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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.

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.

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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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