, a 500-g sample from the first replication was submitted for analysis. End-use quality trait targets are recommended by the Pacific Northwest Quality Council, and represent the general values needed to meet domestic and export quality standards. Before milling, samples were tempered to 14% moisture concentration, then milled on a modified Quadramat system (Jeffers & Rubenthaler, 1979). End-use quality traits included grain volume weight (Approved method 55-10), total flour yield (g kg^{-1} by weight of the total products recovered as straight-grade white flour), break flour yield (g kg^{-1} by weight of the total products recovered as flour off the break rolls of the mill), flour ash (Approved Method 08-01), grain protein concentration (Approved method 39-10 adjusted with Dumas combustion method), flour protein concentration (Approved Method 39-11), cookie diameter (Approved Method 10-50), and sponge cake volume (Approved Method 10-91). A derived trait, milling score (Morris et al., 2011), was calculated as:

$$\left(\left\{100-\left[0.5\times(16-\text{temper level})\right]+(80-\text{flour yield})+\left[50\times(\text{flour ash}-0.30)\right]\right\}\times 1.274\right)-21.602$$

Sockeye CL+ was evaluated from 2019–2022 for low falling number (FN) which is an international standard method (ICC 107/1. ISO 3093-2004, Approve method 56-81B) for detecting damage from pre-harvest sprouting and late-maturity α-amylase in wheat. Also known as the Hagberg-Perten Falling Number method, this test determines the enzyme (α-amylase, β-amylase, and protease) activity which confers the breakdown of starch and protein levels within the wheat kernel (Sjoberg et al., 2020). For the Pacific Northwest area of the United States, a specification of 300 s is

currently requested by most domestic and export market customers. Other soft white wheat quality targets are outlined by the Pacific Northwest Wheat Quality Council (https://wwql.wsu.edu/quality-targets/; accessed March 5, 2025).

2.4 | Genotypic information

At the $F_{3:6}$ generation, Sockeye CL+ was evaluated for the presence of the *Pch1* gene for resistance to strawbreaker foot rot. Marker analysis for the *Pch1* gene was conducted using a Kompetitive Allele Specific polymerase chain reaction (KASP) assay with marker wMAS0000023 developed by the Johns Innes Centre (Wilkinson et al., 2012). The alleles for dwarfing genes *Rht-B1* and *Rht-D1* were evaluated with KASP markers based on the protocols found in Grogan et al. (2016), and for the glutenin subunits at the *Glu-D1* gene (Rasheed et al., 2016). The presence of stripe rust resistance gene *Yr17* was evaluated with the KASP marker referenced in Milus et al. (2015). All KASP assays were performed using PACE Genotyping Master Mix (3CR Bioscience) following the manufacturer's instructions (https://3crbio.com/wp-content/uploads/2020/01/PACE-User-Guide-v1.6.pdf) and endpoint genotyping was conducted from fluorescence using a Lightcycler 480 Instrument II (Roche). Mutant alleles at *Als1* and *Als2* conferring tolerance to imazamox were verified at the F_3 generation as being homozygous using DNA markers provided by BASF.

2.5 | Seed purification

Breeder seed of Sockeye CL+ was produced by head row purification, on the basis of phenotypic uniformity. This was done by selecting 1000 $F_{7:8}$ heads, planting the threshed seed in individual rows, and grown under irrigation in Othello, WA, in 2020. Around 3% of the rows were discarded based on heading date, head type, and plant height. The remaining were bulked at harvest, resulting in the production of 4.0 metric tonnes of breeder seed. A 1-ha foundation seed increase was planted under irrigation in Moses Lake, WA, in the fall of 2020, with a subsequent 4-ha field planted in 2021.

2.6 | Statistical analyses

Yield trial data generated from 2017 to 2022 were analyzed with either the balanced strip-plot (strip-block) procedure (for spray trials) or the general lattice procedure (for breeding trials) in Genovix version 1.5.2332.1 (Agronomix Software, Inc). Location means from 2017 to 2022 were generated via the general lattice adjusted mean, using genotypes as a fixed effect, and block and incomplete block as random effects. Adjusted means were then subjected to analysis of variance. Breeding lines were advanced based on high grain yield within each location, across locations within a region, and across regions within a year. Once Sockeye CL+ was selected for release, final data analysis used entries common to the trials across all years, with a head-to-head analysis also performed in Genovix. For all data except end-use quality, significant differences were determined at $\alpha = 0.05$, whereas for end-use quality significance was determined at $\alpha = 0.01$. End-use quality data were analyzed using analysis of variance with PROC GLM (SAS v9.3; SAS Institute). Data for end-use quality were only analyzed from site-year locations where both Sockeye CL+ and the respective check cultivars were in the same trial.

3 | CHARACTERISTICS

3.1 | General description

Sockeye CL+ is an intermediate height, semi-dwarf (*Rht-B1b*, *Rht-D1a*) SWW wheat cultivar. Coleoptile anthocyanin is absent, and the juvenile plant growth is prostrate to semi-erect. Sockeye CL+ is green in color, and has an erect and twisted flag leaf, with wax absent. The hollow stem is absent of anthocyanin coloration, waxy bloom, and hairiness. Auricle anthocyanin and hairiness are also absent. At maturity, the head is lax and tapering, inclined, and awned. Glume color is white, and glume shoulder is wanting, with a narrow shoulder width and an acuminate beak. Seed shape is ovate to elliptical, with angular cheeks, and medium brush hair length that is not collared. Seed crease width is 80% or less of the kernel and crease depth is 25% or less of the kernel. Seed is soft and white, with a medium germ size and a light brown phenol reaction.

3.2 | Agronomic performance

In trials conducted from 2019 through 2022 by the Washington State University Extension Cereal Variety Testing program, Sockeye CL+ was compared to the SWW cultivars 'Norwest Duet' (PI 681650), 'Norwest Tandem' (PI 681649), 'Stingray CL+', (PI 691557; Carter et al., 2021), and UI Magic CL+. These checks were chosen as they were commercial cultivars grown in the target regions at the time of data collection. Data were collected on mean heading date, plant height, grain yield, and grain volume weight. The heading date of Sockeye CL+ was different than all cultivars except for Stingray CL+, being earlier than Norwest Tandem and UI Magic CL+, but later than Norwest Duet (Table 1). The plant height of Sockeye CL+ was significantly different from all cultivars, being taller than all cultivars except for Norwest

TABLE 1 Head-to-head comparisons of Sockeye CL+ to four widely grown cultivars from Washington State University Extension Uniform Cereal Variety Performance Trials grown from 2019 through 2022 in eastern Washington in the high-rainfall zone >400 mm annual precipitation.

Line	Heading date				Plant height				Grain yield				Grain vol. wt.			
	n	Line	Sockeye CL+		*n*	Line	Sockeye CL+		*n*	Line	Sockeye CL+		*n*	Line	Sockeye CL+	
		Julian days				cm				$kg\ ha^{-1}$				$kg\ hL^{-1}$		
Norwest Duet	26	163	162	***	26	97	94	**	26	7223	7608	**	26	74.9	75.1	ns†
Norwest Tandem	27	159	162	***	27	77	95	***	27	7093	7630	***	27	74.7	74.7	ns
Stingray CL+	30	159	159	ns	30	86	95	***	30	7169	7644	***	30	74.5	74.9	ns
UI Magic CL+	30	158	159	***	30	83	95	***	30	6564	7644	***	30	75.7	74.9	***

Note: Data on heading date, plant height, grain yield, and grain volume weight (grain vol. wt.) were from rainfed trials (Colton, Dayton, Fairfield, Farmington, Mayview, Pullman, St. John, Walla Walla, WA).
***Significantly different at the 0.01 probability level.
**Significantly different at the 0.05 probability level.
†ns, not significantly different at the $P = 0.05$ probability level.

Duet. Averaged over all locations, the grain yield of Sockeye CL+ was 7631 kg ha^{-1}, which was higher ($P < 0.05$) than all of the check cultivars it was compared to. The grain volume weight was equal to all cultivars except for UI Magic CL+, which had a higher grain volume weight than Sockeye CL+. Averaged over all test locations, the grain volume weight of Sockeye CL+ exceeds the target requirement of 78.9 kg/hL.

Sockeye CL+ was tested at various locations in Oregon between 2020 and 2022 under the Oregon State University Extension Uniform Cereal Variety Performance Trials. This data is summarized online at https://cropandsoil.oregonstate.edu/wheat/variety-trials (accessed December 14, 2024). When summarized across the low and high rainfall production trials in Oregon, Sockeye CL+ has grain yield like that of other commercially released Clearfield cultivars. In the intermediate rainfall production trials, Sockeye CL+ has a grain yield higher than the most grown cultivars of UI Magic CL+ and Stingray CL+.

Sockeye CL+ has also been tested in the Washington State University Winter Wheat Program in breeding trials conducted between 2019 through 2022. In the low rainfall trials of <400 mm annual precipitation, testing occurred during 2019, 2021, and 2022, and Sockeye CL+ was compared to the SWW cultivars 'Jasper' (PI 678442; Carter et al., 2017), Norwest Duet, and 'Otto' (PI 667557; Carter et al., 2013). Sockeye CL+ had a heading date similar to Jasper and Norwest Duet, but earlier than Otto by 4 days (Table 2). The plant height of Sockeye CL+ was similar to Otto and Jasper but was 9-cm shorter than Norwest Duet. The grain yield of Sockeye CL+ was similar to that of Jasper and Norwest Duet, but greater than Otto by 300 kg ha^{-1}. The grain volume weight of Sockeye CL+ was higher than both Jasper and Norwest Duet, but similar to Otto, and meets export market specifications.

In breeding trials conducted in the high rainfall (>400 mm annual precipitation) areas of the state, Sockeye CL+ has been tested between 2019 and 2022, and compared to the SWW cultivars Jasper, Norwest Tandem, and Stingray CL+. The heading date for Sockeye CL+ was different than all three checks, being 1 day earlier than Jasper and Stingray CL+, but 3 days later than Norwest Tandem (Table 3). The plant height of Sockeye CL+ was taller than all three check cultivars. Sockeye CL+ had a grain yield similar to all three checks in these trials. Compared to the three checks, the grain volume weight of Sockeye CL+ was higher than Jasper, lower than Norwest Tandem, and not significantly different from Stingray CL+. Due to the low pH soils found in Eastern Washington, Sockeye CL+ was also evaluated for tolerance to low pH soils and was found to be moderately susceptible (score of 2.0). The tolerant cultivars used as checks had scores of 4.5.

Sockeye CL+ was evaluated between 2019 and 2022 in BASF-approved spray trials to evaluate tolerance to the Beyond chemical, as well as performance comparisons to four

TABLE 2 Head-to-head comparisons of Sockeye CL+ to three widely grown cultivars from breeding trials in eastern Washington grown in the low-rainfall zone <400 mm annual precipitation (2019, 2021–2022).

	Heading date				Plant height				Grain yield				Grain vol. wt.			
Line	***n***	**Line**	**Sockeye CL+**		***n***	**Line**	**Sockeye CL+**		***n***	**Line**	**Sockeye CL+**		***n***	**Line**	**Sockeye CL+**	
		——Julian days——				——cm——				——kg ha^{-1}——				——kg hL^{-1}——		
Jasper	15	156	156	ns[†]	15	82	83	ns	15	4165	4246	ns	13	74.9	76.1	**
Norwest Duet	12	154	153	ns	12	91	82	***	12	4085	4035	ns	10	74.9	75.7	**
Otto	12	157	153	***	12	81	82	ns	12	3710	4035	**	10	75.9	75.7	ns

Note: Data on heading date, plant height, grain yield and grain volume weight (grain vol. wt.) were from rainfed trials (Davenport, Harrington, Kahlotus, Lind, Ritzville and Waterville, WA).

***Significantly different at the 0.01 probability level.

**Significantly different at the 0.05 probability level.

[†]ns, not significantly different at the $P = 0.05$ probability level.

TABLE 3 Head-to-head comparisons of Sockeye CL+ to three widely grown cultivars from breeding trials in eastern Washington grown in the high-rainfall zone >400 mm annual precipitation (2019–2022).

	Heading date				Plant height				Grain yield				Grain vol. wt.			
Line	***n***	**Line**	**Sockeye CL+**		***n***	**Line**	**Sockeye CL+**		***n***	**Line**	**Sockeye CL+**		***n***	**Line**	**Sockeye CL+**	
		——Julian days——				——cm——				——kg ha^{-1}——				——kg hL^{-1}——		
Jasper	22	153	152	***	22	100	103	***	22	7,502	7,455	ns[†]	18	75.1	75.9	*
Norwest Tandem	18	147	150	***	18	85	102	***	18	7,256	7,473	ns	15	76.7	76.1	*
Stingray CL+	18	151	150	**	18	94	102	***	18	7,304	7,473	ns	15	75.9	76.1	ns

Note. Data on heading date, plant height, grain yield and grain volume weight (grain vol. wt.) were from rainfed trials (Dayton, Farmington, Pomeroy, Prescott, Pullman and Walla Walla, WA).

***Significantly different at the 0.01 probability level.

**Significantly different at the 0.05 probability level.

*Significantly different at the 0.1 probability level.

[†]ns, not significantly different at the $P = 0.05$ probability level.

TABLE 4 Mean percentage crop injury, plant height, and grain yield after application of 105 g ai ha^{-1} (2X rate) Beyond (imazamox) herbicide of soft white winter wheat cultivar Sockeye CL+ and check cultivars in eastern Washington, 2019–2021 in the high-rainfall zone >400 mm annual precipitation.

Cultivar	Crop injury				Plant height		Heading date		Grain yield	
	Untreated	14 DAT	21 DAT	28 DAT	Untreated	Treated	Untreated	Treated	Untreated	Treated
	%				cm		Julian days		kg ha^{-1}	
Sockeye CL+	0	3.1	2.7	1.7	98	97	153	154	7609	7647
Stingray CL+	0	4.5	3.7	3.0	89	89	153	153	7090	7090
UI Magic CL+	0	4.7	4.7	2.7	85	84	151	151	5649	5678
ORCF-102	0	28	38	37	97	89	154	155	6975	6302
Brundage 96	0	50	75	90	88	–	153	–	6187	–
LSD (0.05)	n/a	2.7	2.7	1.7	4	4	3	4	466	390

Note. Data on mean percent crop injury, heading date, plant height, and grain yield were from seven rainfed trials (Cook Agronomy Farm, Pullman, WA, Palouse Conservation Field Station, Pullman, WA, and a commercial field in Walla Walla, WA).
Abbreviation: DAT, days after treatment; n/a, not applicable.

check cultivars. The check cultivars used included Brundage 96 as the susceptible check, 'ORCF-102' (PI 641787) as the single-gene (*Als1* mutation) check, and UI Magic CL+ and Stingray CL+ as the two-gene (*Als1* and *Als2* mutation) checks. Treatments included an untreated observation as well as a treatment of a 105 g ai ha^{-1} (2X field rate) of Beyond herbicide. Under spray treatments, Sockeye CL+ exhibited very minor (<5%) herbicide injury, and was not significantly different than Stingray CL+ and UI Magic CL+, which is acceptable for commercial production (Table 4). The plant height of Sockeye CL+ was taller than all cultivars except for ORCF-102, and all of the CL+ cultivars showed minimal differences in plant height between treated and untreated plots. The heading date of Sockeye CL+ was not different from any of the check cultivars and again showed minimal differences between treated and untreated plots. Sockeye CL+ had an average grain yield of 7609 kg ha^{-1}, which was higher than all tested check cultivars. Again, the CL+ cultivars showed minimal differences between treated and untreated plots, although ORCF-102 showed a decrease of 673 kg ha^{-1}. Molecular marker data indicates that Sockeye CL+ is homozygous for both the *Als1* and *Als2* mutations conferring tolerance to Beyond herbicide.

3.3 | Disease resistance

Sockeye CL+ was evaluated in both field and greenhouse trials for stripe rust resistance in 2019 and 2020. Field locations included the Spillman and Palouse Conservation Farms (both located near Pullman), as well as in fields near Walla Walla and Lind, WA. Greenhouse trials were conducted on the Washington State University campus in Pullman. Field locations were evaluated with naturally occurring infection, and greenhouse trials were conducted with races PSTv-4, PSTv-14, PSTv-37, PSTv-40, and PSTv-51 in both 2019 and 2020, plus PSTv-198 in 2019. In these trials, Sockeye CL+ was compared to the susceptible check 'PS 279' (Chen, 2014), and the commercially grown cultivar UI Magic CL+. In 2019, the check PS 279 had an infection type (IT) of 8 and a severity of 70%–95%, indicating adequate disease pressure in the field for evaluation. Sockeye CL+ was rated as resistant (IT 2; severity 2%–5%) at the flowering (Feekes 10.51) and soft dough (Feekes 11.2) stages. In comparison, at the same timing, UI Magic CL+ was rated as moderately susceptible (IT 2–7; severity 5%–30%). During the 2020 field evaluation, more severe stripe rust pressure was present in the field, with PS 279 showing an IT of 9 and severity of 90%–100%. Sockeye CL+ was once again rated as resistant (IT 2; severity 2%–5%); in contrast, UI Magic CL+ was rated was susceptible (IT 8; severity 10%–80%).

Sockeye CL+ and UI Magic CL+ were included in greenhouse seedling tests conducted with races PSTv-4, PSTv-14, PSTv-37, PSTv-40, PSTv-51, and PSTv-198 with results from 2019 and 2020 showing the same response. Sockeye CL+, when tested at the low temperature cycles, had seedlings that were susceptible (IT 8) to races PSTv-37 and PSTv-51, but were moderately resistant (IT 5) to PSTv-4, PSTv-14, PSTv-40, and PSTv-198. UI Magic CL+ and PS 279 were both susceptible to all tested races at the seedling stage. Testing at the adult-plant stage at high temperatures with PSTv-14, PSTv-37, and PSTv-40, Sockeye CL+ was rated highly resistant (IT 2), whereas UI Magic CL+ was moderately susceptible (IT 2–5), and the check PS 279 was susceptible (IT 8). These data indicate that Sockeye CL+ has a high level of high-temperature adult-plant resistance to stripe rust. DNA marker analysis indicated Sockeye CL+ carries the gene *Yr17* for stripe rust resistance and is presumed to carry the high-temperature adult-plant resistance tightly linked to *Yr17* (Li et al., 2023) and other

TABLE 5 End-use quality analysis of Sockeye CL+ and check cultivars from winter wheat trials in eastern Washington between 2017 and 2022.

Cultivar	Grain protein concentration	Flour protein concentration	Total flour yield	Break flour yield	Flour ash concentration	Milling score	Cookie diameter	SRC water	Cake volume
	g kg^{-1}	g kg^{-1}	g kg^{-1}	g kg^{-1}	g kg^{-1}	unitless	cm	g kg^{-1}	L
Stephens	107	91	677	439	3.8	83.2	9.10	545	1.171
Sockeye CL+	100	84	680	480	3.5	85.6	9.34	518	1.221
LSD ($\alpha = 0.01$)	2.4	1.9	5.0	4.4	0.1	1.1	0.05	5.0	0.027
$n = 68$									
Curiosity CL+	105	91	680	468	3.7	84.0	9.09	553	1.233
Sockeye CL+	102	86	704	510	3.5	88.6	9.32	523	1.288
LSD ($\alpha = 0.01$)	8.1	5.4	5.9	4.9	0.2	1.7	0.08	13.0	0.033
$n = 10$									

uncharacterized resistance genes based on the field and greenhouse ratings.

Sockeye CL+ was tested in inoculated field trials for resistance to strawbreaker foot rot in Washington in 2020. In these trials, Sockeye CL+ showed a disease index of 49.0, which was significantly higher ($P > 0.05$) than the resistant control Madsen (26.8), but significantly lower than the susceptible control Eltan (70.7). DNA marker analysis indicates Sockeye CL+ is heterogeneous for the *Pch1* gene, revealing 50% of the plants in the population carry the gene and 50% do not. This heterogeneity is the potential reason for the intermediate scores in field trials. In inoculated field trials for Cephalosporium stripe, Sockeye CL+ showed a disease index of 30.3, which was not significantly different than the tolerant control Eltan (39.9) but significantly lower than the susceptible control Stephens (49.0). These results indicate Sockeye CL+ has a moderately high level of tolerance to Cephalosporium stripe.

Sockeye CL+ has been tested for tolerance to snow mold under field conditions near Waterville and Mansfield, WA, between 2018 and 2022. Sockeye CL+ is moderately tolerant (rating of 7) to the snow mold fungi found in Washington, whereas the most tolerant known cultivar 'Mela CL+' (PI 675008; Gill et al., 2020b) had a rating of 8. A moderately tolerant rating to snow mold is sufficient for recommending commercial production of a line in areas where snow mold is prevalent.

3.4 | End-use quality

Sockeye CL+ has been evaluated for end-use quality, using grain produced in 68 breeding and commercial variety testing trials in Washington, at the USDA-ARS Western Wheat Quality Laboratory in Pullman. Trials were conducted between 2017 and 2022 at 25 unique locations, spanning all rainfall zones in Oregon and Washington, and all data are presented in Table 5. 'Stephens' (CItr 17596; Kronstad et al., 1978) and Curiosity CL+ were used as checks in these evaluations. Stephens has a desired range of end-use quality values and is used as a check to generate placement in the Preferred Wheat Varieties brochure (https://wagrains.org/wp-content/uploads/2024/03/PreferredWheatVarieties2024_web.pdf, accessed December 14, 2024). Curiosity CL+, a commonly grown herbicide tolerant cultivar, was compared as it also contains herbicide tolerance and was often included as a check in herbicide tolerance trials.

Grain and flour protein concentration of soft white winter wheat is desired to be low, and Sockeye CL+ had significantly lower concentration than Stephens, and lower than, but not significantly different from Curiosity CL+. Total flour yield and break flour yield are two important characteristics of milling quality. When compared to Stephens, Sockeye CL+ was not significantly different for total flour yield, but did have a significantly higher break flour yield (Table 5). When compared to Curiosity CL+, Sockeye CL+ was significantly higher for both milling traits, indicating improvement over commercially available herbicide tolerant cultivars. Sockeye CL+ also had significantly lower flour ash concentration as compared to both cultivars (Table 5), and this trait, combined with flour yield traits, also resulted in Sockeye CL+ having a significantly higher milling score than either check. Baking characteristics similarly favored Sockeye CL+, with this new cultivar having significantly higher cookie diameter and cake volume, and significantly lower SRC Water scores (Table 5). Overall, Sockeye CL+ was an improvement in all categories as compared to Stephens, and an improvement in both milling and baking characteristics as compared to Curiosity CL+.

An additional end-use quality parameter, falling number, was also evaluated for Sockeye CL+, with data being collected since 2019 using seed from the Washington State

University Extension Uniform Cereal Variety Performance Trials. Data can be found summarized at steberlab.org/project7599.php (accessed December 14, 2024). Sockeye CL+ averaged a falling number score of over 300 s across years, which is the export minimum required for soft white wheat.

4 | AVAILABILITY

Foundation seed of Sockeye CL+ will be maintained by the Washington State Crop Improvement Association under supervision of the WSU Department of Crop and Soil Sciences and the Washington State Agricultural Research Center. Small quantities of seed may be obtained for research purposes from the corresponding author for at least 5 years from the date of publication. A seed sample has been deposited with the National Plant Germplasm System, where it will thereafter be available for distribution. U.S. Plant Variety Protection status for this cultivar has been approved (PVP No. 202100491).

AUTHOR CONTRIBUTIONS

A. H. Carter: Conceptualization; data curation; formal analysis; funding acquisition; investigation; methodology; project administration; resources; writing—original draft. **K. A. Balow**: Data curation; methodology; resources; writing—review and editing. **G. B. Shelton**: Data curation; formal analysis; methodology; resources; writing—original draft. **A. B. Burke**: Data curation; investigation; methodology; resources; writing—review and editing. **K. E. Hagemeyer**: Data curation; methodology; resources. **A. Stowe**: Data curation; methodology; resources. **H. Wetzel**: Formal analysis; resources; writing—review and editing. **C. Neely**: Data curation; methodology; resources. **C. M. Steber**: Data curation; formal analysis; methodology; resources; writing—review and editing. **X. M. Chen**: Data curation; investigation; methodology; resources; writing—review and editing. **A. Kiszonas**: Data curation; formal analysis; investigation; methodology; resources; writing—review and editing.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

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