**Development of the Wheat Practical Haplotype Graph Database as a Resource for Genotyping Data Storage and Genotype Imputation**

Katherine W. Jordan1,2#, Peter J. Bradbury3, Zachary R. Miller4, Moses Nyine1, Fei He1, Max Fraser5, Jim Anderson5, Esten Mason6, Andrew Katz6, Stephen Pearce6, Arron H. Carter7, Samuel Prather7, Michael Pumphrey7, Jianli Chen8, Jason Cook9, Shuyu Liu10, Jackie C. Rudd10, Zhen Wang10, Chenggen Chu10, Amir M. H. Ibrahim10, Jonathan Turkus11, Eric Olson11, Ragupathi Nagarajan12, Brett Carver12, Liuling Yan12, Ellie Taagen4, Mark Sorrells4, Brian Ward13, Jie Ren1,14, Alina Akhunova1,14, Guihua Bai2, Robert Bowden2, Jason Fiedler15, Justin Faris15, Jorge Dubcovsky16, Mary Guttieri2, Gina Brown-Guedira13, Ed Buckler3, Jean-Luc Jannink3, Eduard D. Akhunov1\*

Supplementary Material. Figures S1 and S2; Tables S1-S7.



**Figure S1.** The PHG construction workflow.



**Figure S2.** Imputation Accuracy Estimates of DS75 Wheat Accessions. a) Relationship between imputation accuracy in DS75 wheat accessions performed using the Wheat PHG and Beagle and varying depths of sequence read coverage. The sequence data were generated using exome capture (EC). Lines in blue show results for wheat lines not included into the PHG database; orange lines correspond to imputation accuracy obtained for four wheat lines included into the PHG database; the red line represents accuracy of imputation for cultivar Jagger. b) Imputation accuracy estimates for individual wheat chromosomes in cv. Jagger with PHG and Beagle imputation at 0.01x coverage.

**Table S1.** **Dataset Summary for Wheat PHG**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Dataset** | **Population Size** | **Technology** | **Reads** | **Process Used** | **Target Size** |  **Coverage** |
| **WC65** | 65 | Exome Capture | 2 x 150 | PHG Database Creation | 170Mb | 30x |
| **DS75** | 75 | Exome Capture | 2 x 150 | Imputation Testing | 170Mb | 0.5x,0.1x,0.01x |
| **GBS70** | 70 | GBS | 1x 100 | Imputation Testing | 196Mb | 1x, 2.5x |
| **NAMgbs** | 2100 | GBS | 1x 100 | Imputation Testing | 196Mb | 1x |
| **NAMskim** | 24 | Skim-seq | 2x 150 | Imputation Testing | 16Gb | 0.1x |

**Table S2. Wheat lines used for the Wheat PHG construction.**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Collection/Use** | **Accession\*** | **Collection** | **Mapping Program** | **NGSC PI#** | **Origin** | **Description** |
| **WC65/Exome Capture/Database Creation** | 26R61 | WheatCap | Arkansas | PI 612153 | Indiana, Pioneer | soft red winter wheat |
| AGS2000 | WheatCap | Arkansas | PI 612956 | Georgia | soft red winter wheat |
| CO940610\* | WheatCap | Colorado State | GSTR 10702 | Colorado | hard winter wheat |
| Platte\* | WheatCap | Colorado State | PI 596297 | Kansas | hard white winter wheat |
| OPATA | WheatCap | Cornell | PI 591776 | CIMMYT | spring wheat |
| W7984 (M6) | WheatCap | Cornell | NA | CIMMYT  | synthetic spring wheat |
| Brundage | WheatCap | Idaho | PI599193, GSTR 13701 | Idaho | soft white winter wheat |
| Langdon | WheatCap | Idaho | Cltr 13165 | North Dakota  | *T. durum* |
| SY\_Capstone | WheatCap | Idaho | PI 665404 | Colorado | hard white spring wheat |
| UI\_Platinum | WheatCap | Idaho | PI 672533 | Idaho | hard white spring wheat |
| N87 | WheatCap | Idaho | NA | Idaho | hard spring wheat |
| MN10201-4-116 | WheatCap | Minnesota | NA | Minnesota | hard red spring wheat |
| MN98550-5 | WheatCap | Minnesota | PI 660540 | Minnesota | hard red spring wheat |
| MN99294-1 | WheatCap | Minnesota | NA | Minnesota | hard red spring wheat |
| Prosper | WheatCap | Minnesota | PI 662387 | North Dakota  | hard red spring wheat |
| Shelly | WheatCap | Minnesota | PI 681618 | Minnesota | hard red spring wheat |
| Choteau | WheatCap | Montana State University | PI 633974 | Montana | hard red spring wheat |
| CONAN | WheatCap | Montana State University | PI 607549 | North Dakota  | hard red spring wheat |
| Hank | WheatCap | MSU | PI 613585 | WestBred | hard red spring wheat |
| LA95135 | WheatCap | NCSU | PI 655291 | Lousiana | soft red winter wheat |
| SS\_MPV57 | WheatCap | NCSU |  | Virginia | soft red winter wheat |
| BEN | WheatCap | NDSU |  | North Dakota  | *T. durum* |
| PI41025 | WheatCap | NDSU | PI 41025 | Russia | *T. dicoccum* |
| Cheyenne\* | WheatCap | Nebraka Lincoln | PI 192268 | Nebraska | hard red winter wheat |
| Billings\* | WheatCap | OKSU | PI 656843 | Oklahoma | hard red winter wheat |
| Duster\* | WheatCap | OKSU, Great Plains | PI 644016 | Oklahoma | hard red winter wheat |
| TA1615 | WheatCap | SDSU | NA | WGRC | *Ae. tauschii* |
| TA1662 | WheatCap | SDSU | PI603230 |  | *Ae. tauschii* |
| TA1718 | WheatCap | SDSU | NA | WGRC | *Ae. tauschii* |
| CO960293\* | WheatCap | TAMU | NA | Colorado | hard red winter wheat |
| TAM111\* | WheatCap | TAMU | PI 631352 | Texas | hard red winter wheat |
| Berkut | WheatCap | CIMMT |  | CIMMYT | spring wheat |
| CAP2 | WheatCap | none | PI 610750 | CIMMYT | hard winter wheat |
| RAC875 | WheatCap | Australia |  | Australia | spring wheat |
| RioBlanco\* | WheatCap | UCDavis | PI531244 | Kansas | hard whitewinter wheat |
| Inayama | SWNAM | KSU | PI 382150 | Japan | spring wheat |
| Bakahtawar94 | WheatCap | none |  | Afghanistan | spring wheat |
| LCS\_Star | WheatCap | none | PI673945 | Minnesota Limagrain | hard white spring wheat |
| Overley\* | WheatCap | USDA HWWGRU -KSU | PI 634974 | Kansas | hard red winter wheat |
| PI634974 | WheatCap | USDA HWWGRU -KSU | PI 634974 | Kansas | hard winter wheat |
| Overland\* | WheatCap | USDA HWWGRU -KSU | PI 647959 | Nebraska | hard winter wheat |
| Lyman\* | WheatCap | USDA HWWGRU -KSU | PI 658067 | South Dakota | hard red winter wheat |
| Kelse | WheatCap | WSU | PI653842 | Washington | hard red spring wheat |
| Scarlet | WheatCap | WSU | PI 601814 | Washington | hard red spring wheat |
| Altamo | WheatCap | none |  |  | hard spring wheat |
| CCW3A37 | WheatCap | none |  | Nebraska, chr 3A substitution line | hard winter wheat |
| CCW3A49 | WheatCap | none |  | Nebraska, chr 3A substitution line | hard winter wheat |
| Dayn | WheatCap | KSU | PI666941 | Washington | hard white spring |
| IDO444 | WheatCap | none | GSTR 12902 | Idaho | hard winter wheat |
| KS05HW14-3\* | WheatCap | KSU |  | Kansas | hard winter wheat |
| TAM112\* | WheatCap | TAMU | PI 643143 | Texas | hard winter wheat |
| 2045A  | SWNAM | NSGC | PI 349512 | Switzerland |  spring wheat landrace |
| DharwarDry | SWNAM | none | GSTR 14702 | India | spring wheat cultivar |
| PBW343 | SWNAM | none | GSTR 15234 | India | spring wheat cultivar |
| Camelot\* | Breeding Line | Great Plains | PI 653832 | Nebraska | hard red winter wheat |
| Jagalene\* | Breeding Line | Great Plains | PI 631376 | Texas | hard red winter wheat |
| KanMark\* | Breeding Line | Great Plains | PI675456 | Kansas | hard red winter wheat |
| NuPlains\* | Breeding Line | Great Plains | PI 605741 | Nebraska | hard white winter wheat |
| Excalibur | Breeding Line | none | PI 572701 | Australia | spring wheat |
| KS061193K-2\* | Breeding Line | USDA HWWGRU -KSU | PI690435/BobDole | Kansas | hard red winter wheat |
| KS090387K-20\* | Breeding Line | USDA HWWGRU -KSU |  | Kansas | hard red winter wheat |
| WB-Redhawk\* | Breeding Line | USDA HWWGRU -KSU | PI665063 | Kansas | hard red winter wheat |
| Zenda\* | Breeding Line | USDA HWWGRU -KSU | PI 683512 | Kansas | hard red winter wheat |
| MOUNTRAIL | Breeding Line | USDA, NDSU | PI 607540 | North Dakota  | *T. durum* |
| MTHW0202 | Breeding Line | USDA, NDSU |   | North Dakota  | spring wheat |

\* lines used in winter wheat IBD analysis

**Table S2 continued. Wheat lines used for PHG Imputation Testing - Exome Capture**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Collection/Use** | **Accession\*\*** | **NGSC PI#** | **Origin** | **Description** |
| **DS75/Exome Capture/Imputation Testing** | Alice | PI644223 | South Dakota | hard white winter wheat |
| Antero | PI667743 | Colorado | hard white winter wheat |
| ARTHUR | Cltr14425 | Indiana | soft red winter wheat |
| BESS | PI642794 | Missouri | soft red winter wheat |
| Bolles | PI678430 | Minnesota | hard red spring wheat |
| BRANSON | PI639227 | Ohio | soft red winter wheat |
| BrawlCLPlus |  |  | hard red winter wheat |
| Byrd | PI664257 | Colorado | hard red winter wheat |
| Camelot | PI653832 | Nebraska | hard red winter wheat |
| Danby | PI648010 | Kansas | hard white winter wheat |
| Decade | PI660291 | Montana | hard red winter wheat |
| Denali | PI664256 | Colorado | hard red winter wheat |
| DoubleCL |  |  | hard red winter wheat |
| **Duster\*\*** | PI 644016 | Oklahoma | hard red winter wheat |
| Expedition | PI 629060 | South Dakota | hard red winter wheat |
| Forefront | PI 664483 | South Dakota | hard red spring wheat |
| Freeman | PI667038 | Nebraska | hard red winter wheat |
| Gallagher | PI667569 | Oklahoma | hard red winter wheat |
| GLACIER | PI555586 | Wisconsin | soft red winter wheat |
| Goodstreak | PI 632434 | Nebraska | hard red winter wheat |
| Hatcher | PI638512 | Colorado | hard red winter wheat |
| HILLIARD | PI676271 | Virginia | soft red winter wheat |
| HUNTER | PI468977 | South Carolina, Coker | winter wheat |
| Ideal | SD05118-1 | South Dakota | hard winter wheat |
| Jagalene | PI631376 | Texas | hard red winter wheat |
| Jagger | PI 593688 | Kansas | hard red winter wheat |
| JAMESTOWN | PI653731 | Virginia | soft red winter wheat |
| Jerry | PI632433 | North Dakota | hard red winter wheat |
| KanMark | PI675456 | Kansas | hard red winter wheat |
| Kharkof | PI11603 | Kansas | hard red winter wheat |
| KS061193K-2 | PI690435/BobDole | Kansas | hard red winter wheat |
| KS090387K-20 | NA | Kansas | hard red winter wheat |
| KS13H-9 | NA | Kansas | hard red winter wheat |
| KS14H-180-4 | NA | Kansas | hard red winter wheat |
| LCSChrome |  | Kansas | hard red winter wheat |
| Linkert | PI672164 | Minnesota | hard red spring wheat |
| Lonerider | PI686436 | Oklahoma | hard red winter wheat |
| Mace | PI651043 | Nebraska | hard red winter wheat |
| Mattern | PI665947 | Nebraska | hard winter wheat |
| McGill | PI 659689 | Nebraska | hard red winter wheat |
| Millenium |  |  |   |
| Mott | PI658542 | North Dakota | hard red spring wheat |
| NE10589 | PI675998 | Nebraska | hard red winter wheat |
| **NuPlains\*\*** | PI 605741 | Nebraska | hard white winter wheat |
| NW13493 |  |  |   |
| Oahe | PI684669 | South Dakota |   |
| OK11709W-139122-1W |  | Oklahoma |   |
| OK11D25056 |  | Oklahoma |   |
| OK12716Red | PI690085/Showdown | Oklahoma | hard red winter wheat |
| OK13209 | PI690086/Green Hammer | Oklahoma | hard red winter wheat |
| OK13621 | PI690087/Baker's Ann | Oklahoma | hard red winter wheat |
| **Overley\*\*** | PI 634974 | Kansas | hard red winter wheat |
| Panhandle | PI670462 | Nebraska | hard red winter wheat |
| PEMBROKE | PI675564 | Kentucky | soft red winter wheat |
| Prevail | PI672486 | South Dakota | hard red spring wheat |
| Redfield | PI673131 | South Dakota |   |
| Robidoux | PI 659690 | Nebraska | hard red winter wheat |
| Royal | PI351815 | Illinois | soft red winter wheat |
| Scout66 | Cltr 13996 | Nebraska | hard red winter wheat |
| SD08080 |  |  |   |
| Snowmass | PI658597 | Colorado | hard white winter wheat |
| TAM114 |  | Texas | hard red winter wheat |
| TAM203 |  | Texas | hard red winter wheat |
| TAM204 |  | Texas | hard red winter wheat |
| TAM303 | TX98D1170 | Texas | hard red winter wheat |
| TAM304 |  | Texas | hard red winter wheat |
| TAM305 |  | Texas | hard red winter wheat |
| Traverse | PI 642780 | South Dakota | hard red spring wheat |
| TRIBUTE | PI632689 | Viriginia | soft red winter wheat |
| TX11A001295 |  | Texas | hard red winter wheat |
| TX12M4068 |  | Texas | hard red winter wheat |
| WB-Redhawk | PI665063 | Kansas | hard red winter wheat |
| Wesley | PI 605742 | Nebraska | hard red winter wheat |
| Yellowstone | PI 643428 | Montana | hard red winter wheat |
| **Zenda\*\*** | PI 683512 | Kansas | hard red winter wheat |

\*\* lines used in database construction

**Table S2 continued. Wheat lines used for PHG Imputation Testing – GBS**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Collection/Use** | **Accession** | **NGSC PI#** | **Origin** | **Description** |
| **GBS70/Imputation Testing** | ARTHUR | Cltr 14425 | Purdue | Soft Red winter |
| BESS | PI 642794 | Univ. of Missouri | Soft Red winter |
| BLUEBOY | CItr 14031 | NCSU | Soft Red winter |
| BRANSON | PI 639227 | Ohio State Univ. | Soft Red winter |
| CALDWELL | Cltr 17897 | Purdue | Soft Red winter |
| CALEDONIA | PI 610188 | Cornell | Soft White winter |
| CLARK | PI 512337 | Purdue | Soft Red winter |
| COKER68-15 | CItr 15291 | Coker - South Carolina | Soft Red winter |
| COKER9663 | PI 596345 | Coker - Arkansas | Soft Red winter |
| FL302 | Cltr 17855 | Univ. of Florida | Soft Red winter |
| FOSTER | PI 593689 | Univ. of Kentucky | Soft Red winter |
| FREEDOM | PI 562382 | Ohio State Univ. | Soft Red winter |
| FULTZ | PI 5493 | Landrace - Pennsylvania | Soft Red winter |
| GLACIER | PI 555586 | Univ of Wisonsin | Soft Red winter |
| HART | CItr 17426 | Univ. of Missouri | Soft Red winter |
| HILLIARD | PI 676271 | Virginia Tech | Soft Red winter |
| HOLLEY | CItr 14579 | Univ. of Georgia | Soft Red winter |
| HOWELL | PI 552816 | Univ. of Illinois | Soft Red winter |
| HUNTER | PI468977 | Coker - South Carolina | winter wheat |
| IL00-8061 | NA | Univ. of Illinois | Soft Red winter |
| IL00-8530 | NA | Univ. of Illinois | Soft Red winter |
| IL02-18228 | NA | Univ. of Illinois | Soft Red winter |
| IL07-20728 | NA | Univ. of Illinois | Soft Red winter |
| IL07-4415 | NA | Univ. of Illinois | Soft Red winter |
| IL96-6472 | NA | Univ. of Illinois | Soft Red winter |
| INW0316 | NA | Purdue | Soft Red winter |
| JAMESTOWN | PI 653731 | Virginia Tech | Soft Red winter |
| MASSEY | CItr 17953 | Virginia Tech | Soft Red winter |
| MCCORMICK | PI 632691 | Virginia Tech | Soft Red winter |
| MEDITERRANEAN | CItr 5303 | Landrace - Missouri | Soft Red winter |
| NC05-19896 | NA | NCSU | Soft Red winter |
| NC07-24-337 | NA | NCSU | Soft Red winter |
| NC09-20986 | NA | NCSU | Soft Red winter |
| NC11-22289 | NA | NCSU | Soft Red winter |
| NC11-331-6 | NA | NCSU | Soft Red winter |
| NC8248-20 | NA | NCSU | Soft Red winter |
| NC-NEUSE | PI 633037 | NCSU | Soft Red winter |
| OAKES | PI 658040 | Univ. of Arkansas | Soft Red winter |
| OGLETHORPE | PI 657986 | Univ. of Georgia |  winter |
| PEMBROKE | NA | Univ. of Kentucky | Soft Red winter |
| PIONEER-25R55 | PI 532914 | Pioneer  | Soft Red winter |
| PIONEER-25R80 | PI 561198 | Pioneer  | Soft Red winter |
| PURPLESTRAW | PI500000 | Landrace - Southeaset |  winter |
| RED-MAY | CItr 5336 | Landrace | Soft Red winter |
| ROANE | PI 612958 | Virginia Tech | Soft Red winter |
| ROYAL | PI 351815 | Univ. of Illinois | Soft Red winter |
| SALUDA | PI 480474 | Virginia Tech | Soft Red winter |
| SHIRLEY | PI 656753 | Virginia Tech | Soft Red winter |
| SS8641 | PI 652450 | Univ. of Georgia | Soft Red winter |
| TRIBUTE | PI 632689 | Virginia Tech | Soft Red winter |
| VA12W-241 | NA | Virginia Tech | Soft Red winter |
| PI 192569 | PI 192569 | Sweden | spring landrace |
| PI 565213 | PI 565213 | Bolivia | spring landrace |
| PI 8813 | PI 8813 | Iraq | spring landrace |
| PI 192001 | PI 192001 | Angola | spring landrace |
| PI 278297 | PI 278297 | Greece | spring landrace |
| PI 185715 | PI 185715 | Portugal | spring landrace |
| PI 153785 | PI 153785 | Brazil | spring landrace |
| PI 366716 | PI 366716 | Afghanistan | spring landrace |
| PI 477870 | PI 477870 | Peru | spring landrace |
| PI 192147 | PI 192147 | Ethiopia | spring landrace |
| PI 262611 | PI 262611 | Turkmenistan | spring landrace |
| PI 210945 | PI 210945 | Cyprus | spring landrace |
| PI 82469 | PI 82469 | North Korea | spring landrace |
| PI 470817 | PI 470817 | Algeria | spring landrace |
| PI 166333 | PI 166333 | Turkey | spring landrace |
| Dharwar Dry | GSTR 14702 | India | spring cultivar |
| PBW343 | GSTR 15234 | Indian | spring cultivar |
| PI 382150 | PI 382150 | Japan | spring landrace |
| PIONEER26R61 | PI 612153 | Pioneer | soft red winter |

|  |
| --- |
| **Table S2 continued. NAMgbs - Spring Wheat NAM Families** |
| **Population\*/Use** | **Family** | **Cross** | **# RILs** |
| **NAMgbs/ Imputation Testing** | NAM1 | Berkut x Dharwar Dry | 75 |
| NAM2 | Berkut x PI 572692 | 75 |
| NAM3 | Berkut x PI 283147 | 75 |
| NAM4 | Berkut x PI 366716 | 75 |
| NAM5 | Berkut x PI 382150 | 75 |
| NAM6 | Berkut x PI 470817 | 75 |
| NAM7 | Berkut x PI 565213 | 75 |
| NAM8 | Berkut x PBW343 | 75 |
| NAM9 | Berkut x Vida | 75 |
| NAM10 | Berkut x PI 9791 | 75 |
| NAM11 | Berkut x CI 4175 | 75 |
| NAM12 | Berkut x CI 11223 | 75 |
| NAM13 | Berkut x PI 262611 | 75 |
| NAM14 | Berkut x PI 70613 | 75 |
| NAM15 | Berkut x CI 7635 | 75 |
| NAM16 | Berkut x PI 8813 | 75 |
| NAM17 | Berkut x PI 82469 | 75 |
| NAM18 | Berkut x CI 15144 | 75 |
| NAM19 | Berkut x PI 43355 | 75 |
| NAM20 | Berkut x PI 94567 | 75 |
| NAM23 | Berkut x PI 192001 | 75 |
| NAM24 | Berkut x PI 192147 | 75 |
| NAM25 | Berkut x CI 15134 | 75 |
| NAM26 | Berkut x PI 185715 | 75 |
| NAM27 | Berkut x PI 192569 | 75 |
| NAM28 | Berkut x PI 210945 | 75 |
| NAM29 | Berkut x PI 220431 | 75 |
| NAM30 | Berkut x PI 278297 | 75 |
| **Totals** | 28 |   | 2,100 |

\* Population is described in Jordan, K. W., S. Wang, F. He, S. Chao, Y. Lun et al., 2018 The genetic architecture of genome‐wide recombination rate variation in allopolyploid wheat revealed by nested association mapping. Plant J. 95: 1039–1054

\* Population registered as Blake, N. K., M. Pumphrey, K. Glover, S. Chao, K. Jordan et al., 2019 Registration of the Triticeae-CAP Spring Wheat Nested Association Mapping Population. J. Plant Regist.

|  |  |
| --- | --- |
| **Table S2 continued. NAMskim accessions for imputation testing** |  |
| **Collection/Use** | **NAM cross\*** | **Accession** | **Description** |
| **NAMskim/Imputation Testing** | **Berkut x CI 15144** | EA-1276 | spring wheat |
| EA-1277 | spring wheat |
| EA-1278 | spring wheat |
| EA-1279 | spring wheat |
| EA-1280 | spring wheat |
| EA-1281 | spring wheat |
| EA-1282 | spring wheat |
| EA-1283 | spring wheat |
| EA-1284 | spring wheat |
| EA-1285 | spring wheat |
| EA-1286 | spring wheat |
| EA-1287 | spring wheat |
| EA-1288 | spring wheat |
| EA-1289 | spring wheat |
| EA-1291 | spring wheat |
| EA-1292 | spring wheat |
| EA-1293 | spring wheat |
| EA-1294 | spring wheat |
| EA-1296 | spring wheat |
| EA-1297 | spring wheat |
| EA-1298 | spring wheat |
| EA-1299 | spring wheat |
| EA-1300 | spring wheat |
| EA-1301 | spring wheat |

 \* Population registered as Blake, N. K., M. Pumphrey, K. Glover, S. Chao, K. Jordan et al., 2019 Registration of the Triticeae-CAP Spring Wheat Nested Association Mapping Population. J. Plant Regist.

|  |
| --- |
| **Table S3. Chromosome Summary of Reference Range and Variants in Wheat PHG** |
| **Chromosome** | **Num. reference ranges** | **All variants** | **Bi-Allelic SNPs** |
| 1A | 4402 | 64158 | 63302 |
| 1B | 4752 | 83870 | 82890 |
| 1D | 4467 | 67162 | 66513 |
| 2A | 5858 | 77621 | 76692 |
| 2B | 6221 | 103807 | 102428 |
| 2D | 5939 | 108172 | 106906 |
| 3A | 5313 | 54598 | 53956 |
| 3B | 6026 | 77685 | 76833 |
| 3D | 5381 | 80210 | 79406 |
| 4A | 4914 | 59208 | 58389 |
| 4B | 3948 | 32727 | 32482 |
| 4D | 3612 | 39768 | 39575 |
| 5A | 5491 | 48678 | 48268 |
| 5B | 5664 | 70888 | 70191 |
| 5D | 5590 | 78963 | 78345 |
| 6A | 4162 | 56864 | 55988 |
| 6B | 4679 | 77201 | 76165 |
| 6D | 4016 | 63501 | 62813 |
| 7A | 5621 | 74360 | 73455 |
| 7B | 4951 | 63984 | 63271 |
| 7D | 5477 | 90245 | 89453 |
| **Total** | 106,484 | 1,473,670 | 1,457,321 |
| **Average** | 5,071 | 71,175 | 69,396 |

|  |
| --- |
| **Table S4. The length of IBD segments (in Mb) shared between the parents of the WheatCAP mapping populations** |
| **WheatCap Program** | **Parental Lines** | **Total IBD Length (Mb)** | **A genome** | **B genome** | **D genome** | **Mean IBD (Mb)\*** |
| Arkansas | 26R61, AGS2000 | 562.72 | 57.70 | 112.57 | 392.45 | 12.79 |
| Cornell | W7986, OPATA | 99.85 | 0 | 0 | 99.85 | 12.48 |
| Colorado  | C0940610, Platte | 144.53 | 0 | 19.02 | 125.51 | 9.03 |
| Idaho | SY\_Capstone, UI\_Platinum | 777.04 | 56.84 | 33.23 | 686.97 | 12.33 |
| Kansas | Overley, Lyman | 128.33 | 15.31 | 16.43 | 96.59 | 10.69 |
| Kansas | Overland, Overley | 273.95 | 9.56 | 12.05 | 252.34 | 11.41 |
| Minnesota | MN98550-5, MN99294-1 | 580.06 | 8.76 | 50.04 | 521.26 | 11.60 |
| Minnesota | Prosper, Shelly | 1287.15 | 265.62 | 286.23 | 735.30 | 11.10 |
| Montana | Hank, Conan | 926.50 | 176.49 | 164.19 | 585.83 | 15.70 |
| North Carolina  | SS\_mpv57, LA95135 | 632.12 | 16.12 | 115.67 | 500.32 | 11.09 |
| North Dakota  | PI41025, Ben | 57.69 | 57.69 | 0 | 0 | 57.69 |
| Oklahoma  | Billings, Duster | 435.58 | 43.24 | 2.63 | 389.71 | 11.77 |
| Texas | TAM111, CO960293 | 316.27 | 13.82 | 7.57 | 294.88 | 12.65 |
| California | RAC875, Berkut | 190.24 | 10.86 | 19.85 | 159.54 | 9.51 |
| Washington  | Kelse, Scarlet | 359.49 | 75.06 | 55.42 | 229.01 | 14.98 |
| **Average** |   | **451.43** | **53.80** | **59.66** | **362.11** | **12.18** |
| \* average size per region for IBD segments |  |  |  |  |

|  |  |  |
| --- | --- | --- |
| **Table S5. The length of pairwise IBD segments among winter wheat lines** |  |  |
| **Pairs of lines** | **Total IBD (Mb)** | **A genome** | **B genome** | **D genome** | **Mean (Mb)** | **Proportion of IBD from D genome** |
| Billings CO940610 | 117.77 | 0 | 11.80 | 105.97 | 7.36 | 0.90 |
| Billings Cheyenne  | 383.73 | 64.18 | 24.97 | 294.58 | 15.99 | 0.77 |
| Billings CO960293  | 260.68 | 4.37 | 0 | 256.31 | 13.03 | 0.98 |
| Billings KS090387K-20  | 655.74 | 9.70 | 44.50 | 601.54 | 16.39 | 0.92 |
| Billings Lyman  | 132.74 | 31.99 | 13.61 | 87.14 | 7.81 | 0.66 |
| Billings NuPlains  | 623.56 | 10.80 | 129.37 | 483.39 | 22.27 | 0.78 |
| Billings Platte  | 254.10 | 0 | 0 | 254.10 | 14.95 | 1.00 |
| Billings Rio Blanco  | 251.81 | 71.22 | 1.99 | 178.59 | 13.25 | 0.71 |
| Billings TAM111  | 260.58 | 65.04 | 33.40 | 162.14 | 11.33 | 0.62 |
| Billings TAM112  | 411.36 | 85.27 | 0 | 326.09 | 8.94 | 0.79 |
| Billings Zenda  | 268.57 | 4.23 | 29.64 | 234.70 | 12.21 | 0.87 |
| CO940610 Cheyenne  | 286.02 | 162.95 | 15.26 | 107.81 | 16.82 | 0.38 |
| CO940610 CO960293  | 310.29 | 11.83 | 44.74 | 253.72 | 11.08 | 0.82 |
| CO940610 Duster  | 117.94 | 15.01 | 0 | 102.93 | 10.72 | 0.87 |
| CO940610 Jagalene  | 716.04 | 166.98 | 21.95 | 527.11 | 19.89 | 0.74 |
| CO940610 KS090387K-20  | 381.52 | 183.90 | 15.70 | 181.92 | 16.59 | 0.48 |
| CO940610 Lyman  | 299.58 | 12.22 | 22.17 | 265.18 | 9.66 | 0.89 |
| CO940610 NuPlains  | 217.90 | 16.74 | 11.26 | 189.90 | 9.90 | 0.87 |
| CO940610 Platte  | 144.53 | 0.00 | 19.02 | 125.51 | 9.03 | 0.87 |
| CO940610 Rio Blanco  | 121.25 | 11.26 | 19.86 | 90.13 | 6.06 | 0.74 |
| CO940610 TAM111  | 150.91 | 32.34 | 18.14 | 100.43 | 10.06 | 0.67 |
| CO940610 TAM112  | 1237.69 | 58.77 | 106.87 | 1072.05 | 15.87 | 0.87 |
| CO940610 Zenda  | 162.27 | 14.21 | 0 | 148.06 | 7.73 | 0.91 |
| Camelot Billings  | 299.26 | 4.36 | 7.15 | 287.74 | 12.47 | 0.96 |
| Camelot CO940610 | 280.63 | 13.37 | 0 | 267.26 | 11.23 | 0.95 |
| Camelot Cheyenne  | 253.85 | 1.57 | 0 | 252.28 | 9.07 | 0.99 |
| Camelot CO960293  | 450.17 | 156.51 | 3.36 | 290.30 | 16.08 | 0.64 |
| Camelot Duster  | 334.15 | 6.34 | 8.53 | 319.29 | 11.14 | 0.96 |
| Camelot Jagalene  | 424.34 | 5.60 | 42.29 | 376.45 | 14.63 | 0.89 |
| Camelot KS05HW14-3  | 372.49 | 0 | 42.76 | 329.73 | 13.80 | 0.89 |
| Camelot KS090387K-20  | 551.78 | 20.54 | 154.45 | 376.78 | 20.44 | 0.68 |
| Camelot Lyman  | 194.01 | 7.86 | 40.71 | 145.45 | 10.21 | 0.75 |
| Camelot NuPlains  | 577.04 | 9.65 | 10.63 | 556.76 | 16.97 | 0.96 |
| Camelot Platte  | 289.94 | 0 | 31.51 | 258.43 | 13.18 | 0.89 |
| Camelot Rio Blanco  | 312.95 | 0 | 20.46 | 292.49 | 13.04 | 0.93 |
| Camelot TAM111  | 208.99 | 11.85 | 9.84 | 187.30 | 11.00 | 0.90 |
| Camelot TAM112  | 246.39 | 4.16 | 9.51 | 232.72 | 7.70 | 0.94 |
| Camelot Zenda  | 212.16 | 12.86 | 21.26 | 178.04 | 8.49 | 0.84 |
| Cheyenne CO960293  | 367.67 | 0 | 4.72 | 362.95 | 13.62 | 0.99 |
| Cheyenne Duster  | 292.85 | 3.77 | 21.09 | 267.99 | 13.31 | 0.92 |
| Cheyenne Lyman  | 368.10 | 8.72 | 62.91 | 296.47 | 11.50 | 0.81 |
| Cheyenne Rio Blanco  | 276.29 | 3.22 | 35.31 | 237.75 | 8.91 | 0.86 |
| Cheyenne Zenda  | 321.27 | 0 | 19.85 | 301.42 | 16.06 | 0.94 |
| Duster CO960293  | 160.50 | 7.19 | 0 | 153.31 | 7.30 | 0.96 |
| Duster Lyman  | 301.04 | 2.72 | 45.77 | 252.55 | 15.84 | 0.84 |
| Duster Rio Blanco  | 226.59 | 21.27 | 8.12 | 197.19 | 9.85 | 0.87 |
| Duster Zenda  | 239.10 | 4.91 | 24.59 | 209.60 | 11.96 | 0.88 |
| Jagalene Cheyenne  | 463.78 | 3.24 | 123.57 | 336.97 | 15.46 | 0.73 |
| Jagalene CO960293  | 350.50 | 39.11 | 4.10 | 307.30 | 15.24 | 0.88 |
| Jagalene Duster  | 325.72 | 0 | 153.14 | 172.58 | 11.23 | 0.53 |
| Jagalene Lyman  | 211.65 | 0 | 58.56 | 153.09 | 11.14 | 0.72 |
| Jagalene Rio Blanco  | 376.68 | 17.92 | 70.91 | 287.85 | 11.77 | 0.76 |
| Jagalene Zenda  | 530.44 | 135.81 | 51.02 | 343.62 | 17.11 | 0.65 |
| KanMark Billings  | 245.78 | 24.56 | 8.01 | 213.21 | 8.78 | 0.87 |
| KanMark CO940610 | 255.83 | 2.32 | 6.99 | 246.52 | 13.46 | 0.96 |
| KanMark Camelot  | 269.75 | 10.05 | 3.54 | 256.16 | 12.26 | 0.95 |
| KanMark Cheyenne  | 325.95 | 7.29 | 86.78 | 231.88 | 12.07 | 0.71 |
| KanMark CO960293  | 412.39 | 23.12 | 237.62 | 151.65 | 17.93 | 0.37 |
| KanMark Duster  | 563.43 | 8.78 | 37.81 | 516.84 | 14.09 | 0.92 |
| KanMark Jagalene  | 660.75 | 185.06 | 219.39 | 256.30 | 19.43 | 0.39 |
| KanMark KS05HW14-3  | 526.02 | 161.90 | 144.61 | 219.51 | 18.14 | 0.42 |
| KanMark KS090387K-20  | 648.87 | 27.80 | 137.88 | 483.18 | 16.22 | 0.74 |
| KanMark Lyman  | 295.13 | 2.50 | 39.29 | 253.34 | 13.41 | 0.86 |
| KanMark NuPlains  | 533.09 | 68.89 | 199.66 | 264.54 | 13.67 | 0.50 |
| KanMark Platte  | 374.03 | 63.49 | 44.97 | 265.56 | 12.90 | 0.71 |
| KanMark Rio Blanco  | 357.22 | 28.45 | 26.20 | 302.57 | 11.52 | 0.85 |
| KanMark TAM111  | 473.65 | 113.06 | 69.95 | 290.63 | 18.22 | 0.61 |
| KanMark TAM112  | 783.11 | 110.57 | 132.23 | 540.31 | 12.24 | 0.69 |
| KanMark Zenda  | 358.53 | 13.37 | 27.82 | 317.34 | 11.95 | 0.89 |
| KS05HW14-3 Billings  | 363.19 | 1.80 | 32.02 | 329.36 | 12.11 | 0.91 |
| KS05HW14-3 CO940610 | 385.50 | 8.87 | 52.62 | 324.02 | 10.14 | 0.84 |
| KS05HW14-3 Cheyenne  | 409.63 | 5.89 | 4.89 | 398.85 | 11.07 | 0.97 |
| KS05HW14-3 CO960293  | 638.99 | 64.92 | 26.74 | 547.33 | 11.41 | 0.86 |
| KS05HW14-3 Duster  | 292.18 | 0 | 2.07 | 290.11 | 11.69 | 0.99 |
| KS05HW14-3 Jagalene  | 373.48 | 25.24 | 0 | 348.24 | 14.94 | 0.93 |
| KS05HW14-3 KS090387K-20  | 204.89 | 0 | 39.29 | 165.60 | 8.20 | 0.81 |
| KS05HW14-3 Lyman  | 197.02 | 6.51 | 10.10 | 180.41 | 8.57 | 0.92 |
| KS05HW14-3 NuPlains  | 602.62 | 17.33 | 16.05 | 569.24 | 17.22 | 0.94 |
| KS05HW14-3 Platte  | 396.77 | 0 | 10.36 | 386.41 | 18.04 | 0.97 |
| KS05HW14-3 Rio Blanco  | 552.22 | 3.07 | 31.36 | 517.79 | 14.16 | 0.94 |
| KS05HW14-3 TAM111  | 499.99 | 0 | 48.10 | 451.89 | 20.00 | 0.90 |
| KS05HW14-3 TAM112  | 944.70 | 162.53 | 21.95 | 760.22 | 13.89 | 0.80 |
| KS05HW14-3 Zenda  | 538.49 | 29.81 | 100.78 | 407.90 | 16.32 | 0.76 |
| KS061193K-2 Billings  | 333.73 | 27.81 | 3.32 | 302.60 | 13.35 | 0.91 |
| KS061193K-2 CO940610 | 542.40 | 0 | 12.73 | 529.66 | 16.95 | 0.98 |
| KS061193K-2 Camelot  | 672.79 | 11.83 | 232.40 | 428.57 | 18.18 | 0.64 |
| KS061193K-2 Cheyenne  | 214.80 | 1.90 | 74.15 | 138.75 | 11.93 | 0.65 |
| KS061193K-2 CO960293  | 270.22 | 26.13 | 4.78 | 239.31 | 12.28 | 0.89 |
| KS061193K-2 Duster  | 408.25 | 52.81 | 28.80 | 326.64 | 15.12 | 0.80 |
| KS061193K-2 Jagalene  | 925.45 | 37.28 | 70.51 | 817.66 | 17.14 | 0.88 |
| KS061193K-2 KanMark  | 536.37 | 34.97 | 18.67 | 482.72 | 13.41 | 0.90 |
| KS061193K-2 KS05HW14-3  | 199.26 | 8.55 | 6.95 | 183.75 | 8.30 | 0.92 |
| KS061193K-2 KS090387K-20  | 888.91 | 4.92 | 123.41 | 760.57 | 18.14 | 0.86 |
| KS061193K-2 Lyman  | 233.11 | 0 | 37.95 | 195.17 | 14.57 | 0.84 |
| KS061193K-2 NuPlains  | 365.28 | 20.30 | 10.55 | 334.44 | 14.05 | 0.92 |
| KS061193K-2 Platte  | 86.58 | 0 | 13.52 | 73.06 | 5.41 | 0.84 |
| KS061193K-2 Rio Blanco  | 235.99 | 13.07 | 7.83 | 215.08 | 11.24 | 0.91 |
| KS061193K-2 TAM111  | 231.02 | 0 | 21.24 | 209.78 | 14.44 | 0.91 |
| KS061193K-2 TAM112  | 601.47 | 128.80 | 4.06 | 468.61 | 13.08 | 0.78 |
| KS061193K-2 Zenda  | 900.67 | 153.16 | 74.06 | 673.45 | 13.86 | 0.75 |
| KS090387K-20 Cheyenne  | 232.68 | 14.80 | 4.53 | 213.36 | 11.63 | 0.92 |
| KS090387K-20 CO960293  | 162.74 | 9.18 | 22.52 | 131.04 | 8.57 | 0.81 |
| KS090387K-20 Duster  | 524.78 | 1.51 | 16.05 | 507.22 | 20.18 | 0.97 |
| KS090387K-20 Jagalene  | 773.29 | 160.99 | 24.50 | 587.80 | 19.83 | 0.76 |
| KS090387K-20 Lyman  | 141.97 | 0.00 | 23.78 | 118.19 | 10.14 | 0.83 |
| KS090387K-20 Rio Blanco  | 146.21 | 36.35 | 2.99 | 106.86 | 9.14 | 0.73 |
| KS090387K-20 Zenda  | 563.39 | 7.81 | 6.01 | 549.56 | 18.17 | 0.98 |
| Lyman CO960293  | 301.78 | 0 | 11.57 | 290.20 | 12.07 | 0.96 |
| NuPlains Cheyenne  | 352.63 | 0 | 18.20 | 334.43 | 13.06 | 0.95 |
| NuPlains CO960293  | 360.12 | 0 | 21.21 | 338.90 | 18.95 | 0.94 |
| NuPlains Duster  | 346.44 | 0 | 0 | 346.44 | 14.44 | 1.00 |
| NuPlains Jagalene  | 592.13 | 0 | 187.06 | 405.07 | 14.44 | 0.68 |
| NuPlains KS090387K-20  | 484.73 | 0 | 43.58 | 441.15 | 16.71 | 0.91 |
| NuPlains Lyman  | 381.45 | 182.79 | 12.75 | 185.91 | 18.16 | 0.49 |
| NuPlains Platte  | 612.13 | 13.58 | 0 | 598.55 | 16.54 | 0.98 |
| NuPlains Rio Blanco  | 596.49 | 6.42 | 12.92 | 577.15 | 11.93 | 0.97 |
| NuPlains Zenda  | 605.73 | 166.82 | 40.12 | 398.79 | 14.42 | 0.66 |
| Overland Billings  | 236.61 | 5.39 | 0 | 231.22 | 11.83 | 0.98 |
| Overland CO940610 | 250.61 | 0 | 25.54 | 225.07 | 9.64 | 0.90 |
| Overland Camelot  | 271.77 | 8.75 | 28.86 | 234.16 | 9.71 | 0.86 |
| Overland Cheyenne  | 411.11 | 8.37 | 17.43 | 385.30 | 9.79 | 0.94 |
| Overland CO960293  | 325.30 | 57.27 | 4.61 | 263.42 | 10.49 | 0.81 |
| Overland Duster  | 260.06 | 1.92 | 19.49 | 238.66 | 12.38 | 0.92 |
| Overland Jagalene  | 231.81 | 0 | 19.64 | 212.17 | 13.64 | 0.92 |
| Overland KanMark  | 327.19 | 129.11 | 6.14 | 191.94 | 12.12 | 0.59 |
| Overland KS05HW14-3  | 496.82 | 13.75 | 16.34 | 466.73 | 11.83 | 0.94 |
| Overland KS061193K-2  | 279.06 | 12.20 | 20.28 | 246.58 | 9.00 | 0.88 |
| Overland KS090387K-20  | 337.49 | 19.35 | 82.00 | 236.14 | 12.05 | 0.70 |
| Overland Lyman  | 305.67 | 20.53 | 34.90 | 250.24 | 8.49 | 0.82 |
| Overland NuPlains  | 409.18 | 3.53 | 4.15 | 401.50 | 15.74 | 0.98 |
| Overland Platte  | 154.59 | 0 | 12.11 | 142.49 | 11.04 | 0.92 |
| Overland Rio Blanco  | 285.18 | 17.31 | 34.83 | 233.04 | 8.91 | 0.82 |
| Overland TAM111  | 298.53 | 0 | 24.40 | 274.13 | 12.98 | 0.92 |
| Overland TAM112  | 530.96 | 107.39 | 0 | 423.57 | 13.97 | 0.80 |
| Overland WB-Redhawk  | 335.09 | 0 | 12.69 | 322.40 | 16.75 | 0.96 |
| Overland Zenda  | 219.93 | 5.66 | 12.11 | 202.15 | 8.46 | 0.92 |
| Overley Billings  | 359.95 | 13.31 | 3.32 | 343.31 | 8.57 | 0.95 |
| Overley Camelot  | 586.57 | 0 | 20.29 | 566.29 | 12.75 | 0.97 |
| Overley Cheyenne  | 145.52 | 0 | 23.15 | 122.37 | 7.28 | 0.84 |
| Overley CO960293  | 1337.21 | 466.99 | 309.00 | 561.23 | 22.29 | 0.42 |
| Overley Duster  | 289.37 | 0 | 34.03 | 255.34 | 6.58 | 0.88 |
| Overley Jagalene  | 1724.39 | 155.80 | 49.21 | 1519.38 | 14.37 | 0.88 |
| Overley KanMark  | 346.16 | 126.05 | 7.13 | 212.98 | 9.62 | 0.62 |
| Overley KS05HW14-3  | 810.58 | 5.18 | 103.16 | 702.24 | 13.07 | 0.87 |
| Overley KS061193K-2  | 1371.07 | 77.34 | 83.27 | 1210.46 | 13.44 | 0.88 |
| Overley KS090387K-20  | 710.75 | 112.71 | 17.52 | 580.52 | 12.69 | 0.82 |
| Overley Lyman  | 253.56 | 0 | 0 | 253.56 | 14.09 | 1.00 |
| Overley NuPlains  | 310.20 | 8.64 | 82.79 | 218.77 | 8.62 | 0.71 |
| Overley Overland  | 274.77 | 3.20 | 26.20 | 245.37 | 7.23 | 0.89 |
| Overley Platte  | 386.24 | 0 | 199.35 | 186.90 | 12.07 | 0.48 |
| Overley Rio Blanco  | 494.16 | 27.42 | 3.88 | 462.87 | 16.47 | 0.94 |
| Overley TAM111  | 200.59 | 8.84 | 46.97 | 144.77 | 7.71 | 0.72 |
| Overley TAM112  | 1474.22 | 69.45 | 65.95 | 1338.82 | 12.93 | 0.91 |
| Overley WB-Redhawk  | 1282.80 | 84.99 | 226.85 | 970.96 | 11.45 | 0.76 |
| Overley Zenda  | 962.63 | 29.00 | 282.69 | 650.94 | 10.46 | 0.68 |
| Platte Cheyenne  | 350.54 | 5.08 | 13.89 | 331.57 | 19.47 | 0.95 |
| Platte CO960293  | 543.94 | 0 | 116.24 | 427.70 | 19.43 | 0.79 |
| Platte Duster  | 362.64 | 0 | 140.26 | 222.38 | 12.95 | 0.61 |
| Platte Jagalene  | 523.43 | 2.25 | 232.38 | 288.80 | 10.68 | 0.55 |
| Platte KS090387K-20  | 200.51 | 88.67 | 2.66 | 109.17 | 11.14 | 0.54 |
| Platte Lyman  | 94.75 | 0 | 14.14 | 80.61 | 13.54 | 0.85 |
| Platte Rio Blanco  | 524.30 | 3.46 | 15.06 | 505.77 | 12.79 | 0.96 |
| Platte Zenda  | 164.69 | 0 | 17.86 | 146.83 | 11.76 | 0.89 |
| RioBlanco CO960293  | 353.35 | 19.40 | 8.36 | 325.59 | 12.18 | 0.92 |
| RioBlanco Lyman  | 328.26 | 2.95 | 35.88 | 289.43 | 13.68 | 0.88 |
| RioBlanco Zenda  | 146.01 | 17.46 | 4.64 | 123.91 | 6.35 | 0.85 |
| TAM111 Cheyenne  | 341.39 | 6.05 | 26.86 | 308.48 | 12.64 | 0.90 |
| TAM111 CO960293  | 316.27 | 13.82 | 7.57 | 294.88 | 12.65 | 0.93 |
| TAM111 Duster  | 389.74 | 14.78 | 13.98 | 360.98 | 14.43 | 0.93 |
| TAM111 Jagalene  | 277.96 | 0 | 9.91 | 268.05 | 21.38 | 0.96 |
| TAM111 KS090387K-20  | 332.52 | 6.52 | 4.31 | 321.69 | 16.63 | 0.97 |
| TAM111 Lyman  | 175.23 | 60.05 | 0 | 115.18 | 14.60 | 0.66 |
| TAM111 NuPlains  | 523.40 | 82.01 | 89.27 | 352.13 | 18.69 | 0.67 |
| TAM111 Platte  | 141.50 | 18.67 | 9.91 | 112.91 | 10.11 | 0.80 |
| TAM111 Rio Blanco  | 469.35 | 8.36 | 6.71 | 454.28 | 15.64 | 0.97 |
| TAM111 Zenda  | 188.03 | 11.55 | 22.01 | 154.47 | 12.54 | 0.82 |
| TAM112 Cheyenne  | 525.87 | 8.21 | 5.47 | 512.19 | 14.61 | 0.97 |
| TAM112 CO960293  | 630.70 | 103.61 | 60.53 | 466.56 | 12.61 | 0.74 |
| TAM112 Duster  | 501.75 | 57.37 | 10.03 | 434.36 | 10.04 | 0.87 |
| TAM112 Jagalene  | 809.44 | 5.79 | 59.50 | 744.16 | 16.86 | 0.92 |
| TAM112 KS090387K-20  | 823.87 | 20.79 | 61.40 | 741.68 | 15.26 | 0.90 |
| TAM112 Lyman  | 423.22 | 30.21 | 24.32 | 368.69 | 8.14 | 0.87 |
| TAM112 NuPlains  | 790.38 | 287.69 | 37.76 | 464.93 | 10.98 | 0.59 |
| TAM112 Platte  | 336.91 | 3.26 | 14.16 | 319.49 | 12.96 | 0.95 |
| TAM112 Rio Blanco  | 510.22 | 110.29 | 28.10 | 371.83 | 13.43 | 0.73 |
| TAM112 TAM111  | 856.76 | 15.44 | 83.65 | 757.68 | 12.24 | 0.88 |
| TAM112 Zenda  | 403.83 | 64.15 | 7.95 | 331.73 | 8.78 | 0.82 |
| WB-Redhawk Billings  | 257.26 | 21.72 | 3.92 | 231.62 | 13.54 | 0.90 |
| WB-Redhawk CO940610 | 354.51 | 24.12 | 51.95 | 278.44 | 12.66 | 0.79 |
| WB-Redhawk Camelot  | 664.79 | 114.01 | 7.55 | 543.24 | 22.92 | 0.82 |
| WB-Redhawk Cheyenne  | 119.20 | 15.02 | 40.81 | 63.36 | 7.95 | 0.53 |
| WB-Redhawk CO960293  | 202.23 | 30.84 | 64.20 | 107.19 | 11.23 | 0.53 |
| WB-Redhawk Duster  | 311.92 | 0 | 10.28 | 301.64 | 13.00 | 0.97 |
| WB-Redhawk Jagalene  | 754.22 | 40.32 | 149.41 | 564.49 | 18.40 | 0.75 |
| WB-Redhawk KanMark  | 310.19 | 25.53 | 36.43 | 248.24 | 10.34 | 0.80 |
| WB-Redhawk KS05HW14-3  | 459.66 | 8.08 | 6.54 | 445.05 | 14.36 | 0.97 |
| WB-Redhawk KS061193K-2  | 784.86 | 135.43 | 34.89 | 614.55 | 15.70 | 0.78 |
| WB-Redhawk KS090387K-20  | 437.75 | 9.40 | 41.06 | 387.29 | 11.22 | 0.88 |
| WB-Redhawk Lyman  | 164.48 | 21.74 | 10.79 | 131.96 | 10.97 | 0.80 |
| WB-Redhawk NuPlains  | 606.29 | 27.18 | 16.68 | 562.43 | 16.84 | 0.93 |
| WB-Redhawk Platte  | 211.39 | 7.28 | 15.46 | 188.65 | 11.74 | 0.89 |
| WB-Redhawk Rio Blanco  | 375.12 | 27.53 | 156.98 | 190.61 | 17.86 | 0.51 |
| WB-Redhawk TAM111  | 184.21 | 0 | 44.21 | 139.99 | 9.70 | 0.76 |
| WB-Redhawk TAM112  | 615.78 | 0 | 49.47 | 566.30 | 9.93 | 0.92 |
| WB-Redhawk Zenda  | 615.34 | 15.12 | 57.23 | 542.99 | 12.82 | 0.88 |
| Zenda CO960293  | 244.21 | 15.07 | 0 | 229.14 | 11.63 | 0.94 |
| Zenda Lyman  | 191.35 | 0 | 0 | 191.35 | 13.67 | 1.00 |
| **Average** | **414.96** | **33.73** | **41.27** | **339.96** | **12.99** | **0.83** |

**Table S6. Imputation Accuracy for NAMgbs families**

|  |  |  |
| --- | --- | --- |
| **Family** | **Imputation Accuracy** | **Std Dev** |
| NAM1\* | 90.4% | 0.0044 |
| NAM2 | 89.6% | 0.0075 |
| NAM3 | 89.6% | 0.0054 |
| NAM4 | 89.5% | 0.0072 |
| NAM5\* | 89.8% | 0.0046 |
| NAM6 | 89.2% | 0.0076 |
| NAM7 | 89.4% | 0.0108 |
| NAM8\* | 89.9% | 0.0147 |
| NAM9 | 89.6% | 0.0050 |
| NAM10 | 89.7% | 0.0056 |
| NAM11 | 90.3% | 0.0065 |
| NAM12 | 89.4% | 0.0071 |
| NAM13 | 89.5% | 0.0050 |
| NAM14 | 89.7% | 0.0089 |
| NAM15 | 89.4% | 0.0082 |
| NAM16 | 89.3% | 0.0070 |
| NAM17 | 88.9% | 0.0131 |
| NAM18 | 89.2% | 0.0071 |
| NAM19 | 88.7% | 0.0074 |
| NAM20 | 88.4% | 0.0079 |
| NAM23 | 89.0% | 0.0056 |
| NAM24 | 88.8% | 0.0061 |
| NAM25 | 88.8% | 0.0076 |
| NAM26 | 88.6% | 0.0071 |
| NAM27 | 89.0% | 0.0085 |
| NAM28 | 88.3% | 0.0084 |
| NAM29 | 88.6% | 0.0165 |
| NAM30 | 88.3% | 0.0109 |

 \* Represents NAM families where both parents were used in PHG construction

|  |
| --- |
| **Table S7. Regression Analysis for NAM1 phenotypes** |
| **Trait** | **Chromosome** | **Position, bp** | **Effect\*** | **R2** |  |
| **TCO\*\*** | 1A | 24338410 | 2.8561 | 90.9 |  |
| 2A | 690924031 | -1.0464 |  |
| 2B | 655213027 | 1.224 |  |
| 2B | 681349687 | -5.4315 |  |
| 2D | 641109363 | -5.3329 |  |
| 3A | 8316383 | 4.2101 |  |
| 3A | 13536555 | -2.0524 |  |
| 3A | 24038281 | -2.2197 |  |
| 3A | 574459200 | -2.1884 |  |
| 3A | 732911987 | -2.1622 |  |
| 5B | 564988417 | -2.1359 |  |
| 5D | 41604006 | 1.5155 |  |
| 5D | 562723413 | 1.6485 |  |
| 6B | 15932507 | 1.1151 |  |
| 6D | 346977546 | 2.61 |  |
| 7A | 708319323 | 2.17 |  |
| **HD\*\*** | 1B | 62419179 | -0.5365 | 90.5 |  |
| 1D | 42700817 | 0.4259 |  |
| 2A | 142314578 | -0.7482 |  |
| 2B | 742815469 | 0.9514 |  |
| 2B | 800188720 | 0.6988 |  |
| 3A | 649632776 | -0.4625 |  |
| 3B | 580786270 | 0.5427 |  |
| 3D | 525536813 | -0.6617 |  |
| 4A | 95378425 | -0.7689 |  |
| 5A | 580794434 | -0.79765 |  |
| 5D | 542110241 | -0.57484 |  |
| \*Allelic estimates represent effect for Chinese Spring reference allele \*\* HD – heading date; TCO – total number of crossovers. |