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# Registration of 'Top Shelf' barley: The first glycosidic nitrile-null, winter malting cultivar to be released in North America

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**Abstract**

'Top Shelf' (Reg. no. CV-380, PI 704478), experimental designation DH162310, is a two-row winter barley (*Hordeum vulgare* L.) released by Oregon Agricultural Experiment Station in 2023. It is a malting cultivar that is known to be a non-producer of glycosidic nitrile (GN0). GN0 is the precursor to a regulated compound (ethyl carbamate) in distilled spirits and thus, the GN0 trait is becoming a requisite for malting cultivars geared toward distilling. While GN0 spring cultivars have been available for over 20 years, Top Shelf is the first winter GN0 cultivar to be released in North America, and only the second globally. In addition to its GN0 status it exceeds contemporary agronomic and malt quality expectations. Over 5 years of field trials in Oregon it performed equal to or better than the check entries. It shows high yields, plump grains, and test weights. It also has good resistance to scald (caused by *Rhynchosporium commune*) and preliminary data suggest resistance to barley stripe rust (*Puccinia striiformis* f. sp. *hordei*). Results were confirmed in field trials in southern Idaho, a major malting barley production region, and a target environment for this cultivar. Under standard malting protocols Top Shelf meets the guidelines for malt and all-malt and/or grain distilling, and has high extract, enzymatic activity, and free amino nitrogen. When malted under optimized conditions, mimicking commercial distilling malt production, it produced even better results. As one of only a handful of GN0 cultivars available in the United States with potential for mainstream production, Top Shelf provides an important option for the distilling supply chain.

## 1 | INTRODUCTION

Malted barley (*Hordeum vulgare* L.) is a critical raw material for brewing and distilling, and while quality parameters required for each end use are similar, there are attributes that make them unique (Morrissy et al., 2024). Additionally, distillers seek distinct traits in malting barley between the differing styles of spirit production: grain distilling and all-malt distilling. Grain distilling is a broad term referring to whiskey production in which unmalted grains (primarily maize [*Zea mays* L.], rye [*Secale cereale* L.], and/or wheat [*Triticum aestivum* L.]) make up the majority of the total mash; in the United States this is primarily seen as bourbon and rye whiskey. In this process, malted barley makes up

**Abbreviations:** AMBA, American Malting Barley Association; ASBC, American Society of Brewing Chemists; CCRU, Cereal Crops Research Unit; DP, diastatic power; FAN, free amino nitrogen; GN, glycosidic nitrile; GN0, non-producer of GN; OSU, Oregon State University; OMELT, Oregon Malt Elite Line Trials; PSY, predicted spirit yield; S/T, soluble to total nitrogen ratio.

≤20% of the total mash bill but provides the primary amylolytic enzymes (diastatic power [DP] and α-amylase) and free amino nitrogen (FAN) required for adequate saccharification and fermentation (Bringhurst et al., 2003). This is similar to adjunct brewing, albeit with lower malt inclusion rates, and thus there are even greater needs of those malt quality traits. On the other hand, all-malt distilling is exemplified by Scotch-style single-malt whiskey, in which malted barley is 100% of the mash bill and provides all of the fermentable substrate. This is similar to all-malt brewing, except that malt must also facilitate rapid and maximum fermentability and provide high predicted spirit yield (PSY) (Dolan, 2000). Barley breeding for brewing malt quality has been the default in North America for decades, but in 2017 the American Malting Barley Association (AMBA) adopted specific guidelines for grain distilling and all-malt distilling, respectively, as those involved with the distilling supply chain have more recently worked with breeders to select cultivars that meet the specific expectations for those processes (A. McFarland, AMBA, personal communication, September 2023).

A further distinction of distilling malt from brewing malt is the requirement that barley cultivars be nonproducers of glycosidic nitrile (GN0). The particular glycosidic nitrile (GN) present in malted barley, epiheterodendrin, can be converted via a multi-step pathway during fermentation and distillation into ethyl carbamate, a regulated carcinogen (Cook et al., 1990; Morrissy et al., 2023). As the distilling process is key to its formation, this is not a concern in brewing malt. There is currently only one GN0 selection on the AMBA list of recommended malting barley cultivars, the European bred 'LCS Odyssey' (Limagrain Cereal Seeds, 2024), and none on the list maintained by the Canadian Malting Barley Technical Centre (AMBA, 2023b; CMBTC, 2023). Comparatively, in the United Kingdom, the Maltsters Association of Great Britain produces a list of recommended cultivars for both all-malt and grain distilling, all of which are GN0, as breeding efforts there have made this a priority (MAGB, 2023). Outside of the mainstream, there are currently three known spring-habit GN0 malting cultivars to have been developed and released in the United States, but neither have received an AMBA recommendation and have only seen limited adoption: 'Butta-12' (Gallagher et al., 2020), 'Full Pint' (Hayes, 2014), and 'Oregon Promise' (Hayes et al., 2020).

Unlike previous releases, 'Top Shelf' (Reg. no. CV-380, PI 704478) barley is the first winter-habit cultivar to be released in the United States as a known GN0 and only the second to be released globally (the first was 'SY Vessel'; Syngenta, 2023). Top Shelf is agronomically competitive with adaptation to major barley growing regions and meets the malt quality expectations of North American distillers. Furthermore, as a winter line, it fits within maltsters' desires to add more winter-malting cultivars into their pipeline to diversify barley sources in a changing climate. With only one other known winter GN0 cultivar on the market, this release is a critical addition to the global supply chain.

**Core Ideas**

- 'Top Shelf' is a non-producer of glycosidic nitrile.
- 'Top Shelf' is the first GN0 winter barley released in the United States.
- 'Top Shelf' is well adapted to the Pacific Northwest (Idaho, Oregon, Washington).
- 'Top Shelf' produces exceptional malt quality for distilling purposes.

## 2 | METHODS

### 2.1 | Breeding and field trials

Top Shelf was selected from a population of doubled haploids derived from the cross between DH130939 and 'LCS Calypso' (Limagrain Cereal Seeds, 2014). The cross was made in 2015 and 89 doubled haploids were produced in 2016 and 2017 using anther culture, following the methods of Cistué et al. (2003). DH130939 is an experimental, facultative, two-row malting type from the Oregon State University (OSU) program and is a known GN0 selection. LCS Calypso is a winter, two-row malting type marketed in the United States by Limagrain Cereal Seeds and is a producer of GN (Limagrain Cereal Seeds, 2014).

Top Shelf was advanced through mini-plot, preliminary and advanced yield trials, and elite malt barley trials based on agronomic and malting quality performance from 2018–2023. Primary evaluation was in the Willamette Valley of Oregon, United States, at the OSU Hyslop Crop Science Field Research Lab (Corvallis, OR), and at on farm trials at the Herb Farm (Lebanon, OR). In Crop Year 2022 it was evaluated in the University of Idaho extension trials at two locations in southern Idaho, United States: Aberdeen, ID, and Rupert, ID.

### 2.2 | Malting and malt analysis

Barley grain analysis for malting was performed using American Society of Brewing Chemists (ASBC) methods of analysis (Barley-2, Physical Tests). Protein and moisture were measured using a FOSS Infratec–NOVA near-infrared grain analyser.

Malting evaluations were performed beginning with seed from Crop Year 2019 in differing batch sizes at two different locations. Malting batch size is defined as micro-scale (<1 kg)

and mini-scale (<150 kg). Micro-scale malting was performed at OSU and at the USDA–ARS Cereal Crops Research Unit (CCRU; Madison, WI, USA) using their respective standard malting protocols. Mini-scale malting was performed in 2022 at OSU in the Barley Project mini-malter using optimized protocols for producing distilling malt. The detailed mini-malting protocols are outlined by Morrissy et al. (2024).

Standard malt analysis was performed either at the CCRU or at the Hartwick College Center for Craft Food and Beverage; each followed ASBC methods of analysis (Malt-4, Extract; Malt-6, DP; Malt-7, Alpha-Amylase; Malt-8, Protein; Malt-12, Friability; Beer-31, FAN). PSY was analyzed at Hartwick College following the method developed by Bringhurst et al. (1996). GN production was determined at Hartwick College in two ways: (1) A binary phenotyping (i.e., producer or non-producer) method was used in earlier screenings of material following the method of Cook and Oliver (1991), and (2) a quantitative method was performed on the malts produced in the mini-malting study using the European Brewing Convention method Analytica 4.21, GN in ale, lager, and distilling malts. All analyses were benchmarked against the AMBA guidelines for all-malt and grain distilling, respectively (AMBA, 2023a).

### 2.3 | Statistical analysis

Data were assessed using ANOVA and mean comparisons were performed using Fisher's least significant difference (LSD). Statistical analysis was performed using the R environment for statistical computing (https://www.r-project.org/).

## 3 | CHARACTERISTICS

### 3.1 | Barley & agronomics

The first identified GN0 cultivar to come from the OSU breeding program was the spring malting line Full Pint (Hayes, 2014). The epiheterodendrin null allele was not intentionally introgressed into the OSU breeding germplasm, but rather made its way into the program serendipitously via germplasm from the CIMMYT collection (Morrissy et al., 2023). While Full Pint has seen moderate success within the craft brewing industry, it has not been widely adopted and has seen little use by distillers. That said, it has become critical in the breeding program as the primary donor of the GN0 allele, and Top Shelf inherited its GN0 allele from a daughter of Full Pint, DH130939. The other two known GN0 cultivars previously released in the United States also gained their GN0 allele from Full Pint. Oregon Promise, released by OSU, is a daughter of Full Pint and Butta-12, released by UC-Davis, is a granddaughter (Gallagher et al., 2020, Hayes et al., 2020). However, as with Full Pint, they have also seen limited commercial adoption. While Top Shelf was hypothesized to be GN0 based on pedigree and the inheritance pattern of the allele, it was confirmed via phenotyping as a non-producer in 2020 by Hartwick College.

After advancing through a series of seed increases and yield trials, Top Shelf was evaluated as part of the Oregon Malt Elite Line Trials (OMELT) for 3 years at Corvallis, OR. In the OMELT, many winter habit experimental genotypes are assessed using three check cultivars ('Endeavor' [Hayes et al., 2019], 'Thunder' [Montana State University–Barley Breeding, 2014], and 'Wintmalt' [Obert et al., 2009], all of which are producers of GN). Data for Top Shelf and the checks are shown in Table 1. Statistical analysis was only performed on this subset separate from the full trial. Additionally, protein, percentage of plump seeds, and test weight (TW) were only measured on one replicate per year and thus no analysis was performed. Over the 3 years, there was a significant cultivar × year interaction for yield, heading date, plant height, and susceptibility to scald. Top Shelf had the highest yield in each year, with Top Shelf in 2021 having the highest overall yield throughout the experiment, only grouping with Thunder grown in 2021. Top Shelf entries showed the greatest resistance to scald, most notably in 2022 when scald was prevalent among the checks (≥80%). While not compared statistically, Top Shelf had the highest percentage of plump seeds and the highest or second highest test weight in all years, both of which are positive traits for malting barley. Top Shelf also had an earlier heading date which can offer advantages by better capturing early spring moisture and avoiding summer heat stress. Another data set from field trials at two locations in the Willamette Valley, comparing Top Shelf to the same three checks, is shown in Table 2. These data are aggregated from multiple trials to provide an estimate of performance over multiple station years. This data set confirms the results from the replicated OMELT with Top Shelf showing high yields, high percentages of plump seed, high test weight, and resistance to scald. Barley stripe rust (caused by *Puccinia striiformis* f. sp. *hordei*) was also assessed in these trials. Although disease pressure was light, Top Shelf appeared to be among the least susceptible entries.

As a potential grain distilling malting cultivar, Top Shelf was observed under increasing field nitrogen (N) rates to assess grain protein response and subsequent effects on other agronomic outcomes (Table 3). Rates were measured as total field N (soil N + exogenous N applied in spring), and the treatments were as follows: N1–121 kg/ha; N2–144 kg/ha; N3–144 kg/ha + 28 kg/ha at flowering. This trial compared Top Shelf to another elite GN0 selection (experimental line DH170472) which is a sister of Top Shelf, and the check cultivar Thunder, also known for high protein and commonly used for adjunct brewing malt. Top Shelf is prone to high grain protein and even under the N1 rate was still 11.6%. All lines expectedly saw a positive correlation to

**TABLE 1** Agronomic results from 2021–2023 of Top Shelf in the Oregon Malt Elite Line Trials compared to three check cultivars. Mean separation was performed for variables which showed significant ($p \leq 0.05$) cultivar × year interactions.

| | | Yield | Protein | Plump | TW | Heading | Height | Scald |
|---|---|---|---|---|---|---|---|---|
| **Cultivar** | **Year** | **kg/ha** | **%** | **% ≥6/64″** | **g/L** | **DOY** | **cm** | **%** |
| Top Shelf | 2021 | 10141.1a | 12.9 | 99 | 702.0 | 112i | 113ab | 0g |
| Top Shelf | 2022 | 6884.8de | 12.0 | 96.2 | 679.8 | 112i | 120a | 5fg |
| Top Shelf | 2023 | 7780.2c | 10.8 | 99.4 | 719.6 | 121f | 106bcd | 12ef |
| Endeavor | 2021 | 7852.7c | 10.4 | 95.3 | 714.6 | 115h | 105 cd | 15de |
| Endeavor | 2022 | 4166.0f | 11.5 | 64.1 | 639.4 | 118g | 97ef | 90a |
| Endeavor | 2023 | 6469.7e | 10.2 | 94.1 | 724.1 | 130b | 101cdef | 33c |
| Thunder | 2021 | 9482.8ab | 11.8 | 98.7 | 703.0 | 118g | 108bc | 7efg |
| Thunder | 2022 | 4300.3f | 12.4 | 87.3 | 649.9 | 117g | 97ef | 90a |
| Thunder | 2023 | 6767.1de | 9.9 | 99.2 | 721.1 | 127c | 93fg | 23d |
| Wintmalt | 2021 | 9088.2b | 11.8 | 98.2 | 711.0 | 122e | 104cde | 8efg |
| Wintmalt | 2022 | 3846.7f | 12.8 | 89.0 | 636.8 | 124d | 98def | 80b |
| Wintmalt | 2023 | 7499.3 cd | 9.7 | 98.6 | 715.4 | 132a | 88 g | 23d |

*Note*: Letters following values indicate mean separation between cultivar × years. Entries using the same letters are not significantly different using LSD ($p \leq 0.05$). Columns without annotation indicate no significant differences. Protein, plump, and test weight were only measured on one replicate and thus no analysis was performed. Abbreviations: DOY, day of year.

**TABLE 2** Mean agronomic results for all harvest years in which Top Shelf was assessed in standard field plots at Corvallis and Lebanon, OR (Crop Years 2019–2023). Data were extracted from multiple trials of varying replications; all Lebanon data were single replicate.

| **Corvallis, OR** | **Yield** | **Protein** | **Plump** | **TW** | **Heading** | **Height** | **Lodging** | **Scald** | **BSR** |
|---|---|---|---|---|---|---|---|---|---|
| **Cultivar** | **kg/ha** | **%** | **% ≥6/64″** | **g/L** | **DOY** | **cm** | **%** | **%** | **%** |
| Top Shelf | 8654.9 | 12.0 | 98.3 | 701.0 | 113 | 116 | 0 | 5 | 3 |
| Endeavor | 6492.4 | 10.9 | 79.1 | 674.7 | 116 | 104 | 36 | 53 | 2 |
| Thunder | 6643.2 | 11.7 | 90.0 | 662.0 | 117 | 101 | 21 | 48 | 7 |
| Wintmalt | 6269.8 | 11.5 | 89.4 | 648.5 | 123 | 99 | 13 | 45 | 9 |
| **Lebanon, OR** | **Yield** | **Protein** | **Plump** | **TW** | **Heading** | **Height** | **Lodging** | **Scald** | **BSR** |
| **Cultivar** | **kg/ha** | **%** | **% ≥6/64″** | **g/L** | **DOY** | **cm** | **%** | **%** | **%** |
| Top Shelf | 8038.4 | 10.5 | 97.6 | 685.0 | n.d. | 119 | 2 | 0 | 0 |
| Endeavor | 5510.8 | 9.6 | 80.7 | 658.2 | n.d. | 94 | 34 | 30 | 4 |
| Thunder | 5879.2 | 9.9 | 93.5 | 652.4 | n.d. | 96 | 24 | 9 | 20 |
| Wintmalt | 6080.4 | 9.3 | 94.4 | 652.7 | n.d. | 94 | 30 | 29 | 18 |

Abbreviations: BSR, barley stripe rust; DOY, day of year; TW, test weight.

increasing N rates, but at each N level Top Shelf had the highest grain protein. There was a significant cultivar effect for all metrics, but neither N treatment nor the interaction with cultivar were significant sources of variation. The one exception was grain protein, which showed a significant N treatment effect. Top Shelf yielded similarly to Thunder and greater than DH170472, but yield did not have a significant relationship with increasing field nitrogen. Both Top Shelf and DH170472 showed resistance to scald, whereas Thunder had mild susceptibility. Top Shelf again had the highest percentage of plump kernels and highest TW of all entries, which is positive as high grain protein grain is typically negatively correlated with these metrics.

A target growing environment for Top Shelf is southern Idaho, a major malting barley production region in the United States. Top Shelf was assessed as part of the University of Idaho variety trials in Aberdeen, ID (Table 4), and Rupert, ID (Table 5). The data reported here show a subset of the complete dataset and compare Top Shelf to DH170472 and four check cultivars, all of which are producers of GN ('Charles' [Obert et al., 2006], Endeavor, Thunder, and Wintmalt). At Aberdeen, Top Shelf outyielded all the check cultivars except for Thunder and yielded less than DH170472. It was in the highest grouping for test weight, outperforming two of the checks. It performed similarly for lodging to most of the checks but fared better than Charles. Results from Rupert

**TABLE 3** Agronomic results from the Distiller's Delight nitrogen response trials in Corvallis, OR, for Crop Year 2021, comparing Top Shelf to another elite GN0 line (DH170472) and Thunder. The cultivar effect was significant ($p \leq 0.05$) for all variables and mean separation is reported at the cultivar level only.

| Cultivar | Yield kg/ha | Protein[a] % | Plump % ≥6/64″ | TW g/L | Heading DOY | Height cm | Scald % |
|---|---|---|---|---|---|---|---|
| Top Shelf | 9859.2a | 12.7a | 99.4a | 710.8a | 114b | 112a | 2a |
| *N1* | *9198.4* | *11.6* | *99.4* | *705.0* | *115* | *108* | *2* |
| *N2* | *10281.7* | *12.7* | *99.4* | *715.0* | *114* | *113* | *2* |
| *N3* | *10097.7* | *13.7* | *99.4* | *712.3* | *113* | *113* | *3* |
| DH170472 | 9266.7ab | 12.0a | 99.1b | 691.4b | 118a | 113a | 2a |
| *N1* | *8502.8* | *10.9* | *98.7* | *684.6* | *118* | *108* | *3* |
| *N2* | *9221.4* | *11.6* | *99.1* | *690.4* | *117* | *113* | *3* |
| *N3* | *10075.9* | *13.7* | *99.4* | *699.1* | *119* | *117* | *0* |
| Thunder | 8360.3b | 11.1b | 98.6c | 704.8a | 117ab | 99b | 18b |
| *N1* | *7655.5* | *10.3* | *98.5* | *703.2* | *115* | *97* | *15* |
| *N2* | *8807.7* | *11.0* | *98.7* | *705.9* | *117* | *100* | *20* |
| *N3* | *8617.8* | *12.0* | *98.6* | *705.3* | *118* | *100* | *18* |

*Note*: Letters following values indicate mean separation between cultivars. Entries using the same letters are not significantly different using LSD ($p \leq 0.05$). N1, N2, and N3 refer to the nitrogen treatments in ascending order. Trial means are shown next to the respective cultivar heading, with treatment means separated below.
Abbreviations: DOY, day of year; TW, test weight.
[a]N treatment was significant at the $p \leq 0.05$ level for protein only. Treatment means and mean separation are not reported.

**TABLE 4** Agronomic data from University of Idaho extension trials in Aberdeen, ID, for Crop Year 2022, comparing Top Shelf to another elite GN0 line (DH170472) and four check cultivars.

| Cultivar | Yield kg/ha | TW g/L | Spring stand % | Heading DOY | Height cm | Lodging % |
|---|---|---|---|---|---|---|
| Top Shelf | 10,501.9c | 659.0a | 100 | 148a | 104ab | 14ab |
| DH170472 | 11,152.5a | 643.6ab | 100 | 154b | 112a | 1a |
| Charles | 9462.2e | 603.7c | 100 | 153b | 102b | 68c |
| Endeavor | 9942.4d | 648.7ab | 100 | 155b | 109ab | 9ab |
| Thunder | 11,089.7b | 656.5a | 100 | 153b | 102b | 26b |
| Wintmalt | 9968.6d | 625.6bc | 100 | 155b | 104a | 8ab |

*Note*: Letters following values indicate mean separation between cultivars. Entries using the same letters are not significantly different using LSD ($p \leq 0.05$). Columns without annotation indicate no significant differences.
Abbreviations: DOY, day of year; TW, test weight.

**TABLE 5** Agronomic data from University of Idaho extension trials in Rupert, ID, for Crop Year 2022, comparing Top Shelf to another elite GN0 line (DH170472) and four check cultivars.

| Cultivar | Yield kg/ha | TW g/L | Spring stand % | Heading DOY | Height cm | Lodging % |
|---|---|---|---|---|---|---|
| Top Shelf | 8109.9c | 642.3ab | 100 | 147a | 102 | 21a |
| DH170472 | 7103.5d | 599.8 cd | 100 | 152bc | 107 | 19a |
| Charles | 6548.7e | 574.1d | 100 | 152bc | 107 | 66b |
| Endeavor | 7155.5d | 617.9bc | 100 | 153c | 107 | 55b |
| Thunder | 10,507.3a | 648.7a | 100 | 150b | 99 | 21a |
| Wintmalt | 8268.1b | 616.6bc | 100 | 152bc | 99 | 5a |

*Note*: Letters following values indicate mean separation between cultivars. Entries using the same letters are not significantly different using LSD ($p \leq 0.05$). Columns without annotation indicate no significant differences.
Abbreviations: DOY, day of year; TW, test weight.

**TABLE 6** Winter survival of Top Shelf compared to check cultivars and DH170472 from 2023 trials. Only locations that saw differential survival and where at least one check cultivar was included are shown.

| Cultivar | Becker, MN[a] % | St. Paul, MN[a] % | Ithaca, NY[a] % | Logan, UT-1[b] % | Logan, UT-2[a] % | Alburgh, VT[a] % | Tulelake, CA[c] % |
|---|---|---|---|---|---|---|---|
| Top Shelf | 0 | 20 | 82 | 50 | 87 | 50 | 70 |
| DH170472 | 2 | 3 | 78 | 32 | 17 | 69 | 75 |
| Charles | 0 | 30 | 30 | n.d. | 100 | 65 | n.d. |
| Thunder | n.d. | n.d. | n.d. | 45 | n.d. | n.d. | 45 |
| Wintmalt | 4 | 43 | 65 | 25 | 77 | 87 | n.d. |

Abbreviation: n.d., no data available or line not included in location.
[a]Winter Malting Barley Trials.
[b]American Malting Barley Association trial.
[c]University of California-Intermountain Research and Extension Center yield trial.

were fairly similar in performance against the checks, but in this environment, Top Shelf performed much better than DH170472. Yields for all lines were lower than in Aberdeen, but Top Shelf outperformed two of the four checks, yielding more than Charles and Endeavor. It again fell in the highest grouping for test weight. Lodging was slightly more problematic for all lines at this location. All entries but one showed at least 19% lodging, but Top Shelf performed better than Charles and Endeavor, and was statistically the same as Thunder and Wintmalt. The results across both locations point to Top Shelf's suitability for the environment and potential as an agronomically successful GN0 alternative for growers. At both locations all entries had 100% spring stand which, while positive, does not allow for comparisons for winter survival. However, early results from a series of trials harvested in 2023 (26 locations in total) show that Top Shelf has sufficient winter survival relative to the check cultivars among locations that showed differential survival (6 locations) (Table 6). Top Shelf struggled the most at the two Minnesota locations; however, it performed similarly to the checks in the other four. Generally, Top Shelf shows similar winter hardiness to the check cultivars and performs well in contemporary winter barley growing areas.

## 3.2 | Malting quality

Over multiple years and trials and between two malting scales (micro and mini), Top Shelf produced excellent malt quality and frequently outperformed the check cultivars. As with agronomic assessments, all check cultivars used as malting study controls are producers of GN. Generally, Top Shelf meets most of the expectations for grain distilling, but throughout all trials it also met the extract (% fine grind dry basis) requirements for all-malt distilling, exceeding 82.0% in every assessment. For all malting trials, except the mini-malts produced in 2021, grain was malted under standard protocols for brewing malt as is typical for cultivar assessment rather than an optimized protocol for distilling malt (AMBA, 2023a). In practice, distilling malting protocols promote proteolytic modification and should result in even better malt quality for the end-user. Due to sample limitations and the cost and infrastructure associated with malting, all trials were single-replicate, and thus no statistical analysis was performed.

The first malting assessment was part of the breeding line evaluations performed at the CCRU. Top Shelf was benchmarked for micro-malt quality against three check cultivars (Endeavor, Thunder, and Wintmalt) over 4 crop years (2019–2022) from two locations in the Willamette Valley of Oregon. The cultivar means over the 4 years are shown in Table 7. Top Shelf had the highest malt protein and extract at both locations over the 4 years, which is interesting as these parameters are typically in opposition of each other, but may be related to kernel size, as Top Shelf was also the plumpest grain at both locations. Under the standard malting protocols of the CCRU, Top Shelf appears more apt for grain distillation based on being the highest or second highest at each location for DP, α-amylase, and FAN. The Corvallis Top Shelf mean met the AMBA grain distilling guidelines for seven of eight metrics. Interestingly, while Thunder was closest to Top Shelf for the key grain distilling metrics, it also had significantly higher S/T which implies that Top Shelf may have more room for modification with malt house adjustments. Even with lower average grain protein at Lebanon, Top Shelf met grain distillation guidelines for five parameters (most of any entry at that location) and was able to meet four of the guidelines for all-malt distilling (second behind Wintmalt). Further, as starch synthesis is affected by drought and heat, Top Shelf's high extract even with high protein may indicate some potential resiliency in a changing climate (Gous et al., 2015).

In 2021, Top Shelf was compared to Thunder in a mini-malting assessment which used optimized malting protocols for distilling malt (Table 8). This protocol was designed to promote proteolytic modification by increasing target steep-out moisture and retaining enzymatic activity with a gentler kiln cycle. The optimized malts were also benchmarked

**TABLE 7** Micro-malt data of Top Shelf and three check cultivars averaged over Crop Years (2019–2022) from Corvallis and Lebanon, OR. Malts were produced at the Cereal Crop Research Unit under standard malting protocols.

| Location | Cultivar | Protein % | Plump ≥6/64″ | Extract FGDB % | S/T % | β-glucan ppm | DP °ASBC | α-amylase DU | FAN ppm |
|---|---|---|---|---|---|---|---|---|---|
| Corvallis | Top Shelf | 12.3[b] | 98.5[ab] | 83.2[ab] | 49.3[b] | 113 | 226[b] | 111[b] | 303[b] |
| | Endeavor | 10.4[a] | 87.6 | 82.1[ab] | 54.5[b] | 192 | 157 | 110[b] | 241 |
| | Thunder | 12.1[b] | 94.2 | 82.0[ab] | 53.1[b] | 120 | 191 | 132[b] | 300[b] |
| | Wintmalt | 11.7[a] | 91.9 | 80.0[b] | 43.1[a] | 93[a] | 159 | 69[a] | 179[a] |
| Lebanon | Top Shelf | 10.4[a] | 98.7[ab] | 84.2[ab] | 50.6[b] | 95[a] | 178 | 117[b] | 265[b] |
| | Endeavor | 9.9[a] | 89.7 | 82.1[ab] | 52.8[b] | 162 | 143[a] | 92[b] | 226 |
| | Thunder | 10.2[a] | 96.0 | 82.6[ab] | 58.0[b] | 41[a] | 151 | 125[b] | 269[b] |
| | Wintmalt | 9.6[a] | 96.4 | 81.3[ab] | 49.2[b] | 71[a] | 136[a] | 61[a] | 171[a] |

Abbreviations: DP, diastatic power; DU, dextrinizing units; FAN, free amino nitrogen; FGDB, fine grind, dry basis; S/T, soluble to total protein ration.
[a]Meets American Malting Barley Association (AMBA) guidelines for all-malt distilling.
[b]Meets AMBA guidelines for grain distilling. Due to the nature of the process, there is no β-glucan specification for grain distilling.

**TABLE 8** Malt quality data of Top Shelf and Thunder from Crop Year 2021. Micro-malts (500 g) were malted under standard protocols and mini malts (~75 kg) were malted under optimized protocols for each cultivar. Malts were produced at Oregon State University.

| Malt type | Cultivar | Protein % | Extract FGDB % | S/T % | β-glucan ppm | DP °ASBC | α-amylase DU | FAN ppm | PSY (LAA/t) | GN g/tonne |
|---|---|---|---|---|---|---|---|---|---|---|
| Micro | Top Shelf | 10.5[a] | 84.0[ab] | 51.0[b] | 88[a] | 141[a] | 65.1[a] | 251[b] | 405[a] | n.d. |
| Micro | Thunder | 9.7[a] | 82.8[ab] | 55.5[b] | 52[a] | 120[a] | 77.0[b] | 266[b] | 398 | n.d. |
| Mini | Top Shelf | 12.1[b] | 84.4[ab] | 50.5[b] | 70[a] | 200[b] | 80.9[b] | 284[b] | 409[a] | 0.3[ab] |
| Mini | Thunder | 10.7[a] | 83.4[ab] | 52.6[b] | 83[a] | 162 | 85.3[b] | 267[b] | 405[a] | 1.1 |

Abbreviations: DP, diastatic power; DU, dextrinizing units; FAN, free amino nitrogen; FGDB, fine grind, dry basis; GN, glycosidic nitrile; LAA, liters of absolute alcohol; PSY, predicted spirit yield; S/T, soluble to total protein ration.
[a]Meets American Malting Barley Association (AMBA) guidelines for all-malt distilling.
[b]Meets AMBA guidelines for grain distilling. Due to the nature of the process, there is no β-glucan or PSY specification for grain distilling.

against micro malts which underwent the normal brewing malt protocol. Top Shelf again had exceptional extract as well as greater DP and FAN. As this assessment was geared towards distilling malt evaluation, the PSY of each entry was measured. PSY is a key malt quality indicator for all-malt distilling and is measured analytically but is roughly a balance of extract and amylolytic enzymes, which can be challenging with very low or very high protein barley. Top Shelf had higher PSY than Thunder under both protocols, exceeding the AMBA threshold in both. In this assessment, mini malts were quantified for GN. Top Shelf was again confirmed as GN0 at 0.3 g/tonne, which is below the 0.5 g/tonne threshold. It should be noted that the trace GN detected in even non-producers is simply an artifact of the assay. Thunder on the other hand quantified at 1.1 g/tonne, confirming its status as a producer.

Finally, Top Shelf and Thunder underwent trials comparing malt quality at four grain protein levels (Table 9). Grain protein is known to correlate positively with many of the malting parameters of interest for grain distilling (DP, α-amylase, and FAN) but negatively with malt extract (Halstead et al., 2022). At each protein level, Top Shelf exceeded Thunder for extract, DP, and FAN, but not for α-amylase. While Top Shelf is well suited for grain distilling, particularly when grain protein ≥12.0%, the lowest protein Top Shelf met many of the metrics for all-malt distilling and had an impressive 85.1% extract.

## 4 | CONCLUSION

Top Shelf is the first winter-habit, GN0 malting cultivar to be released in the United States, and given its agronomic performance and malting quality, it offers a competitive option for mainstream malt production. Top Shelf was bred for fall-planting in the Pacific Northwest: target environments include southern Idaho as well as the Palouse, Columbia Basin, and western valleys of Oregon and Washington. It has performed well in assessments in Oregon and Idaho and performance in a broader selection of growing regions is ongoing. Top Shelf showed high yields, percentage of plump seeds, and test weights in all field trials. In all environments, Top Shelf performed equal to or better than the check cultivars for all metrics. Additionally, Top Shelf shows strong scald resistance

**TABLE 9** Micro-malt quality data of Top Shelf compared to Thunder at four increasing grain protein levels from Crop Year 2021 in Corvallis, OR.

| Cultivar | Protein % | Plump ≥6/64″ | Extract FGDB % | S/T % | β-glucan ppm | DP °ASBC | α-amylase DU | FAN ppm |
|---|---|---|---|---|---|---|---|---|
| Top Shelf | 9.4[a] | 99.7[ab] | 85.1[ab] | 62.6[b] | 69[a] | 193 | 115[b] | 309[b] |
| Top Shelf | 12.5[b] | 99.6[ab] | 83.4[ab] | 55.6[b] | 82[a] | 259[b] | 120[b] | 349[b] |
| Top Shelf | 12.9[b] | 99.6[ab] | 82.9[ab] | 54.2[b] | 117 | 256[b] | 119[b] | 346[b] |
| Top Shelf | 13.2[b] | 99.6[ab] | 82.4[ab] | 53.6[b] | 87[a] | 279[b] | 109[b] | 355[b] |
| Thunder | 9.0[a] | 99.0[ab] | 84.2[ab] | 63.7[b] | 58[a] | 125[a] | 123[b] | 275[b] |
| Thunder | 10.6[a] | 99.5[ab] | 83.3[ab] | 63.1[b] | 127 | 174 | 117[b] | 323[b] |
| Thunder | 11.2[b] | 99.5[ab] | 82.8[ab] | 61.1[b] | 81[a] | 191 | 125[b] | 352[b] |
| Thunder | 12.7[b] | 99.6[ab] | 81.7[ab] | 56.0[b] | 180 | 261[b] | 131[b] | 376[b] |

Abbreviations: DP, diastatic power; DU, dextrinizing units; FAN, free amino nitrogen.; FGDB, fine grind, dry basis; S/T, soluble to total protein ration.
[a]Meets American Malting Barley Association (AMBA) guidelines for all-malt brewing and distilling.
[b]Meets AMBA guidelines for grain distilling. Due to the nature of the process, there is no β-glucan specification for grain distilling.

and some evidence of resistance to barley stripe rust. Across multiple years of malting trials, Top Shelf produced quality malt and outperformed check cultivars for both all-malt and grain distilling potential. It performed particularly well when malted under optimized malting protocols for distilling. Unlike many barley cultivars whose malt modification patterns typically dictate their end use to one stream of malt type, Top Shelf has exhibited attributes that make it an appealing malting barley cultivar for both all-malt and grain distilling. This flexibility offers growers and maltsters greater assurance of meeting malt quality specifications, knowing that their barley will produce quality malt at varying grain protein levels. Given that grain protein is positively correlated with heat and drought stress, this is an appealing trait given an uncertain climate future. As the first winter GN0 malting cultivar to be released in the United States, there is an excitement at the potential for rapid adoption of Top Shelf within the overall distilling supply chain.

## 5 | AVAILABILITY

The production of certified classes of seed is proceeding as follows. Breeder seed was produced from head row purification blocks planted at Hyslop Farm, near Corvallis, OR, in 2021 and harvested in 2022. Approximately one quarter of an acre of this seed was planted in the fall of 2022 in Othello, WA, by Washington State Crop Improvement Association to produce foundation seed. This seed was harvested in 2023 and 50 kg will be used for planting a second round of Foundation seed increase in the fall of 2023. This production will be available for sale as foundation seed and can be used to produce Registered and/or Certified classes of seed. Top Shelf was released with a nonexclusive license. There is a one-time application fee of $250 for each nonexclusive license. Those interested in a license should contact Denis Sather at the OSU Office of Commercialization and Corporate Development (denis.d.sather@oregonstate.edu). Top Shelf seed, for planting purposes, 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 from the certified production must be disposed of by malting or feeding, unless permission is obtained—in writing—from OSU to use the seed for other purposes, including replanting. Plant Variety Protection will not be sought for Top Shelf 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 sales for planting purposes 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 OSU recognized as the owner of the cultivar. Furthermore, Oregon, Idaho and Washington state trademarks will specify that the cultivar can only be sold under the name of 'Top Shelf'. Seed of Top Shelf has been deposited into the USDA-ARS National Laboratory for Genetic Resources, where it will be available immediately upon publication.

## AUTHOR CONTRIBUTIONS

**Campbell Morrissy**: Data curation; formal analysis; investigation; methodology; writing—original draft; writing—review and editing. **Tanya P Filichkin**: Data curation; investigation. **Scott Fisk**: Data curation; formal analysis; investigation; methodology; writing—review and editing. **Laura Helgerson**: Data curation; investigation. **Patrick Hayes**: Conceptualization; data curation; formal analysis; investigation; project administration; resources; supervision; writing—review and editing.

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## CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

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## REFERENCES

AMBA. (2023a). *Guidelines for malting barley breeders*. American Malting Barley Association. https://ambainc.org/news-details.php?id=63d2780a0c948

AMBA. (2023b). *Recommended malting barley varieties*. American Malting Barley Association. https://ambainc.org/recommended-varieties.php

Bringhurst, T. A., Broadhead, A., & Brosnan, J. (2003). Grain whisky: Raw materials and processing. In I. Russell, G. G. Stewart, & C. W. Bamforth (Eds.), *Whisky: Technology, production, and marketing* (2nd ed., pp. 75–112). Elsevier Science.

Bringhurst, T. A., Brosnan, J. M., McInnes, B., & Steele, G. M. (1996). Methods for determining the fermentability and predicted spirit yield of distilling malts. *Journal of the Institute of Brewing*, *102*(6), 433–437. https://doi.org/10.1002/j.2050-0416.1996.tb00927.x

Cistué, L., Vallés, M., Echávarri, B., Sanz, J., & Castillo, A. (2003). Barley anther culture. In M. Maluszynski, K. J. Kasha, B. P. Forester, & I. Szarejko, (Eds.), *Doubled haploid production in crop plants* (pp. 29–34). Springer Science & Business Media. https://doi.org/10.1007/978-94-017-1293-4_5

CMBTC. (2023). *Recommended barley varieties: 2023–2024*. Canadian Malting Barley Technical Centre. https://cmbtc.com/wp-content/uploads/2022/11/CMBTC-2023-24-Malting-Barley-Recommended-List.pdf

Cook, R., McCaig, N., McMillan, J. M. B., & Lumsden, W. B. (1990). Ethyl carbamate formation in grain-based spirits: Part III. The primary source. *Journal of the Institute of Brewing*, *96*(4), 233–244. https://doi.org/10.1002/j.2050-0416.1990.tb01032.x

Cook, R., & Oliver, W. B. (1991). Rapid detection of cyanogenic glycosides in malting barley. In E. Rui Vilar (Ed.), *Proceedings of the 23rd Congress of the European Brewery Convention* (pp. 513–520). Oxford Academic. https://doi.org/10.1093/oso/9780199632831.003.0063

Dolan, T. C. S. (2000). Scotch malt whisky distillers malted barley specifications. Twenty years of fermentable extract and predicted spirit yield. *Journal of the Institute of Brewing*, *106*(4), 245–250. https://doi.org/10.1002/j.2050-0416.2000.tb00064.x

Gallagher, L. W., Silberstein, R., Prato, L., & Vogt, H. (2020). 'Butta 12', a two-rowed malting barley adapted to the California Central Valley with proven floor-malting success and craft brewer acceptance. *Journal of Plant Registrations*, *14*(3), 250–265. https://doi.org/10.1002/plr2.20067

Gous, P. W., Warren, F., Mo, O. W., Gilbert, R. G., & Fox, G. P. (2015). The effects of variable nitrogen application on barley starch structure under drought stress. *Journal of the Institute of Brewing*, *121*(4), 502–509. https://doi.org/10.1002/jib.260

Halstead, M., Morrissy, C. P., Fisk, S. P., Fox, G. P., Hayes, P. M., & Carrijo, D. (2022). Barley grain protein is influenced by genotype, environment, and N management and is the major driver of malting quality. *Crop Science*, *63*(1), 115–127. https://doi.org/10.1002/csc2.20842

Hayes, P. M. (2014). *Proposed release of Full Pint spring 2-row barley*. Oregon Agricultural Experiment Station, Oregon State University. http://washingtoncrop.com/wp-content/uploads/2014/03/Full-Pint-2-Row-Spring.pdf

Hayes, P. M., Filichkin, T., Fisk, S., Helgerson, L., Meints, B., & Mundt, C. (2019). *Release of thunder two-row winter barley*. Oregon Agricultural Experiment Station, Oregon State University. https://barleyworld.org/sites/barleyworld.org/files/thunder_release_web.pdf

Hayes, P. M., Fisk, S., Carrijo, D., Filichkin, T., Helgerson, L., Hernandez, J., & Meints, B. (2020). *Release of 'Oregon Promise' two-row spring malting barley*. Oregon Agricultural Experiment Station, Oregon State University. https://barleyworld.org/sites/barleyworld.org/files/oregon_promise_release.pdf

Limagrain Cereal Seeds. (2014). *LCS Calypso: Malting barley*. https://limagraincerealseeds.com/malting-barley-seed/lcs-calypso/

Limagrain Cereal Seeds. (2024). *LCS Odyssey: Malting barley*. https://limagraincerealseeds.com/malting-barley-seed/lcs-odyssey/

MAGB. (2023). *Malting barley committee*. The Maltster's Association of Great Britain. https://www.ukmalt.com/uk-malting-industry/malting-barley-committee/

Montana State University–Barley Breeding. (2014). *KWS Wintmalt*. Montana State University. https://www.montana.edu/barleybreeding/learning-center/barley-variety-dictionary/winter-barley/Wintmalt.html

Morrissy, C. P., Fisk, S. P., Gollihue, J. W., Sutton, H., Bettenhausen, H. M., Berron, B. J., & Hayes, P. M. (2024). Malting barley for North American distillers: Novel GN0 winter barley varieties meet and exceed contemporary expectations. *Journal of Distilling Science*, *3*(1), 1–8. https://doi.org/10.61855/JDS0301.02

Morrissy, C. P., Thomas, W., Bettenhausen, H., Fisk, S., & Hayes, P. (2023). *Glycosidic nitrile and ethyl carbamate in malting barley*. Artisan Spirit Magazine, Winter, 78–82. https://www.artisanspiritmag.com/spirit-mag-issues/winter-2023

Obert, D. E., Evans, C. P., Windes, J. M., Wesenberg, D. M., Ulrich, S. E., Budde, A., Chen, X., & Jackson, E. W. (2009). Registration of 'Endeavor' winter barley. *Journal of Plant Registrations*, *3*(2), 124–126. https://doi.org/10.3198/jpr2008.10.0618crc

Obert, D. E., Wesenberg, D. M., Burrup, D., Jones, B., & Erickson, C. (2006). Registration of 'Charles' barley. *Crop Science*, *46*(1), 468–469. https://doi.org/10.2135/cropsci2005.0149

Syngenta. (2023). *SY VESSEL: Innovation in the UK malt distilling sector*. https://www.syngenta.co.uk/sy-vessel-innovation-uk-malt-distilling-sector

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