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CULTIVAR

Registration of 'UC Tahoe', a California Adapted Two-Rowed Spring Barley for Craft-Scale Malting

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Abstract

California has a vibrant and growing craft brewing industry and a nascent malting industry interested in locally sourced products, which has created a demand for malting barley (*Hordeum vulgare* L.) production in California. 'UC Tahoe' (Reg. No. CV-365, PI 678971) is the first malting barley cultivar released by the University of California and is well adapted to California's Central Valley (Sacramento and San Joaquin Valleys). UC Tahoe is a two-rowed spring barley with good resistance to powdery mildew and tolerance to yellow dwarf viruses. UC Tahoe combines four quantitative trait loci for resistance to *Cereal yellow dwarf virus* (CYDV) that were previously identified in the cross between 'Butta 12' and 'Madre Selva'. While not currently a cultivar approved by the American Malting Barley Association, UC Tahoe meets the quality needs of a craft malting and brewing industry interested in sourcing locally grown barley.

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California has a vibrant and growing craft brewing industry, including over 650 breweries that in 2012 generated more than $4.7 billion in total economic impact within the state (Richey and Watson, 2013; Brewers Association, 2016). Despite a production of more than 386 million L of beer, nearly all malted barley (*Hordeum vulgare* L.) used in California is currently imported from other states (Brewers Association, 2016). The demand for malted barley and the growing interest of craft breweries in locally sourced products have encouraged the recent development of a craft-scale malting industry in California (Bustamante, 2017). The University of California barley-breeding program is working with this nascent malting industry to develop malting barley cultivars well adapted to the unique challenges of California environments and pathogens.

The Central Valley of California has a Mediterranean climate, with rainfall concentrated in the winter. In this environment, spring cereals are sown in the fall (as winter cereals) to take advantage of the winter precipitation. Fall-sown winter cereals or spring-sown spring cereals typically perform poorly in this Mediterranean environment; therefore, a dedicated selection effort is required to develop cultivars well adapted to the California environments. In addition, barley cultivars grown in the Central Valley require good levels of resistance to stripe rust (caused by *Puccinia striiformis* Westend.) and tolerance to *Barley yellow dwarf virus* and *Cereal yellow dwarf virus* (CYDV) collectively referred to here as yellow dwarf virus (YDV). Strong straw is also required to prevent lodging in the highly productive soils of this region. Finally, these cultivars need to have adequate malting quality that satisfies the requirements of a growing craft brewing industry in California.

An important milestone in selecting a well-adapted malting barley cultivar for California was the development of 'Butta 12', a breeding line with good malting quality, resistance to barley stripe rust, and acceptable yield. However, this line showed

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Abbreviations: AA, α–amylase; AMBA, American Malting Barley Association; CIMMYT, International Maize and Wheat Improvement Center; CYDV, *Cereal yellow dwarf virus*; DP, diastatic power; FAN, free amino nitrogen; ICARDA, International Center for Agricultural Research in the Dry Areas; QTL, quantitative trait locus; RIL, recombinant inbred line; S/T, soluble-to-total protein ratio; YDV, yellow dwarf viruses.

insufficient tolerance to CYDV and displayed some lodging problems. To address the issue of insufficient virus tolerance, Butta 12 was crossed with the CYDV-tolerant line 'Madre Selva' (Capettini et al., 2002) and a population of 184 recombinant inbreed lines (RILs) was developed. Tolerance to CYDV was assessed for each RIL by inoculating seedlings under greenhouse conditions with viruliferous aphids (*Rhopalosiphum padi*). These data revealed four quantitative trait loci (QTL) for CYDV tolerance (del Blanco et al., 2014). Seven lines, each carrying all four CYDV tolerance QTL, were selected. Among these lines, we focused on UC1409, released as the cultivar 'UC Tahoe' (Reg. No. CV-365, PI 678971) on the basis of its superior malting quality profile, good agronomic performance, and relatively better resistance to lodging. UC Tahoe represents a first step in the development of high-quality and high-yielding two-rowed malting barley cultivars for California.

Methods

Early Generation Population Development

UC Tahoe was selected from the cross between Butta 12 (UC1360) and Madre Selva. Butta 12 was one of the best malting lines of the University of California, Davis, barley program at the time of the cross and had intermediate tolerance to CYDV. Butta 12 originated from the cross of 'BU27' (an Oregon State University line) by a University of California, Davis, selection from the F_2 population of Triumph/Tyra//Arupo 'S'*2/Abyssinian, provided by the International Center for Agricultural Research in the Dry Areas (ICARDA) and the International Maize and Wheat Improvement Center (CIMMYT), Mexico. Madre Selva is a line from ICARDA/CIMMYT reported as tolerant to CYDV (Capettini et al., 2002). The progeny of this cross was advanced by single-seed descendent to the F_5 generation to generate a population of 184 RILs.

Selection

Among the seven lines carrying the four QTL for tolerance to CYDV (del Blanco et al., 2014), two retained good agronomic characteristics and malting quality. These two lines together with Butta 12 were entered into the California Small Grains Regional Testing Program in the 2014–2015 growing season and were sown in replicated yield trials throughout the state. UC Tahoe was selected among these lines on the basis of its superior malting quality parameters, good agronomic performance, and relatively better resistance to lodging.

Evaluation in Replicated Trials

The locations of the field experiments used to evaluate UC Tahoe, its parental line Butta 12, and the unrelated two-rowed malting barley cultivar 'Full Pint', developed at Oregon State University and grown at some California locations, are summarized in Table 1. Four of the locations received irrigation, and five were rainfed. Disease and lodging notes were taken on a scale from 1 to 8, where 1 = trace evidence of infection or minimal lodging and 8 = plots with a robust infection or severe lodging.

Statistical analyses for these trials were conducted using SAS version 9.4 (SAS Institute). Each location-year combination was considered as an environment and treated as a random factor. The Shapiro-Wilks test was used to test the assumption of normality, and the Levene's test was used to test for homogeneity of the treatment variances. When these assumptions were not met, appropriate transformations were implemented to perform the analysis. Dunnett's test was used to detect trait means that were significantly different from UC Tahoe, while controlling the experiment-wise error rate.

Malting Quality

Evaluation of malting quality was conducted at the USDA–ARS Cereal Crops Research Unit in Madison, WI, following their standard protocols. In the early evaluations, samples sent for malting quality evaluations were from small, unreplicated observation rows. In later yield trials, samples were collected from multiple replications and locations of the yield trials.

Seed Production

Seed multiplication for all yield and quality testing as well as for breeder seed production originated from single observation rows grown in Davis, CA, during the 2013–2014 growing season. In June 2014, 250 spikes were collected from homogeneous head rows, threshed individually, and sown as 250 separate rows in July 2014 near Hollister, CA. In October 2014, 1000 spikes were collected, threshed individually, and sown in Davis in November 2014 to produce pure breeder seed. Simultaneously, the remaining seed was harvested in Hollister in October 2014, bulked, and used for yield trials and quality testing.

Table 1. Site locations, type of irrigation, and years of sowing. All locations are in California.

Experiment name	Location	Irrigation	Years of sowing
Chico Regional	Butte Co., Sierra Nevada Brewery, Chico	Irrigated	2015†
Clarksburg Regional	Yolo Co., Joe Perry Farm, Clarksburg	Irrigated	2015, 2016
Davis AMBA	Yolo Co., UC Davis Experimental Field Station, Davis	Rainfed	2017†
Davis Regional	Yolo Co., UC Davis Experimental Field Station, Davis	Rainfed	2015, 2016,† 2017
Davis Quality	Yolo Co., UC Davis Experimental Field Station, Davis	Rainfed	2012,†‡ 2015†
Fresno Regional	Fresno Co., UC Westside REC, Five Points	Irrigated	2015, 2016, 2017
Merced Quality	Merced Co., Scoto Farm, Merced	Irrigated	2016†‡
Rio Vista Quality	Solano Co., Anderson Farm, Birds Landing	Rainfed	2016†‡
San Luis Obispo Regional	SLO Co., White Ranch, Shandon	Rainfed	2016
Tehama Regional	Tehama Co., Endres Ranch, Corning	Rainfed	2015, 2016
Tulare Regional	Tulare Co., Changala Farms, Ducor	Rainfed	2016, 2017

† Site-years for which quality samples were submitted to USDA.

‡ Site-years for which yield and agronomic data are unavailable.

Characteristics

Agronomic Description

UC Tahoe is genetically a spring cultivar, requiring no vernalization to flower and it is adapted to fall sowing in California. UC Tahoe is an early-maturing (flowers 5 d later than Full Pint) and medium-tall (average 84 cm) line. The stem of UC Tahoe has five nodes and extends 10 to 15 cm from the flag leaf to the base of the spike, has a strait neck and an open collar, and lacks visible anthocyanin. The leaves are glabrous and glossy and lack noticeable anthocyanin accumulation. The spikes of UC Tahoe are two-rowed, erect, and glossy, with rough awns shorter than the length of the spike.

Agronomic Performance

Across the 16 environments of testing over 3 yr, UC Tahoe performed well, with an overall average yield of 4125 kg ha^{-1}, which was not significantly different from Butta 12 (4168 kg ha^{-1}) or Full Pint (3832 kg ha^{-1}, Table 2). When considering the irrigated and rainfed sites separately, grain yields were slightly higher for UC Tahoe than Butta 12 in the irrigated environments, a trend that was reversed in the rainfed sites, although neither trend was statistically significant. The only site at which cultivars certified by the American Malting Barley Association (AMBA) were tested alongside UC Tahoe in California was the AMBA pilot malting trial conducted in Davis in 2017, which represents the first year and first step of the AMBA variety certification process. In this trial, UC Tahoe performed well, with an average yield of 5517 kg ha^{-1}, which was significantly higher than the cultivars 'Harrington' (4425 kg ha^{-1}; $P = 0.0122$), 'Merit 57' (4381 kg ha^{-1}; $P = 0.0093$), and 'Metcalfe' (3829 kg ha^{-1}; $P = 0.0003$).

UC Tahoe headed on average 3 d later than Butta 12 and 5 d later than Full Pint. UC Tahoe reached an average height of 84 cm, significantly taller ($P = 0.0013$) than Full Pint (75 cm) but significantly shorter ($P = 0.0157$) than Butta 12 (90 cm). UC Tahoe was less prone to lodging during grain fill (average score 2.96) compared with Butta 12 (average score 4.04) but not as good as Full Pint (average score 2.00). Although these differences were not significant in the overall analysis (Table 2), they were significant in some of the individual environments (Table 3). On average, at the six sites where lodging was a significant problem, Full Pint had less severe lodging than the other two cultivars. At Clarksburg and Davis in 2015, UC Tahoe displayed significantly less lodging than Butta 12, which had the highest average lodging severity at all but one location.

The overall statistical analysis used environments as a random variable, which resulted in the inclusion of the genotype × environment interaction in the error term. These interactions were large for several traits (due to the diverse climatic conditions of the testing environments), resulting in very stringent statistical tests. This explains why several traits that were not significant in the overall analysis (Table 2), were significant in specific environments (Table 3).

Table 3. Agronomic characteristics of barley cultivars at specific sites in California with varying challenges.

Trait	Unit	Cultivar		
		UC Tahoe	Butta 12	Full Pint
Chico, 2015				
Yield	kg ha^{-1}	3963	4032	2253*
LHV†	1–8	6.0	6.8	5.0
Net blotch	1–8	2.25	4.5*	4.75**
Clarksburg, 2015				
Yield	kg ha^{-1}	6434	5831	5395*
LGF‡	1–8	1.0	2.8*	1.0
LHV	1–8	2.3	5.0*	1.3
YDV§	1–8	1.0	1.0	2.25*
Fresno, 2015				
Yield	kg ha^{-1}	5309	4687	3767*
LHV	1–8	5.0	6.3	5.8
PM¶	1–8	1.0	1.25	6.5**
Davis, 2015				
Yield	kg ha^{-1}	5885	5629	5769
LGF	1–8	4.0	7.25*	1*
YDV	1–8	1.0	1.0	3.25**
Davis, 2016				
Yield	kg ha^{-1}	3959	3600	2981
YDV	1–8	1.25	3.0*	3.75*
Tehama, 2015				
Yield	kg ha^{-1}	1394	2206	1061
YDV	1–8	1.75	3.25*	5.0**

* $P < 0.05$ compared with UC Tahoe in Dunnett's test.

** $P < 0.001$ compared to UC Tahoe in Dunnett's test.

† Lodging at harvest: 1 = trace evidence; 8 = severely affected.

‡ Lodging at grain fill.

§ Yellow dwarf virus.

¶ Powdery mildew.

Disease Resistance

Overall, UC Tahoe displayed good resistance to YDV, net blotch [caused by *Drechslera teres* (Sacc.) Shoemaker], and powdery mildew (caused by *Erysiphe graminis* DC. f. sp. *hordei* Em. Marchal), having the lowest average infection value for each of these three diseases (Table 2). Substantial net blotch infection was observed only at the Chico, CA, site in 2015, where UC Tahoe displayed significantly more resistance than Butta 12 (P

Table 2. Agronomic performance and disease resistance of barley cultivar UC Tahoe from 15 site-years from 2015 to 2017.

Cultivar	Yield			Kernel weight	Plant height	Days to heading	Lodging at grain fill	YDV
	All	Irrigated	Rainfed					
	kg ha^{-1}			mg	cm	d from 1 Mar.	1–8†	
UC Tahoe	4125	4928	3590	43.2	83.8	35.9	2.96	1.25
Butta 12	4168	4756	3777	48.3*	89.8*	32.5	4.04	2.06
Full Pint	3832	4388	2845	42.5	74.9*	30.6	2.00	3.56*

* Significantly different from UC Tahoe at the 0.05 level in Dunnett's test.

† Lodging score: 1 = no lodging; 8 = severely affected.

= 0.0013) or Full Pint (P = 0.0007) (Table 3). In the case of YDV tolerance, the differences from Full Pint were significant in the overall analysis (P = 0.0013, Table 2) and at four individual locations (Table 3). The improved YDV values relative to Butta 12 were significant in only two environments where infections were most severe (Table 3).

At locations where significant disease pressure was observed, UC Tahoe outperformed the other lines in grain yield, which demonstrates the value of the additional genetic resistance present in UC Tahoe (Table 3). For example, the better net blotch resistance of UC Tahoe relative to Full Pint under a strong net blotch outbreak in Chico 2015 correlated with significantly higher grain yield levels in the first cultivar (Table 3). At the Fresno site in 2015, a strong powdery mildew infection occurred and UC Tahoe performed significantly better than Full Pint both in disease resistance and grain yield (Table 3). At the two sites where the YDV symptoms were most severe, Davis 2016 and Tehama 2015, UC Tahoe showed better tolerance and higher (although not significant) grain yields than Butta 12 and Full Pint (Table 3).

Malting Quality

Malting quality was evaluated on grain from seven locations across 4 yr by the USDA Cereal Crops Research laboratory in Wisconsin; the results are presented in Table 4. The only parameter that was significantly different between UC Tahoe and Butta 12 was the average kernel weight, where UC Tahoe kernels averaged 39.0 mg and Butta 12 kernels averaged 42.4 mg (P = 0.03). Compared with Full Pint, UC Tahoe produced grains that were significantly plumper as measured by the proportion of grains retained on a 2.4-mm (6/64") screen, 75.3% for Full Pint versus 95.5% for UC Tahoe (P < 0.0001). Full Pint produced a significantly more cloudy wort with a significantly higher soluble protein content, soluble-to-total protein (S/T) ratio and free amino nitrogen (FAN) level as compared to UC Tahoe. Additionally, Full Pint malt had significantly higher α-amylase activity than did UC Tahoe (P = 0.0087).

The USDA Cereals Crop Research laboratory assigns points to each malting quality parameter, using a tiered system with an ideal range (USDA, 1992; Table 4) and decreasing points as values move further from this ideal range. UC Tahoe showed malting quality values within the top tier for grain plumpness, grain protein content, diastatic power (DP), and α–amylase (AA). Average kernel weight of UC Tahoe was below the top tier for the samples sent for malting quality analyses (39.0 mg) but was in the top tier when all environments were considered (43.2 mg, Table 2). Values were at intermediate tiers for malt extract and in the lowest tier for S/T, FAN, and β glucan content. Both S/T and FAN showed some environmental variability, with 22 and 33% of the environments showing values in higher quality tiers. These two parameters were also low in Butta 12. Additionally, in most of the environments, UC Tahoe, like Butta 12 and Full Pint had β-glucan contents that were much higher than preferred values. In contrast, at the Davis site in 2012, both UC Tahoe and Butta 12 showed β-glucan values within the top tier, suggesting a strong environmental effect on this trait.

Depending on the end use of the malted barley, different quality parameters are preferred. The USDA quality parameter preferences are based on malt primarily used in adjunct brewing where other grains such as rice (*Oryza sativa* L.) and corn (*Zea mays* L.) are added to the mash. In this end use, it is preferred that the malted barley produce high wort protein, FAN, and DP and have high AA activity. In the case of craft brewing, which predominantly uses barley malt exclusively, the desired parameters are slightly different. The Brewers Association and AMBA have produced separate guidelines for all barley malt craft brewing, which are more closely aligned with the quality profile of UC Tahoe (AMBA, 2017; Brewers Association, 2017) (Table 4). The lower wort protein and FAN produced by UC Tahoe meets these quality preferences. However, the average DP of

Table 4. Malting quality profile of UC Tahoe. Rows 1 to 3 are averages of multiple sites grown in 2012, 2015, and 2016 compared with Butta 12 and Full Pint. Rows 4 to 7 are single samples from Davis 2017 compared with three American Malting Barley Association (AMBA)-certified cultivars. Rows 8 and 9 are preferred values as described by the USDA and AMBA.

Cultivar	*n*†	Kernel weight	Plump kernel	Malt extract	Barley protein	Wort protein	S/T‡	DP‡	α-amylase‡	β-glucan	FAN‡
		mg			%			°ASBC	20°DU	ppm	ppm
UC Tahoe	9	39.0	95.5	78.5	12.6	4.18	34.4	164	52	522	156
Butta 12	9	42.4*	96.0	79.0	12.8	4.35	36.2	190	55	460	174
Full Pint	3	35.9	75.2**	78.3	12.7	5.17*	42.2*	181	80*	368	231*
UC Tahoe§	1	38.0	97.3	79.9	11.8	4.15	35.7	185	66	398	124
Harrington§	1	32.0	67.4	79.0	13.1	4.68	36.2	120	79	447	230
Metcalfe§	1	33.9	82.6	82.1	11.5	4.72	44.7	163	114	104	253
Merit 57§	1	37.6	83.7	81.9	12.5	4.82	40.2	160	118	258	260
USDA¶		>42.0	>90.0	>81.1	11–13	4.4–5.6	40–47	>120	>45	<100	>190
AMBA All Malt#			>90.0	>81.0	<12	<5.3	38–45	110–150	40–70	<100	140–190

* Significantly different from UC Tahoe at the 0.05 level in Dunnett's test.

** Significantly different from UC Tahoe at the 0.001 level in Dunnett's test.

† Number of samples included for each line.

‡ S/T, soluble-to-total protein; DP, diastatic power measured in °ASBC (level based on protocol from American Society of Brewing Chemists); α-amylase measured in 20°DU (dextrinising units at 20°C); FAN, free amino nitrogen level.

§ This and following rows are samples from the first UC Davis AMBA Pilot Malting trial in Davis, 2017.

¶ USDA malt quality preference (adapted from Clancy and Ullrich, 1988).

AMBA malt quality recommendations for all malt two-rowed applications (AMBA, 2017).

UC Tahoe is somewhat higher than the preferred range, and the β-glucan values are high for all barley malt craft brewing.

Beta-glucan is a major component of the endosperm cell walls and is broken down during the malting process by β-glucanase enzymes (Fincher, 1975). When present in excessive amounts, β-glucan causes high viscosity and poor filtration of wort and can lead to a hazy product with poor shelf stability (Barrett et al., 1973; Vis and Lorenz, 1997; Sá and Palmer, 2004). The amount of β-glucan in the grain is partially due to the genetics of the cultivar but can also be significantly influenced by environmental factors. It has been shown that high temperatures between heading and maturity, as well as number of days above 30°C (which are frequent in California), increased β-glucan content while lower temperatures and moisture availability during grain fill was associated with reduced β-glucan content (Zhang et al., 2001). This environmental influence of β-glucan content is consistent with our observations that UC Tahoe and Butta 12 had β-glucan content of 83 and 65 ppm, respectively, in 2012, a relatively normal year for temperature and rainfall, and very high β-glucan content (>500 ppm) in 2015 and 2016 when California was experiencing high temperatures and a serious drought. Similarly, the AMBA-certified cultivar Harrington, which typically produces malt with a low β-glucan content, had more than four times the maximum preferred β-glucan content when grown at Davis in 2017.

Conditions during the malting process can also have a strong effect on the β-glucan content of the resulting malt. It has been shown that steeping barley grain at a lower temperature can enhance the development of β-glucanases, which will result in lower β glucan levels in the finished malt (Rimsten et al., 2002). Additionally, extending the germination time allows for the β-glucanases to further reduce β-glucan content of the finished malt (Li et al., 2008). However, this strategy can also increase soluble protein, DP, FAN, and AA. Considering the average values of UC Tahoe for these parameters (Table 4), these secondary effects may be beneficial for FAN and AA but detrimental for soluble protein and DP for all malt applications. The primary end users of UC Tahoe will be local craft-scale maltsters who have a greater degree of flexibility in their malting protocols. With this flexibility, malting protocols have already been developed that produce high-quality malt from UC Tahoe despite the high β-glucan content (J. Mahon, Grizzly Malt, personal communication, 2016).

Availability

Breeder seed for UC Tahoe was delivered to the UC Davis Foundation Seed Program in October 2015, which has maintained foundation seed since September 2016. US Plant Variety Protection of UC Tahoe is pending (PVP Application No. 201700009). Certified seed is available for purchase from Adams Grain in Arbuckle, CA (http://www.adamsgrp.com/adams-grain.shtml). Seed of UC Tahoe has been deposited into the USDA–ARS National Plant Germplasm System, where it will be available after the end of PVP protection. Small amounts of seed (5 g) for research purposes can be requested from the corresponding author for at least 5 yr.

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CULTIVAR

Registration of 'Canmore' Barley

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Abstract

Interest has been growing in barley (*Hordeum vulgare* L.) cultivars that meet the specialized needs of a diverse marketplace while still providing producers with robust, high-yielding types. In response to this challenge, the Alberta Barley Commission worked closely with Sanwa Shurui Co., Ltd. and the Field Crop Development Centre (FCDC) to develop selection criteria in barley for shochu production. Shochu is a popular alcoholic beverage in Japan. As part of the project, 'Canmore' (Reg. No. CV-366, PI 685640; Canadian Food Inspection Agency Reg. No. 7392; Canadian PBR Appl. No. 5237), a two-rowed, hulled, spring barley for food and general purpose uses, was developed. Canmore was derived using single seed descent from one F_2 seed to a F_5 headrow. It was tested as J02039005 in FCDC trials from 2004 to 2012 and as TR10694 in Prairie Recommending Committee for Oat and Barley trials in 2010 and 2011. It was registered in Canada as Canmore. Canmore has excellent pearling properties, starch content, and alcohol yield for shochu production. It is resistant to surface-borne and loose smuts, moderately resistant to scald and spot form of net blotch, and intermediately resistant to common root rot, spot blotch, and Fusarium head blight. Canmore has good potential in the food barley market for shochu as well as good yield, disease resistance, and agronomic traits for general production in the northern Great Plains.

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SHOCHU is a popular alcoholic beverage in Japan. It can be made from barley (*Hordeum vulgare* L.), rice (*Oryza sativa* L.), sweet potato (*Ipomoea batatas* L.), or other starch sources. Characterization of the requirements of barley for the production of shochu was determined during an initial study conducted by the Alberta Barley Commission (ABC). At the completion of the initial study, it was thought that it would be possible to further improve barley if selection could be made for desirable traits. Therefore, ABC initiated a project entitled the Multi-Purpose High Starch Shochu Barley Selection Program, with funding from the Canadian Agricultural Adaptation Program (CAAP). While the principal objective was to identify lines with superior traits for shochu, it was felt that a cultivar developed for this market would also have potential for malt or feed end uses due to its high starch content, a priority requirement for the shochu market.

'Canmore' barley (Reg. No. CV-366; PI 685640; Canadian Food Inspection Agency [CFIA] Reg. No. 7392; Canadian PBR No. 5237) is a two-rowed, hulled, spring barley for food and general purpose uses developed by the Field Crop Development Centre (FCDC). It was tested in Canada as J02039005 in FCDC trials from 2004 to 2012 and as TR10694 in the 2010 and 2011 Western Cooperative Two-row Barley Registration Tests (Coop) run under the auspices of the Prairie Recommending Committee for Oat and Barley (PRCOB). It was supported for registration by the PRCOB in February 2013 and registered in Canada as Canmore by the CFIA on 31 May 2013. It was granted Plant Breeders Rights in Canada by the CFIA on 4 Feb. 2016. Canmore is the first two-rowed, hulled, spring cultivar recognized as a food barley by the Canadian Grain Commission (2017).

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Abbreviations: AAF, Alberta Agriculture and Forestry; AAFC, Agriculture and Agri-Food Canada; ABC, Alberta Barley Commission; BQET, Barley Quality Evaluation Team; CAAP, Canadian Agricultural Adaptation Program; CFIA, Canadian Food Inspection Agency; CIMMYT, International Wheat and Maize Improvement Center; CDC, Crop Development Centre; FCDC, Field Crop Development Centre; Coop, Western Cooperative Two-row Barley Registration Tests; FHB, Fusarium head blight; NIRS, near infrared spectroscopy; ICARDA, International Center for Agricultural Research in the Dry Areas; PRCOB, Prairie Recommending Committee for Oat and Barley; WUE, water use efficiency.

Canmore is derived from the cross H92013289Z/'Ponoka'. H92013289Z was derived from the cross of 'AC Oxbow'/'CDC Thompson'. AC Oxbow (TR226) is a two-rowed, hulled barley for malting developed by D. Metcalfe and B. Legge, Agriculture and Agri-Food Canada (AAFC), from the cross TR233/WPG8020//WPG823/TR222. AC Oxbow was tested in the 1987, 1988, and 1989 Coop trials and supported for interim registration in Canada in 1990 and full registration in 1994 (CFIA, 2017a). CDC Thompson (TR129) was granted interim registration in 1994 and full registration in 1999 and is a two-rowed, hulled, semidwarf, spring barley for malting developed by B. Harvey and B. Rossnagel (CFIA, 2017g). While it had a short life as a malting barley, it has had a long life as a feed cultivar due to its good straw strength and moderate resistance to scald [caused by *Rhynchosporium commune* Zaffarano, McDonald and Linde sp. nov., formerly *Rhynchosporium secalis* (Oudem.) J.J. Davis]. Ponoka is a two-rowed, hulled, spring barley for general purpose use developed by Juskiw et al. (2005). Ponoka was selected from the cross H92001F_1/TR229. H92001F_1 was the F_1 generation of the cross 'Harrington'/'Camelot' made at the FCDC. Harrington is a two-rowed, hulled, spring barley for malting developed at the University of Saskatchewan, Saskatoon, SK, Canada (Harvey and Rossnagel, 1984). Camelot is a two-rowed, hulled, spring barley introduced to the FCDC as entry 19 in the 13th International Barley Yield Trial supplied by the International Center for Agricultural Research in the Dry Areas (ICARDA)/International Wheat and Maize Improvement Center (CIMMYT), Mexico (F. Capettini, personal communication, 2003).

Methods

Breeding Method

The original cross for Canmore was made in 2002. The F_2 bulk was grown in the field at Lacombe, AB, Canada, in 2003. Two hundred spikes were selected on the basis of a visual assessment and advanced to the F_5 generation in the J.H. Helm Growth Facility during winter 2003–2004 via single seed descent, with no further selection. Two hundred F_5 headrows were grown out in the field at Lacombe in summer 2004, from which the line J02039005 was selected on the basis of resistance to scald and smut (caused by *Ustilago* spp.), quality (protein and other traits based on near infrared spectroscopy [NIRS] analyses [Helm, 2006]), and agronomic traits (straw strength, maturity). The headrows were inoculated by spreading disease-infested straw that had been collected from a field infested with scald in the previous year. In 2005, the line designated as J02039005 was tested in a nonreplicated yield plot at Lacombe. In this year, two heads per plot were inoculated with *U. nuda* using the air-brush technique (Wolfe, 1993). These heads were harvested and grown out in the growth room during winter to determine resistance.

Line Evaluation

In 2006 and 2007, J02039005 was tested in replicated multisite field tests throughout Alberta. In 2008 and 2009, J02039005 was tested in yield tests across western Canada. In 2010, 2011, and 2012, J02039005 was grown in yield trials in Alberta alongside commonly grown commercial cultivars. Locations in all years were Calmar, Morrin, Lacombe (high fertility site, low fertility site, second date of seeding site), Trochu, and Olds (the Olds site was lost to hail in 2012). The high fertility site was planted into alfalfa (*Medicago sativa* L.) plow down with over 90 kg ha^{-1} of N, while the low fertility site was planted after a cereal crop, with between 40 and 50 kg ha^{-1} of N. The second date of seeding site was planted 2 to 3 wk after the other sites. Plots were eight rows, 0.15-m spacing, and trimmed to 2.7 m before harvest. Layout was a randomized complete block (RCBD) with two replications in 2006 and three replications in all subsequent years. Yield, test weight, kernel weight, percentage plump kernels, days to anthesis, days to maturity, height, and lodging of this line were evaluated in these tests. Data from FCDC trials were analyzed using PROC ANOVA of SAS software (SAS Institute). Each site of the field trial data was analyzed as a RCBD and kept as valid if test coefficients of variation for yield were <15%. Lodging data was assessed at most sites, but significant differential lodging was only noted at nine locations, so data was entered into the data set only from these locations. These data were stored in the Field Crop Data Miner, a customized system for data storage and analyses based on SAS software, so that data could be reanalyzed over locations and years. Data were analyzed using PROC GLM of SAS with years, locations, and lines as fixed effects.

From 2006 to 2009, J02039005 was assessed in the field at the AAFC Brandon Research and Development Centre in Brandon, MB, for reactions to Fusarium head blight {FHB, predominantly caused by *Fusarium graminearum* Schwabe [teleomorph *Gibberella zeae* (Schwein.) Petch]}, net blotch [caused by *Drechslera teres* (Sacc.) Shoemaker, *Pyrenophora teres* Drechs. (teleomorph)], and spot blotch [caused by *Cochliobolus sativus* (Ito & Kuribayashi) Drechs. ex Dastur, *Bipolaris sorokiniana* (Sacc.)]. The FHB nursery was inoculated using corn (*Zea mays* L.) spawn inoculum at 5 g per row. Spot blotch and net blotch were evaluated in hill plots with inoculated spreader rows.

From 2006 to 2009, J02039005 was assessed in the field at the University of Saskatchewan, Crop Development Centre (CDC) in Saskatoon, SK, for reactions to spot blotch and net blotch. At the CDC, spot blotch-infested straw was spread throughout the hill plot nursery. Net blotch was allowed to develop naturally.

At the AAFC Lacombe Research and Development Centre in Lacombe, AB, scald, common root rot [caused by *Bipolaris sorokiniana* (Sacc.) Shoemaker], loose smut [caused by *U. nuda* (C.N. Jensen) Rostr. nom. nud.], and covered smut [caused by *U. hordei* (Pers.) Lagerh.] resistance were assessed. Scald assessments were done in field nurseries inoculated with straw and spore suspensions, run at Lacombe by AAFC and at Edmonton, AB, by AAFC in 2005 to 2007 and then by Alberta Agriculture and Forestry (AAF) in 2010 and 2011. Common root rot was assessed in single row plots in the root rot screening nursery at AAFC Lacombe. Loose smut assessment was done in the field by inoculation using the air-brush technique developed by Wolfe (1993). The inoculated heads were harvested, and the seed was grown out in growth rooms during the following winter. This evaluation was done twice, once in 2005 and again in 2009. Covered smut was evaluated in field nurseries at Lacombe in 2007 and again in 2009, by vacuum infiltration of teliospores under the hull of the seed, as originally reported

by Fischer and Holton (1957) and Nielsen (1976), with inoculum provided by Dr. J. Menzies, AAFC Morden Research and Development Centre.

At the ICARDA/CIMMYT Centre in Mexico, J02039005 was assessed in field nurseries for scald, leaf rust (caused by *Puccinia hordei* G. Otth.), stripe rust (caused by *P. striiformis* Westend, f. sp. *hordei* Eriks.), and FHB. Scald assessment was done at the Toluca site, where inoculation was by spore suspension. Leaf rust was assessed at the Ciudad Obregón site, where inoculation was done by spore suspension application to spreader rows. Stripe rust was assessed at the Toluca site and was dependent on natural inoculation. We assessed FHB in inoculated plots in 2006 at the Toluca site and from 2007 to 2010 at the El Batán site. Plots were inoculated using spore suspensions.

Using NIRS with the NIRS6500 (FOSS NIRSystems, Inc.) and calibrations developed by Helm (2006), Helm et al. (2000, 2003), and Temelli and Helm (1999), J02039005 was assessed for grain quality traits of protein, protein digestibility, energy digestibility, digestible energy, lysine, starch, β-glucan, pentosan, lipid, total fiber, soluble fiber, grain color, pearl color, pearl rating, and malting quality traits such as fine extract, diastatic power, and α-amylase.

J02039005 was tested for water use efficiency (WUE) as described by Juskiw et al. (2009a). Assessments were made on a yearly basis from 2008 to 2011. The two-rowed checks were 'AC Metcalfe' (Legge et al., 2003) and 'Xena' (CFIA, 2017j). The assessment protocol for WUE using pots with limited watering was validated by Anyia et al. (2007) using field and ^{13}C techniques.

Determination of silage potential was made as described by Juskiw et al. (2009a). Biomass yield was measured from 2008 to 2011 in trials grown at Lacombe. The checks were 'Seebe' (Helm et al., 1996) and Xena. Quality was determined on ground samples using previously developed NIRS calibrations.

Based on yield, disease, and quality data, J02039005 was entered into the Coop trials as TR10694 (see PRCOB [2016] for the protocols for running the Coop trials). Check cultivars for the tests were established on a yearly basis by the PRCOB. Field trials were run as three replicate RCBD. The test coordinator of the two-row coop ran ANOVA on each site, and sites were maintained in the roll-ups if yield CVs were less than 15%. Least significant differences at $\alpha = 0.05$ were determined by the test coordinator based on their software or calculated from standard errors of the means provided with the trial results. As part of the cooperative assessment, disease evaluations were performed (PRCOB, 2016). In addition to the Coop trials, TR10694 was included in one year of Collaborative trials coordinated by the Brewing and Malting Barley Research Institute. Five sites were selected for micro-malting, and data were rolled-up and SDs determined. Details of the statistical analyses can be found in PRCOB (2016).

Shochu Evaluation

Samples from the Coop and Collaborative trials were collected for the CAAP shochu project. Samples from 2010 and 2011 were sent to Japan for standard analyses of shochu production at Sanwa Shurui Co. Ltd. Hardness, weight, moisture, and diameter of individual kernels were measured using a Perten Instruments single-kernel characterization system (SKCS) device. Pearling to 70% of the initial weight was conducted using the Satake Test Mill-05. The pearling test was performed using 150 g of hulled barley sample per location. When pearled to 65% of the initial weight, broken kernels are separated from sound kernels. Both subsamples were weighed, and the yield and the broken kernel ratio (BKR) were calculated according to the following formulas:

$$\text{Yield \%} = 100 \times [\text{sound kernels (g)}/150]$$

$$\text{BKR \%} = 100 \times \{\text{broken kernels (g)}/[\text{sound kernels (g)} + \text{broken kernels (g)}]\}$$

Moisture, starch, and protein content of the pearled samples were determined using standard methods. Moisture content was determined by weighing the pearled grain sample before drying, drying the sample in an oven at 105 C for 12 h, following by cooling in a desiccator, weighing dry and calculating as follows:

$$\text{Moisture \%} = [\text{(wet sample weight)} - \text{(dry sample weight)}]/\text{wet sample weight} \times 100\%$$

Starch content was determined using a Megazyme Total Starch Assay Kit (Megazyme International Ireland), AOAC Official Method 996.11 (Association of Official Analytical Chemists, 2016). Protein content was measured using a Tru-Mac-N (Leco Corporation) and calculating as follows:

$$\text{Protein content (\%,dry)} = \text{N content (\%)} \times 6.25 \times [100/(100 - \text{Moisture (\%)})]$$

After pearling, the samples were steeped to a moisture content of approximately 35%. After that, they were steamed to change the structure of the barley starch. Then, a type of mold, taxonomically classified as *Aspergillus luchuensis* mut. *kawachii,* was inoculated on the steamed barley to make barley Koji.

Koji acidity was determined by titration with 0.1 mol L^{-1} of NaOH. The acidity value was equal to the volume of titrant. Koji total conversion power was calculated by determination of the digestion and saccharification values. The Koji digestion test was done by preheating 100 mL of deionized water to 55 C° in a water bath. Then, 30 g of Koji was added into the bottle, and the lid was sealed tightly. The bottle was incubated at 55 C° for 5 h and swirled thoroughly every 30 min. The solution was filtered with gauze into a volumetric cylinder after the solution stood for 30 min. This measurement was the volume (A). Then the Brix value (°Bx) of the filtered solution (saccharification value) was determined using a standard method. The digestion value and the saccharification value were determined according to the following formulas:

$$\text{Koji total conversion power} = \text{digestion value} \times \text{saccharification value}$$

$$\text{Digestion value} = (A) \times 100/\{100 + [(\text{moisture\% of Koji}/100) \times 30]\}$$

$$\text{Saccharification value} = \text{°Bx}/[(100 - \text{moisture\% of Koji})/100]$$

Mash alcohol yield was determined at the end of fermentation. The Koji was mixed with water and shochu yeast in a fermentation tank. The mixture was fermented for approximately

5 d, and then the mash was transferred to a larger tank and mixed with more water and steamed barley. The mash was fermented further for 10 d until the final alcohol content of the mash was 18 to 20%. A sensory test on the resultant shochu was conducted using a five-point evaluation method with 19 trained panelists in 2010 and 16 in 2011. The panelists scored the shochu for aroma and taste using a scale of 1 to 5, where 1 is very good, 2 is good, 3 is fair, 4 is poor, and 5 is bad.

Seed Purification and Increase

In 2006, an increase plot was established from the 2005 yield plot and 300 heads were selected as described in the line description (i.e., two-rowed, rough awned, spike traits [density, attitude, and length], and any other distinguishing traits), then threshed and grown out as a bulk increase in 2007. In 2007, 200 heads were selected for type and then grown out as 200 head rows in 2008. These purification increases were run for removal of variants and to compile detailed descriptions (i.e., seedling traits, vegetative traits, spike traits, and seed traits). In 2008, five heads were picked from each row, one to provide the source for the pre-breeder headrow nursery that was grown in 2009 and the remainder as backup to reconstitute the breeder seed if required. All off-type rows with smut were discarded. One hundred ninety-two F_{11} breeder head rows and plots were grown out in 2010. Of these rows and plots, all were selected to be harvested, and seed was bulked to form the first breeder seed grown out in 2011.

Characteristics

Unique Characteristics

In the 3 yr of FCDC yield trials for cultivar comparison, Canmore was the second highest yielding cultivar, with a yield advantage of 17% over AC Metcalfe and yield equal to Xena (Table 1). Canmore reached anthesis around the same time as AC Metcalfe and Xena. Canmore had intermediate maturity and was not significantly later or earlier than any of the other cultivars tested.

Kernel weight of Canmore was heavier than that of AC Metcalfe. Canmore was a high test weight cultivar, with higher test weight than the malting checks AC Metcalfe and 'CDC Copeland' (CFIA, 2017d). Percentage of plump kernels for Canmore was higher than for AC Metcalfe and CDC Copeland.

Canmore has intermediate height, intermediate-low lodging rating, and intermediate WUE when based on biomass or grain yield.

Relative to the other cultivars tested, Canmore was among those with high biomass yields (dry matter yields at the soft-dough stage timed to simulate harvest for silage production) (Table 2). As for forage quality, Canmore had similar in vitro fiber digestibility to the other cultivars tested, although it was lower than that for 'Champion' (CFIA, 2017h). The lignin content of forage from all cultivars was similar. Canmore had low acid detergent fiber and neutral detergent fiber, although this difference was significant only with 'CDC Cowboy' (CFIA,

Table 1. Yield and agronomic traits of Canmore and other commercial barley cultivars in Field Crop Development Centre tests run in 2010, 2011, and 2012 at Calmar, Lacombe (high fertility, low fertility, and late seeding), Morrin, Olds (2010 and 2011 only), and Trochu, AB, Canada.

Entry	Grain yield	Anthesis	Maturity	Kernel weight	Test weight	Plump kernels†	Height	Lodging‡	Water use efficiency§	
									Biomass	Grain
	kg ha^{-1}	d		mg	kg hL^{-1}	% > 2.44 mm	cm	Stage % scale	kg m^{-2} mm^{-1}	kg m^{-2} mm^{-1}
AC Metcalfe	6897	57.1	102.9	43.2	63.8	82.1	90.2	226	42.1	21.3
Bentley¶	7653	57.3	104.4	49.1	63.8	91.5	92.5	165	44.3	24.0
Busby¶	7590	55.7	103	51.4	65.6	90.2	95.8	159	44.3	22.3
Canmore	8042	57.5	103.3	45.8	65.4	89	89.6	182	42.7	21.4
CDC Austenson¶	8320	59.5	104.6	46.8	65.7	84.9	91.1	155	42.1	20.2
CDC Coalition	7628	57.1	102.8	46.1	64.3	84.2	83.2	157	41.4	20.2
CDC Copeland	7360	58.5	102.5	45.2	63.1	82.7	95.3	186	38.4	19.0
CDC Cowboy¶	6760	58.2	105.7	54.2	64.7	88.9	109.7	233	36.7	18.9
CDC Meredith¶	7394	58.8	104.6	45.4	61.8	85.4	87.3	281	43.1	21.1
Champion¶	7906	55.3	101.7	47.5	64.9	82.9	86.8	182	45.7	23.4
Gadsby¶	7959	59.4	105.6	53.9	65.0	93.3	95.0	250	37.3	19.1
Major¶	7754	57.6	103.1	45.2	63.3	83.4	87.1	202	38.0	17.5
Merit 57¶	7793	57.2	104.8	43.6	62.8	83	87.9	223	41.6	20.8
Newdale¶	7645	57.1	102.9	43.6	63.2	80.9	84.8	221	40.2	20.5
Norman¶	7101	57.5	102.7	43.6	64.9	86	86.5	224	40.5	19.1
Ponoka	7429	59.5	105.1	44.9	64.7	82.8	89.0	214	39.3	18.5
Xena	7900	56.5	102.5	47.5	64.6	84.9	86.8	197	42.1	19.6
$LSD_{0.05}$	730.2	1.70	3.30	2.10	1.40	6.20	5.00	65.2	2.57	1.39
No. of station years	20	20	14	20	20	20	20	9	3	3

† Amount of seed (by weight) retained over a screen with slot size of 2.44 mm.

‡ Lodging was measured at Lacombe (high fertility 2011 and 2012, low fertility 2011 and 2012, late seeding 2011 and 2012), Olds and Morrin in 2011, and Trochu in 2012 using the stage-percent scale (Jedel et al., 1998) where the first digit refers to the stage (1, harvest; 2, hard dough; 3, soft dough; 4, anthesis) and the last two digits refer to the percentage lodging, so that low numbers are more resistant to lodging than high numbers.

§ Data from 2010 to 2012 from tests run at Lacombe, AB.

¶ 'Bentley' (Juskiw et al., 2009a), 'Busby' (Juskiw et al., 2009b), 'CDC Austenson' (CFIA, 2017b), 'CDC Coalition' (CFIA, 2017c), 'CDC Cowboy' (CFIA, 2017e), 'CDC Meredith' (CFIA 2017f), 'Champion' (CFIA, 2017h), 'Gadsby' (Juskiw et al., 2011), 'Major' (Legge et al., 2013), 'Merit 57' (CFIA, 2017i), 'Newdale' (Legge et al., 2008), 'Norman' (Legge et al. (2011).

Table 2. Biomass yield and quality traits of Canmore and other commercial barley cultivars in Field Crop Development Centre tests run in 2010, 2011, and 2012 at Lacombe (high fertility), AB, Canada.

Entry	Biomass dry matter yield†	In vitro fiber digestibility	Lignin content	Starch content	Acid detergent fiber content	Neutral detergent fiber content	Protein content
	kg ha^{-1}	% dry matter basis					
AC Metcalfe	13,800.1	48.5	4.1	19.7	30.0	47.6	10.6
Bentley	14,948.8	48.5	4.0	20.6	29.2	47.3	10.5
Busby	14,277.6	46.2	4.1	19.9	29.2	46.7	10.4
Canmore	15,404.6	48.4	3.9	20.4	29.6	46.4	9.8
CDC Austenson	15,382.9	46.8	4.2	19.2	30.0	48.0	9.9
CDC Coalition	14,441.9	50.8	3.7	20.2	28.8	46.2	10.1
CDC Copeland	15,434.5	46.8	4.4	18.6	32.2	50.9	10.2
CDC Cowboy	14,483.3	47.9	4.4	17.2	32.7	51.4	10.4
CDC Meredith	13,628.7	49.3	4.0	18.3	29.8	47.2	10.3
Champion	14,412.4	51.6	3.9	19.2	30.0	47.3	10.4
Gadsby	14,699.6	49.3	4.0	18.5	29.5	47.1	10.4
Major	13,975.8	50.4	4.1	18.1	31.7	49.7	10.0
Merit 57	13,825.8	50.4	3.9	18.5	29.9	47.1	10.7
Newdale	14,640.7	49.2	4.0	19.3	30.5	47.6	10.5
Norman	13,987.9	49.9	3.8	19.3	29.9	46.6	10.7
Ponoka	14,074.3	49.6	4.1	18.0	32.1	49.6	10.4
Xena	13,636.7	48.1	4.1	19.1	29.9	48.0	10.9
$LSD_{0.05}$	494.01	2.7	0.8	4.8	3.2	4.6	0.9
R^2‡	NA	0.80	0.73	0.77	0.95	0.95	0.99

† Data from 2010 to 2012 from tests run at Lacombe, AB.

‡ Correlation of the original calibration set. NA = not applicable.

2017 g). Canmore also had low protein, but this was significant only with Xena. Therefore, Canmore combines high biomass yields with good quality that would make it an excellent choice as a forage barley.

In the 2010 and 2011 Coop trials, Canmore had higher yields than the malting check cultivars AC Metcalfe and CDC Copeland and similar yields to the feed check Xena (Table 3). Days to heading for Canmore were slightly later than the check cultivars Xena and AC Metcalfe but earlier than CDC Copeland. Its maturity was later than the three checks. Its height was shorter than CDC Copeland and similar to the other two check cultivars. Canmore's lodging score (1–9 scale) was lower than the malting checks and similar to Xena's. The average test weight for Canmore was heavier than for the malting checks and similar to Xena. Canmore had a heavier kernel than the malting check cultivars but was lighter than Xena. Canmore had an average kernel plumpness of 95%, higher than all the checks. This combination of high yield, good lodging resistance, and good kernel traits mean that this cultivar would be an excellent choice for general feed production.

The Disease Evaluation Team of the PRCOB rated Canmore as resistant to the surface-borne smuts and true loose smut (Table 4). Canmore was rated as moderately resistant to the spot form of net blotch but moderately susceptible to the net form (caused by *P. teres* forma *teres*). Canmore was scored as having intermediate resistance to FHB (scab), common root rot, and spot blotch. Canmore was graded as moderately susceptible to stem rust (caused by *P. graminis* Pers. f. sp. *tritici* Erikss. and Henn). Canmore was evaluated as susceptible to septoria speckled leaf blotch (caused by *Septoria passerinii* Sacc.).

Canmore was evaluated by the Barley Quality Evaluation Team (BQET) of the PRCOB on attributes that would make it suitable for the new Canadian Grain Commission (August 2012) food grades. In the Coop tests, the BQET noted that Canmore had higher percentage plump kernels and heavier kernels than the checks (Table 3). In the 2 yr of testing by Sanwai Shurui Co, Ltd., Canmore showed good pearling, Koji, and shochu characteristics (Table 5). Canmore was similar to the check AC Metcalfe for kernel hardness and in 2011 met the expected pearling yield of being >60%. Starch content of the

Table 3. Grain yield and agronomic traits of Canmore and barley check cultivars from the 2010 and 2011 Western Cooperative Two-row Barley Registration Tests.

Entry	Grain yield	Heading	Maturity	Height	Lodging score	Test weight	Kernel weight	Plump kernels
	kg ha^{-1}	d		cm	1–9†	kg hL^{-1}	mg	% > 2.44 mm
CDC Copeland	5587	59.3	95.1	83.4	3.2	63.3	45.2	89.7
Xena	6105	58.0	95.1	77.2	2.9	65.8	48.0	90.1
AC Metcalfe	5355	58.0	94.4	77.5	3.5	65.2	44.5	89.9
Canmore	6059	58.3	95.9	77.9	1.7	66.3	46.7	94.6
$LSD_{0.05}$	215.9	0.49	0.66	1.61	0.81	0.67	0.97	2.34
No. of station years	32	26	22	30	7	30	30	23

† Lodging score, where 1 = not lodged, and 9 = totally lodged.

Table 4. Reaction to diseases for Canmore and barley check cultivars from the 2010 and 2011 Western Cooperative Two-row Barley Registration Tests.

Entry	Net blotch (*Pyrenophora teres*)							
	Winnipeg seedling						Melfort field	
	Isolate 102†		Isolate 858†		Isolate 857‡			
	2010	2011	2010	2011	2010	2011	2010	2011
	—— 0–10§ ——						—— 0–9§ ——	
CDC Copeland	3	2	9	10	3	3	1.0	1.0
Xena	9	8	10	10	7	3	1.5	1.5
AC Metcalfe	9	8	9	10	3	3	3.5	4.0
Canmore	5	5	9	9	2	3	1.5	1.0

Entry	Spot blotch (*Cochliobolis sativus*)								
	Brandon Field			Melfort Field		Saskatoon Field		Winnipeg	
	Rating 1	Rating 2						Isolate 1903	
	2010	2010	2011	2010	2011	2010	2011	2010	2011
	—— 1–9§ ——			—— 0–9§ ——				—— 0–10§ ——	
CDC Copeland	7.0	8.5	7.5	7.5	7.0	7.5	7.0	6.5	8
Xena	5.5	8.0	7.5	6.0	5.0	5.5	5.0	8	8
AC Metcalfe	5.0	7.0	5.5	4.5	3.0	4.0	5.0	6.5	9
Canmore	4.0	6.0	5.0	5.0	4.5	4.3	4.5	6.5	6

Entry	Fusarium head blight (*Graminearium* spp.)							
	Brandon				Portage-la-Prairie			
	Field rating		DON#		Field rating		DON#	
	2010	2011	2010	2011	2010	2011	2010	2011
	—— 0–5†† ——		—— ppm ——		—— 0–5†† ——		—— ppm ——	
CDC Copeland	3.5	1.0	33.7	1.1	2.5	NA	NA	NA
Xena	3.0	1.5	22.2	1.6	2.5	NA	NA	1.5
AC Metcalfe	2.3	1.0	28.0	2.7	2.5	NA	NA	1.0
Canmore	3.5	1.3	34.4	1.6	3.0	NA	NA	1.8

Entry	Stem rust (*Puccinia graminis*)							
	Winnipeg seedling		Winnipeg field				CDC Rpg1 marker	
	MCC infection		Severity		Infection		+ Rpg1-rpg1	
	2010	2011	2010	2011	2010	2011	2010	2011
	—— Type‡‡ ——		—— % ——		—— Reaction¶ ——			
CDC Copeland	0;	0;1	2	1	R	R	+	+
Xena	0;	00;	5	1	R	R	+	+
AC Metcalfe	0;	0;1 =	2	1	R	R	+	+
Canmore	13.0	0;1	10	15	MS	MS	–	–

Entry	Scald (*Rhyncosporium secalis*)											
	Lacombe field				Winnipeg seedling		Edmonton field			Trochu	Calmar	
	Date 1	4 July	Date 2	2 Aug.	Isolate WRS2275		27 July	2 Aug.	11 Aug.			
	2010	2011	2010	2011	2010	2011	2010	2011	2011	2010	2010	2011
	—— 0–9 scale§ ——				— Reaction¶ —		—— 0–9§ ——					
CDC Copeland	3.0	2.5	7.5	9.0	NA	S	6.0	6.0	7.5	5.7	8.7	6.7
Xena	3.0	3.0	7.5	9.0	NA	S	6.0	5.5	8.0	5.3	7.3	5.7
AC Metcalfe	2.0	3.0	6.0	8.5	NA	S	4.0	5.5	6.0	7.0	7.3	5.0
Canmore	2.5	1.0	6.0	6.0	NA	MR	4.0	4.5	6.5	5.7	6.3	4.0
$LSD_{0.05}$										1.47	1.27	2.19

Entry	Smut (*Ustilago* spp.)							
	Saskatoon				Winnipeg			
	U hordei		U. nuda		U. hordei		U. nigra	
	2010	2011	2010	2011	2010	2011	2010	2011
	—— % ——							
CDC Copeland	8.0	23.2	100	DNG§§	40.0	0.0	13.0	25.0
Xena	16.0	1.3	100	69.2	25.0	8.5	10.0	15.0
AC Metcalfe	5.0	8.8	DNG	0.0	20.0	0.0	3.0	20.0
Canmore	0.0	0.0	0§§	DNG	0§§	5.0	0.0	0.0

Table 4. Continued.

Entry	Barley yellow dwarf	Winnipeg seedling *Septoria* spp.	Lacombe common root rot(*Bipolaris sorokiniana*)				
	2011	2010	2010	2011		2010	2011
	0–10§	Reaction¶	%	% of 0–1 type	% of 0–3 type	—— Reaction ——	
CDC Copeland	–	S	64	40	77	S	MS
Xena	–	S	35	5	52	R	R
AC Metcalfe	–	S	41	15	59	MR	MR
Canmore	9.9	S	44	17	64	MR	MR/MS

† *Pyrenophora teres* net-form isolates.

‡ *Pyrenophora teres* spot-form isolate.

§ Rating of 1 to 10 or 1 to 9 where 9 or 10 = susceptible.

¶ S = susceptible, MS = moderately susceptible, I = intermediate resistance, MR = moderate resistance, R = resistant.

DON, deoxynivalenol.

†† Ratings range of 0 to 5, where 5 = susceptible.

‡‡ IT = infection type on seedlings using the modified Cobb scale (Peterson et al., 1948).

§§ Less than 10 plants, or DNG = did not grow.

pearled barley was higher than AC Metcalfe and protein content was less. The acidity of the Koji was >4, and total conversion power >1300, which are the minimum acceptable levels. Alcohol percentage and yield in the shochu made from these samples of Canmore were higher than for the shochu made from AC Metcalfe. In the sensory evaluation, aroma and taste scores for the shochu made from Canmore were lower than those for the shochu made from AC Metcalfe, indicating that shochu made from Canmore was more pleasing to the palate.

Morphological Description

As a seedling, Canmore has a semi-erect growth habit with a white coleoptile of intermediate length. The leaf sheath and blade of Canmore are glabrous and green at both the seedling and booting stages. By the booting stage, the leaves do not have a waxy appearance, although the flag leaf has a pronounced waxy bloom. Its flag leaf is glabrous and of medium length and narrow width, with an erect attitude. The auricles of Canmore are purple colored and glabrous. After heading, the stem of Canmore is exerted 3 to 10 cm. The stem is of medium thickness and medium green color. The collar is platform shaped and the culm neck is straight. The spike is parallel in shape, of medium density and length, with a horizontal attitude and slight waxiness. When looking at the side of the spike, the sterile spikelets of Canmore are weakly divergent from the rachis. The first rachis internode is short with a slight curve. The rachis margin is strongly pubescent. The glumes are medium long with a band of medium-length glume hairs at the base of the glume. The glume awns are rough and equal in length to the glume. The glume awn tip color is purple. The lemma awns are longer than the spike, are rough, have a green tip, and their lateral veins are glabrous. The lemma nerve color is green. The kernel has a midlong rachilla with long rachilla hairs. The kernel has a colorless (yellow/white) aleurone and is of medium length and width with a horseshoe basal marking. The lodicules are frontal.

Table 5. Pearling, Koji and shochu traits of Canmore compared to AC Metcalfe from samples grown in Canada in 2010 and 2011 with analyses done in Japan by Sanwa Shurui Co., Ltd. Means with SD in parenthesis.

Trait	Unit	2010		2011	
		Canmore	AC Metcalfe	Canmore	AC Metcalfe
		Pearling traits			
Hardness index	SKCS unit†	53.6 (13.89)	59.5 (12.78)	45.5 (12.08)	48.8 (13.26)
Yield	%	59.3	63.9	62.2	61.2
Broken	%	9.4	3.1	6.4	7.3
Starch	% (dry wt. basis)	79.3 (0.39)	74.9 (1.68)	76.7 (0.86)	76.3 (0.88)
Protein	% (dry wt. basis)	7.1 (0.01)	9.9 (0.01)	7.8 (0.01)	8.7 (0.02)
		Koji traits			
Acidity	pH	5.7	5.0	4.4	4.6
Total conversion power	ml per °Bx	1400.3	1265.9	1499.0	1356.0
		Shochu traits			
Alcohol content	%	19.5	18.6	19.5	18.5
Alcohol yield	L t^{-1}	469	442	468	444
Aroma	1–5‡	2.63	2.80	2.42	3.06
Taste	1–5‡	2.53	2.75	2.65	2.88

† SKCS, single-kernel characterization system.

‡ 1-to-5 scale, where 1 = good and 5 = bad.

Conclusion

Canmore is the first food barley released in Canada with potential for the shochu market. With excellent yield, disease resistance, and quality traits, Canmore should be an excellent choice for producers who wish to grow a barley for food, feed, or forage in the barley growing areas of the Great Plains.

Availability

Breeder seed of Canmore will be maintained by the Field Crop Development Centre, Lacombe, AB, Canada. Application for variety protection was granted for Canmore. Prior to termination of plant breeder's rights or 20 years from deposit in the USDA–ARS National Plant Germplasm System, all seed requests should be sent to the corresponding author. Seed deposited in the National Plant Germplasm System will be available for research purposes after plant breeder's rights are terminated or in 20 years. Where this cultivar is used as a parent in the development of new cultivars, it is requested that recognition be made of its use. Commercial seed distribution rights of Canmore were granted to Canterra Seeds, Suite 201 1475 Chevrier Blvd., Winnipeg, MB, Canada R3T 1Y7, Tel: (204) 988–9750, Fax: (204) 487–7682, www.canterra.com.

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