

MEMORANDUM

FROM: Michael J. Giroux and Andrew C. Hogg
DATE: 12/20/2019
RE: Motion for Release of MTD16005 spring durum wheat with supporting documentation.

RECOMMENDATION Public, protected **NAME** To be determined

CONTRIBUTORS

- Dr. Mike Giroux and Mr. Andy Hogg, MSU Bozeman, MT
- Dr. Pat Carr and Dr. Jed Eberly, MSU-CARC, Moccasin, MT
- Dr. Chengci Chen, Ms. Calla Kowatch, and Dr. Frankie Crutcher, MSU-EARC, Sidney, MT
- Dr. Darrin Boss and Ms. Peggy Lamb, MSU-NARC, Havre, MT
- Dr. Ken Kephart, MSU-SARC, Huntley, MT
- Dr. Gadi Reddy, Mr. John Miller, Ms. Julie Orcutt, Ms. Julie Prewett, MSU-WTARC, Conrad, MT
- Dr. Linda Dykes, USDA-ARS, Fargo, ND
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Crop Science

Entomology

Horticulture

Plant Biology

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PEDIGREE

Divide//Mountrail/M175

- **Mountrail- North Dakota State University public release 1998**

“Mountrail was tested as D901313 and was selected from the cross D8479/’Renville’ (1) made in 1987 by R.G. Cantrell. The parent D8479 was derived from the cross D7984/D7926//D7982/D79155. D7982 and D7984 were derived from the cross D6973/’Ward’//D74110. D6973 was derived from the cross D65150/D65151. D65150 was derived from the cross Pi//’Tomclair’//2* ’Tehuacan’/3/’Zenati Bouteille’/’Wells’. The pedigree of D65151 is ’Stewart’//ld 379/ld357/3/Dw F4/’Langdon’/4/’Leeds’. D74110 was derived from the Cross ’Edmore’/Ward. The Pedigree of D7926 is D7456/’Vic’. D7456 was derived from the cross D6771/ ’Rugby’. The pedigree of D6771 is ’Stewart 63’//ld 393/Stewart. D79155 was derived from the cross D7224/’Calvin’. The pedigree of D7224 is D6530/D6654. D6530 was derived from the cross 561/’Cappelli’. D6654 was derived from the cross D61130/Leeds. D61130 was derived from the cross ’Lakota’//Dw F4/Langdon”

- Elias, E.M. and J.D. Miller. Registration of ‘Mountrail’ Durum Wheat. 2000. Crop Science. 40:1499-1500.

- **Divide- North Dakota State University public release 2005**

“Divide was tested as the experimental line D971511 and was selected from the cross ‘Ben’ (PI 596557)/D901282//’Belzer’ (PI 603286) made in 1993 (Elias and Miller, 1998) and (Elias et al., 1999). The parent D901282 was derived from the cross D84102/’Regold’. The pedigree of D84102 is D7984/D7926. The parents of D7984 are ‘Ward’ (CI 15892) and ‘Vic’ (CI 17789), (Quick et al., 1974, 1980). D7926 was derived from the cross D7456/Vic. D7456 was derived from the cross D6771/’Rugby’ (CI 17284) (Quick et al., 1975). The pedigree of D6771 is ‘Stewart 63’ (CI 12066)//Yt54/N10B (Knott, 1964).”

- Elias, E.M. and F.A. Manthey. Registration of ‘Divide Durum Wheat. 2007. Journal of Plant Registrations. 1:1:7-8.

- **PI330546 (ICARDA IG86105, common name - Affine, submitted 1968 from Univ. of Reading, England)**

PI330546 was obtained from the National Small Grains Collection and carries an allele for low cadmium accumulation and a null starch synthase IIa A (*ssIIa-A*) allele (deletion in first exon at

position 145-174 of coding sequence) that confers firmer pasta (Martin et al. 2012). PI330546 is resistant to stem rust and has adult plant resistance to stripe rust but is susceptible at the seedling stage. PI330546 is susceptible to Hessian Fly and is taller than modern varieties (approximately 55 in.). PI330546 has long slender heads that have white awns and glumes with oblong brown/tan seeds. Further pedigree information could not be found on this accession.

- **M175**

M175 was selected from an ethyl methanesulfonate (EMS) mutant population that had the parents Mountrail/PI330546. Offspring from the cross Mountrail/PI330546 were advanced to the F₅ generation via single seed descent with selection for agronomics and yellow/amber grain color. In the F₅ generation the best agronomic plants possessing the *ssIIa-A* null allele were selected and bulked F₆ seed from selected lines was treated with 0.5% EMS. Mutagenized plants were advanced two generations in the greenhouse to the M₂ generation. Plants were genotyped in the M₂ for novel mutations in *ssIIa-B*. Line M175 was homozygous for the low cadmium allele, the null *ssIIa-A* allele from PI330546 and for a newly created allele in *ssIIa-B* that contains a missense mutation resulting in amino acid change D327N (Hogg et al., 2012).

- Martin, J.M., Hogg, A.C., Hofer, P., Manthey, F.A., and M.J. Giroux. Impacts of SSIIa-A Null Allele on Durum Wheat Noodle Quality. 2012. Cereal Chemistry 91(2):176-182.
- Hogg, A.C., Gause, K., Hofer, P., Martin, J.M., Grayboshch, R.A., Hansen, L.E. and M.J. Giroux. 2012. Creation of a high-amylose durum wheat through mutagenesis of starch synthase II (SSIIa). J. Cereal Sci. 57:377-383.

SELECTION HISTORY

MTD16005 is an offspring of the cross Divide//Mountrail/M175. M175 was first crossed to Mountrail and the resultant F₁ was then crossed to Divide. The resultant F₁'s were genotyped for the two mutations in *ssIIa-A* and B and dual heterozygous plants were advanced. Approximately 600 F₂'s from F₁'s were advanced by single seed descent to the F₄ generation at which point a whole head was harvested. In 2014, 262 F₅'s were planted in spaced head-rows in Bozeman, MT at the Post Agronomy Farm and the best agronomic plant (tillering, height, disease, head size) was selected from each row and threshed using a single plant thresher. Lines were genotyped for *ssIIa-A*, *ssIIa-B*, and *cdul* (gene controlling cadmium accumulation). In 2015, 262 F_{5:6} lines were grown in replicated short rows (4 ft) at the Post Agronomy Farm under

dryland and irrigated conditions. Lines were evaluated for agronomic traits (height, heading date, maturity date, yield) and quality traits (protein, seed size) and a single row from the irrigated environment was harvested with a binder and Vogel thresher for seed stock. The top 40 yielding lines across both environments were selected for further testing and F_{5:7} plants were grown in replicated plots (4x10 ft) in 2016 at the Post Farm under dryland and irrigated conditions and in Conrad, MT under dryland conditions. Lines were evaluated for agronomic traits (height, heading date, maturity date) and quality traits (protein, mixograph, semolina color). The top performing lines (MTD16001-11) were selected for statewide testing. MTD16005 was tested for three years at 15 locations across Montana to evaluate agronomics and quality traits were assessed by the USDA quality lab in Fargo. MTD16005 (F_{5:8}) was grown in the 2017 Montana intrastate durum trial at 9 locations. In 2018, MTD16005 (F_{5:9}) was grown at 8 MAES locations across Montana and 6 off-station locations, and again as F_{5:10} in 2019. MAES locations tested included Bozeman Post Agronomy Farm (irrigated and dryland), SARC (dryland), EARC (irrigated, dryland and 3 off-stations), WTARC (dryland), CARC (dryland), and NARC (dryland and 3 off-stations).

PURIFICATION OF SEED STOCK

In early 2014, a single F₄ head was harvested from the greenhouse and planted in a head-row in spring 2014. A single F₅ plant was selected and harvested by hand and threshed with a single plant thresher. In 2015, a F_{5:6} short row was harvested by binder and threshed with a Vogel for seed stock. In 2016, F_{5:7} plants were grown in a 4'x10' plot and harvested by plot combine. In 2017, F_{5:8} plants were grown in a 4'x10' plot and were harvested cleanly by plot combine from the 1st rep of the irrigated Bozeman location for seed. In 2018, F_{5:9} plants were grown in 4'x70' plot under dryland conditions to be used for seed increase. The rows were rogued for off types several times throughout the season and harvested cleanly using a plot combine. In 2019, a 0.3-acre field of F_{5:10} plants were planted from the 2018 seed increase. The field was rogued to eliminate off-types and the increase was harvested using a plot combine that was thoroughly cleaned before use. Approximately 25 bushels of F_{5:11} seed was delivered to the Foundation Seed Program for foundation planting in spring 2020.

AGRONOMIC CHARACTERISTICS

MTD16005 is a spring durum wheat (*Triticum turgidum* ssp. *durum*) developed at MSU that carries the *cdu1* allele for low cadmium accumulation in the grain as well as a null *ssIIa-B* allele that increases pasta firmness. MTD16005 is approximately 35 inches tall, similar to other full height durum varieties, has white glumes and awns, and has a heading date (June 28th) similar to Tioga and Divide, but two days later than Joppa and five days later than Alzada (Table 3). Under all locations and conditions (2017-19, 23 loc-year, no off-station) MTD16005 (74.8 bu/ac) yielded significantly more than the top grown cultivars Divide (72.7 bu/ac), Joppa (71.2 bu/ac), Tioga (72.1 bu/ac), and Alzada (66.0 bu/ac) (Tables 1 & 2). Under only dryland conditions (2017-19, 17 loc-year, no off-station) MTD16005 (61.0 bu/ac) yielded significantly higher than Divide (57.9 bu/ac), Joppa (57.3 bu/ac), Tioga (57.5 bu/ac), and Alzada (55.2 bu/ac) (Table 3). Averaged over EARC, WTARC, CARC, NARC dryland environments (2017-19, 12 loc-years, no off-station) MTD16005 was the highest yielding line (51.4 bu/ac) which was significantly higher than Divide (46.8 bu/ac), Joppa (46.3 bu/ac), Tioga (47.1 bu/ac), and Alzada (47.1 bu/ac) (Table 4). Over three years at EARC dryland (2017-19, no off-station) MTD16005 had an average yield (65.6 bu/ac) higher than Divide (61.5 bu/ac), Joppa (58.7 bu/ac), Tioga (63.6 bu/ac), and Alzada (57.5 bu/ac), however no significant differences were detected (Table 5). At CARC, NARC, and WTARC (2017-19, 9 loc-years, no off-station), MTD16005 was the second highest yielding line (46.6 bu/ac) which was significantly higher than Divide (42.0 bu/ac), Joppa (42.1 bu/ac), Tioga (41.7 bu/ac), and Alzada (43.6 bu/ac) (Table 6).

QUALITY CHARACTERISTICS

MTD16005 has grain protein, test weight, and individual kernel size comparable to the top grown cultivars Divide, Joppa, and Alzada (2017-19, 24 loc-years, Table 7). MTD16005 (5.0) has improved protein strength based on mixograph scores compared to Mountrail (3.1), but comparable to Divide (5.1) and lower than Joppa (5.9) and Alzada (6.9) (Table 8). Gluten index was measured in 2017 from Bozeman irrigated samples and MTD16005 (41.3) has a similar gluten index to Divide (43.8) that is higher than Mountrail (4.0) but not as high as Alzada (93.2). The average semolina yield of MTD16005 (61.7 %) falls within the range of currently grown cultivars as does its semolina brightness (L) and yellowness (b*) (L=84.7, b*=28.6) (Table 8). Semolina from MTD16005 had higher protein content (13.5%) than Divide, Joppa and Alzada

and an ash content similar to Divide and Joppa, but lower than Alzada (Table 8). In 2017, whole grain samples from EARC dryland experiments were evaluated for cadmium accumulation. Compared to lines with the high accumulation allele (avg=0.17 ppm) MTD16005 had half the amount of cadmium present (0.08ppm) as expected due to the presence of the low accumulation allele (Table 9).

DISEASE EVALUATIONS

MTD16005 was evaluated for resistance/susceptibility to stripe rust for two years at Mt. Vernon, WA and Pullman, WA. MTD16005 has a similar stripe rust reaction as the top grown cultivars, with high susceptibility at the seedling stage and adult plant resistance (Tables 10 & 11). Fusarium head blight susceptibility was evaluated for two years at EARC. MTD16005 performed similarly as the top grown cultivars in terms of severity, fusarium damaged kernels and DON (Table 12 & 13). MTD16005 was found to be resistant to leaf rust isolate PBJJG (Table 14) and very resistant to the most prevalent stem rust race in Montana TCMLK (Table 15). In 2019, MTD16005 was evaluated for leaf spot caused by naturally occurring *Stagonospora nodorum* and/or *Pyrenophora tritici-repentis* in Bozeman under irrigated and dryland conditions. In both environments MTD16005 had moderate resistance to leaf spots with more symptoms than Divide or Joppa, but significantly less than Alzada which was very susceptible (Table 16). Unrelated to plant disease, MTD16005 was also tested in Washington for tolerance to acidic soils and was determined to be as susceptible as currently grown varieties.

Table 1. 2018 Montana Cultivar share of planted acres³ (2018 USDA Durum Quality Report).

Cultivar	2018 % ¹	2016 % ¹
Joppa	37.6	1.8
Alzada	20.2	15.2
Tioga	13.5	8.6
Divide	11.8	27.1
Transcend	5.3	Na
Mountrail	5.3	20.7
Carpio	2.7	0.5
Kyle	1.1	5.9
Other ²	2.7	20.2

¹Percentage may not add to 100 due to rounding.

²Includes varieties with less than 1% of acreage in 2018 and unknown varieties.

³1,000 acres (1 acre = 0.405 hectares), 2018 = 840,000 acres, 2016 = 780,000 acres.

Table 2. Yield and protein evaluation from all statewide durum trials 24 location-years (2017-19).

Cultivar	-----Yield (bu/ac) ¹ -----				-----Protein (%) ² -----			
	3 year	2017	2018	2019	3 Year	2017	2018	2019
Mountrail	73.3	64.0	77.3	79.3*	14.5	14.5	14.5	14.5
Divide	72.7	66.5*	75.2	76.9	14.6	14.8	14.6	14.4
Alkabo	73.6	64.7	75.9	81.3*	14.2	14.2	14.2	14.1
Grenora	74.8*	66.4*	77.5	81.4*	14.4	14.4	14.4	14.5
Tioga	72.1	65.4	74.1	77.5	14.9	15.0	14.9	15.0
Carpio	72.9	67.0*	76.8	75.2	14.4	14.6	14.4	14.3
Joppa	71.2	63.9	73.6	76.7	14.3	14.3	14.3	14.4
Alzada	66.0	60.4	67.7	70.4	14.6	14.6	14.6	14.5
CDC-Dynamic	73.1	62.8	78.0	79.3*	15.6	16.1	15.5	15.1
CDC-Fortitude	71.9	62.1	78.2	76.0	15.2	15.5	15.0	14.9
CDC-Precision	73.8*	64.3	77.0	80.9*	15.2	15.4	15.1	15.0
CDC-Vivid	73.2	62.1	76.1	82.6*	15.4	15.4	15.4	15.1
MTD16001	76.4**	66.6*	83.0**	80.0*	14.0	14.4	13.8	13.7
MTD16002	73.1	66.3*	76.0	77.5	14.6	14.7	14.5	14.6
MTD16004	75.9*	68.8*	80.1*	79.3*	14.3	14.4	14.3	14.1
MTD16005	74.8*	65.4	76.0	84.3**	14.6	14.7	14.6	14.6
MTD16006	73.5	66.5*	77.6	76.9	14.5	14.6	14.5	14.5
MTD16007	74.9*	69.1*	77.0	79.0*	14.7	14.7	14.6	14.6
MTD16008	71.7	63.0	73.5	79.7*	14.7	14.5	15.0	14.6
MTD16009	69.1	61.9	73.3	72.6	15.4	15.5	15.4	15.2
MTD16010	71.6	64.9	74.8	75.7	14.9	15.0	14.9	14.9
MTD16011	72.9	66.4*	73.3	79.8*	14.6	14.9	14.6	14.3
Average	72.8	64.9	76.0	78.3	14.7	14.8	14.7	14.6
LSD (0.05)	2.7	3.3	4.7	5.3	0.3	0.4	0.4	0.5
Prob > F	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
CV (%)	6.3	5.2	6.2	6.4	2.9	3.0	2.8	2.8

¹Grain yield reported on a 13% moisture basis.

²Grain protein reported on a 12% moisture basis.

** Indicates highest yielding cultivar within a column.

* Indicates cultivars yielding equal to the highest yielding entry based on Fisher's Protected LSD at the 0.05 probability level.

Table 3. Agronomic evaluation from all dryland statewide durum trials 17 location-years (2017-19).

Cultivar	Yield bu/ac ¹	Protein % ²	Test	Plant	Heading Date	
			Weight lb/bu	Height inch	Julian	Calendar
Mountrail	59.2*	14.5	60.2	34.0	178.0	Jun 27 th
Divide	57.9	14.6	60.5	35.4	178.3	Jun 27 th
Alkabo	59.1*	14.2	61.0	33.6	177.1	Jun 26 th
Grenora	60.4*	14.4	60.3	32.4	176.6	Jun 26 th
Tioga	57.5	15.0	60.3	36.5	178.2	Jun 27 th
Carpio	57.5	14.5	59.9	34.2	179.1	Jun 28 th
Joppa	57.3	14.4	60.7	35.3	177.0	Jun 26 th
Alzada	55.2	14.6	60.4	28.4	174.2	Jun 23 rd
CDC-Dynamic	58.5*	15.7	60.0	34.6	179.3	Jun 28 th
CDC-Fortitude	58.0*	15.2	60.4	32.9	178.1	Jun 27 th
CDC-Precision	59.0*	15.2	60.5	34.3	177.4	Jun 26 th
CDC-Vivid	59.3*	15.4	60.6	34.6	178.0	Jun 27 th
MTD16001	61.5*	14.0	59.6	34.6	178.7	Jun 28 th
MTD16002	59.4*	14.5	60.0	36.3	180.3	Jun 29 th
MTD16004	61.6**	14.3	61.5	33.7	177.6	Jun 27 th
MTD16005	61.0*	14.6	59.8	35.2	178.9	Jun 28th
MTD16006	60.2*	14.5	60.6	36.2	177.9	Jun 27 th
MTD16007	60.7*	14.7	61.0	34.4	178.1	Jun 27 th
MTD16008	56.7	14.8	59.2	35.1	177.4	Jun 26 th
MTD16009	53.7	15.4	56.9	35.2	179.4	Jun 28 th
MTD16010	57.4	15.0	60.8	35.4	178.6	Jun 28 th
MTD16011	58.6	14.7	59.9	34.9	179.1	Jun 28 th
Average	58.6	14.7	60.2	34.4	178.1	Jun 27 th
LSD (0.05)	2.7	0.3	0.4	0.9	0.6	-
CV (%)	6.7	2.9	1.0	3.7	0.5	-
Prob > F	<0.001	<0.001	<0.001	<0.001	<0.001	-

¹Grain yield reported on a 13% moisture basis.

²Grain protein reported on a 12% moisture basis.

** Indicates highest yielding cultivar within a column.

* Indicates cultivars yielding equal to the highest yielding entry based on Fisher's Protected LSD at the 0.05 probability level.

Table 4. Yield evaluation of low yielding dryland locations 12 location-years (CARC, EARC, NARC, WTARC, 2017-19).

ID	Yield bu/ac	Protein %	Test weight lb/bu	Plant Height inch	Heading Date Julian
Mountrail	48.2	14.1	59.8	30.4	176.1
Divide	46.8	14.2	60.1	31.8	176.4
Alkabo	48.2	14.0	60.5	30.1	175.5
Grenora	50.3*	14.1	59.9	29.0	174.8
Tioga	47.1	14.7	59.8	33.0	176.2
Carpio	46.3	14.1	59.5	30.7	177.3
Joppa	46.3	14.1	60.4	31.7	175.3
Alzada	47.1	14.2	60.4	26.9	172.6
CDC-Dynamic	48.8*	15.2	59.8	31.3	177.5
CDC-Fortitude	48.0	14.7	60.1	29.7	176.2
CDC-Precision	48.2	14.8	60.2	30.8	175.4
CDC-Vivid	49.6*	15.0	60.2	31.0	176.4
MTD16001	49.7*	13.6	59.2	31.3	176.9
MTD16002	49.1*	14.2	59.6	32.8	178.6
MTD16004	49.6*	13.9	61.1	30.3	176.0
MTD16005	51.4**	14.1	59.6	31.8	177.0
MTD16006	49.4*	14.1	60.3	32.4	176.0
MTD16007	50.5*	14.3	60.6	31.1	176.0
MTD16008	45.8	14.5	59.0	31.3	175.5
MTD16009	44.1	15.0	56.5	31.8	177.5
MTD16010	47.5	14.7	60.3	31.7	176.8
MTD16011	48.7*	14.2	59.5	31.4	177.0
Average	48.2	14.4	59.8	31.0	176.2
LSD (0.05)	3.1	0.4	0.5	1.0	0.7
CV (%)	8.0	3.2	1.0	3.8	0.5
Prob > F	<0.001	<0.001	<0.001	<0.001	<0.001

¹Grain yield reported on a 13% moisture basis.

²Grain protein reported on a 12% moisture basis.

** Indicates highest yielding cultivar within a column.

* Indicates cultivars yielding equal to the highest yielding entry based on Fisher's Protected LSD at the 0.05 probability level.

Table 5. Yield evaluation from EARC dryland (2017-19).

Cultivar	-----Yield (bu/ac) ¹ -----			
	2017	2018	2019	3 year
Mountrail	44.6*	64.2*	81.5	63.4
Divide	40.4	62.7*	81.3	61.5
Alkabo	45.8*	60.4	92.6	66.3
Grenora	46.4*	65.9*	85.5	65.9
Tioga	45.3*	65.7*	79.7	63.6
Carpio	42.5	65.2*	68.8	58.8
Joppa	40.8	61.0	74.4	58.7
Alzada	42.7*	58.1	71.8	57.5
CDC-Dynamic	44.2*	66.5*	83.0	64.6
CDC-Fortitude	41.6	62.6*	84.3	62.8
CDC-Precision	42.4	62.4*	80.5	61.8
CDC-Vivid	44.8*	65.1*	94.9**	68.3**
MTD16001	45.3*	67.9**	69.2	60.8
MTD16002	45.5*	66.5*	89.5	67.2
MTD16004	46.3*	62.6*	78.9	62.6
MTD16005	42.9	60.0	93.8	65.6
MTD16006	42.8	58.8	78.7	60.1
MTD16007	45.3*	57.3	81.5	61.4
MTD16008	42.2	62.5*	82.5	62.4
MTD16009	41.7	59.9	76.6	59.4
MTD16010	48.3**	57.5	75.7	60.5
MTD16011	48.1*	58.1	86.7	64.3
Mean	44.1	62.3	81.4	62.6
LSD (0.05)	4.4	6.5	16.6	7.6
CV (%)	6.1	6.4	12.4	7.4
Prob > F	0.022	0.036	0.120	0.315

¹Grain yield reported on a 13% moisture basis.

** Indicates highest yielding cultivar within a column.

* Indicates cultivars yielding equal to the highest yielding entry based on Fisher's Protected LSD at the 0.05 probability level.

Table 6. Yield evaluation of North Central dryland locations 9 location-years (CARC, NARC, WTARC, 2017-19).

ID	Yield bu/ac	Protein %	Test weight lb/bu	Plant Height inch	Heading Date Julian
Mountrail	43.1	14.2	58.7	30.6	176.8
Divide	42.0	14.4	59.2	31.7	176.9
Alkabo	42.2	13.8	59.6	30.1	176.1
Grenora	45.1*	14.2	59.1	29.0	175.3
Tioga	41.7	14.6	58.8	33.2	176.8
Carpio	42.2	14.2	58.3	30.9	178.0
Joppa	42.1	14.2	59.4	31.7	175.8
Alzada	43.6	14.3	59.6	27.1	173.4
CDC-Dynamic	43.5	15.4	58.8	31.3	177.9
CDC-Fortitude	43.1	15.0	59.1	29.9	176.9
CDC-Precision	43.7*	15.0	59.2	30.8	175.6
CDC-Vivid	43.4	15.2	59.2	31.1	176.9
MTD16001	46.1*	13.7	58.2	31.3	177.8
MTD16002	43.1	14.3	58.6	33.0	179.4
MTD16004	45.3*	13.9	60.1	30.6	176.3
MTD16005	46.6*	14.4	58.7	32.2	177.6
MTD16006	45.8*	14.2	59.4	32.8	176.4
MTD16007	46.8**	14.5	59.7	31.4	176.4
MTD16008	40.2	14.5	58.0	31.6	176.0
MTD16009	39.0	15.2	55.4	31.8	178.4
MTD16010	43.2	14.7	59.3	31.8	177.4
MTD16011	43.5	14.3	58.6	31.5	177.6
Average	43.4	14.5	58.9	31.1	176.8
LSD (0.05)	3.2	0.4	0.6	1.1	0.9
CV (%)	8.0	2.6	1.1	3.8	0.5
Prob > F	<0.001	<0.001	<0.001	<0.001	<0.001

¹Grain yield reported on a 13% moisture basis.

²Grain protein reported on a 12% moisture basis.

** Indicates highest yielding cultivar within a column.

* Indicates cultivars yielding equal to the highest yielding entry based on Fisher's Protected LSD at the 0.05 probability level.

Table 7. Seed quality evaluation from 24 location-years (2017-19) (Dr. Linda Dykes, USDA-Fargo, ND).

Cultivar	Test weight lb/bu	Large seeds %	Small seeds %	Hardness index	Individual seed weight mg	Individual seed diameter mm	Grain protein 1%	Grain ash %	Falling number sec
Mountrail	60.2	44.9	15.5	74.5	40.3	2.8	14.5	1.46	430.5
Divide	60.8	58.1	11.4	73.7	41.6	2.8	14.6	1.41	420.9
Alkabo	61.3**	58.0	10.6	74.5	41.9	2.8	14.3	1.46	413.1
Grenora	60.4	58.1	10.6	76.8	41.9	2.8	14.4	1.50	425.4
Tioga	60.6	62.3	10.1	73.0*	42.8	2.9	15.0	1.49	412.7
Carpio	60.3	61.1	10.7	73.9	40.9	2.8	14.4	1.44	430.1
Joppa	61.0	56.9	11.6	76.2	41.4	2.8	14.4	1.46	420.1
Alzada	60.3	75.6**	5.5*	74.5	44.8**	3.0**	14.6	1.52	445.3
CDC-Dynamic	60.5	48.8	12.9	80.2	38.7	2.8	15.4	1.54	417.6
CDC-Fortitude	60.4	57.7	11.6	81.8	37.7	2.8	15.1	1.53	424.5
CDC-Precision	60.9	57.9	10.1	82.3	38.8	2.8	14.9	1.55**	446.0**
CDC-Vivid	60.9	62.1	9.7	78.5	40.0	2.8	15.5	1.49	415.1
MTD16001	59.7	49.0	14.5	77.0	40.1	2.8	14.0*	1.43	421.5
MTD16002	60.1	43.1*	15.9**	81.8	37.3	2.7	14.6	1.41	445.2
MTD16004	61.6	65.5	8.7	79.5	40.2	2.9	14.1	1.44	430.6
MTD16005	60.0	50.0	12.4	74.6	41.0	2.8	14.6	1.41*	433.4
MTD16006	60.8	66.2	8.5	74.9	43.6	2.9	14.4	1.47	421.5
MTD16007	61.1	54.4	11.2	77.7	39.3	2.8	14.6	1.45	418.2
MTD16008	59.4	65.5	8.6	73.4	42.8	2.9	14.7	1.48	435.5
MTD16009	57.0*	44.6	14.2	74.5	37.5	2.7	15.6**	1.51	410.5*
MTD16010	61.3	48.4	14.0	83.3**	37.2*	2.7*	14.9	1.48	445.9
MTD16011	59.9	44.8	14.0	75.0	40.2	2.7	14.7	1.41	436.0
Average	60.4	56	11.5	76.9	40.5	2.8	14.7	1.47	427.3
LSD (0.05)	0.4	4.0	1.8	1.3	0.9	0.0	0.3	0.03	12.8
Prob > F	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
CV (%)	1.1	12.6	28.0	3.0	3.9	2.0	3.4	3.8	5.3

¹Grain protein reported on a 12% moisture basis

²Grain ash reported on a 14% moisture basis

**highest value in column, *lowest value in column

Table 8. Semolina quality evaluation from 24 location-years (2017-19) (Dr. Linda Dykes, USDA-Fargo, ND).

Cultivar	Bran %	Shorts %	Semolina %	Semolina protein % ¹	Semolina ash % ¹	L	<i>b</i> *	<i>a</i> *	Mixograph pattern
Mountrail	27.7	10.1	62.2**	13.5	0.64	85.2	25.7	-2.7	3.1*
Divide	27.7	10.1	62.2	13.2	0.60	85.1	27.3	-2.9	5.1
Alkabo	27.9	10.3	61.7	13.0	0.59	85.1	29.5	-3.1	4.5
Grenora	28.7	10.5	60.8	13.2	0.63	85.1	28.9	-3.1	4.6
Tioga	27.7	10.1*	62.2	13.8	0.62	84.9	29.3	-3.1	6.0
Carpio	28.1	10.6	61.3	13.2	0.62	84.9	30.6	-3.4*	6.9**
Joppa	27.8	10.4	61.8	13.2	0.61	85.0	29.4	-3.1	6.0
Alzada	26.0*	11.8**	62.1	13.3	0.67**	84.2	30.8	-3.0	6.8
CDC-Dynamic	28.3	10.4	61.3	14.1	0.63	84.4	31.9	-3.2	5.6
CDC-Fortitude	29.7	10.7	59.6	13.8	0.64	84.6	31.6	-3.3	6.1
CDC-Precision	29.8	10.5	59.7	13.8	0.65	84.5	32.4**	-3.3	6.0
CDC-Vivid	27.6	11.0	61.3	14.0	0.65	84.1	31.8	-3.2	6.0
MTD16001	27.8	10.2	62.1	12.9*	0.58*	85.0	28.1	-3.0	4.8
MTD16002	28.8	10.6	60.5	13.5	0.59	84.8	27.5	-3.0	4.1
MTD16004	28.4	10.6	61.0	13.0	0.61	84.7	24.9	-2.5	4.4
MTD16005	27.6	10.7	61.7	13.5	0.60	84.7	28.6	-2.9	5.0
MTD16006	28.0	10.5	61.5	13.3	0.61	85.1	25.3	-2.6	4.8
MTD16007	28.8	10.3	60.9	13.3	0.62	85.3**	22.1*	-2.3	5.0
MTD16008	27.9	10.9	61.3	13.5	0.64	83.8*	26.6	-2.1**	4.5
MTD16009	30.6**	10.6	58.8*	14.4**	0.65	84.6	25.6	-2.5	5.0
MTD16010	28.1	10.5	61.4	13.8	0.60	84.9	26.5	-2.7	4.9
MTD16011	27.7	10.7	61.6	13.5	0.61	84.7	29.2	-2.9	5.0
Average	28.2	10.6	61.2	13.5	0.62	84.8	28.3	-2.9	5.2
LSD (0.05)	0.5	0.2	0.5	0.3	0.02	0.2	0.4	0.1	0.4
Prob > F	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

¹Reported on a 14% moisture basis

²Color measurements L=whiteness, b*=yellowness, a* =redness

**highest value in column, * lowest value in column

Table 9. Elemental Cadmium analysis of whole grain from EARC dryland 2017 (Univ. of Georgia).

ID	<i>Cdu1</i> ¹	Cd ²
Divide	High	0.17
MTD16001	High	0.12
MTD16002	Low	0.05
MTD16004	High	0.16
MTD16005	Low	0.08
MTD16006	Low	0.07
MTD16007	Low	0.09
MTD16008	Low	0.06
MTD16009	High	0.13
MTD16010	High	0.14
MTD16011	Low	0.07

¹*Cdu1* allele that confers high or low Cadmium accumulation.

²Cadmium ppm

European import standards are set to 0.2 ppm Cd

Table 10. Stripe Rust evaluation 2018 (Dr. Xianming Chen, USDA-Pullman, WA).

Location Date Feekes Cultivar	Pullman, WA		Mt. Vernon, WA			
	7/17		6/7		6/27	
	Fks 10.53		Fks 6		Fks 10.5	
	Infection type	Severity %	Infection type	Severity %	Infection type	Severity %
Mountrail	5	10	7	70	3	30
Divide	2	5	6	70	2	15
Alkabo	5	10	8	80	3	30
Grenora	5	10	8	80	2	20
Tioga	2	1	5	50	2	20
Carpio	2	2	5	50	2	15
Joppa	3	10	8	80	5	30
Alzada	2	5	7	50	2	15
CDC-Dynamic	2	5	5	50	3	20
CDC-Fortitude	3	5	7	50	2	20
CDC-Precision	3	5	5	50	2	20
CDC-Vivid	2	2	7	70	2	10
MT112219	5	10	7	40	2	15
MTD16001	2	5	5	50	2	10
MTD16002	2	1	5	50	2	20
MTD16003	5	5	5	60	2	15
MTD16004	2	5	5	50	2	15
MTD16005	2	10	7	70	3	20
MTD16006	2	5	7	70	3	20
MTD16007	2	1	5	50	2	20
MTD16008	2	5	7	60	3	30
MTD16009	3	5	5	50	3	30
MTD16010	2	5	5	50	3	20
MTD16011	2	5	7	50	3	20
Check	8	100	8	90	8	100

^aInfection Type (IT) was recorded based on the 0-9 scale with ITs 8 and 9 combined as 8 (the most susceptible reaction) in field data. Generally, IT 0-3 are considered resistant, 4-6 intermediate, and 7-9 susceptible.

^bEntries with a high IT in the first note, but a low IT in the second note at Mt. Vernon may indicate that they have high-temperature, adult-plant (HTAP) resistance.

^cFeekes scale of wheat growth stage.

Table 11. Stripe Rust evaluation 2019 (Dr. Xianming Chen, USDA-Pullman, WA).

Location Date Feekes ^c Cultivar	Pullman, WA 7/17 Fks 10.53		Mt. Vernon, WA ^b			
	Infection type ^a	Severity %	6/7 Fks 6		6/27 Fks 10.5	
			Infection type ^a	Severity %	Infection type ^a	Severity %
Mountrail	5	15	8	100	3	30
Divide	5	10	5	40	2	15
Alkabo	5	25	8	80	5	40
Grenora	5	15	8	80	2	20
Tioga	5	10	5	40	2	20
Carpio	5	10	5	40	2	20
Joppa	5	15	8	100	5	40
Alzada	5	10	5	40	2,8	5,80
CDC-Dynamic	5	10	5	40	3	30
CDC-Fortitude	5	10	5	40	2	20
CDC-Precision	5	10	5	40	2	20
CDC-Vivid	5	10	8	100	2	15
MT112219	5	15	3	30	2	20
MTD16001	5	5	5	40	3	30
MTD16002	5	10	5	50	2	20
MTD16003	5	15	8	100	3	30
MTD16004	5	10	5	40	2	20
MTD16005	5	10	5	40	3	30
MTD16006	5	5	5	40	2	20
MTD16007	5	5	5	40	2	20
MTD16008	5	15	5	40	3	30
MTD16009	5	10	8	60	3	20
MTD16010	5	10	5	40	3	20
MTD16011	5	10	5	40	3	30
Check	8	100	8	100	8	100

^aInfection Type (IT) was recorded based on the 0-9 scale with ITs 8 and 9 combined as 8 (the most susceptible reaction) in field data. Generally, IT 0-3 are considered resistant, 4-6 intermediate, and 7-9 susceptible.

^bEntries with a high IT in the first note, but a low IT in the second note at Mt. Vernon may indicate that they have high-temperature, adult-plant (HTAP) resistance.

^cFeekes scale of wheat growth stage.

Table 12: Fusarium head blight evaluation 2018 (Dr. Frankie Crutcher, EARC).

Cultivar	^a Incidence (%)	^b Severity (%)	^c % FDK	^d DON (ppm)	Yield (lb/A)
Alkabo	30.00 C	2.50 D	9.58 BCD	0.30 F	35.90 AB
Alzada	41.00 ABC	4.30 CD	13.33 ABCD	1.10 DEF	26.70 AB
Carpio	34.00 BC	2.80 CD	16.25 ABC	0.90 DEF	22.89 B
Divide	40.00 BC	3.55 CD	12.08 ABCD	1.25 DEF	38.24 AB
CDC-Dynamic	63.00 A	6.15 ABCD	9.58 BCD	2.25 ABCDE	45.01 A
CDC-Fortitude	43.00 ABC	5.50 BCD	12.08 ABCD	1.95 BCDEF	30.68 AB
Grenora	36.00 BC	2.65 CD	10.83 ABCD	1.10 DEF	43.51 A
Joppa	41.00 ABC	4.50 CD	9.17 BCD	0.95 DEF	28.38 AB
Mountrail	30.00 C	4.15 CD	10.00 ABCD	2.00 ABCDEF	35.87 AB
MT112219	35.00 BC	3.70 CD	11.25 ABCD	2.75 ABCD	40.88 AB
MTD16001	40.00 BC	4.05 CD	6.67 D	1.10 DEF	30.76 AB
MTD16002	43.00 ABC	9.25 AB	16.67 ABC	3.45 ABC	36.56 AB
MTD16003	32.00 C	2.70 CD	9.58 BCD	0.95 DEF	30.26 AB
MTD16004	52.00 ABC	5.05 BCD	10.42 ABCD	1.20 DEF	42.64 A
MTD16005	46.00 ABC	4.45 CD	16.25 ABC	1.95 BCDEF	41.56 AB
MTD16006	48.00 ABC	7.30 ABC	12.92 ABCD	2.20 ABCDE	32.89 AB
MTD16007	44.00 ABC	5.00 BCD	8.33 CD	1.10 DEF	40.94 AB
MTD16008	45.00 ABC	5.10 BCD	15.42 ABCD	0.80 EF	39.61 AB
MTD16009	33.00 C	4.75 BCD	17.08 ABC	1.50 DEF	31.80 AB
MTD16010	56.00 AB	10.55 A	17.50 AB	3.85 A	39.35 AB
MTD16011	44.00 ABC	4.10 CD	11.67 ABCD	1.80 BCDEF	35.55 AB
CDC-Precision	48.00 ABC	4.40 CD	18.75 A	1.60 CDEF	39.90 AB
Tioga	37.00 BC	3.75 CD	14.12 ABCD	2.75 ABCD	41.41 AB
CDC-Vivid	48.00 ABC	5.95 ABCD	15.42 ABCD	36.0 AB	30.13 AB
Mean	42.04	4.84	12.71	1.77	35.77
CV (%)	26.56	52.10	35.52	1.88	24.42
LSD (0.05)	22.27	4.70	8.93	64.56	18.90

Letters in common did not differ significantly according to a t-test at a significance level of 5%.

^aPest Incidence: Percent of 50 plants with FHB.

^bPest Severity: Average percent area of 50 plants covered by disease.

^cFusarium Diseased Kernels.

^dConcentration of DON (vomitoxin) in ppm.

Table 13: Fusarium head blight evaluation 2019 (Dr. Frankie Crutcher, EARC).

Cultivar	Severity(%) ^a 7/21	Incidence(%) ^b 7/21	Severity(%) ^a 7/30	Incidence(%) ^b 7/30	% FDK ^c	Yield (Bu/A)	DON (ppm) ^d
Alkabo	10.41 BC	86.67 AB	64.00 A-C	100.00 A	12.50 DE	36.83 E-I	9.0 D
Alzada	36.83 A	98.33 A	70.33 A	100.00 A	22.50 B	15.21 J	16.2 A-D
Carpio	9.08 C	71.67 B	43.17 FG	100.00 A	20.00 BC	51.99 A	13.1 A-D
Divide	11.08 BC	86.67 AB	46.83 D-G	98.33 AB	15.00 C-E	50.39 AB	12.0 A-D
CDC-Dynamic	22.08 B	93.33 A	53.83 B-F	100.00 A	15.00 C-E	41.41 A-H	20.0 AB
CDC-Fortitude	15.42 BC	91.67 A	61.17 A-E	100.00 A	12.50 DE	31.28 HI	17.5 A-D
Grano	20.83 BC	100.00 A	55.17 A-F	100.00 A	15.00 C-E	39.98 B-H	20.6 AB
Grenora	13.83 BC	93.33 A	47.17 D-G	100.00 A	15.00 C-E	40.96 A-H	12.3 A-D
Joppa	10.50 BC	86.67 AB	45.17 E-G	96.67 B	15.00 C-E	45.07 A-F	13.0 A-D
Mountrail	12.25 BC	86.67 AB	55.33 A-F	98.33 AB	15.00 C-E	40.18 B-H	14.7 A-D
MTD16001	12.92 BC	90.00 A	42.67 FG	98.33 AB	17.50 B-D	49.38 A-C	13.9 A-D
MTD16002	17.25 BC	98.33 A	60.00 A-E	100.00 A	12.50 DE	38.32 C-I	13.4 A-D
MTD16004	17.67 BC	100.00 A	64.00 A-C	100.00 A	15.00 C-E	36.00 E-I	14.7 A-D
MTD16005	17.67 BC	96.67 A	64.33 A-C	98.33 AB	20.00 BC	39.50 B-I	17.7 A-D
MTD16006	18.67 BC	98.33 A	68.33 AB	100.00 A	17.50 B-D	34.40 F-I	21.8 A
MTD16007	21.67 BC	100.00 A	57.33 A-F	100.00 A	20.00 BC	41.26 A-H	21.4 AB
MTD16008	19.25 BC	96.67 A	64.83 A-C	100.00 A	35.00 A	29.72 HI	16.4 A-D
MTD16009	20.75 BC	98.33 A	69.83 AB	100.00 A	22.50 B	27.89 HI	16.3 A-D
MTD16010	19.50 BC	93.33 A	57.50 A-F	98.33 AB	17.50 B-D	33.01 G-I	16.7 A-D
MTD16011	18.08 BC	98.33 A	61.63 A-D	100.00 A	17.50 B-D	36.14 E-I	19.5 A-C
CDC-Precision	15.00 BC	95.00 A	50.33 C-G	100.00 A	8.00 E	43.82 A-G	9.8 CD
Riveland	11.00 BC	85.00 AB	34.00 G	98.33 AB	9.00 E	46.37 A-E	14.0 A-D
Tioga	15.25 BC	95.00 A	49.50 C-G	98.33 AB	22.50 B	49.24 A-D	11.7 B-D
CDC-Vivid	12.67 BC	83.33 AB	42.83 FG	96.67 B	11.50 DE	37.61 D-I	12.9
Mean	16.65	92.64	55.39	99.24	16.81	40.00	15.4
CV (%)	43.71	9.73	20.44	1.59	36.00	23.33	32.0
LSD (0.05)	12.9	16.9	16.4	3.3	7.4	11.7	9.9

Letters in common did not differ significantly according to a t-test at a significance level of 5%.

^aPest Severity: Average percent area of head covered by disease. Thirty heads were evaluated for each plot.

^bPest Incidence: Percent of thirty plants per plot that had visible FHB symptoms.

^cFusarium diseased kernels.

^dConcentration of DON (vomitoxin) in ppm.

Table 14. Leaf rust evaluation 2018 (Dr. Li Huang, MSU).

Cultivar	Infection type ^a	Score
Mountrail	1 -	R
Divide	1 -	R
Alkabo	2+ 3	S
Grenora	3	S
Tioga	3 2	S
Carpio	3	S
Joppa	1 =	R
Alzada	2 3	S
CDC-Dynamic	1+ 2	MR
CDC-Fortitude	2+ 3	S
CDC-Precision	1-	R
CDC-Vivid	1+ 2	MR
MT112219	1 =	R
MTD16001	; 1 =	R
MTD16002	; 1 =	R
MTD16003	1 =	R
MTD16004	; 1 =	R
MTD16005	; 1 =	R
MTD16006	1	R
MTD16007	1 -	R
MTD16008	; 1 =	R
MTD16009	1 =	R
MTD16010	1 =	R
MTD16011	1 = 2	R/MR
Fielder	3	S

Inoculated with rust isolate PBJJG on 4/3/18 scored 4/11/18.

^a0=immune, ;=Very Resistant, 1=Resistant, 2=Moderately resistant, 3=Moderately susceptible, 4=Susceptible.

Table 15. Stem rust evaluation 2018 (Dr. Li Huang, MSU).

Cultivar	Infection type ^a	Score
Mountrail	;	R
Divide	;	R
Alkabo	;	R
Grenora	; 1= C	R
Tioga	; C++	R
Carpio	;	R
Joppa	; C	R
Alzada	; 1= C+	R
CDC-Dynamic	1= C++	R
CDC-Fortitude	1=C++	R
CDC-Precision	1= C+	R
CDC-Vivid	; 1= C	R
MT112219	; C	R
MTD16001	;	R
MTD16002	;	R
MTD16003	; C	R
MTD16004	;	R
MTD16005	;	R
MTD16006	;1= C-	R
MTD16007	; 1= C	R
MTD16008	1 C+	R
MTD16009	;	R
MTD16010	;	R
MTD16011	; 1= C+	R
Alpowa	3+	S

Inoculated with rust isolate TMLKC on 7/16/18 scored 7/30/18.

^a0=immune, ;=Very Resistant, 1=Resistant, 2=Moderately resistant, 3=Moderately susceptible, 4=Susceptible.

Table 16. Leaf spot evaluation 2019 irrigated and dryland at the Post Agronomy Farm in Bozeman, MT.

Cultivar	Dryland Leaf Spot 1-5 ⁴	Irrigated Leaf Spot 1-5 ⁴
Mountrail	0.0	0.4
Divide	0.0	0.0
Alkabo	0.0	0.0
Grenora	0.0	0.0
Tioga	0.0	0.0
Carpio	0.3	0.0
Joppa	0.0	0.6
Riveland	0.0	0.0
Grano	0.0	0.0
Alzada	4.0	4.3
CDC-Dynamic	0.0	0.0
CDC-Fortitude	3.0	3.3
CDC-Precision	0.7	1.3
CDC-Vivid	1.0	2.7
MT112219	4.0	1.3
MTD16001	0.0	0.0
MTD16002	1.7	1.9
MTD16003	0.0	0.0
MTD16004	4.0	4.1
MTD16005	1.7	2.1
MTD16006	0.7	0.0
MTD16007	4.0	4.8
MTD16008	1.3	0.2
MTD16009	0.3	0.0
MTD16010	0.3	0.5
MTD16011	2.0	1.8
Average	1.1	0.7
LSD (0.05)	0.9	0.4
Prob > F	<0.001	<0.001
CV (%)	50.6	90.6
Lattice RE (%) ³	100.0	102.4

¹ Leaf spot disease assessed using a severity scale of 0-5, with 0 have no visible leaf spot symptoms, 1 =10 %, 2=25%, 3=50%, 4=75% and 5 having 100% of upper canopy leaves having symptoms.