**Table S1. Open-pollinated families included in the study population**

|  |  |  |  |
| --- | --- | --- | --- |
| Family a | No. of Trees | Family | No. of Trees |
| GW92 | 17 | KB72 | 122 |
| GW99 | 84 | KB75 | 82 |
| GW109 | 65 | KB77 | 108 |
| GW119 | 71 | KB78 | 60 |
| GW122 | 7 | KB80 | 63 |
| GW124 | 114 | KB81 | 37 |
| GW139 | 49 | KB82 | 54 |
| GW140 | 87 | KB83 | 64 |
| GW141 | 48 | KB86 | 47 |
| GW149 | 15 | KB87 | 19 |
| GW151 | 111 | KB88 | 49 |
| GW154 | 73 | KB89 | 8 |
| GW155 | 83 | KB92 | 61 |
| GW156 | 46 | KB95 | 80 |
| GW157 | 70 | KB96 | 73 |
| GW158 | 74 | KB97 | 74 |
| GW160 | 83 | KB98 | 56 |
| KB48 | 12 | KB99 | 51 |
| KB53 | 11 | KB100 | 68 |
| KB66 | 4 | KB101 | 74 |
| KB67 | 67 | KB102 | 63 |
| KB68 | 65 | KB103 | 72 |
| Total | | | |
| 2,643 | | | |

a GW and KB mean that female parent is plus tree from Gangwon and Kyeongbuk provenance, respectively.

**Table S5. Family heritability by ANOVA in each site and combined analysis**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Site | DBH | Height | Straightness | Volume |
| Taean | 0.134 | 0.435 | 0.259 | 0.260 |
| Chuncheon | 0.304 | 0.471 | 0.258 | 0.276 |
| Gongju | 0.342 | 0.503 | 0.362 | 0.408 |
| Kyeongju | 0.053 | 0.089 | 0.231 | 0.025 |
| Naju | 0.023 | 0.055 | 0.429 | 0.134 |
| Wanju | 0.074 | 0 | 0.310 | 0.088 |
| Combined | 0.427 | 0.733 | 0.639 | 0.545 |

**Table S6.** **GBLUP accuracy and predictive ability according to the marker quality threshold**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Trait | Site a | Accuracy | | | Predictive ability | | |
|  |  | loose | moderate | strict | loose | moderate | strict |
| DBH | T | 0.29 (0.04) | 0.28 (0.04) | 0.22 (0.04) | 0.11 (0.04) | 0.05 (0.05) | 0.02 (0.04) |
| C | 0.5 (0.04) | 0.44 (0.03) | 0.38 (0.04) | 0.29 (0.05) | 0.21 (0.04) | 0.19 (0.05) |
| G | 0.33 (0.04) | 0.31 (0.03) | 0.24 (0.04) | 0.18 (0.05) | 0.17 (0.04) | 0.11 (0.05) |
| K | 0.25 (0.06) | 0.22 (0.08) | 0.17 (0.07) | 0.05 (0.05) | 0.05 (0.08) | 0.03 (0.08) |
| N | 0.44 (0.05) | 0.36 (0.04) | 0.37 (0.03) | 0.32 (0.06) | 0.25 (0.03) | 0.24 (0.03) |
| W | 0.25 (0.05) | 0.07 (0.05) | 0.02 (0.06) | 0.19 (0.06) | -0.03 (0.05) | -0.08 (0.06) |
| Height | T | 0.5 (0.04) | 0.33 (0.04) | 0.3 (0.04) | 0.44 (0.04) | 0.16 (0.03) | 0.15 (0.03) |
| C | 0.42 (0.01) | 0.36 (0.03) | 0.33 (0.02) | 0.26 (0.03) | 0.2 (0.04) | 0.18 (0.03) |
| G | 0.48 (0.04) | 0.37 (0.05) | 0.35 (0.04) | 0.41 (0.05) | 0.26 (0.05) | 0.26 (0.05) |
| K | 0.25 (0.06) | 0.07 (0.07) | 0.03 (0.06) | 0.19 (0.07) | -0.02 (0.08) | -0.05 (0.07) |
| N | 0.44 (0.04) | 0.43 (0.03) | 0.31 (0.03) | 0.32 (0.05) | 0.3 (0.04) | 0.21 (0.03) |
| W | 0.16 (0.04) | 0.17 (0.05) | 0.12 (0.06) | 0.06 (0.06) | 0.05 (0.04) | 0.03 (0.05) |
| Straight-ness | T | 0.32 (0.04) | 0.25 (0.04) | 0.2 (0.03) | 0.1 (0.04) | 0.01 (0.05) | 0 (0.04) |
| C | 0.43 (0.03) | 0.37 (0.03) | 0.31 (0.03) | 0.17 (0.03) | 0.11 (0.03) | 0.1 (0.04) |
| G | 0.34 (0.03) | 0.28 (0.03) | 0.22 (0.03) | 0.21 (0.04) | 0.16 (0.03) | 0.11 (0.04) |
| K | 0.36 (0.05) | 0.34 (0.04) | 0.34 (0.05) | 0.21 (0.05) | 0.19 (0.05) | 0.2 (0.05) |
| N | 0.29 (0.05) | 0.21 (0.06) | 0.16 (0.07) | 0.18 (0.05) | 0.11 (0.06) | 0.06 (0.07) |
| W | 0.26 (0.06) | 0.26 (0.05) | 0.28 (0.05) | 0.17 (0.05) | 0.17 (0.04) | 0.19 (0.05) |
| Volume | T | 0.34 (0.05) | 0.33 (0.04) | 0.29 (0.04) | 0.18 (0.05) | 0.11 (0.05) | 0.09 (0.04) |
|  | C | 0.49 (0.03) | 0.43 (0.03) | 0.37 (0.04) | 0.3 (0.04) | 0.21 (0.03) | 0.19 (0.04) |
|  | G | 0.36 (0.03) | 0.34 (0.04) | 0.29 (0.05) | 0.22 (0.05) | 0.21 (0.05) | 0.17 (0.06) |
|  | K | 0.24 (0.07) | 0.24 (0.08) | 0.17 (0.07) | 0.02 (0.06) | 0.05 (0.09) | 0.02 (0.09) |
|  | N | 0.44 (0.05) | 0.37 (0.04) | 0.36 (0.03) | 0.31 (0.05) | 0.24 (0.03) | 0.19 (0.03) |
|  | W | 0.23 (0.05) | 0.07 (0.04) | -0.02 (0.05) | 0.18 (0.06) | -0.01 (0.03) | -0.09 (0.05) |

Mean (standard error) of accuracy and predictive ability from 10-fold cross-validation

a T, Taean; C, Chuncheon; G, Gongju; K, Kyeongju; N, Naju; W, Wanju

**Table S7. GBLUP accuracy and predictive ability according to the number of randomly selected markers**

| Trait | Site a | No. of markers | | | |
| --- | --- | --- | --- | --- | --- |
|  |  | 2K | 6K | 10K | 17K |
| Accuracy | | | | | |
| DBH | T | 0.17 (0.03) | 0.27 (0.03) | 0.28 (0.03) | 0.28 (0.04) |
|  | C | 0.35 (0.04) | 0.47 (0.03) | 0.48 (0.04) | 0.5 (0.04) |
|  | G | 0.18 (0.05) | 0.26 (0.05) | 0.28 (0.04) | 0.31 (0.04) |
|  | K | 0.16 (0.04) | 0.23 (0.06) | 0.25 (0.06) | 0.25 (0.06) |
|  | N | 0.38 (0.07) | 0.42 (0.06) | 0.44 (0.05) | 0.44 (0.05) |
|  | W | 0.23 (0.05) | 0.22 (0.06) | 0.25 (0.05) | 0.26 (0.05) |
| Height | T | 0.46 (0.03) | 0.46 (0.04) | 0.49 (0.04) | 0.51 (0.03) |
|  | C | 0.34 (0.03) | 0.38 (0.02) | 0.42 (0.01) | 0.42 (0.01) |
|  | G | 0.37 (0.06) | 0.43 (0.04) | 0.44 (0.06) | 0.46 (0.04) |
|  | K | 0.11 (0.07) | 0.18 (0.06) | 0.24 (0.06) | 0.24 (0.06) |
|  | N | 0.37 (0.06) | 0.4 (0.03) | 0.41 (0.05) | 0.45 (0.04) |
|  | W | 0.09 (0.06) | 0.18 (0.05) | 0.19 (0.06) | 0.22 (0.06) |
| Straight-ness | T | 0.24 (0.04) | 0.31 (0.04) | 0.32 (0.04) | 0.32 (0.04) |
| C | 0.32 (0.04) | 0.37 (0.03) | 0.41 (0.03) | 0.43 (0.03) |
| G | 0.24 (0.04) | 0.31 (0.03) | 0.34 (0.03) | 0.35 (0.04) |
| K | 0.25 (0.04) | 0.31 (0.05) | 0.32 (0.05) | 0.34 (0.04) |
| N | 0.15 (0.03) | 0.21 (0.05) | 0.24 (0.05) | 0.26 (0.05) |
| W | 0.23 (0.06) | 0.29 (0.06) | 0.29 (0.06) | 0.26 (0.06) |
| Volume | T | 0.24 (0.04) | 0.3 (0.04) | 0.32 (0.03) | 0.33 (0.04) |
|  | C | 0.36 (0.04) | 0.45 (0.03) | 0.47 (0.03) | 0.49 (0.03) |
|  | G | 0.23 (0.03) | 0.31 (0.04) | 0.32 (0.04) | 0.35 (0.03) |
|  | K | 0.13 (0.05) | 0.21 (0.07) | 0.24 (0.07) | 0.24 (0.07) |
|  | N | 0.35 (0.07) | 0.43 (0.05) | 0.44 (0.05) | 0.45 (0.04) |
|  | W | 0.21 (0.04) | 0.21 (0.05) | 0.25 (0.05) | 0.26 (0.05) |
| Predictive ability | | | | | |
| DBH | T | 0 (0.03) | 0.1 (0.03) | 0.07 (0.03) | 0.09 (0.03) |
|  | C | 0.21 (0.05) | 0.28 (0.04) | 0.3 (0.04) | 0.31 (0.05) |
|  | G | 0.1 (0.05) | 0.1 (0.07) | 0.12 (0.05) | 0.16 (0.05) |
|  | K | 0 (0.04) | 0.05 (0.05) | 0.04 (0.05) | 0.05 (0.05) |
|  | N | 0.33 (0.06) | 0.31 (0.06) | 0.32 (0.05) | 0.32 (0.06) |
|  | W | 0.18 (0.07) | 0.18 (0.06) | 0.19 (0.06) | 0.2 (0.06) |

**Table S7. (Continued)**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Trait | Site a | No. of markers | | | |
|  |  | 2K | 6K | 10K | 17K |
| Height | T | 0.43 (0.04) | 0.42 (0.04) | 0.44 (0.04) | 0.46 (0.04) |
|  | C | 0.21 (0.02) | 0.24 (0.03) | 0.27 (0.03) | 0.27 (0.03) |
|  | G | 0.33 (0.07) | 0.35 (0.05) | 0.37 (0.06) | 0.4 (0.05) |
|  | K | 0.08 (0.06) | 0.08 (0.07) | 0.18 (0.07) | 0.16 (0.07) |
|  | N | 0.27 (0.06) | 0.28 (0.05) | 0.28 (0.06) | 0.33 (0.05) |
|  | W | 0 (0.06) | 0.08 (0.06) | 0.09 (0.07) | 0.11 (0.07) |
| Straight-ness | T | 0.06 (0.04) | 0.15 (0.04) | 0.11 (0.04) | 0.11 (0.04) |
| C | 0.15 (0.04) | 0.13 (0.02) | 0.17 (0.03) | 0.17 (0.03) |
| G | 0.14 (0.04) | 0.2 (0.04) | 0.21 (0.03) | 0.21 (0.04) |
| K | 0.11 (0.05) | 0.17 (0.05) | 0.17 (0.05) | 0.18 (0.05) |
| N | 0.05 (0.04) | 0.11 (0.06) | 0.12 (0.05) | 0.14 (0.06) |
| W | 0.15 (0.06) | 0.24 (0.05) | 0.21 (0.05) | 0.17 (0.06) |
| Volume | T | 0.1 (0.04) | 0.15 (0.04) | 0.15 (0.04) | 0.16 (0.05) |
|  | C | 0.21 (0.04) | 0.28 (0.04) | 0.31 (0.04) | 0.32 (0.04) |
|  | G | 0.15 (0.05) | 0.16 (0.06) | 0.17 (0.05) | 0.21 (0.05) |
|  | K | -0.03 (0.05) | 0.01 (0.07) | 0.01 (0.07) | 0.02 (0.06) |
|  | N | 0.27 (0.05) | 0.31 (0.05) | 0.31 (0.04) | 0.32 (0.05) |
|  | W | 0.16 (0.06) | 0.18 (0.06) | 0.19 (0.06) | 0.2 (0.05) |

Mean (standard error) of accuracy and predictive ability from 10-fold cross-validation

a T, Taean; C, Chuncheon; G, Gongju; K, Kyeongju; N, Naju; W, Wanju

**Table S8. GBLUP accuracy and predictive ability according to the marker selection based on minor allele frequency**

| Trait | Site a | Minor allele frequency | | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  | maf≥0.25 | 0.25>maf ≥0.05 | | 0.05>maf ≥0.0005 | | 0.0005>maf >0 | |
| Accuracy | | | | | | | | |
| DBH | T | 0.27 (0.04) | 0.29 (0.04) | | 0.28 (0.04) | | 0.28 (0.04) | |
|  | C | 0.48 (0.03) | 0.5 (0.04) | | 0.5 (0.04) | | 0.5 (0.04) | |
|  | G | 0.3 (0.04) | 0.33 (0.04) | | 0.31 (0.04) | | 0.31 (0.04) | |
|  | K | 0.21 (0.07) | 0.25 (0.06) | | 0.25 (0.06) | | 0.25 (0.06) | |
|  | N | 0.41 (0.06) | 0.44 (0.05) | | 0.44 (0.05) | | 0.44 (0.05) | |
|  | W | 0.25 (0.05) | 0.25 (0.05) | | 0.26 (0.05) | | 0.26 (0.05) | |
| Height | T | 0.43 (0.03) | 0.5 (0.04) | | 0.51 (0.03) | | 0.51 (0.03) | |
|  | C | 0.39 (0.02) | 0.42 (0.01) | | 0.42 (0.01) | | 0.42 (0.01) | |
|  | G | 0.43 (0.05) | 0.48 (0.04) | | 0.46 (0.04) | | 0.46 (0.04) | |
|  | K | 0.14 (0.07) | 0.25 (0.06) | | 0.24 (0.06) | | 0.24 (0.06) | |
|  | N | 0.4 (0.04) | 0.44 (0.04) | | 0.45 (0.04) | | 0.45 (0.04) | |
|  | W | 0.15 (0.05) | 0.16 (0.04) | | 0.22 (0.06) | | 0.22 (0.06) | |
| Straight-ness | T | 0.31 (0.03) | 0.32 (0.04) | | 0.32 (0.04) | | 0.32 (0.04) | |
| C | 0.42 (0.03) | 0.43 (0.03) | | 0.43 (0.03) | | 0.43 (0.03) | |
| G | 0.32 (0.04) | 0.34 (0.03) | | 0.35 (0.04) | | 0.35 (0.04) | |
| K | 0.32 (0.05) | 0.36 (0.05) | | 0.34 (0.04) | | 0.34 (0.04) | |
| N | 0.24 (0.06) | 0.29 (0.05) | | 0.26 (0.05) | | 0.26 (0.05) | |
| W | 0.21 (0.06) | 0.26 (0.06) | | 0.26 (0.06) | | 0.26 (0.06) | |
| Volume | T | 0.31 (0.04) | 0.34 (0.05) | | 0.33 (0.04) | | 0.33 (0.04) | |
|  | C | 0.47 (0.03) | 0.49 (0.03) | | 0.49 (0.03) | | 0.49 (0.03) | |
|  | G | 0.33 (0.04) | 0.36 (0.03) | | 0.35 (0.03) | | 0.35 (0.03) | |
|  | K | 0.22 (0.07) | 0.24 (0.07) | | 0.24 (0.07) | | 0.24 (0.07) | |
|  | N | 0.41 (0.05) | 0.44 (0.05) | | 0.45 (0.04) | | 0.45 (0.04) | |
|  | W | 0.22 (0.05) | 0.23 (0.05) | | 0.26 (0.05) | | 0.26 (0.05) | |
| Predictive ability | | | | | | | | |
| DBH | T | 0.08 (0.03) | 0.11 (0.04) | | 0.09 (0.03) | | 0.09 (0.03) | |
|  | C | 0.27 (0.05) | 0.29 (0.05) | | 0.31 (0.05) | | 0.31 (0.05) | |
|  | G | 0.16 (0.05) | 0.18 (0.05) | | 0.16 (0.05) | | 0.16 (0.05) | |
|  | K | -0.01 (0.06) | 0.05 (0.05) | | 0.05 (0.05) | | 0.05 (0.05) | |
|  | N | 0.3 (0.06) | | 0.32 (0.06) | | 0.32 (0.06) | | 0.32 (0.06) |
|  | W | 0.17 (0.06) | | 0.19 (0.06) | | 0.2 (0.06) | | 0.2 (0.06) |

**Table S8. (Continued)**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Trait | Site a | Minor allele frequency | | | |
|  |  | maf≥0.25 | 0.25>maf ≥0.05 | 0.05>maf ≥0.0005 | 0.0005>maf >0 |
| Height | T | 0.36 (0.04) | 0.44 (0.04) | 0.46 (0.04) | 0.46 (0.04) |
|  | C | 0.23 (0.03) | 0.26 (0.03) | 0.27 (0.03) | 0.27 (0.03) |
|  | G | 0.34 (0.06) | 0.41 (0.05) | 0.4 (0.05) | 0.4 (0.05) |
|  | K | 0 (0.08) | 0.19 (0.07) | 0.16 (0.07) | 0.16 (0.07) |
|  | N | 0.25 (0.05) | 0.32 (0.05) | 0.33 (0.05) | 0.33 (0.05) |
|  | W | 0.04 (0.06) | 0.06 (0.06) | 0.11 (0.07) | 0.11 (0.07) |
| Straight-ness | T | 0.11 (0.04) | 0.1 (0.04) | 0.11 (0.04) | 0.11 (0.04) |
| C | 0.15 (0.04) | 0.17 (0.03) | 0.17 (0.03) | 0.17 (0.03) |
| G | 0.19 (0.04) | 0.21 (0.04) | 0.21 (0.04) | 0.21 (0.04) |
| K | 0.17 (0.05) | 0.21 (0.05) | 0.18 (0.05) | 0.18 (0.05) |
| N | 0.12 (0.06) | 0.18 (0.05) | 0.14 (0.06) | 0.14 (0.06) |
| W | 0.13 (0.05) | 0.17 (0.05) | 0.17 (0.06) | 0.17 (0.06) |
| Volume | T | 0.13 (0.04) | 0.18 (0.05) | 0.16 (0.05) | 0.16 (0.05) |
|  | C | 0.28 (0.05) | 0.3 (0.04) | 0.32 (0.04) | 0.32 (0.04) |
|  | G | 0.18 (0.06) | 0.22 (0.05) | 0.21 (0.05) | 0.21 (0.05) |
|  | K | -0.02 (0.07) | 0.02 (0.06) | 0.02 (0.06) | 0.02 (0.06) |
|  | N | 0.28 (0.05) | 0.31 (0.05) | 0.32 (0.05) | 0.32 (0.05) |
|  | W | 0.15 (0.05) | 0.18 (0.06) | 0.2 (0.05) | 0.2 (0.05) |

Mean (standard error) of accuracy and predictive ability from 10-fold cross-validation

a T, Taean; C, Chuncheon; G, Gongju; K, Kyeongju; N, Naju; W, Wanju

**Table S9. Accuracy and predictive ability according to predictive models**

| Trait | Site a | Predictive model b | | | |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  | ABLUP | GBLUP | BRR | BL | Bayes A | Bayes B | Bayes C |
| Accuracy | | | | | | | | |
| DBH | T | 0.68 (0.02) | 0.29 (0.04) | 0.28 (0.04) | 0.3 (0.04) | 0.28 (0.04) | 0.28 (0.04) | 0.28 (0.04) |
|  | C | 0.64 (0.02) | 0.5 (0.04) | 0.49 (0.04) | 0.5 (0.04) | 0.49 (0.04) | 0.49 (0.04) | 0.49 (0.04) |
|  | G | 0.51 (0.05) | 0.33 (0.04) | 0.33 (0.03) | 0.32 (0.04) | 0.33 (0.03) | 0.33 (0.04) | 0.33 (0.03) |
|  | K | 0.57 (0.05) | 0.25 (0.06) | 0.24 (0.05) | 0.25 (0.06) | 0.24 (0.06) | 0.23 (0.06) | 0.24 (0.06) |
|  | N | 0.55 (0.05) | 0.44 (0.05) | 0.44 (0.05) | 0.45 (0.05) | 0.44 (0.05) | 0.44 (0.06) | 0.44 (0.05) |
|  | W | 0.49 (0.04) | 0.25 (0.05) | 0.23 (0.05) | 0.24 (0.05) | 0.23 (0.04) | 0.23 (0.05) | 0.24 (0.05) |
| Height | T | 0.59 (0.03) | 0.5 (0.04) | 0.5 (0.04) | 0.5 (0.04) | 0.5 (0.04) | 0.5 (0.04) | 0.5 (0.04) |
|  | C | 0.57 (0.03) | 0.42 (0.01) | 0.41 (0.01) | 0.42 (0.01) | 0.42 (0.01) | 0.42 (0.01) | 0.42 (0.01) |
|  | G | 0.53 (0.05) | 0.48 (0.04) | 0.49 (0.04) | 0.49 (0.04) | 0.49 (0.04) | 0.5 (0.04) | 0.49 (0.04) |
|  | K | 0.32 (0.07) | 0.25 (0.06) | 0.24 (0.06) | 0.24 (0.06) | 0.24 (0.06) | 0.25 (0.06) | 0.24 (0.06) |
|  | N | 0.5 (0.03) | 0.44 (0.04) | 0.45 (0.04) | 0.46 (0.04) | 0.45 (0.04) | 0.46 (0.04) | 0.46 (0.04) |
|  | W | 0.42 (0.09) | 0.16 (0.04) | 0.17 (0.06) | 0.16 (0.06) | 0.16 (0.06) | 0.15 (0.06) | 0.17 (0.05) |
| Straight-ness | T | 0.62 (0.02) | 0.32 (0.04) | 0.31 (0.03) | 0.31 (0.03) | 0.32 (0.03) | 0.31 (0.03) | 0.31 (0.04) |
| C | 0.72 (0.02) | 0.43 (0.03) | 0.41 (0.03) | 0.42 (0.03) | 0.42 (0.03) | 0.4 (0.04) | 0.41 (0.03) |
| G | 0.61 (0.02) | 0.34 (0.03) | 0.33 (0.04) | 0.34 (0.03) | 0.33 (0.03) | 0.33 (0.03) | 0.34 (0.03) |
| K | 0.56 (0.03) | 0.36 (0.05) | 0.35 (0.04) | 0.36 (0.05) | 0.36 (0.05) | 0.36 (0.05) | 0.35 (0.05) |
| N | 0.48 (0.04) | 0.29 (0.05) | 0.29 (0.05) | 0.27 (0.05) | 0.29 (0.05) | 0.3 (0.05) | 0.29 (0.05) |
| W | 0.52 (0.05) | 0.26 (0.06) | 0.27 (0.06) | 0.27 (0.06) | 0.26 (0.06) | 0.26 (0.06) | 0.26 (0.06) |

**Table S9. (Continued)**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Trait | Site | Predictive model \* | | | | | | |
|  |  | ABLUP | GBLUP | BRR | BL | Bayes A | Bayes B | Bayes C |
| Volume | T | 0.68 (0.01) | 0.34 (0.05) | 0.33 (0.04) | 0.33 (0.04) | 0.33 (0.04) | 0.32 (0.05) | 0.33 (0.05) |
|  | C | 0.65 (0.02) | 0.49 (0.03) | 0.48 (0.03) | 0.49 (0.03) | 0.48 (0.03) | 0.47 (0.03) | 0.48 (0.03) |
|  | G | 0.52 (0.04) | 0.36 (0.03) | 0.36 (0.03) | 0.35 (0.03) | 0.36 (0.03) | 0.35 (0.03) | 0.36 (0.03) |
|  | K | 0.55 (0.05) | 0.24 (0.07) | 0.24 (0.06) | 0.26 (0.06) | 0.24 (0.06) | 0.24 (0.06) | 0.25 (0.06) |
|  | N | 0.56 (0.04) | 0.44 (0.05) | 0.43 (0.05) | 0.45 (0.04) | 0.44 (0.05) | 0.43 (0.05) | 0.43 (0.05) |
|  | W | 0.44 (0.04) | 0.23 (0.05) | 0.2 (0.04) | 0.22 (0.05) | 0.22 (0.04) | 0.22 (0.05) | 0.21 (0.04) |
| Predictive ability | | | | | | | | |
| DBH | T | 0.11 (0.04) | 0.11 (0.04) | 0.12 (0.04) | 0.11 (0.04) | 0.12 (0.04) | 0.11 (0.04) | 0.11 (0.04) |
|  | C | 0.15 (0.03) | 0.29 (0.05) | 0.28 (0.05) | 0.29 (0.05) | 0.29 (0.05) | 0.28 (0.05) | 0.29 (0.05) |
|  | G | 0.21 (0.07) | 0.18 (0.05) | 0.19 (0.05) | 0.17 (0.05) | 0.19 (0.05) | 0.18 (0.05) | 0.18 (0.05) |
|  | K | 0.04 (0.07) | 0.05 (0.05) | 0.04 (0.05) | 0.05 (0.05) | 0.03 (0.05) | 0.02 (0.05) | 0.04 (0.05) |
|  | N | 0.08 (0.06) | 0.32 (0.06) | 0.33 (0.06) | 0.32 (0.06) | 0.32 (0.06) | 0.32 (0.06) | 0.32 (0.06) |
|  | W | 0.06 (0.06) | 0.19 (0.06) | 0.15 (0.05) | 0.17 (0.06) | 0.15 (0.05) | 0.15 (0.05) | 0.16 (0.05) |
| Height | T | 0.17 (0.05) | 0.44 (0.04) | 0.44 (0.04) | 0.44 (0.04) | 0.44 (0.04) | 0.44 (0.04) | 0.44 (0.04) |
|  | C | 0.22 (0.04) | 0.26 (0.03) | 0.26 (0.03) | 0.27 (0.03) | 0.27 (0.03) | 0.27 (0.02) | 0.26 (0.03) |
|  | G | 0.25 (0.06) | 0.41 (0.05) | 0.41 (0.05) | 0.42 (0.05) | 0.42 (0.04) | 0.43 (0.04) | 0.42 (0.05) |
|  | K | -0.18 (0.07) | 0.19 (0.07) | 0.19 (0.07) | 0.18 (0.07) | 0.19 (0.07) | 0.19 (0.07) | 0.19 (0.07) |
|  | N | 0.07 (0.03) | 0.32 (0.05) | 0.32 (0.05) | 0.33 (0.05) | 0.32 (0.05) | 0.33 (0.05) | 0.33 (0.05) |
|  | W | 0.07 (0.09) | 0.06 (0.06) | 0.05 (0.07) | 0.06 (0.06) | 0.06 (0.07) | 0.04 (0.07) | 0.06 (0.06) |

**Table S9. (Continued)**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Trait | Site | Predictive model \* | | | | | | |
|  |  | ABLUP | GBLUP | BRR | BL | Bayes A | Bayes B | Bayes C |
| Straight-ness | T | 0.05 (0.04) | 0.1 (0.04) | 0.09 (0.03) | 0.1 (0.04) | 0.1 (0.04) | 0.09 (0.03) | 0.1 (0.04) |
| C | 0.06 (0.03) | 0.17 (0.03) | 0.17 (0.03) | 0.16 (0.03) | 0.17 (0.03) | 0.16 (0.03) | 0.16 (0.03) |
| G | 0.2 (0.03) | 0.21 (0.04) | 0.2 (0.04) | 0.21 (0.04) | 0.21 (0.04) | 0.2 (0.04) | 0.2 (0.04) |
| K | 0.22 (0.05) | 0.21 (0.05) | 0.21 (0.05) | 0.22 (0.05) | 0.21 (0.05) | 0.21 (0.05) | 0.21 (0.05) |
| N | 0.18 (0.05) | 0.18 (0.05) | 0.19 (0.05) | 0.16 (0.05) | 0.2 (0.05) | 0.2 (0.05) | 0.2 (0.05) |
| W | 0.04 (0.07) | 0.17 (0.05) | 0.17 (0.05) | 0.17 (0.06) | 0.16 (0.05) | 0.17 (0.04) | 0.17 (0.05) |
| Volume | T | 0.14 (0.04) | 0.18 (0.05) | 0.18 (0.05) | 0.18 (0.05) | 0.18 (0.05) | 0.17 (0.05) | 0.18 (0.05) |
|  | C | 0.17 (0.03) | 0.3 (0.04) | 0.29 (0.04) | 0.3 (0.05) | 0.29 (0.05) | 0.28 (0.04) | 0.29 (0.04) |
|  | G | 0.22 (0.06) | 0.22 (0.05) | 0.23 (0.04) | 0.21 (0.05) | 0.23 (0.05) | 0.22 (0.05) | 0.22 (0.04) |
|  | K | -0.02 (0.07) | 0.02 (0.06) | 0.02 (0.07) | 0.03 (0.06) | 0.01 (0.07) | 0.01 (0.06) | 0.02 (0.06) |
|  | N | 0.06 (0.05) | 0.31 (0.05) | 0.31 (0.05) | 0.31 (0.04) | 0.31 (0.05) | 0.3 (0.05) | 0.3 (0.05) |
|  | W | 0.09 (0.06) | 0.18 (0.06) | 0.12 (0.05) | 0.16 (0.05) | 0.15 (0.05) | 0.16 (0.05) | 0.14 (0.05) |

Mean (standard error) of accuracy and predictive ability from 10-fold cross-validation

a T, Taean; C, Chuncheon; G, Gongju; K, Kyeongju; N, Naju; W, Wanju

**b** ABLUP, additive best linear unbiased prediction; GBLUP, genomic BLUP; BRR, Bayesian ridge regression; BL, Bayesian LASSO

**Table S10. GBLUP accuracy and predictive ability by cross-validation fold number.**

| Trait | Site a | Cross-validation folds | | | |
| --- | --- | --- | --- | --- | --- |
|  |  | CV3 | CV5 | CV10 | CV20 |
| Accuracy | | | | | |
| DBH | T | 0.3 (0.02) | 0.2 (0.04) | 0.29 (0.04) | 0.3 (0.05) |
|  | C | 0.47 (0.04) | 0.49 (0.03) | 0.5 (0.04) | 0.5 (0.03) |
|  | G | 0.33 (0.05) | 0.35 (0.07) | 0.33 (0.04) | 0.37 (0.04) |
|  | K | 0.18 (0.05) | 0.25 (0.07) | 0.25 (0.06) | 0.27 (0.05) |
|  | N | 0.36 (0.06) | 0.39 (0.06) | 0.44 (0.05) | 0.44 (0.06) |
|  | W | 0.2 (0.09) | 0.19 (0.04) | 0.25 (0.05) | 0.23 (0.07) |
| Height | T | 0.49 (0.04) | 0.51 (0.03) | 0.5 (0.04) | 0.49 (0.03) |
|  | C | 0.41 (0.05) | 0.41 (0.04) | 0.42 (0.01) | 0.43 (0.02) |
|  | G | 0.48 (0.01) | 0.47 (0.02) | 0.48 (0.04) | 0.5 (0.03) |
|  | K | 0.21 (0.05) | 0.19 (0.08) | 0.25 (0.06) | 0.22 (0.05) |
|  | N | 0.36 (0.03) | 0.41 (0.03) | 0.44 (0.04) | 0.41 (0.04) |
|  | W | 0.14 (0.07) | 0.18 (0.06) | 0.16 (0.04) | 0.21 (0.06) |
| Straight-ness | T | 0.3 (0.01) | 0.29 (0.04) | 0.32 (0.04) | 0.3 (0.05) |
| C | 0.39 (0.05) | 0.42 (0.03) | 0.43 (0.03) | 0.42 (0.03) |
| G | 0.33 (0.04) | 0.32 (0.04) | 0.34 (0.03) | 0.34 (0.03) |
| K | 0.37 (0.02) | 0.34 (0.04) | 0.36 (0.05) | 0.37 (0.05) |
| N | 0.22 (0.05) | 0.3 (0.03) | 0.29 (0.05) | 0.31 (0.06) |
| W | 0.2 (0.07) | 0.23 (0.07) | 0.26 (0.06) | 0.26 (0.06) |
| Volume | T | 0.33 (0.01) | 0.27 (0.05) | 0.34 (0.05) | 0.33 (0.05) |
|  | C | 0.47 (0.04) | 0.47 (0.02) | 0.49 (0.03) | 0.49 (0.03) |
|  | G | 0.36 (0.04) | 0.35 (0.06) | 0.36 (0.03) | 0.39 (0.04) |
|  | K | 0.16 (0.03) | 0.24 (0.08) | 0.24 (0.07) | 0.25 (0.06) |
|  | N | 0.35 (0.07) | 0.4 (0.04) | 0.44 (0.05) | 0.46 (0.05) |
|  | W | 0.17 (0.1) | 0.18 (0.04) | 0.23 (0.05) | 0.23 (0.07) |
| Predictive ability | | | | | |
| DBH | T | 0.13 (0.03) | 0.03 (0.02) | 0.11 (0.04) | 0.13 (0.04) |
|  | C | 0.27 (0.03) | 0.27 (0.03) | 0.29 (0.05) | 0.29 (0.04) |
|  | G | 0.18 (0.06) | 0.21 (0.07) | 0.18 (0.05) | 0.21 (0.05) |
|  | K | -0.04 (0.03) | 0.04 (0.05) | 0.05 (0.05) | 0.07 (0.06) |
|  | N | 0.25 (0.06) | 0.28 (0.04) | 0.32 (0.06) | 0.32 (0.05) |
|  | W | 0.13 (0.12) | 0.14 (0.05) | 0.19 (0.06) | 0.18 (0.06) |

**Table S10. (Continued)**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Trait | Site a | Cross-validation folds | | | |
|  |  | CV3 | CV5 | CV10 | CV20 |
| Height | T | 0.42 (0.02) | 0.44 (0.05) | 0.44 (0.04) | 0.43 (0.03) |
|  | C | 0.27 (0.06) | 0.26 (0.04) | 0.26 (0.03) | 0.27 (0.03) |
|  | G | 0.39 (0.02) | 0.38 (0.02) | 0.41 (0.05) | 0.43 (0.04) |
|  | K | 0.18 (0.03) | 0.13 (0.08) | 0.19 (0.07) | 0.18 (0.06) |
|  | N | 0.27 (0.06) | 0.29 (0.04) | 0.32 (0.05) | 0.32 (0.04) |
|  | W | 0.06 (0.06) | 0.1 (0.06) | 0.06 (0.06) | 0.11 (0.07) |
| Straight-ness | T | 0.11 (0.02) | 0.11 (0.05) | 0.1 (0.04) | 0.09 (0.04) |
| C | 0.14 (0.05) | 0.16 (0.02) | 0.17 (0.03) | 0.17 (0.03) |
| G | 0.19 (0.03) | 0.19 (0.03) | 0.21 (0.04) | 0.2 (0.04) |
| K | 0.23 (0.04) | 0.19 (0.03) | 0.21 (0.05) | 0.22 (0.05) |
| N | 0.1 (0.03) | 0.18 (0.03) | 0.18 (0.05) | 0.21 (0.07) |
| W | 0.15 (0.01) | 0.15 (0.07) | 0.17 (0.05) | 0.17 (0.06) |
| Volume | T | 0.18 (0.04) | 0.11 (0.03) | 0.18 (0.05) | 0.18 (0.05) |
|  | C | 0.28 (0.04) | 0.27 (0.03) | 0.3 (0.04) | 0.3 (0.04) |
|  | G | 0.23 (0.07) | 0.22 (0.06) | 0.22 (0.05) | 0.24 (0.05) |
|  | K | -0.07 (0) | 0.01 (0.05) | 0.02 (0.06) | 0.02 (0.06) |
|  | N | 0.23 (0.07) | 0.29 (0.03) | 0.31 (0.05) | 0.35 (0.05) |
|  | W | 0.1 (0.11) | 0.13 (0.05) | 0.18 (0.06) | 0.17 (0.06) |

Mean (standard error) of accuracy and predictive ability from 3, 5, 10, 20-fold cross-validation

a T, Taean; C, Chuncheon; G, Gongju; K, Kyeongju; N, Naju; W, Wanju

**Table S11. GBLUP accuracy and predictive ability according to the environment of training and test population**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Trait | Site a | Accuracy | | Predictive ability | |
|  |  | within | between | within | between |
| DBH | T | 0.29 (0.04) | 0.42 (0.02) | 0.11 (0.04) | 0.05 (0.03) |
| C | 0.5 (0.04) | 0.45 (0.03) | 0.29 (0.05) | 0.17 (0.03) |
| G | 0.33 (0.04) | 0.39 (0.05) | 0.18 (0.05) | 0.09 (0.04) |
| K | 0.25 (0.06) | 0.49 (0.05) | 0.05 (0.05) | 0.1 (0.07) |
| N | 0.44 (0.05) | 0.41 (0.05) | 0.32 (0.06) | 0.1 (0.07) |
| W | 0.25 (0.05) | 0.34 (0.06) | 0.19 (0.06) | 0.08 (0.03) |
|  | Combined | 0.38 (0.02) | | 0.12 (0.02) | |
| Height | T | 0.5 (0.04) | 0.46 (0.04) | 0.44 (0.04) | 0.16 (0.04) |
| C | 0.42 (0.01) | 0.46 (0.04) | 0.26 (0.03) | 0.19 (0.04) |
| G | 0.48 (0.04) | 0.43 (0.04) | 0.41 (0.05) | 0.18 (0.04) |
| K | 0.25 (0.06) | 0.44 (0.04) | 0.19 (0.07) | 0.17 (0.05) |
| N | 0.44 (0.04) | 0.37 (0.05) | 0.32 (0.05) | 0.11 (0.06) |
| W | 0.16 (0.04) | 0.45 (0.05) | 0.06 (0.06) | 0.24 (0.06) |
|  | Combined | 0.48 (0.02) | | 0.09 (0.02) | |
| Straight-ness | T | 0.32 (0.04) | 0.4 (0.03) | 0.1 (0.04) | 0.09 (0.06) |
| C | 0.43 (0.03) | 0.38 (0.02) | 0.17 (0.03) | 0.1 (0.03) |
| G | 0.34 (0.03) | 0.52 (0.04) | 0.21 (0.04) | 0.23 (0.06) |
| K | 0.36 (0.05) | 0.39 (0.04) | 0.21 (0.05) | 0.1 (0.06) |
| N | 0.29 (0.05) | 0.36 (0.07) | 0.18 (0.05) | 0.09 (0.07) |
| W | 0.26 (0.06) | 0.41 (0.05) | 0.17 (0.05) | 0.13 (0.03) |
|  | Combined | 0.45 (0.02) | | 0.18 (0.03) | |
| Volume | T | 0.34 (0.05) | 0.46 (0.02) | 0.18 (0.05) | 0.1 (0.02) |
|  | C | 0.49 (0.03) | 0.47 (0.03) | 0.3 (0.04) | 0.19 (0.03) |
|  | G | 0.36 (0.03) | 0.42 (0.05) | 0.22 (0.05) | 0.13 (0.05) |
|  | K | 0.24 (0.07) | 0.48 (0.05) | 0.02 (0.06) | 0.12 (0.06) |
|  | N | 0.44 (0.05) | 0.41 (0.07) | 0.31 (0.05) | 0.11 (0.05) |
|  | W | 0.23 (0.05) | 0.34 (0.06) | 0.18 (0.06) | 0.13 (0.05) |
|  | Combined | 0.42 (0.02) | | 0.07 (0.01) | |

Mean (standard error) of accuracy and predictive ability from 10-fold cross-validation

a T, Taean; C, Chuncheon; G, Gongju; K, Kyeongju; N, Naju; W, Wanju

**Table S12. Annual genetic gain from phenotypic selection, family selection, and genomic selection in each site for four traits.**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Trait | Site a | Genetic gain c | | |
|  |  | ΔGPS (%) | ΔGFS (%) | ΔGGS (%) |
| DBH | T | 0.209 | 0.0302 | 0.2842 |
| C | 0.556 | 0.1192 | 0.8532 |
| G | 0.354 | 0.12 | 0.3904 |
| K | 0.058 | 0.0175 | 0.128 |
| N | 0.530 | 0.0071 | 0.6329 |
| W | 0.228 | 0.0355 | 0.292 |
| Height | T | 0.407 | 0.0617 | 0.4767 |
| C | 0.202 | 0.0738 | 0.2718 |
| G | 0.450 | 0.1224 | 0.5141 |
| K | 0.351 | 0.0203 | 0.2328 |
| N | 0.450 | 0.011 | 0.4979 |
| W | 0.072 | 0 | 0.0726 |
| Straight-ness | T | 0.122 | 0.0632 | 0.204 |
| C | 0.192 | 0.0581 | 0.3434 |
| G | 0.297 | 0.0842 | 0.3392 |
| K | 0.298 | 0.0676 | 0.3375 |
| N | 0.040 | 0.0154 | 0.0371 |
| W | 0.217 | 0.0709 | 0.2154 |
| Volume | T | 0.677 | 0.1329 | 0.8712 |
| C | 1.319 | 0.209 | 1.8799 |
| G | 0.909 | 0.3497 | 1.0529 |
| K | 0.012 | 0.0195 | 0.0837 |
| N | 1.200 | 0.0998 | 1.4631 |
| W | 0.528 | 0.1089 | 0.587 |

a T, Taean; C, Chuncheon; G, Gongju; K, Kyeongju; N, Naju; W, Wanju

b GSAC, GS accuracy, r(GEBV, EBV) EBV was estimated by GBLUP with all phenotype data

c Ratio of genetic gain per year to mean. ΔGPS, the genetic gain of phenotypic selection; ΔGFS, the genetic gain of family selection; ΔGGS, the genetic gain of genomic selection.

**Table S13. Type-B genetic correlation between the open-pollinated progeny test sites**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| DBH |  |  |  |  |  |  | |
|  | Taean | Chuncheon | Gongju | Kyeongju | Naju | Wanju | |
| Taean | - |  |  |  |  |  | |
| Chuncheon | 0.123 | - |  |  |  |  | |
| Gongju | -0.071 | 0.472\*\* | - |  |  |  | |
| Kyeongju | -0.183 | 0.062 | 0.241 | - |  |  | |
| Naju | 0.062 | 0.088 | -0.030 | 0.198 | - |  | |
| Wanju | -0.057 | 0.197 | -0.020 | 0.041 | 0.031 | - | |
| Height |  |  |  |  |  |  | |
|  | Taean | Chuncheon | Gongju | Kyeongju | Naju | Wanju | |
| Taean | - |  |  |  |  |  | |
| Chuncheon | 0.307\* | - |  |  |  |  | |
| Gongju | 0.283 | 0.188 | - |  |  |  | |
| Kyeongju | -0.078 | 0.211 | 0.203 | - |  |  | |
| Naju | 0.296 | 0.433\*\* | 0.335\* | 0.306 | - |  | |
| Wanju | 0.050 | 0.322\* | 0.061 | 0.114 | -0.007 | | - |
| Straightness | | | | | | | |
|  | Taean | Chuncheon | Gongju | Kyeongju | Naju | Wanju | |
| Taean | - |  |  |  |  |  | |
| Chuncheon | 0.207 | - |  |  |  |  | |
| Gongju | 0.233 | 0.351\* | - |  |  |  | |
| Kyeongju | 0.210 | 0.136 | 0.158 | - |  |  | |
| Naju | 0.190 | 0.157 | 0.074 | 0.076 | - |  | |
| Wanju | 0.250 | 0.387\*\* | 0.278 | -0.126 | -0.005 | - | |
| Volume |  |  |  |  |  |  | |
|  | Taean | Chuncheon | Gongju | Kyeongju | Naju | Wanju | |
| Taean | - |  |  |  |  |  | |
| Chuncheon | 0.181 | - |  |  |  |  | |
| Gongju | -0.042 | 0.515\*\*\* | - |  |  |  | |
| Kyeongju | -0.207 | 0.185 | 0.331\* | - |  |  | |
| Naju | 0.171 | 0.191 | 0.090 | 0.205 | - |  | |
| Wanju | -0.023 | 0.278 | 0.044 | 0.131 | 0.017 | - | |

\* 0.01<p-value<0.05, \*\* 0.001<p-value<0.01, \*\*\* p-value<0.001