

## REGISTRATION

## Cultivar

## Registration of 'Lightning' barley

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Assigned to Associate Editor Eric Olson.

Registration by CSSA.

## Abstract

'Lightning' (Reg. no. CV-374, PI 698654), experimental designation DH130910, is a two-row facultative barley (*Hordeum vulgare* L.) released by Oregon Agricultural Experiment Station in 2020. It was bred for fall planting and is well adapted to the U.S. Pacific Northwest and New York State. Because it does not require vernalization for a timely vegetative to reproductive transition, Lightning can be planted in the spring and will flower and mature in a similar time frame as spring growth habit cultivars. Lightning is a doubled haploid produced via anther culture and was advanced through fall-planted trials from 2013 to 2019. Facultative growth habit was validated in unreplicated trials in multiple years; replicated yield trial data are available for 2020. Lightning was developed with the goal of commercial production as a malting cultivar. It was tested in the American Malting Barley Association (AMBA) Pilot Program, but it is not on the AMBA recommended list, due to unsatisfactory quality when malted using standard protocols. Because Lightning will produce excellent malt with adjustments to malting protocol, it was released as a cultivar based on its potential for malting and based on its yield and test weight advantage over check cultivars 'Endeavor' and 'Wintmalt'. Furthermore, it has broad-spectrum disease resistance (moderate to high resistance to scald, stripe rust, powdery mildew, net blotch, and Fusarium head blight).

## 1 | INTRODUCTION

'Lightning' (Reg. no. CV-374, PI 698654) is a two-row facultative malting barley (*Hordeum vulgare* L.) cultivar that was released by the Oregon Agricultural Experiment Station in 2020. Facultative growth habit is defined, in this context, as the capacity to acclimate and achieve levels of winterhardiness comparable to winter growth habit checks coupled with a lack of vernalization sensitivity. The latter attribute means that under spring-planted conditions the cultivar will achieve

a timely vegetative to reproductive transition and be ready for harvest at the same time as spring growth habit types. The name *Lightning* was chosen based on the theme set by the preceding winter malting barley released by Oregon State University, 'Thunder'. Before being named, Lightning was tested under the experimental designation DH130910. Lightning was released on the basis of its excellent agronomic performance and competitive malting quality in fall-planted trials. Its greatest strengths are high yields, high test weights, and broad-spectrum disease resistance, including scald (caused by *Rhynchosporium commune*), stripe rust (caused by *Puccinia striiformis* f. sp. *hordei*), net blotch (caused by *Pyrenophora teres*), powdery mildew (caused by *Blumeria graminis*), and Fusarium head blight (caused by *Fusarium graminearum*).

**Abbreviations:** AMBA, American Malting Barley Association; DON, deoxynivalenol; DP, diastatic power; FAN, free amino nitrogen; S/T, soluble/total protein; WMBT, Winter Malting Barley Trial.

Lightning is well adapted to the U.S. Pacific Northwest (South Idaho, Palouse, Columbia Basin, and western valleys of Oregon and Washington) and New York, but trials conducted throughout the United States suggest that it may have broader adaptation. Lightning was bred for fall planting; if planted in the spring, it will flower in a timely fashion, although other spring growth habit cultivars may be higher yielding.

Lightning is a doubled haploid derived from the  $F_1$  of the cross between TC6W265 and 29494\_2991. TC6W265 is a six-row facultative barley breeding line developed by Oregon State University, which is part of the TCAP FAC-WIN6 barley panel (Belcher et al., 2015). 29494\_2991 is an experimental winter two-row barley developed from the program of Markus Herz (Germany). From 2013 to 2016, Lightning advanced through fall-planted mini-plot, preliminary, and advanced yield trials in the Willamette Valley of Oregon, based on agronomic and malting quality performance. From 2016 to 2019, it progressed to fall-planted regional and national trials, which included barley production areas in Idaho, Oregon, and New York, in addition to the Winter Malting Barley Trial (WMBT), which included multiple locations throughout the United States. Lightning was included in growth habit screening trials simultaneous with fall-planted agronomic trials. In 2020, Lightning was included in spring-planted yield trials at two locations in Idaho.

## 2 | METHODS

### 2.1 | Doubled haploid production and line selection

The cross between TC6W265 and 29494\_2991 was made in 2012 at Oregon State University, and in 2013 the doubled haploids were produced via anther culture following the protocol developed by Cistue et al. (2003). Seed from each doubled haploid plant was harvested in the greenhouse and subsequently planted in field mini-plots (2.3 m<sup>2</sup>) at the Oregon State University Hyslop Farm in Corvallis, OR, in fall 2013. Lightning was selected from the mini-plot trial and progressed to preliminary and advanced trials (9.3-m<sup>2</sup> replicated plots), which were planted in the fall of 2014 and 2015, respectively, at two locations in Oregon (Corvallis and Lebanon).

After 3 yr of field trials in Oregon, Lightning was selected based on agronomic performance and malting quality and advanced to regional and national trials. In addition to continuing testing in fall-planted trials in Oregon (Corvallis and Lebanon), Lightning was included in the WMBT for 4 yr (fall-planted in 2016, 2017, 2018, and 2019) and in the University of Idaho Extension trials for 2 yr (fall-planted in 2018 and 2019 and spring-planted in 2020). In New York, Lightning was tested in fall-planted statewide trials for 3 yr (2017, 2018 and 2019). Agronomic characteristics evaluated during test-

### Core Ideas

- ‘Lightning’ is a two-row barley cultivar.
- Lightning barley has a facultative growth habit.
- Lightning produces excellent malt with adjustments to malting protocol.

ing at multiple locations and across years include but are not limited to yield, test weight, plant height, lodging, winterhardiness, heading date, and reaction to a range of diseases.

### 2.2 | Genotyping

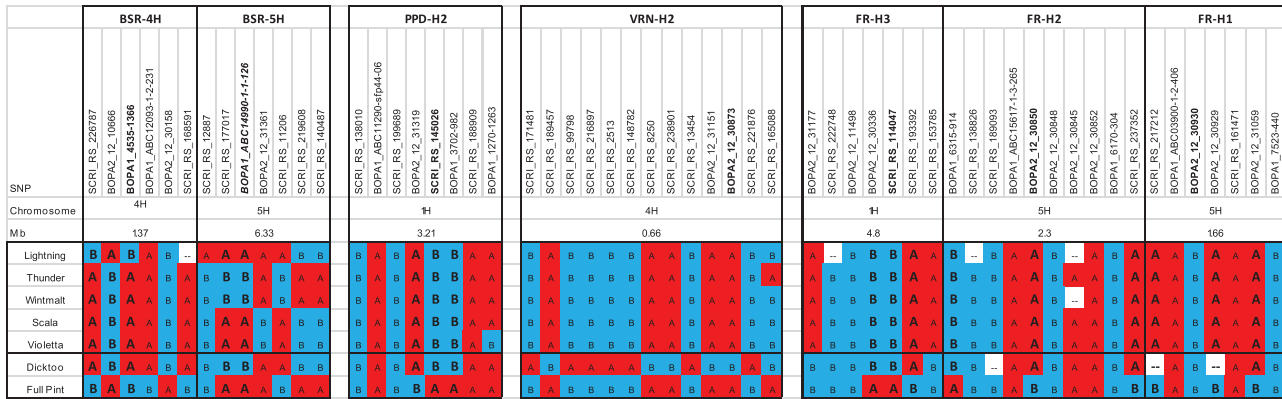
Lightning was genotyped using the Barley 50k iSelect single nucleotide polymorphism array developed by Bayer et al. (2017). Seed from the first doubled haploid generation was grown in the greenhouse and leaf tissue was collected at the two-leaf stage and genotyped at the USDA North Central Small Grains Genotyping Lab in Fargo, ND.

### 2.3 | Malt quality analysis

Malt quality was evaluated on samples from all trials conducted in Oregon (a total of 11 trials) and three trials conducted in Ithaca, NY. Micro-malting and malt analyses were performed at the USDA-ARS Cereal Crops Research Unit (CCRU) in Madison, WI, following standard protocols (USDA-ARS, 2020).

### 2.4 | Statistical analyses

All statistical analyses were conducted using R version 3.5.1 (R Core Team). In the Oregon, WMBT, and Idaho trials, Lightning was compared with ‘Endeavor’ (Obert et al., 2009; PI 654824) and ‘Wintmalt’. In the New York trials, Lightning was compared with ‘KWS Scala’ and Endeavor. For all traits, data on the three entries (Lightning and two checks) were extracted from each trial and averaged across replications, if applicable. Data from trials conducted in similar environments (e.g., trials in Corvallis and Lebanon were considered part of western Oregon) were analyzed together. Each trait was fit to a linear mixed effect model with entry as a fixed effect and station-year (e.g. Corvallis, 2017) as a random effect. Analysis of variance (ANOVA) was conducted on each trait, followed by means separation using Fisher’s least significance difference method. Normality of residuals and



**FIGURE 1** Graphical haplotypes for Lightning compared to current winter malting cultivars (Thunder, Wintmalt, Scala, Violetta), facultative check (Dicktoo), and spring check (Full Pint) at stripe rust resistance (Barley Stripe Rust, BSR), growth habit (Photoperiod, PPD, and Vernalization, VRN), and low temperature tolerance (Frost Resistance, FR) genes/quantitative trait loci (QTL) regions. In bold are the peak markers at each QTL/gene, and potentially informative haplotypes. Chromosome and Mb position based on Mascher et al. (2017)

**TABLE 1** Agronomic performance of fall-planted Lightning compared with check cultivars. Average of 2014–2019 trials in western Oregon (Corvallis and Lebanon)

Entry	Yield	Test weight	Plant height	Lodging	Stripe rust <sup>a</sup>	Scald <sup>b</sup>
	kg ha <sup>-1</sup>	g L <sup>-1</sup>	cm		%	
Station years	10	11	11	11	6	11
Lightning	7,849 a	700 a	114 a	26 a	5 a	5 c
Endeavor	6,205 b	663 b	99 b	27 a	5 a	69 a
Wintmalt	6,567 b	659 b	99 b	23 a	19 a	46 b

Note. Different letters within a column indicate significant ( $p < .05$ ) differences between cultivars.

<sup>a</sup>Statistical analysis is based on transformed data  $[\log(1+x)]$ .

<sup>b</sup>Statistical analysis is based on transformed data  $\{\arcsin[\text{square root}(x)]\}$ .

heterogeneity of variance was assessed, and data were transformed when needed.

### 3 | CHARACTERISTICS

#### 3.1 | Botanical description and genotypic information

Lightning is a rough-awned, hulled, two-row facultative barley with long rachilla hairs, white auricles, closed collars, pubescent leaf sheaths, and glabrous leaf blades. Lightning was genotyped with a 50K single nucleotide polymorphism array to obtain a dense coverage of the genome. The genotype data are at <https://barley.triticeaetoolbox.org>. A graphical haplotype for Lightning contrasted to current relevant cultivars at some important genes/quantitative trait loci regions is shown in Figure 1.

#### 3.2 | Agronomic performance

Across all trials in the western Oregon, WMBT, and Idaho environments, Lightning yielded higher than at least one

of the checks (Tables 1–3). In New York, yields were not significantly different between Lightning and the checks, although Lightning had a 317 kg/ha yield advantage on average (Table 4). However, when spring-planted in New York, Lightning yielded on average 19% less than the current check cultivars, ‘KWS Tinka’ and ‘AAC Synergy’ (data not shown). Where test weight was measured (western Oregon and New York), Lightning showed higher test weight than both checks. Lightning was taller than one or both checks in some environments, but this did not translate into higher lodging. On the contrary, in Idaho, where Lightning and the checks were of the same height, lodging percentage was lower for Lightning than for Endeavor. This suggests a possible advantage of Lightning in arid, irrigated environments where high yields and fast growth can promote lodging.

Winter survival was assessed in 34 trials in the WMBT (Table 2), in five trials in New York (Table 5) and in four trials in Idaho (Table 3). In the WMBT, Lightning had a slightly higher survival rate than Endeavor and was similar to Wintmalt. Based on these results, Lightning can be considered to have similar levels of winterhardiness as Wintmalt, which is a widely grown winter growth habit cultivar. In Idaho, Lightning had the same winter survival rate compared with both checks. Similarly, in New York, Lightning had

**TABLE 2** Agronomic performance of fall-planted Lightning compared with check cultivars. Average of the 2016, 2017, 2018, and 2019 Winter Malting Barley Trial

Entry	Yield kg ha <sup>-1</sup>	Heading d of year	Plant height cm	Winter survival <sup>a</sup> %	Lodging score <sup>b</sup> 0–9
Station years	52	42	44	33	31
Lightning	5,369 a	126 b	83 a	76 a	2.1 ab
Endeavor	4,842 b	123 c	81 a	70 b	2.5 a
Wintmalt	5,112 ab	128 a	79 b	74 ab	1.6 b

Note. Different letters within a column indicate significant ( $p < .05$ ) differences between cultivars.

<sup>a</sup>Statistical analysis is based on transformed data {arcsine[square root(x)]}.

<sup>b</sup>Lodging score, where 0 = no lodging and 9 = 100% of the plot is lodged.

**TABLE 3** Agronomic performance of fall-planted Lightning compared to check cultivars. Average of the 2018 and 2019 University of Idaho Extension Trials (Aberdeen and Rupert)

Entry	Yield kg ha <sup>-1</sup>	Heading d of year	Plant Height cm	Lodging %	Winter survival
Station years	4	4	4	4	4
Lightning	8,462 a	144 b	101 a	16 b	99 a
Endeavor	7,529 b	146 a	107 a	63 a	98 a
Wintmalt	8,212 ab	146 a	101 a	35 b	98 a

Note. Different letters within a column indicate significant ( $p < .05$ ) differences between cultivars.

statistically the same rate of winter survival compared with the checks, even though its survival rate was 10% points higher than Endeavor.

Disease susceptibility was measured for the principal diseases in each location. In the Pacific Northwest, especially west of the Cascades, a high rainfall environment, stripe rust and scald are the principal diseases threatening barley. In western Oregon, stripe rust severity in Lightning averaged 5% and was statistically similar to checks (Table 1). In contrast, scald severity of Lightning was 5-fold and 14-fold lower than that of Wintmalt and Endeavor, respectively. Since the checks Wintmalt and Endeavor are considered resistant/moderately resistant to stripe rust but susceptible to scald, Lightning can be considered resistant/moderately resistant to both stripe rust and scald. In corroboration with the results observed in west-

ern Oregon, in New York, where scald is also an important disease of barley, scald severity measured of Lightning was on average fourfold lower than that of the checks KWS Scala and Endeavor, averaging only 1.3% across 5 site-years (Table 5).

The fungal diseases net blotch and powdery mildew were assessed across the WMBT locations (Table 6). Lightning was compared with the checks Endeavor and Wintmalt, which are considered resistant to both diseases. All three entries were rated equally for net blotch, while Lightning was rated more resistant to powdery mildew than both checks.

Fusarium head blight (FHB) is a concerning disease because in addition to promoting yield losses, the fungus produces deoxynivalenol (DON), a mycotoxin whose levels in barley grain are regulated by the U.S. Federal Drug Administration. Both FHB and DON levels were assessed in New

**TABLE 4** Agronomic performance of fall-planted Lightning compared with check cultivars. Average of the 2017–2019 New York statewide trials

Entry	Yield kg ha <sup>-1</sup>	Test weight g L <sup>-1</sup>	Heading d of year	Plant height cm	Lodging score <sup>a</sup> 1–9
Station years	10	10	5	5	5
Lightning	5,210 a	638 a	145 a	81 ab	2.5 a
KWS Scala	4,848 a	600 b	146 a	77 b	3.6 a
Endeavor	4,938 a	610 b	146 a	87 a	6.7 a

Note. Different letters within a column indicate significant ( $p < .05$ ) differences between cultivars.

<sup>a</sup>Lodging score, where 0 = no lodging and 9 = 100% of the plot is lodged.

**TABLE 5** Agronomic performance and disease data from fall planted Lightning compared to check cultivars. Average of the 2017 to 2019 New York statewide trials

Entry	Winter survival	Scald	FHB <sup>a</sup>	DON <sup>a</sup>	Preharvest sprouting score <sup>b</sup>
	%			ppm	0–9
Station years	5	5	2	2	5
Lightning	52 a	1.3 b	5.4 a	28.8 a	0.06 c
KWS Scala	48 a	4.2 a	6.9 a	16.8 a	0.84 b
Endeavor	42 a	4.4 a	3.3 a	18.8 a	5.54 a

Note. Different letters within a column indicate significant ( $p < .05$ ) differences between cultivars.

<sup>a</sup>FHB, Fusarium head blight; DON, deoxynivalenol.

<sup>b</sup>Statistical analysis is based on log transformed data. 0 = no preharvest sprouting and 9 = 100% of the plot shows symptoms of preharvest sprouting.

**TABLE 6** Disease data of fall planted Lightning compared to check cultivars. Average of the 2016, 2017, 2018, and 2019 Winter Malting Barley Trial

Entry	Net blotch <sup>a</sup>	Powdery mildew <sup>b</sup>	FHB <sup>c</sup>	DON <sup>d</sup>
	0–9		%	ppm
Station years	7	11	4	4
Lightning	2.1 a	0.1 b	11.4 a	2.5 a
Endeavor	1.5 a	0.8 a	12.5 a	4.5 a
Wintmalt	1.6 a	1.2 a	17.8 a	9.5 a

Note. Different letters within a column indicate significant ( $p < .05$ ) differences between cultivars.

<sup>a</sup>Statistical analysis is based on log transformed data.

<sup>b</sup>Statistical analysis is based on log transformed data [ $\log(x+1)$ ].

<sup>c</sup>FHB, Fusarium head blight; DON, deoxynivalenol.

<sup>d</sup>Net blotch and powdery mildew scores, where 0 = no symptoms and 9 = 100% of the plot shows symptoms.

York (Table 5) and in the WMBT trials (Table 6). In both environments, FHB and DON levels were similar between Lightning and the checks. In the New York trials, KWS Scala and Endeavor were rated as moderately resistant and resistant, respectively, to FHB; however, other data from statewide trials in New York indicate KWS Scala and Endeavor as being susceptible and moderately susceptible, respectively, to FHB. In the WMBT trials, generally lower levels of FHB and DON were observed across all entries, compared with New York.

Preharvest sprouting is extremely undesirable in malting barley, since the malting process requires germination. In New York, the often wet weather around harvest time promotes favorable conditions. Across five New York statewide trials, preharvest sprouting was close to zero in Lightning, compared with a rating (0–9) of 0.8 in KWS Scala and 5.5 in Endeavor. These results indicate that Lightning is highly resistant to preharvest sprouting.

The spring-planted agronomic data are presented in Table 7, where Lightning is compared with two high performing spring cultivars. The data support that Lightning flowers at the same time as spring-habit cultivars and has similar test weight, lodging, and stand. Lightning was slightly taller

than the two check cultivars, but that did not affect lodging. However, Lightning was significantly lower yielding and had higher grain protein, which was above the desired range for malt (the maximum level proposed by the American Malting Barley Association (AMBA) is 13% for adjunct malt and 12% for all-malt). Therefore, the facultative growth habit of Lightning can facilitate seed production (e.g., spring-planted seed production for subsequent fall planting). However, commercial spring-planted production of Lightning is not recommended in environments like those encountered at Parma and Rupert, ID. Nonetheless, Lightning serves as a proof-of-concept for facultative growth habit and confirmation that vernalization sensitivity is not a prerequisite for low temperature tolerance.

### 3.3 | Malting quality

Malting barley cultivars must meet stringent requirements for AMBA approval (AMBA, 2019). Adjunct two-row and all malt two-row malting barley represent 95% of AMBA's members interests (AMBA, 2019). The most important malting quality parameters evaluated by AMBA were assessed in samples from 11 trials in western Oregon (Table 8) and 3 trials in New York (Table 9). Lightning was compared with the AMBA checks Endeavor and Wintmalt in western Oregon and to Endeavor and KWS Scala in New York.

Overall, the malting quality of Lightning was superior to the checks in western Oregon and comparable to the checks in New York. In both environments, Lightning exhibited higher plumpness and lower alpha amylase levels than at least one of the checks. The low alpha amylase levels in Lightning were probably responsible for the extremely low levels of preharvest sprouting observed in New York (Table 5) and in western Oregon during the unusually wet 2019 harvest (data not shown). Malt extract percentage was not different between Lightning and the checks, averaging 81.6% in western Oregon and 80.2% in New York.

In western Oregon, Lightning had the highest (although within specification) barley protein percentage across the



**TABLE 7** Agronomic performance of spring planted Lightning compared to two high performing cultivars that were common across locations. Trials were planted in the 2020 University of Idaho Extension Trials in Parma (P) and Rupert (R)

Entry	Yield kg ha <sup>-1</sup>	Test weight g L <sup>-1</sup>	Heading d of year	Plant height cm	Grain protein %	Lodging %	Stand
Locations	P, R	P, R	R	R	P	R	R
Lightning	5,542 b	660 a	157	84	14.1	0	100
KWS Jessie	8,931 a	662 a	155	66	10.0	0	100
KWS Chrissie	8,232 a	665 a	155	74	10.0	0	100

Note. When traits were evaluated in both locations, values were averaged across locations and different letters within a column indicate significant ( $p < .05$ ) differences between cultivars.

**TABLE 8** Malt quality of Lightning and check cultivars using data from analyses of barley samples grown in 2014–2019 in western Oregon (Corvallis and Lebanon). Data courtesy of the USDA-ARS Cereal Crops Research Unit, Madison, WI

Entry	Plump kernels %	Malt extract %	Barley protein %	Wort protein %	S/T <sup>a</sup> %	DP <sup>a</sup> °ASBC	Alpha amylase <sup>b</sup> 20°DU	Beta glucan <sup>c</sup> ppm	FAN <sup>a</sup>
Station years	11	11	11	11	11	11	11	11	11
Lightning	98.2 a	81.5 a	11.3 a	4.74 b	44.4 b	167 a	42.3 c	80.8 b	191 b
Endeavor	79.5 c	81.9 a	10.6 ab	5.06 a	51.8 a	165 a	99.9 a	194.5 a	233 a
Wintmalt	96.1 b	81.4 a	10.3 b	4.21 c	43.9 b	141 b	55.9 b	58.5 b	168 c
Adjunct	>90	>81	≤13	4.8–5.6	40–47	>140	<50	<100	>210
All malt	>90	>81	≤12	<5.3	38–45	110–150	40–70	<100	140–190

Note. Different letters within a column indicate significant ( $p < .05$ ) differences between cultivars.

<sup>a</sup>S/T, soluble/total protein; DP, diastatic power; FAN, free amino nitrogen.

<sup>b</sup>Statistical analysis is based on transformed data {arcsine[square root(x)]}.

<sup>c</sup>Statistical analysis is based on log transformed data.

three cultivars (Table 8). However, intermediate wort protein levels in Lightning translated into similarly intermediate soluble/total protein (S/T) percentage. Diastatic power (DP) in Lightning was higher than in Wintmalt but similar to that in Endeavor. Beta glucan concentration was lower in Lightning and Wintmalt compared with that in Endeavor. Free amino nitrogen (FAN) concentration in Lightning was intermediate compared with the checks and only 1% point above the specification for the all-malt criteria. To summarize the results from western Oregon, for both the adjunct and all-malt criteria, Lightning met specifications for seven out

of nine parameters evaluated. The parameters that Lightning failed to meet included wort protein (by only 0.06%) and FAN for the adjunct criteria, and DP and FAN (by only 1%) for the all-malt criteria. As a comparison, Endeavor met specifications for five and three parameters, and Wintmalt met specifications for five and nine (all) parameters for the adjunct and all-malt criteria, respectively. Based on these data, Lightning could serve both as an all-malt and as an adjunct cultivar when grown in Western Oregon.

In New York, barley and wort protein percentage, S/T percentage, DP, beta glucan, and FAN concentrations were not

**TABLE 9** Malt quality of Lightning and check cultivars using data from analyses of barley samples grown in Ithaca, NY (2017–2019). Data courtesy of the USDA-ARS Cereal Crops Research Unit, Madison, WI

Entry	Plump kernels %	Malt extract %	Barley protein %	Wort protein %	S/T <sup>a</sup> %	DP <sup>a</sup> °ASBC	Alpha amylase 20°DU	Beta glucan ppm	FAN <sup>a</sup>
Station years	3	3	3	3	3	3	3	3	3
Lightning	96.3 a	80.4 a	12.2 a	5.77 a	49.5 a	160 a	48.5 b	168 a	182 a
Endeavor	82.1 b	80.2 a	11.9 a	5.17 a	49.5 a	166 a	92.2 a	232 a	211 a
KWS Scala	97.7 a	79.9 a	11.6 a	4.67 a	47.7 a	172 a	44.3 b	101 a	171 a
Adjunct	>90	>81	≤13	4.8–5.6	40–47	>140	<50	<100	>210
All malt	>90	>81	≤12	<5.3	38–45	110–150	40–70	<100	140–190

Note. Different letters within a column indicate significant ( $p < .05$ ) differences between cultivars.

<sup>a</sup>S/T, soluble/total protein; DP, diastatic power; FAN, free amino nitrogen.

different between the three cultivars (Table 9). Across the three cultivars, barley and wort protein, S/T, and beta glucan were generally higher in New York compared with western Oregon and often exceeded specification values, indicating a notable environmental effect. Out of nine parameters evaluated, Lightning met specifications for four parameters for the adjunct criteria and three parameters for the all-malt criteria. As a comparison, Endeavor met specifications for four and two parameters, while KWS Scala met specifications for four and five parameters for the adjunct and all-malt criteria, respectively. Therefore, on average across 3 yr, Lightning malt quality in New York was comparable to that of the checks.

Although the malting profile for Lightning in New York aligns more closely with the adjunct criteria, it is important to consider that in New York the emphasis is on “All Malt Quality” because the brewing industry in the U.S. northeast is predominantly craft brewing. Based on Table 8, if Lightning was used as all-malt two-row barley, it would fail to meet specifications for malt extract, barley and wort protein, S/T, DP, and beta glucan. All of these parameters fall only slightly outside of the recommended specification, with the exception of beta glucan, which was 68% higher than specification. Depending on grain quality and potential adjustments to the malting process, it may be possible to more closely meet target specifications. If necessary, one option for reducing beta glucan levels during the brewing process is with the addition of exogenous enzymes (e.g., beta glucanase) to the mash (Scheffler & Bamforth, 2005). Also note that the data presented in Table 9 represent average values from 3 yr of trials and that in 2017 and 2018, Lightning outperformed both checks for the purpose of all-malt brewing (data not shown). Therefore, our results indicate that Lightning malt quality in New York is comparable, and sometimes superior, to that of KWS Scala and Endeavor.

Lightning was tested in the American Malting Barley Association (AMBA) Pilot Program, but it is not on the AMBA recommended list, due to unsatisfactory quality when malted using standard protocols. Lightning will produce excellent malt with adjustments to malting protocol, notably with attention paid to potential dormancy and water sensitivity.

## 4 | AVAILABILITY

### 4.1 | Seed production

The production of certified classes of seed is proceeding in two ways. (a) Breeder seed was produced from head row purification blocks at Hyslop Farm in 2019. Approximately 0.5 ha of this seed was planted in the fall of 2019 in Othello, WA, by Washington State Crop Improvement Association for the production of foundation seed. This seed was harvested in 2020, passed certification, and is available for sale. (b) In New York, approximately 0.5 ha of breeder seed was

planted in spring 2019 using seed harvested from rogued trial plots. This lot was rogued thoroughly and inspected by the New York Seed Improvement Project and used for foundation seed production (2020 harvest). This seed is available for sale.

### 4.2 | Licensing and royalties

Lightning was released with a nonexclusive license. Release with nonexclusive licenses is a condition for receipt of research funding from the AMBA. There is a one-time application fee of \$250 for each nonexclusive license. Those interested in a license should contact Denis Sather at the Oregon State University Office of Commercialization and Corporate Development (denis.d.sather@oregonstate.edu). Lightning can only be sold as a class of certified seed with a royalty of \$0.03/lb (approximately \$0.067/kg). The \$0.03/lb royalty will be paid on sale of this seed. All grain harvested must be used for malting, feed, food, or otherwise disposed of unless permission is obtained—in writing—from Oregon State University to use the harvested grain as seed for replanting. In New York, a research fee will be charged per pound of foundation seed sold in order to cover costs and support further barley research. The New York Seed Improvement Project will be authorized to produce breeder and foundation seed as needed for seed production in the U.S. northeast.

### 4.3 | Variety protection

Plant Variety Protection will not be sought for Lightning due to the special status of malting barley in the United States, where the malting barley supply chain is based on sale of certified seed. By specifying that all seed sales must be a class of certified seed, we will ensure that growers will be purchasing seed from the seed dealers with nonexclusive licenses. There is not an open market in the United States for malting barley that is not grown from a class of certified seed: the risk to the maltster is too great. The cultivar will be protected by Federal Seed Law and Oregon State University recognized as the owner of the variety. Furthermore, Oregon, Idaho, and Washington State trademarks will specify that the cultivar can only be sold under the name of “Lightning.”

## ACKNOWLEDGMENTS

The development of Lightning was supported by the following entities: American Malting Barley Association, Great Western Malting, Oregon Agricultural Experiment Station and Oregon Wheat Commission. Support at Cornell was provided, in part, by the USDA National Institute of Food and Agriculture, Hatch project 149-447.

## AUTHOR CONTRIBUTIONS

P. Hayes: Conceptualization, Funding acquisition, Project administration, Supervision, Writing-review & editing. D. R. Carrijo: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing-original draft, Writing-review & editing. T. Filichkin: Conceptualization, Investigation, Resources, Visualization. S. Fisk: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Resources, Software, Writing-review & editing. L. Helgerson: Conceptualization, Investigation, Methodology, Resources, Writing-review & editing. J. Hernandez: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing-review & editing. B. Meints: Resources, Supervision, Writing-review & editing. M. E. Sorrells: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Writing-review & editing.

## CONFLICT OF INTEREST

The authors declare no conflict of interest.

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**How to cite this article:** Hayes P, Carrijo DR, Filichkin T, et al. Registration of ‘Lightning’ barley. *J Plant Regist.* 2021;1–8. <https://doi.org/10.1002/plr2.20129>