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REGISTRATION

Cultivar

Registration of 'Cameo' soft white winter club wheat

Kimberly Garland-Campbell[1] | **Brian S. Bellinger**[1] | **Arron H. Carter**[2] | **Xianming Chen**[1] | **Patricia DeMacon**[2] | **Doug Engle**[1] | **Christina H. Hagerty**[3] | **Alecia Kiszonas**[1] | **Emily Klarquist**[2] | **Timothy Murray**[4] | **Craig Morris**[1] | **Clark Neely**[2] | **Steven Odubiyi**[5] | **Arash Rashad**[5] | **Deven See**[1] | **Camille Steber**[1] | **Nuan Wen**[2]

[1]USDA-ARS Wheat Health, Genetics and Quality Research Unit, 209 Johnson Hall, Washington State Univ., Pullman, WA 99164-6420, USA

[2]Dep. of Crop and Soil Sciences, Washington State Univ., Box 646420, Pullman, WA 99164-6420, USA

[3]Dep. of Botany and Plant Pathology, Columbia Basin Agricultural Research Center, Oregon State Univ., Adams, OR 97810, USA

[4]Dep. of Plant Pathology, Washington State Univ., Box 646430, Pullman, WA 99164-6430, USA

[5]Dep. of Entomology, Plant Pathology and Nematology, Univ. of Idaho, 875 Perimeter Dr. MS2329, Moscow, ID 83844-2329, USA

Correspondence
Kimberly Garland-Campbell, USDA-ARS Wheat Health, Genetics and Quality Research Unit, 209 Johnson Hall, Washington State Univ., Pullman, WA 99164-6420, USA.
Email: kim.garland-campbell@usda.gov

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Abstract

Soft white club winter wheat (*Triticum aestivum* L. ssp. *compactum*) is an important component of soft white wheat production in the Pacific Northwest of the United States. Most of the current club wheat production is in the <350 mm annual precipitation zone in central Washington, but there is interest in club wheat in the Palouse region of the United States (the counties of Whitman and Garfield in Washington and in Latah County in Idaho). Growers are continuing to grow the older club wheat cultivars 'Cara' and 'Coda', and there is a need for a new winter club wheat targeted to this region. 'Cameo' club wheat (Reg. no. CV-1192, PI 699960), tested as ARS09X492-6CBW, with awned spikes and soft white kernels, was developed using the bulk-pedigree breeding method from the cross ARSC96059-2/IL01-11934//ARSC96059-2-0-16. Cameo has better agronomic performance than other club wheat cultivars in trials on the Palouse, better stripe rust resistance than the club wheat 'ARS Crescent', tolerance to several major biotic and abiotic stressors, consistent good grain volume weight, mid-season maturity and moderate height, excellent club wheat quality, and tolerance to low falling numbers. Cameo is not as competitive for grain yield in the traditional club wheat growing area in central Washington but is well suited to increasing the acreage of club wheat in the Palouse region of Idaho and Washington.

Abbreviations: IT, infection type; KASP, Kompetitive amplified specific polymerase chain reaction; PNW, Pacific Northwest; SBWMV, *Soilborne wheat mosaic virus*; WACVT, Washington Extension cereal variety trial.

1 | INTRODUCTION

Wheat (*Triticum aestivum* L.) is a primary human food grain. Global production of wheat was 775.8 t in 2020/2021, as compared to 505 t of rice (*Oryza sativa* L.) (Shabandeh, 2021). Soft white winter wheat is a high-value component of the total wheat crop with production primarily in the Pacific Northwest (PNW) of the United States. Club wheat [*T. aestivum* subsp. *compactum* (Host) Mac Key] is a subclass of soft white wheat with up to 90% of annual production exported to Asian markets as Western White in a 10–20% blend with soft white common wheat. Club wheat is produced commercially only in the PNW of the United States, where it makes up 5–10% of the annual wheat crop. In 2020, club wheat was seeded on approximately 50,000 ha with a value of approximately US$50 million in farm income. Although the primary club wheat production area in the PNW is in the low to intermediate rainfall regions of central Washington state, there is significant interest in club wheat in the Palouse region of the United States, including the counties of Whitman and Garfield in Washington, Latah and Nez Perce Counties in Idaho, and Umatilla County in Oregon (Figure 1).

Growers in these areas continue to grow the older club wheat cultivars ‘Cara’ (PI 643435) and ‘Coda’ (PI 594372) (Allan et al., 2000; Garland-Campbell et al., 2013). The spring club wheat cultivars ‘JD’ (PI 656790) and ‘Melba’ (PI 682073) are also popular. Although spring club wheat will continue to be an important tool in rotations, there is a need for a new winter club wheat targeted to this region. The winter club wheat ‘ARS Crescent’ (PI 665048) (Garland Campbell, Allan, Burke, et al., 2021) has competitive grain yield in the higher rainfall regions and has good end-use quality; however, ARS Crescent is susceptible in the seedling stage to race race PSTv37 of stripe rust (caused by *Puccinia striiformis* Westend. f. sp. *tritici* Erikss.), the predominant race of the stripe rust pathogen in the club wheat growing area. In recent years, growers have had to apply fungicide to ARS Crescent multiple times to reduce damage from stripe rust due to the over-wintering Stripe rust fungus, coupled with cool spring conditions.

‘Cameo’ (Reg. no. CV-1192, PI 699960) winter club wheat was selected for better seedling and adult plant resistance to stripe rust than ARS Crescent and for resistance to multiple biotic and abiotic stressors that affect wheat production on the Palouse region. Cameo has earlier maturity than ARS Crescent, which is wanted in the targeted growing region. For these reasons, the USDA-ARS and Washington State University jointly released Cameo as an alternative for ARS Crescent, Cara, and Coda in the high-rainfall region because soft white club wheat represents an important component of the Western White market class targeted for cake, cookie, and pastry uses.

Core Ideas

- Club wheat is a high-value component of the soft white wheat crop.
- Cameo club wheat will improve the end use quality of the soft white wheat crop.
- Cameo club wheat possesses resistance to multiple biotic and abiotic stressors.
- Cameo is best adapted to northeastern Oregon, northern Idaho, and eastern Washington.
- Cameo was developed from a diverse pedigree that includes club, soft white, and soft red winter wheat.

2 | METHODS

2.1 | Pedigree and experimental designation

The cross that resulted in Cameo was made in 2009 with the pedigree ARSC96059-2/IL01-11934//ARSC96059-2-0-16. The pedigree of ARSC96059-2 is Coda/WA7766. WA7766 (PI 574537) is a spring wheat breeding line, also in the pedigree of JD spring club wheat. WA7766 is a sibling of the soft white spring wheat ‘Wawawai’ (PI 574538). IL01-11934 is a soft red winter wheat breeding line that was subsequently released for licensing in Illinois. The pedigree of IL01-11934 is IL90-6364(P76788G2-5-4-94//Caldwell/IL77-2656)/IL94-1909(OH416/IL87-2834-1). This line was included as entry 12 in the Uniform Eastern Soft Red Regional Nursery in 2007. The bulk-pedigree breeding method was used to advance and select the line, and it was given experimental number ARS09X492-6CBW when it was entered into regional and state testing (Table 1).

2.2 | Evaluation of agronomic traits

Grain yields and other characteristics of Cameo were evaluated at Pullman, WA, in 2016, at three locations in Oregon and Washington in 2017 and in the breeding program of the USDA-ARS breeding trials at 11 locations per year in Idaho, Oregon, and Washington from 2018 to 2020 (Table 1). Data presented below are from 2018–2020 over a total of 29 location-years. Plot size ranged from 6.5 to 10.2 m^2, depending on the location. At each location, trials were designed as augmented designs of multiple replicated checks, with a single replication of all breeding lines. Procedures for plot establishment, fertility, and herbicide treatments were applied as recommended for dryland wheat in the region (Lyon, 2021).

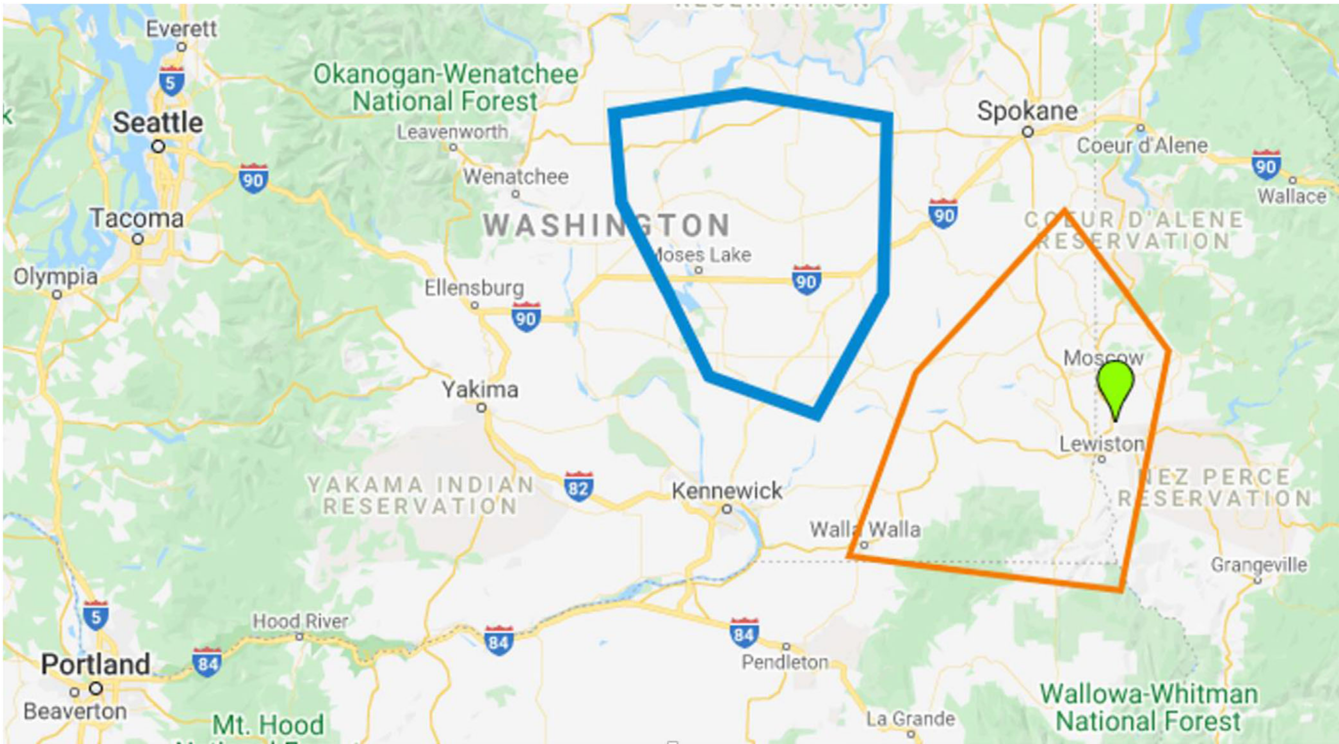

FIGURE 1 Dryland wheat production region of northern Idaho, northern Oregon, and eastern Washington. Blue polygon marks the traditional club wheat–growing region; orange polygon marks the target production region for Cameo

Agronomic traits were measured on a plot basis. Heading date was measured as days from 1 January; plant height was measured as the distance from the soil surface to the top of the spike; grain yield and grain volume weight were measured on a p basis using either a Wintersteiger Classic (Wintersteiger USA) or a Zürn 150 small plot combine (Zürn Harvesting GmbH & Co.). Both combines were equipped with Harvest Master grain gauges (Juniper Systems & HarvestMaster, Inc.). Grain yield was converted to kilograms per hectare. In the PNW, the moisture of grain is typically low and uniform (8–10%) at harvest; therefore, grain yield was not adjusted for moisture.

Cameo was entered in the Washington Extension Cereal Variety Trials (WACVTs) beginning in 2019, in the North Idaho Cereal Variety Trials beginning in 2020, and in the 2020 Western Regional Soft Winter Wheat Nursery. Trials were designed as either randomized complete block or alpha lattice designs with two to four replications. Plot size ranged from 1.5 to 2.4 m^2, depending on the location. Total trial size per location ranged from 39 to 50 entries. Field management, planting date, fertility, and herbicide treatments were applied as recommended for dryland wheat in the region as described in the trial reports. Specific trial methods are described in the variety testing websites for Idaho (University of Idaho Extension, 2021) and Washington (Neely, 2021). Agronomic data from the USDA-ARS breeding nursery trials were analyzed using mixed models over testing environments with the MIXED procedure of SAS/STAT version 9.4 software (SAS Institute, 2021), with all genotypes and environments considered fixed and replications considered random.

Comparisons between Cameo and check cultivars grown in the USDA-ARS trials were made after environments were grouped into those with ≤380 or >380 mm annual precipitation to minimize variance heterogeneity. The model used to analyze multi-environment trials was $Y_{ijkl} = u + G_i + E_j + GE_{ij} + R(E)_{k(j)} + b(RE)_{l(ki)} + e_{ijkl}$, where Y is the plot trait, μ is the overall mean (intercept), G_i is the genotype effect, E_j is the environment (location × year) effect, GE_{ij} is the genotype × environment interaction, $R(E)_{k(i)}$ is the replication effect within each environment, b is the block effect within each replication, and e is the residual variance.

Agronomic data from the University of Idaho 2020 Soft White Winter Wheat Variety Trials were analyzed within each environment using ANOVA with all effects fixed, with the model $Y_{ik} = u + G_i + R_k + e_{ik}$, where Y is the plot trait, μ is the overall mean (intercept), G_i is the genotype effect, R_k is the replication effect, and e_{ik} is the residual variance. Agronomic data from the 2019–2020 WACVT environments were grouped within precipitation zone and analyzed using ANOVA with all effects fixed.

TABLE 1 Breeding history of Cameo soft white club wheat

Year	Generation	Population advance method, location, and traits selected
2007	initial cross	ARSC96059-2/IL01-11934 at WSU-PGF
2009	final cross	ARSC96059-2/IL01-11934//ARSC96059-2 at WSU-PGF at WSU-PGF
2009	F_1	Bulk population increase at WSU-PGF
2010	F_2	Bulk population increase at WSU-PGF
2012	F_3	A bulk increase was grown in a 4-m^2 plot on at WSU-SF, Pullman, WA, and selected for resistance to stripe rust, plant height, maturity, club head type, and kernel color (131 heads selected).
2013	F_4	Seed from each of the 131 heads was planted as $F_{3:4}$ head-rows at WSU-SF, Pullman, WA, and selected for stripe rust resistance, plant height, maturity, club head type, and kernel color (24 heads selected from individual rows).
2015	F_5	Seed from each of the 24 heads was planted as $F_{4:5}$ head-rows at WSU-SF, Pullman, WA, and selected for resistance to stripe rust, eyespot, *Cephalosporium* stripe disease resistance and for plant height, maturity, club head type, and kernel color.
2016	F_6	Evaluated as an $F_{5:6}$ breeding line in a nonreplicated nursery with replicated commercial checks at the WSU-SF, Pullman, WA. Plot size was ∼6.5 m^2. Breeding lines were selected based on resistance to stripe rust, plant height, maturity, grain protein concentration, grain volume weight, grain yield, milling, and baking quality. Selection for these traits was continued for the rest of Cameo's breeding history.
2017	F_7	In 2017 and 2018, Cameo was tested as 09X492-0-0-6*CBW and evaluated as an $F_{5:7}$ breeding line in a nonreplicated nursery with replicated commercial checks at three locations: Harrington and Pullman, WA, and Pendleton, OR.
2018	F_8	Evaluated as $F_{5:8}$ breeding line in replicated elite yield trials over 11 environments: Central Ferry, Farmington, Harrington, Kahlotus, Lind, Pullman, Ritzville, St. Andrews, and Walla Walla, WA; Pendleton, OR; and Genesee, ID.
2019–2021	F_9, F_{10}, F_{11}	Evaluated as $F_{5:9}$ breeding line in replicated elite yield trial over 11 environments as for the F_8 generation in Washington, Oregon, and Idaho (tested as ARS09X492-6CBW). Evaluated in the Washington State Extension Cereal Variety Testing Soft Winter Wheat Trials (2019–2021), the Western Regional Soft Winter Wheat Nursery (2020). and the Univ. of Idaho Northern Idaho Winter Wheat Extension Trials (2020 and 2021). In 2019, 1000 $F_{9:10}$ heads were selected from a plot grown in Pullman, WA.
2020	F_{11}	Purification $F_{9:10}$ head rows of ARS09X492-6CBW were grown at Pullman, WA. A total of 1,500 $F_{10:11}$ heads were selected from selected rows and given to Washington State Crop Improvement Association for breeder seed increase at Othello, WA, in 2021.

Note. WSU-PGF, Washington State University Plant Growth Facility; WSU-SF, Washington State University Spillman Agronomy Farm.

2.3 | Evaluation of abiotic stress tolerance

Freezing tolerance was evaluated annually from 2016 to 2020 in artificial freezing trials conducted at the Washington State University Wheat Plant Growth Facility in three or four replications as in Skinner and Garland-Campbell (2014). Winter survival was described as percent survival where the average survival in the experiment was just 50%. Data were combined over the 3 yr of testing and analyzed using generalized linear models using the GLIMMX procedure of SAS with a T-Central distribution. In this analysis, genotype was considered as a fixed effect and testing run was considered a random effect. Because the trials were unbalanced when combined over 3 yr, the BLUEs for survival were compared using confidence limits.

Resistance to aluminum (Al) toxicity was evaluated at Rockford, WA, in 2018 and 2019 as in Froese and Carter (2016), where lower numbers denoted better growth in the presence of toxic levels of exchangeable Al. Data were analyzed using ANOVA with all effects fixed.

2.4 | Evaluation of resistance to diseases and pests

Resistance to eyespot [caused by *Oculimacula yallundae* (Wallwork & Spooner) Crous & W. Gams and *O. Oculimacula* (Boerema, R. Pieters, & Hamers) Crous & W. Gams] was evaluated in inoculated field trials of three or four replications per genotype in a randomized complete block design as described in Murray and Sheng (2020) over 2019 and 2020. Resistance was rated as a disease index on a scale of 0–100, where 0 represents no symptoms and 100 represents severe

TABLE 2 Agronomic data for Cameo compared with check cultivars in USDA-ARS breeding trials conducted from 2018 to 2020

Name	Grain yield	SE	LSD[a]	Grain vol. wt.	SE	LSD	Head date	SE	LSD	Plant ht.	SE	LSD
	t ha^{-1}			kg hl^{-1}			d from 1 Jan.			cm		
<350 mm annual precipitation (14 location-years)[b]												
Cameo	4.2	3.4	bc	75.5	1.4	a	145	2.7	bc	81	3.0	ab
ARS Crescent	4.6	2.7	ab	76.9	1.3	a	149	2.7	a	81	3.0	ab
Bobtail[d]	3.7	3.4	c	73.8	1.4	a	147	2.7	bc	76	3.0	c
Bruehl	4.4	3.4	abc	74.5	1.4	a	149	2.7	a	84	3.0	ab
Castella	4.2	3.4	abc	76.2	1.5	a	145	2.7	bc	81	1.3	ab
Jasper[d]	4.2	2.7	bc	74.3	1.1	a	146	2.7	c	81	3.0	b
Pritchett	4.7	2.7	a	75.8	1.1	a	147	2.7	b	84	3.3	a
>350 mm annual precipitation (15 location-years)[c]												
Cameo	8.2	2.7	a	77.3	1.5	ab	158	3.0	abc	94	1.2	bc
ARS Crescent	7.5	2.7	bc	77.3	1.5	ab	160	2.9	ab	94	1.2	c
Bobtail[d]	8.3	2.7	a	74.9	1.5	c	156	2.9	bc	89	1.2	d
Bruehl	7.0	2.7	c	74.8	1.5	c	160	2.9	ab	99	1.2	a
Castella	7.8	2.7	ab	78.5	1.5	a	154	3.0	c	97	1.2	bc
Jasper[d]	8.1	2.0	a	76.8	1.5	b	160	2.7	a	94	1.5	c
Pritchett	7.9	2.0	ab	75.6	1.5	c	157	2.7	bc	97	1.5	b

[a]Means separated by the same letter are not different at $p < .05$.

[b]Less than 350 mm locations include Kahlotus, Lind, Ritzville, and St. Andrews, WA, in 2018 and Harrington, Kahlotus, Lind, Ritzville, and St. Andrews, WA, in 2019 and 2020.

[c]Greater than 350 mm locations include Genesee, ID; Pendleton, OR; and Farmington, Pullman, and Walla Walla, WA in 2018 – 2020.

[d]Bobtail (PVP 201400488) and Jasper (PI 678442; Carter et al., 2017) are soft white wheat checks; all other entries are club wheat.

disease compared with the resistant check cultivar 'Madsen' (Allan et al., 1989) and the susceptible check cultivar 'Eltan' (C. J. Peterson et al., 1991). Data were analyzed using ANOVA with all effects fixed. Reaction to *Soilborne wheat mosaic* virus (SBWMV) was evaluated in a naturally infected nursery in Walla Walla, WA, in 2019. Visual symptoms were rated seven times during the growing season, and area under the disease progress curve was calculated as described in Kroese et al. (2020). Grain yield and area under the disease progress curve were analyzed using ANOVA with all effects fixed. Yield loss was calculated based on harvest of plots with a plot combine. Cameo was screened for tolerance to snow mold (*Microdochium* [*Fusarium*] *nivale*, *Typhula idahoensis*, *Typhula ishikariensis*, and *Typhula incarnata*) in three locations (two sites near Waterville, WA, and one near Mansfield, WA) per year in areas prone to natural inoculation of this disease. An initial rating indicated the level of injury right after the snow had receded, and a second rating taken 4–5 wk later indicated amount of recovery and regrowth. Both ratings were based on a scale of 0–9, with 0 indicating severe injury and no recovery and 9 indicating no injury and a high level of recovery. Data were analyzed using ANOVA with all effects fixed. Resistance to a mixed Hessian fly biotype population originating from the PNW was evaluated as described in Ando et al. (2018).

Resistance to stripe rust was evaluated annually in naturally infected trials at multiple locations in Washington. Data from 2019 and 2020 are presented here. Field screening was conducted in Lind, Mount Vernon, Pullman, and Walla Walla, WA. Resistance to individual races (PSTv-4, PSTv-14, PSTv-37, PSTv-40, and PSTv-51) of *P. striiformis* f. sp. *tritici* was evaluated under controlled conditions in seedling and adult-plant tests. These races represent the common virulence patterns prevalent in the PNW (Wan et al., 2016). Seedling tests were conducted under a low diurnal temperature cycle gradually changing from 4 ˚C at 2:00 a.m. to 20 ˚C at 2:00 p.m. (Chen & Line, 1992). Adult plant tests were evaluated as three replications over time under the high diurnal temperature cycle, gradually changing from 10 ˚C at 2:00 a.m. to 30 ˚C at 2:00 p.m. (Hou et al., 2015). In all screening environments, reaction to stripe rust was rated as infection type (IT) on a scale of 0–9, where 0 indicates most resistant and 9 indicates most susceptible (Line & Qayoum, 1992). Adult plant reaction was also rated as disease severity as percent leaf area in the row infected, using the modified Cobb Scale as in R. F. Peterson et al. (1948). The susceptible club wheat breeding line WA7821 (also known as PS279), which does not possess known genes for stripe rust resistance, was included in all trials as a susceptible check. Means were obtained over the replications for each trait within each trial.

TABLE 3 Agronomic performance of Cameo compared with club wheat cultivars in the University of Idaho 2020 Soft White Winter Wheat Variety Trials

Name	Tensed, ID		Genesee, ID		Moscow, ID	
	Grain yield	Grain vol. wt.	Grain yield	Grain vol. wt.	Grain yield	Grain vol. wt.
	t ha^{-1}	kg hl^{-1}	t ha^{-1}	kg hl^{-1}	t ha^{-1}	kg hl^{-1}
Cameo	9.3	78.7	8.5	79.4	10.4	78.4
Castella	8.7	79.5	7.9	81.0	9.5	89.3
Coda	8.4	80.6	7.3	81.7	9.7	80.5
Pritchett	8.5	58.2	7.7	77.5	9.6	75.8
Trial avg.	8.7	78.2	8.0	80.0	9.7	77.7
$LSD_{.05}$	0.8	0.7	0.8	0.5	0.5	0.7
	Nez Perce, ID		Tammany, ID		Bonners Ferry, ID	
Cameo	8.0	80.1	9.5	78.6	6.3	75.2
Castella	8.2	80.3	8.6	80.0	elk	elk
Coda	8.5	80.9	8.5	80.6	6.8	78.6
Pritchett	8.6	76.2	9.2	75.6	6.5	74.3
Trial avg.	8.9	78.4	9.7	79.1	7.1	76.8
$LSD_{.05}$	1.8	0.5	0.6	0.8	1.0	1.0

Note. Trials conducted by Dr. K. Schroeder, University of Idaho. https://www.uidaho.edu/extension/cereals/north/variety-trials.

TABLE 4 Reaction of club and soft white wheat cultivars to stressors prevalent in the Pacific Northwest, 2019–2020

Name	Eyespot disease index	SBMV[a]	Aluminum tolerance index	Freezing tolerance; avg. survival (±95 CL)[b]
	0–100	0–100 (AUDPC)	1–5	%
Cameo	32.4	22.0	3.0	45 (±24)
ARS Crescent	–[c]	–	3.5	65 (±16)
Bruehl	–	–	4.5	54 (±17)
Castella	47.2	20.9	2.5	51 (±17)
Devote[c]	37.0	–	–	
Eltan	70.7	–	5.0	73 (±11)
Jasper	–	–	5.0	32 (±17)
Madsen	26.8	–	–	29 (±19)
LCS Artdeco	–	54.9	–	25 (±17)
Otto	–	–	4.5	58 (±15)
Pritchett	33.8	0.0	4.9	56 (±17)
SY Ovation	–	0.0	–	–
$LSD_{.05}$	14.3	26.1	1.5	–[d]

Note. PI of PVP and reference for the following cultivars: Devote (PI 693628) (Carter et al., 2021), LCS Artdeco (PVP 201300198), Otto (PI 667557) (Carter et al., 2013), SY Ovation (PVP 201100387). Other cultivars have previously been referenced.

[a]SBMV, *Soilborne mosaic virus*; AUDPC, area under the disease progress curve.

[b]CL, confidence limit. Freeze tolerance experiments were not balanced so confidence limits are the best way to compare genotypes.

[c]Dash means genotype was not tested for this stressor.

[d]Survival data were compared as best linear unbiased predictors over 3 yr of testing. LSD could not be calculated because trials were unbalanced.

2.5 | Evaluation of end-use quality

End-use quality tests were conducted at the USDA-ARS Western Wheat Quality Laboratory on grain samples from nurseries grown in Oregon and Washington. Quality tests have been conducted on Cameo since 2016. Data from 2016 through 2020 are presented here. Quality analyses for milling and baking tests were performed according to the American Association of Cereal Chemists (now Cereal and Grains Association) Approved Methods of Analysis (Cereals

& Grains Association, 2021). Starch breakdown due to α-amylase enzyme activity was measured by the falling number test (Perten, 1964) on grain samples collected after harvest from the WACVT. Falling number tests were performed on whole grain meal with the Hagberg–Perten falling number system (Perkin Elmer Inc.) as in Sjoberg et al. (2020). End-use quality data for Cameo were compared with the predominant club and soft white cultivars using paired *t* tests from nurseries grown from 2012 to 2019. The actual number of data pairs for the *t* tests ranged from 3 to 22 depending on the trait and cultivar comparison.

2.6 | Genotype data

Cameo was assayed using the single-nucleotide polymorphism–based genotyping method KASP (Kompetitive allele specific polymerase chain reaction) with diagnostic markers associated with specific loci, including *Almt-D1*, *CBF12*, *Glu-D1a* and *Glu-D1d*, *Lr34-Yr18-Sr57*, *Lr37-Yr17-Sr38*, *Pch1*, *Phs1-646* and *Phs1-666* at *TaMKK3 (Phs1)*, *Rht-B1* and *Rht-D1*, *SBWMV1*, Exon 4 of *Vrn-A1*, *Yr15-R5* and *Yr15-R8* flanking *Yr15*, and *Yr39* (Chapman et al., 2008; Coram et al., 2008; Díaz et al., 2012; Ellis et al., 2002; Helguera et al., 2003; Lagudah et al., 2009; M. Liu et al., 2015; S. Liu et al., 2008, 2014, 2021; Ramirez-Gonzalez et al., 2015; Zhu et al., 2014). For additional details see MASwheat (2021).

3 | CHARACTERISTICS

3.1 | Agronomic characteristics

The grain yield performance of Cameo is superior to club wheat cultivars ARS Crescent and Bruehl (PI 606764) (Jones et al., 2001) and equal to Castella (PI 695319) (Garland Campbell, Allan, Carter, et al., 2021) and Pritchett (PI 678944) (Garland-Campbell et al., 2017) in the high-rainfall region, especially on the Palouse centered around Moscow, ID (Tables 2 and 3). Cameo was the highest-yielding club wheat in four of the six trials in Idaho (Table 3). The average heading date for Cameo in the USDA-ARS trials in the high-rainfall region (>350 mm) recommended production zone is not significantly different from the other club cultivars, but it does tend to be earlier than Bruehl and ARS Crescent. The moderately early maturity is an advantage in the Palouse region, facilitating harvest operations because the cropping system there includes spring crops and subsequent field operations. In addition, early maturity provides some terminal drought stress avoidance. The average height of Cameo in the USDA-ARS trials in the recommended production zone is less than Bruehl and similar to other clubs. The average grain volume weight

TABLE 5 Genotypes of Cameo vs. comparison wheat cultivars for major genes using KASP markers[a]

Name	ALMT-1	CBF-12	Glu-D1-1 Glu-D1-2	Lr34-Yr18-Sr57	Lr37-Yr17-Sr38	PCH-1	PHS1-646	PHS1-666	Rht-B1	Rht-D1	SBWMV-1	Vrn-A1 Exon 4	Yr-15-R5	Yr-15-R8	Yr-39
Cameo	S[2]	R	2,12[b]	S	S	R	R	R	WT	D	S	L	R	S	R
Castella	S	R	5,10	S	S	R	R	R	WT	D	S	L	S	S	S
ARS Crescent	S	R	2,12	S	S	R	S	S	WT	D	S	L	S	S	S
Bruehl	S	R	2,12	S	S	S	S	S	D	WT	R	L	R	S	S
Cara	S	R	5,10	S	R	R	R	R	WT	D	S	L	S	S	S
Pritchett	S	R	2,12	S	S	R	S	S	D	WT	R	L	R	S	S

[a]Cameo was assayed with Kompetitive Allele Specific PCR (KASP) markers (LGC Genomics) developed based on analysis of specific genes including *Alm-1* for tolerance to aluminum, *CBF12* for frost tolerance, *Glu-D1* for gluten strength; *Lr34-Yr18-Sr57* for rust resistance, *Lr37-Yr17-Sr38* for rust resistance, *Pch1* for eyespot resistance, *Phs-1-646* and *Phs-1-666* for resistance to preharvest sprouting, *Rht-B1 and Rht-D1* for reduced height, *SBMV1* for resistance to *Soilborne mosaic virus*, *VrnA1Exon4/7* for vernalization response, *Yr15* for resistance to stripe rust, and *Yr39* for adult plant resistance to stripe rust (Chapman et al., 2008; Coram et al., 2008; Diaz et al., 2012; Ellis et al., 2002; Helguera et al., 2003; Lagudah et al., 2009; Liu et al., 2008, Liu, et al., 2013, 2020; Ramirez Gonzales et al., 2015; Zhu et al., 2014). For details see Marker Assisted Selection in Wheat (https://maswheat.ucdavis.edu). D, dwarfing; L, long vernalization; R, resistant; S, susceptible; St, short vernalization; WT, wild type.

[b]5,10 and 2,12 refer to the protein subunit designations for the Glu-D1 alleles.

TABLE 6 Number of environments tested for falling number and environments with low falling numbers in Washington, 2019–2020[a]

		No. of environments[b]			
Name	**Year of test**	**No. tested**	**<300 s**	**<250 s**	**% below 300 s**
Cameo	2020	4	0	0	
	2019	10	3	1	
	all	14	3	1	28.6a
ARS Crescent	2020	7	0	0	
	2019	11	2	1	
	all	18	2	1	16.7a
Bruehl	2020	9	2	1	
	2019	6	5	1	
	all	15	7	2	60.0b
Castella	2020	18	0	0	
	2019	10	4	1	
	all	28	4	1	17.9a
Pritchett	2020	7	2	1	
	2019	6	3	2	
	all	13	5	3	61.5b
Jasper	2020	20	5	1	
	2019	11	5	6	
	all	31	10	7	54.8b
Total		104	24	13	35.6a

Note. The percentage of low falling number values is significantly different among cultivars. Chi squared test of significant difference = 12.67, df = 5, p = .027. Difference between Cameo and ARS Crescent is not significant: Paired χ^2 test between Cameo and ARS Crescent = 2.006, p = 1.0. Means followed by the same letter are not significantly different from each other.

[a]Data from PNW Falling Number website (http://steberlab.org/project7599.php).

[b]Falling number is rated between 60 and 500 s. Values above 300 are desired.

for Cameo in the USDA-ARS trials in the recommended production zone is similar to ARS Crescent and Castella but greater than Bruehl and Pritchett. Club wheat frequently has lower grain volume weight than soft white wheat, and higher grain volume weight is an advantage. The U.S. standards for No. 1 wheat require a grain volume weight of 77.2 kg hl^{-1} (60 lb bu^{-1}) for all classes except hard red spring or white club wheat, which require 74.6 kg hl^{-1} (58 lb bu^{-1}) (USDA, 2005). Cameo not been observed to lodge in the environments where it was evaluated.

3.2 | Resistance to abiotic and biotic stressors

Based on screening trials conducted at the Washington State University Plant Growth Facility between 2016 and 2020, Cameo has freeze tolerance that is similar to other major soft white and club wheat cultivars (Table 4). Notes on winter injury from cooperators in the 2020 Western Regional Soft Winter Wheat Nursery indicated no problems with winter survival.

Cameo carries the *Pch1* gene for resistance to eyespot and has moderate resistance to that disease, equivalent to the resistant check cultivar Madsen. Cameo has moderate resistance to SBWMV and moderate tolerance to acid soils (Table 4). Cameo was susceptible to snow mold in our screening trials (caused by *Typhula* sp.) and to stem rust (caused by *Puccinia graminis* f. sp. *tritici*), as evaluated by Dr. Yue Jin at the USDA-ARS Cereal Disease Laboratory in St. Paul, MN. Reaction to other wheat diseases is unknown. Cameo was evaluated for resistance to the local PNW biotype of Hessian fly (*Mayetiola destructor* Say) and was resistant, with 0% infested plants as compared to the susceptible check cultivar Alturas (PI 620631) with 100% infested plants.

Cameo has combined seedling and adult plant resistance to stripe rust. Cameo was tested, together with other entries, in a total of 22 stripe rust screening nurseries at Lind, Mt. Vernon, Pullman, and Walla Walla, WA, between 2018 and 2020. In the field trials, Cameo was highly resistant, with ITs 0–3 (on a scale of 1–9) and severity 0–10% (on a scale of 0–100%) in the late growth stages. Based on the field data, Cameo was classified as R (resistant) or rated 1 or 2 using the 1 (most resistant) to 9 (most susceptible) index. Cameo was tested with other entries in 2019 and 2020 in the greenhouse with selected predominant or highly virulent races (PSTv-4, PSTv-14, PSTv-37, PSTv-40, and PSTv-51, with PSTv-198 only

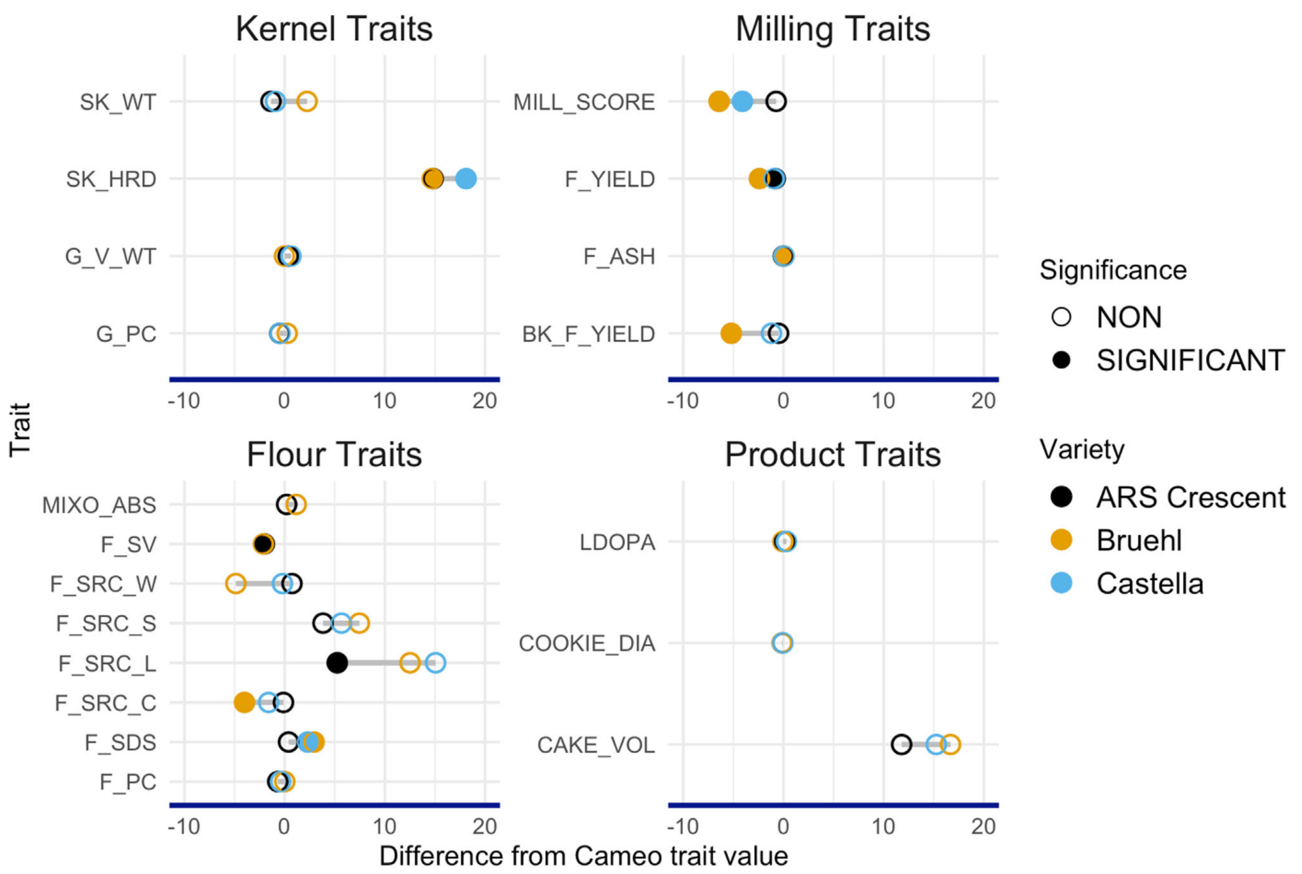

FIGURE 2 Quality traits for Cameo compared with other club wheat check cultivars. Cameo is 0 on all charts. Open circles are nonsignificantly different from Cameo;e closed circles are significantly different at $p = .05$. Cameo was compared with ARS Crescent, Bruehl, and Castella for all traits, and some comparisons are overlapping (as in the case of flour ash and cookie diameter). BK_F_YELD, percent break flour yield; CAKE_VOL, sponge cake volume; COOKIE_DIA, cookie diameter; F_ASH, percent flour ash; F_PC, flour protein concentration; F_SDS, flour sedimentation test; F_SRC_C, flour solvent retention capacity in $NACO_3$ solution; F_SRC_L, flour solvent retention capacity in lactic acid solution; F_SRC_S, flour solvent retention capacity in sucrose solution; F_SRC_W, flour solvent retention capacity in water; F_SV, flour swelling volume; F_YIELD, percent flour yield; G_V_WT, grain volume weight; G_PC, whole grain protein concentration; LDOPA, polyphenol oxidase as measured with LDOPA; MILL_SCORE, milling score, an index calculated from flour yield and flour ash; MIXO_ABS, mixograph water absorption; SK_HRD, single kernel hardness (these traits were characterized with the Perten Single Kernel Characterization System); SK_WT, single kernel weight

in 2019) of the wheat stripe rust pathogen under controlled temperature conditions. The seedling tests were evaluated at low-temperature (4–20 ˚C) cycle, and the adult plant tests were evaluated at high-temperature (10–30 ˚C) cycle. At the low-temperature profile, seedlings of Cameo were consistently resistant (IT2) to race PSTv-4 and intermediate (IT5) to PSTv-14. When tested with race PSTv-37, the line had a mixed reaction (IT2–IT3 or IT5). A mixed reaction was also seen with race PSTv-40 (IT3 or IT8) and PSTv-51 (IT3 or IT5). Cameo was resistant (IT2) to race PSTv-198. The seedling data show that Cameo has all-stage resistance to some races and may be segregating for resistance to other races. Although the KASP data indicate that Cameo has the resistant allele at *YR15-R5*, it does not have the resistant allele at the *Yr15-R8* marker, and there is no indication that Cameo has *Yr15* based on its pedigree. It is possible that Cameo does have a resistance gene linked to the *YR15* locus that is also present in Cara, Coda, JD, and other club wheats (Case et al., 2014). When tested at the high-temperature profile, adult plants of Cameo were highly to moderately resistant (IT2–IT5). Based on the seedling and adult plant tests, Cameo has high temperature adult plant resistance to stripe rust, and the level of resistance is like that of Bruehl and Pritchett and better than that of ARS Crescent.

Cameo was assayed with several KASP markers (Table 5), and it possesses alleles for weaker gluten strength at *Glu-D1* on chromosome 1D, the dwarfing allele for reduced height on chromosome 4D, the allele for resistance to eyespot at *Pch1* on 7D, the previously mentioned gene that is present in several club wheat cultivars on chromosome 1B for stripe rust resistance, and the resistant allele at Yr39 on chromosome 7B. Cameo also has the allele for greater cold tolerance at *CBF12* on 5A, two of the markers associated with preharvest sprouting resistance at *TaMKK3* on chromosome 3A, and the long vernalization allele in exon 4 of *vrn-A1*.

3.3 | End-use quality assessment

Cameo has outstanding club wheat milling and baking quality (Figure 2). Milling score is better than Bruehl and Castella and equal to ARS Crescent. The break flour yield is greater than Bruehl by over 5%, a very nice margin in club wheat milling. The kernels of Cameo are substantially softer than other cultivars, as measured using the Single Kernel characterization system, and can be classified as "super soft" (Morris et al., 2020). The cookie and cake baking performance is similar to the high-quality baking properties of the check varieties.

Cameo was evaluated by the PNW Wheat Quality Council in 2020. The overall summary score was 6.5 for dough quality on a scale where scores for soft wheat ranged from 4.4 to 6.8. It was given an overall score of 6.8 for product quality (range, 3.9–6.8). The overall quality score was 7.2 (range, 4.1–7.2). In the 2020 PNW Quality Council, the U.S. Federal Grain Inspection Service graded samples of Cameo as white club. Because 90% of club wheat is exported to the discriminating Japanese market, Cameo was evaluated by the Japanese Flour Millers Association Technical Exchange in 2020. Cameo was judged to perform similarly to the control Bruehl and without problems. Cameo possesses awned elliptical spikes, white chaff, and white kernels.

Cameo is similar to ARS Crescent and Castella (moderately tolerant) and better than Bruehl and Pritchett (susceptible) for tolerance to environmental conditions that result in starch breakdown and low falling numbers at harvest. It was evaluated in 2019 and 2020 from grain samples collected from the WACVT (Table 6).

4 | CONCLUSION

As compared to other club wheat cultivars grown in the high-rainfall region, Cameo has better agronomic performance than other clubs in trials on the Palouse, better stripe rust resistance than ARS Crescent, and tolerance to eyespot, SBWMV, acid soils, and Hessian fly. Cameo has consistent high grain volume weight, mid-season maturity, moderate height, excellent club wheat quality, and moderate tolerance to low falling numbers, and it consistently grades as white club. Cameo is best adapted to the Palouse region of Idaho, Oregon, and Washington.

5 | AVAILABILITY

Purification of Cameo was performed in 2020 when 3,000 heads were collected from head rows selected for uniformity and stripe rust resistance. These were given to the Washington Crop Improvement Association, and 1,000 headrows were planted on 0.2 ha in fall 2020 at Othello, WA. Foundation seed of Cameo will be maintained by the Washington State Crop Improvement Association. Plant Variety Protection status for this cultivar is pending. Cameo is sold as foundation, registered, and certified seed. Small amounts (5 g) of seed are available from the corresponding author for research purposes. Cameo has been deposited in the USDA-ARS National Plant Germplasm System, where seed will be available five years from publication.

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AUTHOR CONTRIBUTIONS

Kimberly Garland-Campbell: Conceptualization; Data curation; Investigation; Project administration; Resources; Supervision; Writing – original draft; Writing – review & editing. Brian S. Bellinger: Data curation; Investigation; Methodology; Validation. Arron H. Carter: Conceptualization; Investigation; Methodology; Resources; Supervision; Writing – review & editing. Xianming Chen: Data curation; Methodology; Resources; Validation; Writing – review & editing. Patricia DeMacon: Data curation; Formal analysis; Investigation; Methodology; Writing – review & editing. Doug Engle: Data curation; Formal analysis; Investigation; Methodology; Validation. Christina H. Hagerty: Data curation; Formal analysis; Investigation; Methodology; Validation; Writing – review & editing. Alecia Kiszonas: Data curation; Formal analysis; Investigation; Methodology; Visualization; Writing – review & editing. Emily Klarquist: Data curation; Formal analysis; Investigation; Methodology; Validation; Writing – review & editing. Timothy Murray: Data curation; Formal analysis; Investigation; Methodology; Validation; Writing – review & editing. Craig Morris: Data curation; Formal analysis; Investigation; Methodology; Project administration; Supervision; Visualization; Writing – original draft. Clark Neely: Data curation;

Formal analysis; Investigation; Methodology; Validation. Steven Odubiyi: Data curation; Investigation; Methodology; Validation. Arash Rashad: Data curation; Investigation; Methodology; Validation. Deven See: Formal analysis; Investigation; Methodology; Validation. Camille Steber: Data curation; Formal analysis; Investigation; Project administration; Validation; Visualization; Writing – review & editing. Nuan Wen: Data curation; Formal analysis; Investigation; Methodology; Validation; Visualization; Writing – review & editing.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

ORCID

Kimberly Garland-Campbell https://orcid.org/0000-0003-4747-3270
Arron H. Carter https://orcid.org/0000-0002-8019-6554
Emily Klarquist https://orcid.org/0000-0001-5003-1743
Timothy Murray https://orcid.org/0000-0002-6772-202X

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