Table 1: Reports the breeding goals of the winter crosses made since the inception of the winter barley breeding program.

Table 1: Winter Breeding Program Crosses Since Inception

	Breeding Goals	2015	2016	2017	2018	2019	2020	2021
	Forage					8	39	24
	Cold tolerance					21	57	17
	Malt/feed					45	53	57
	Hull-less						3	2
	Low beta glucan						4	
	Low GN						2	
	Stay green						4	
	Stripe Rust							3
	Fast hydrating/dormant						8	
	low proline						1	
Winter	**Total**					**74**	**171**	**103**

In Table 2, we report the survival and agronomic data for the winter barley advanced yield trial in Bozeman MT, 2021. We also report the malt quality of this trial in Table 3. The material included in this trial was from OSU advanced experimental lines. Overall the material does not have adequate cold tolerance for Montana. It also needs improvement for malt quality. We are incorporating the OSU material into our crossing block, utilizing Vavilov lines to improve cold tolerance and MT spring malt lines to improve malt quality. One line malted with this trial, which came from material developed by the previous MSU breeder noted below as Pat's Pops, had surprisingly good malt quality. We are currently malting other material from our winter barley archives, which we assumed would be good for feed, to determine if it has adequate malt quality.

Table 2: Advanced Winter Yield Trial Bozeman MT 2021

Line	Yield (bu/ac)	Spring Survival (1-5)	June % Plot Fill	Heading date Julian	Maturity date Julian	Plant Height cm	Pedigree
DH180807	**83.7**	nd	91.0	160.3	194.3	58.3	DH140963/Mateo
DH190100	**80.2**	2.0	92.3	159.0	193.3	56.0	DH140963/Mateo
DH190088	**79.4**	3.3	91.0	159.0	192.3	67.0	DH140963/Mateo
DH190104	**77.9**	2.5	85.7	161.3	198.7	58.0	DH140963/Mateo
DH190250	**77.6**	3.0	91.7	165.3	194.0	56.0	DH140963/Mateo
DH171854	**77.4**	2.7	94.3	159.3	191.7	57.0	DH131038/Calypso
DH180800	**76.7**	2.5	82.7	158.7	192.7	50.7	DH140963/DH130939
DH190089	**72.5**	3.3	83.7	162.0	197.3	58.7	DH140963/Mateo
DH180806	**71.9**	2.0	89.0	157.7	194.0	55.7	DH140963/Mateo
DH190249	**71.7**	3.0	85.7	161.3	194.3	59.7	DH140963/Mateo
DH180268	**71.6**	4.0	98.7	160.7	192.0	67.0	DH131038/Calypso
DH190117	**71.3**	2.5	95.7	161.7	194.3	58.3	DH141944/DH120304
DH190195	69.9	3.0	87.0	159.7	196.7	57.0	DH140963/DH120304
DH190108	68.8	2.0	71.0	158.7	195.3	55.3	DH140963/Mateo
DH190044	68.5	2.5	96.7	159.3	194.3	61.0	DH140963/DH130939
DH190105	68.4	3.5	93.7	159.7	196.0	55.7	DH140963/Mateo
DH190118	67.4	2.5	76.3	160.0	193.7	57.3	DH141944/DH120304
DH190247	67.2	2.3	90.3	163.0	197.3	52.7	DH140963/Mateo
DH190056	67.1	1.5	90.0	159.7	195.0	57.0	DH140963/DH130939
DH171677	66.9	1.7	86.3	162.0	196.3	60.7	DH131038/Calypso
DH190106	66.7	2.0	88.0	159.7	197.3	57.3	DH140963/Mateo
DH171356	66.4	3.0	93.7	158.0	192.7	60.7	DH131038/Calypso
DH190248	66.3	2.3	90.0	168.0	200.0	56.0	DH140963/Mateo
Thunder	66.1	2.0	85.0	164.7	196.3	58.7	Wintmalt/Charles
DH190103	65.7	2.7	93.0	159.7	195.3	50.3	DH140963/Mateo
DH190233	65.4	4.0	92.3	164.7	196.0	61.0	DH120304/Mateo
DH180379	64.1	3.3	87.7	163.3	196.0	52.3	DH130004/04_028_36
Wintmalt	60.2	2.3	98.7	165.3	200.3	58.7	(Opal x 3087/96)x1922-23
DH190151	59.9	2.3	84.3	160.0	195.7	58.7	DH141944/Lyberac
DH190148	59.6	2.0	84.0	164.3	202.0	64.7	DH141944/Lyberac
DH190053	58.4	3.7	90.3	161.7	199.0	55.0	DH140963/DH130939
DH190077	58.1	3.5	76.3	159.3	196.3	52.7	DH120304/Mateo
DH190074	55.1	3.0	85.0	161.7	197.3	55.7	DH120304/Mateo
DH180281	27.0	2.7	41.7	159.7	203.3	56.7	DH131038/Calypso
Mean	**67.5**	**2.7**	**87.1**	**161.1**	**195.9**	**57.6**	
LSD	13.0						
CV	10.4						

Table 3: Malt Quality of Advanded Lines Bozeman 2021

Name	Grain Protein %	Extract (CG db) %	S. Protein %	FAN ppm	B-Glucan ppm	Alpha Amylase ° DU	DP °ASBC	S/T
DH171854	13.3	79.3	5.1	151.9	393.2	38.5	146.8	38.2%
DH162134	13.4	78.2	4.9	169.4	122.7	41.3	179.7	36.6%
DH190195	12.9	78.1	4.8	169.1	206.8	36.0	137.4	37.1%
DH180804	14.5	77.9	5.3	185.8	234.0	45.8	180.0	36.4%
Pats Pop 31	14.6	77.9	6.3	257.8	98.1	43.9	208.6	43.3%
DH190044	14.9	77.8	6.1	247.9	184.9	72.5	198.0	40.8%
Charles	13.6	77.6	4.5	166.8	366.3	78.9	158.8	33.5%
DH190074	15.0	77.3	5.9	219.6	68.5	42.5	209.0	39.1%
DH180800	14.8	76.9	4.9	174.4	308.2	68.3	174.8	33.1%
DH160968	15.0	76.9	6.3	245.2	182.2	63.6	142.5	42.2%
DH180268	13.8	76.0	4.5	145.7	259.8	40.4	172.4	32.3%
DH190233	14.5	75.9	5.4	235.7	63.4	59.0	211.8	37.2%
DH141940	14.2	75.8	4.8	174.0	452.8	40.1	178.3	33.8%
DH171356	14.4	75.7	4.7	161.2	234.9	47.6	173.9	32.8%
DH190103	14.2	75.5	4.1	148.4	558.4	38.4	151.4	28.6%
DH190117	13.6	75.2	4.7	174.3	304.6	36.6	159.3	34.5%
DH161265	14.8	75.0	4.5	198.8	493.5	71.4	160.0	30.6%
DH140963	14.2	74.9	4.5	144.5	531.5	30.1	113.1	31.5%
DH180807	13.6	74.8	3.7	132.0	541.8	36.6	132.9	27.6%
DH180802	14.2	74.3	4.4	173.0	402.6	49.7	98.7	30.6%
DH190089	14.1	74.1	4.1	138.1	720.3	27.4	132.2	28.8%
DH180714	15.0	73.7	4.6	178.5	353.5	51.8	159.5	30.5%
DH171354	15.5	73.6	3.9	144.2	732.7	24.2	154.4	25.1%
DH190249	13.8	73.4	4.4	135.6	540.1	32.0	131.0	31.8%
DH16099	14.7	72.8	3.7	123.9	807.3	31.8	147.5	25.4%
DH190250	14.7	72.5	3.9	128.3	724.9	30.5	208.4	26.3%
DH190049	15.6	72.0	3.8	134.0	638.3	33.6	172.9	24.6%
DH190105	16.0	70.5	3.8	156.1	1103.7	40.7	90.7	23.7%
DH190088	13.6	70.2	4.1	148.4	853.3	32.3	139.0	30.4%
DH161788	15.0	69.9	3.1	134.5	1222.6	37.5	87.6	20.5%
DH180379	15.4	69.3	3.5	135.9	1590.9	33.5	79.3	23.0%
DH161365	15.0	67.0	3.0	129.4	1466.3	35.4	83.6	19.8%

Winter Forage Barley: A winter barley forage line with a Lavina and Vavilov 13976 as parents survived better at NWARC than the winter checks. It also had good grain yield. This material is being tested around the state and in Williston ND in 2022.

Forage Survival and Grain Yields NWARC 2021

Winter Family or Cultivar	pedigree	Generation 2020-21	Ave # plants/1m row	Ave % Survival	Ave Test Weight (lb/Bu)	Ave grain yield (g)
MTF4_50	Lavina/Vavilov_13976	F4(F2)	60.80	80.00	44.63	3377.04
MTF4_51	Lavina/Dicktoo	F4(F2)	58.80	68.50	41.25	3158.84
MTF5_130	Lavina/Karioka	F5(F4)	32.33	45.83	41.83	2547.42
MTF5_131	LAVINA/Vavilov_13976	F5(F4)	32.62	56.15	45.00	2621.61
MTF5_132	LAVINA/Vavilov_19041	F5(F4)	38.77	77.31	42.85	2869.20
CHARLES			46.33	64.17	46.03	3749.70
WINTMALT			63.67	76.67	47.45	3689.22

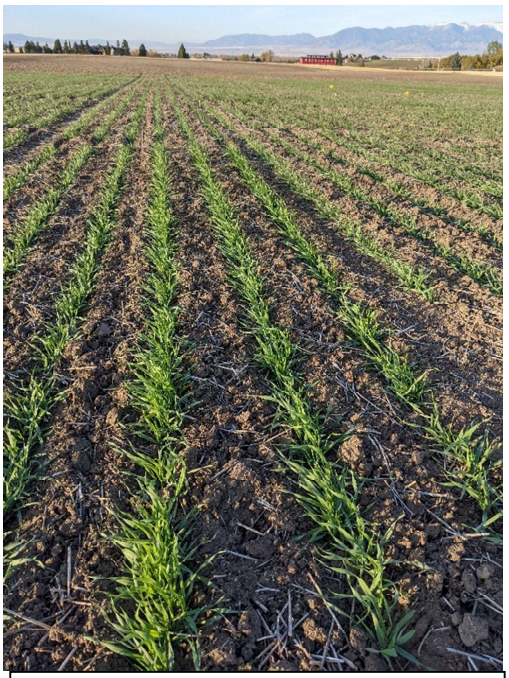
The Winter Barley PYT grown in Bozeman in 2021 indicates lines in the pipeline with higher yield potential than current winter checks.

Winter PYT Yields Bozeman 2021

Name	Ave bu/ac	Pedigree
MTW_19:08	101.07	Vavilov_13906/Cervoise
MTW_19:05	89.73	Vavilov_13470/Arturio
MTW_19:26	88.46	Vavilov_22607/Salanandre
MTW_19:48	83.77	Gigga/Vavilov_19917
MTW_19:24	81.84	Vavilov_20251/Azurel
MTW_19:68	80.99	Salanandre/Vavilov_13587
MTW_19:32	80.33	Azurel/Vavilov_13587
MTW_19:67	80.05	NH05H31/MARIS OTTER
MTW_19:17	77.58	Vavilov_17985/Vavilov_19070
THUNDER	76.24	THUNDER
MTW_19:40	75.78	Charles/Salanandre
MTW_19:20	71.39	Vavilov_19070/dicktoo
MTW_19:37	64.94	Bearpaw/Dicktoo
MTW_19:61	60.65	MT16M02204/MARIS OTTER
MTW_19:63	59.25	MT16M02204/Karioka
MTW_19:54	56.87	MT124069/Maris Otter
WINTMALT	55.86	WINTMALT
MTW_19:60	55.17	MT124128/Salanandre
MTW_19:64	51.99	MT16M02204/Salanandre
CHARLES	51.81	CHARLES
MTW_19:59	51.67	MT124128/Vavilov_17642
MTW_19:57	50.30	Buzz/Maris Otter
MTW_19:57	47.15	Buzz/Maris Otter
MTW_19:35	37.53	Bearpaw/MarisOtter
MTW_19:65	30.09	MT16M08806/MARIS OTTER

Cold Tolerance Screening: A post-doc and assistant plant breeder for the winter program, Traci Hoogland, developed a protocol for greenhouse testing of winter barley cold tolerance. Field based cold tolerance testing is a limiting factor in a winter barley breeding program for several key reasons: 1) Only a single generation can be advanced per year, 2) Across field variation can be high, and 3) Year-to-year variation in winter temperatures and precipitation make testing conditions unpredictable – in a mild winter no selection pressure may be exerted, while in an extremely cold or dry year, whole generations could be lost.

Other winter breeders have suggested that spring by winter crosses can be used to improve winter barley. Also, that the obligate winter phenotype is not necessary for cold tolerance. Therefore upon initiation of the winter barley breeding program, we derived lines in two ways for the spring by winter crosses: 1) F2 seeds from crosses were planted directly into the field in the fall to undergo cold selection pressure while genetic diversity was high, 2) lines were inbred in the greenhouse through the F4 generation (as we do with spring barley) without cold tolerance selection until inbred. Preliminary data from the two different methods indicates that cold tolerance selection pressure early in the breeding process (F2 stage) is vital to deriving the most cold-tolerant lines possible. In the spring of 2018 a cross was made between the MT line Lavina and a Russian line designated V_13976 and lines derived as described above. Lines derived with each of these methods were then tested against each other in Kalispell for winter survival in the 2020-2021 field season. Lines derived with Method 1 (under cold pressure at the F2 stage) had nearly twice the survival of lines derived with Method 2.



Winter trial Fall 2021 Bozeman MT

So, cold tolerance selection at the F2 stage is important, but as previously discussed field testing is slow and can be unreliable. Thus, the MSU Winter Barley program began working on the development of a greenhouse based cold tolerance test. Such a test could be used in the early generations of a breeding program to ensure that selection for winter survival can be implemented while genetic diversity is high.

Based on a deep dive into cold temperature testing literature, a preliminary greenhouse testing protocol was developed. From August to November of 2021, a 16 week protocol and a condensed 13 week protocol were evaluated. In each protocol, eight lines with a range of cold tolerance (Charles, Dicktoo, WWheat, 5 experimental Vavilov lines) were tested in two soil types and two container types. In each protocol, lines were exposed to colder and colder temperatures for a period of four to six weeks to harden them and allow them, if possible, to make the necessary physiological changes to survive freezing. Four different final (coldest) temperatures were tested to find the best temperature to use for selection: (15, 10, 5, and -0.5 ºF) – with a goal of at least 50% plant death during selection.

Over the course for several months, over 3,000 plants were evaluated and out of this testing a successful protocol was found. Cone-type containers with a 50/50 soil/peat mix were found to provide the best conditions for distinguishing cold tolerances. Negative 0.5 ºF was found to provide excellent selection pressure on tested lines (Table 6). For breeding purposes, a less

severe temperature of 5 °F may be best for initial selection. The condensed 13 week protocol was also found to provide sufficient hardening for successful cold testing.

With the results from this study, the MSU Winter Barley Breeding Program now has an invaluable tool for testing and advancing winter crosses through the first several generations of the breeding process. This tool will allow us to progress from the F2 to the F4 generation in a single year without losing the vital cold tolerance selection, instead of only advancing one generation per year.

Table 6: Percent survival of variety at -0.5 °F (cone-type containers, 50/50 soil mix)

Variety	Percent survival
Charles	25
Dicktoo	58.33333
Winter Wheat	100
Vavilov_13976	66.66667
Vavilov_13906	54.16667
Vavilov_30209	41.66667
Vavilov_22607	70.83333
Vavilov_13587	66.66667