Additional file 4

Table S1. Reliabilities of genomic breeding values for crossbred performance with a purebred reference population and a genetic correlation equal to 0.3. Reliabilities were computed with (With) and without (Without) availability of genotyping data, using a reference population with 2000 or 4000 breed A animals, and separated from the breed A selection candidates by 1 (G1), 2 (G2), or 3 (G3) generation(s). Results are averages (SD) across replicates.

Heritability	Number of animals	Method	Related breeds			Unrelated breeds		
			G1	G2	G3	G1	G2	G3
0.20	2000	With	0.014 (0.000)	0.011 (0.000)	0.009 (0.000)	0.015 (0.000)	0.012 (0.000)	0.011 (0.000)
		Without	0.009 (0.000)	0.008 (0.000)	0.008 (0.000)	0.010 (0.000)	0.010 (0.000)	0.010 (0.000)
	4000	With	0.023 (0.000)	0.018 (0.000)	0.015 (0.000)	0.025 (0.000)	0.020 (0.000)	0.018 (0.000)
		Without	0.016 (0.000)	0.016 (0.000)	0.015 (0.000)	0.018 (0.000)	0.018 (0.000)	0.017 (0.000)
0.40	2000	With	0.028 (0.000)	0.022 (0.000)	0.019 (0.000)	0.030 (0.000)	0.025 (0.000)	0.022 (0.000)
		Before	0.016 (0.000)	0.016 (0.000)	0.015 (0.000)	0.018 (0.000)	0.018 (0.000)	0.017 (0.000)
	4000	With	0.042 (0.000)	0.034 (0.000)	0.030 (0.000)	0.045 (0.000)	0.038 (0.000)	0.034 (0.000)
		Without	0.027 (0.000)	0.026 (0.000)	0.026 (0.000)	0.030 (0.000)	0.030 (0.000)	0.029 (0.000)
0.95	2000	With	0.051 (0.000)	0.042 (0.000)	0.037 (0.000)	0.055 (0.000)	0.047 (0.000)	0.043 (0.000)
		Without	0.030 (0.000)	0.030 (0.000)	0.029 (0.000)	0.034 (0.000)	0.033 (0.000)	0.033 (0.000)
	4000	With	0.072 (0.000)	0.062 (0.000)	0.057 (0.000)	0.075 (0.000)	0.067 (0.000)	0.063 (0.000)
		Without	0.045 (0.000)	0.045 (0.000)	0.044 (0.000)	0.049 (0.000)	0.048 (0.000)	0.048 (0.000)

Table S2. Reliabilities of genomic breeding values for crossbred performance with a purebred reference population and a genetic correlation equal to 0.7. Reliabilities were computed with (With) and without (Without) availability of genotyping data, using a reference population with 2000 or 4000 breed A animals, and separated from the breed A selection candidates by 1 (G1), 2 (G2), or 3 (G3) generation(s). Results are averages (SD) across replicates.

Heritability	Number of animals	Method	Related breeds			Unrelated breeds		
			G1	G2	G3	G1	G2	G3
0.20	2000	With	0.074 (0.001)	0.058 (0.000)	0.049 (0.000)	0.082 (0.001)	0.066 (0.001)	0.058 (0.000)
		Without	0.047 (0.000)	0.046 (0.000)	0.045 (0.000)	0.055 (0.000)	0.054 (0.000)	0.052 (0.000)
	4000	With	0.123 (0.000)	0.098 (0.000)	0.083 (0.000)	0.135 (0.000)	0.111 (0.001)	0.097 (0.000)
		Without	0.086 (0.001)	0.084 (0.001)	0.082 (0.000)	0.099 (0.001)	0.097 (0.001)	0.094 (0.001)
0.40	2000	With	0.152 (0.001)	0.121 (0.001)	0.104 (0.001)	0.166 (0.001)	0.137 (0.001)	0.121 (0.001)
		Without	0.086 (0.001)	0.084 (0.001)	0.082 (0.001)	0.099 (0.001)	0.097 (0.001)	0.094 (0.001)
	4000	With	0.228 (0.000)	0.186 (0.000)	0.163 (0.000)	0.243 (0.001)	0.205 (0.001)	0.184 (0.001)
		Without	0.147 (0.001)	0.144 (0.001)	0.141 (0.001)	0.164 (0.001)	0.161 (0.001)	0.158 (0.001)
0.95	2000	With	0.278 (0.001)	0.230 (0.001)	0.204 (0.001)	0.300 (0.002)	0.258 (0.002)	0.234 (0.001)
		Without	0.165 (0.001)	0.162 (0.001)	0.159 (0.001)	0.183 (0.001)	0.181 (0.001)	0.177 (0.001)
	4000	With	0.390 (0.000)	0.339 (0.001)	0.309 (0.001)	0.409 (0.000)	0.366 (0.001)	0.342 (0.001)
		Without	0.247 (0.001)	0.244 (0.001)	0.240 (0.001)	0.267 (0.001)	0.264 (0.001)	0.260 (0.001)

Table S3. Reliabilities of genomic breeding values for crossbred performance with a crossbred reference population originated from two related breeds. Reliabilities were computed with (With) and without (Without) availability of genotyping data, based on an across-breed SNP genotype model (ASGM) or on a breed-specific allele substitution effects model (BSAM), and using a reference population with 2000 or 4000 crossbred AB animals. Reference animals were separated from the breed A selection candidates by 1 (G1), 2 (G2), or 3 (G3) generation(s). Results are averages (SD) across replicates.

Heritability	Generation	Model	2000 animals		4000 animals	
			With	Without	With	Without
0.20	G1	ASGM	0.090 (0.001)	0.081 (0.001)	0.157 (0.001)	0.150 (0.001)
		BSAM	0.064 (0.001)	0.051 (0.000)	0.112 (0.001)	0.097 (0.001)
	G2	ASGM	0.081 (0.000)	0.079 (0.000)	0.141 (0.001)	0.146 (0.001)
		BSAM	0.054 (0.000)	0.049 (0.000)	0.096 (0.001)	0.094 (0.001)
	G3	ASGM	0.075 (0.000)	0.076 (0.000)	0.132 (0.001)	0.142 (0.001)
		BSAM	0.048 (0.000)	0.048 (0.000)	0.087 (0.000)	0.091 (0.001)
0.40	G1	ASGM	0.195 (0.001)	0.150 (0.001)	0.309 (0.001)	0.261 (0.001)
		BSAM	0.139 (0.001)	0.097 (0.001)	0.228 (0.001)	0.176 (0.001)
	G2	ASGM	0.176 (0.001)	0.146 (0.001)	0.284 (0.001)	0.255 (0.001)
		BSAM	0.120 (0.001)	0.094 (0.001)	0.199 (0.001)	0.172 (0.001)
	G3	ASGM	0.165 (0.001)	0.142 (0.001)	0.268 (0.001)	0.249 (0.001)
		BSAM	0.108 (0.001)	0.091 (0.001)	0.182 (0.001)	0.168 (0.001)
0.95	G1	ASGM	0.376 (0.002)	0.295 (0.002)	0.582 (0.001)	0.456 (0.002)
		BSAM	0.265 (0.002)	0.202 (0.001)	0.428 (0.002)	0.337 (0.002)
	G2	ASGM	0.348 (0.001)	0.289 (0.001)	0.552 (0.001)	0.448 (0.002)
		BSAM	0.234 (0.001)	0.198 (0.001)	0.389 (0.001)	0.331 (0.002)
	G3	ASGM	0.330 (0.001)	0.282 (0.001)	0.532 (0.001)	0.440 (0.002)
		BSAM	0.215 (0.001)	0.193 (0.001)	0.365 (0.001)	0.323 (0.002)

Table S4. Reliabilities of genomic breeding values for crossbred performance with a crossbred reference population originated from two unrelated breeds. Reliabilities were computed with (With) and without (Without) availability of genotyping data, based on an across-breed SNP genotype model (ASGM) or on a breed-specific allele substitution effects model (BSAM), and using a reference population with 2000 or 4000 crossbred AB animals. Reference animals were separated from the breed A selection candidates by 1 (G1), 2 (G2), or 3 (G3) generation(s). Results are averages (SD) across replicates.

Heritability	Generation	Model	2000 animals		4000 animals	
			With	Without	With	Without
0.20	G1	ASGM	0.089 (0.001)	0.079 (0.001)	0.154 (0.001)	0.147 (0.001)
		BSAM	0.075 (0.001)	0.059 (0.000)	0.130 (0.001)	0.112 (0.001)
	G2	ASGM	0.080 (0.001)	0.077 (0.001)	0.139 (0.001)	0.144 (0.001)
		BSAM	0.065 (0.001)	0.058 (0.001)	0.114 (0.001)	0.109 (0.001)
	G3	ASGM	0.074 (0.000)	0.075 (0.001)	0.130 (0.001)	0.140 (0.001)
		BSAM	0.059 (0.000)	0.056 (0.000)	0.105 (0.001)	0.106 (0.001)
0.40	G1	ASGM	0.192 (0.001)	0.147 (0.001)	0.305 (0.001)	0.256 (0.002)
		BSAM	0.162 (0.001)	0.112 (0.001)	0.260 (0.001)	0.201 (0.001)
	G2	ASGM	0.174 (0.001)	0.144 (0.001)	0.281 (0.001)	0.251 (0.001)
		BSAM	0.143 (0.001)	0.109 (0.001)	0.233 (0.001)	0.197 (0.002)
	G3	ASGM	0.163 (0.001)	0.140 (0.001)	0.265 (0.001)	0.246 (0.001)
		BSAM	0.131 (0.001)	0.106 (0.001)	0.216 (0.001)	0.192 (0.001)
0.95	G1	ASGM	0.374 (0.001)	0.291 (0.002)	0.582 (0.001)	0.450 (0.002)
		BSAM	0.309 (0.001)	0.230 (0.002)	0.489 (0.001)	0.374 (0.002)
	G2	ASGM	0.347 (0.001)	0.285 (0.002)	0.553 (0.002)	0.443 (0.002)
		BSAM	0.279 (0.001)	0.226 (0.002)	0.453 (0.002)	0.368 (0.002)
	G3	ASGM	0.329 (0.001)	0.279 (0.002)	0.534 (0.001)	0.436 (0.002)
		BSAM	0.260 (0.001)	0.220 (0.002)	0.430 (0.001)	0.361 (0.002)

Table S5. Reliabilities of genomic breeding values for crossbred performance with a mixed reference population assuming two related breeds and a genetic correlation of 0.3. Reliabilities were computed with (With) and without (Without) availability of genotyping data, based on an across-breed SNP genotype model (ASGM) or on a breed-specific allele substitution effects model (BSAM). The reference population included 4000 breed A animals, and 2000, or 4000, crossbred AB animals. Reference animals were separated from the breed A selection candidates by 1 (G1), 2 (G2), or 3 (G3) generation(s). Results are averages (SD) across replicates.

Heritability	Generation	Model	6000 animals		8000 animals	
			With	Without	With	Without
0.20	G1	ASGM	0.097 (0.002)	0.094 (0.001)	0.153 (0.004)	0.161 (0.001)
		BSAM	0.069 (0.003)	0.065 (0.000)	0.117 (0.003)	0.109 (0.001)
	G2	ASGM	0.089 (0.001)	0.092 (0.001)	0.140 (0.003)	0.157 (0.001)
		BSAM	0.059 (0.003)	0.064 (0.000)	0.101 (0.002)	0.107 (0.001)
	G3	ASGM	0.084 (0.000)	0.089 (0.001)	0.132 (0.002)	0.153 (0.001)
		BSAM	0.053 (0.002)	0.062 (0.000)	0.091 (0.002)	0.104 (0.001)
0.40	G1	ASGM	0.190 (0.007)	0.169 (0.001)	0.286 (0.010)	0.275 (0.001)
		BSAM	0.149 (0.005)	0.119 (0.001)	0.235 (0.004)	0.194 (0.001)
	G2	ASGM	0.175 (0.006)	0.165 (0.001)	0.266 (0.008)	0.270 (0.001)
		BSAM	0.130 (0.004)	0.116 (0.001)	0.207 (0.003)	0.191 (0.001)
	G3	ASGM	0.165 (0.005)	0.161 (0.001)	0.253 (0.007)	0.264 (0.001)
		BSAM	0.118 (0.003)	0.113 (0.001)	0.190 (0.002)	0.186 (0.001)
0.95	G1	ASGM	0.354 (0.014)	0.318 (0.001)	0.532 (0.017)	0.469 (0.002)
		BSAM	0.284 (0.006)	0.231 (0.001)	0.440 (0.004)	0.357 (0.002)
	G2	ASGM	0.331 (0.012)	0.312 (0.001)	0.509 (0.015)	0.462 (0.002)
		BSAM	0.253 (0.005)	0.227 (0.001)	0.402 (0.003)	0.351 (0.002)
	G3	ASGM	0.317 (0.011)	0.305 (0.001)	0.493 (0.013)	0.454 (0.002)
		BSAM	0.234 (0.005)	0.222 (0.001)	0.378 (0.003)	0.344 (0.002)

Table S6. Reliabilities of genomic breeding values for crossbred performance with a mixed reference population assuming two related breeds and a genetic correlation of 0.7. Reliabilities were computed with (With) and without (Without) availability of genotyping data, based on an across-breed SNP genotype model (ASGM) or on a breed-specific allele substitution effects model (BSAM). The reference population included 4000 breed A animals, and 2000, or 4000, crossbred AB animals. Reference animals were separated from the breed A selection candidates by 1 (G1), 2 (G2), or 3 (G3) generation(s). Results are averages (SD) across replicates.

Heritability	Generation	Model	6000 animals		8000 animals	
			With	Without	With	Without
0.20	G1	ASGM	0.185 (0.006)	0.154 (0.001)	0.236 (0.005)	0.213 (0.001)
		BSAM	0.095 (0.017)	0.129 (0.001)	0.139 (0.014)	0.168 (0.001)
	G2	ASGM	0.175 (0.009)	0.151 (0.001)	0.223 (0.007)	0.208 (0.001)
		BSAM	0.084 (0.014)	0.126 (0.001)	0.122 (0.011)	0.164 (0.001)
	G3	ASGM	0.170 (0.011)	0.147 (0.001)	0.215 (0.009)	0.203 (0.001)
		BSAM	0.076 (0.012)	0.123 (0.001)	0.111 (0.010)	0.160 (0.001)
0.40	G1	ASGM	0.293 (0.007)	0.258 (0.001)	0.377 (0.006)	0.344 (0.002)
		BSAM	0.195 (0.027)	0.218 (0.001)	0.271 (0.019)	0.278 (0.001)
	G2	ASGM	0.276 (0.003)	0.253 (0.001)	0.356 (0.002)	0.338 (0.001)
		BSAM	0.174 (0.022)	0.214 (0.001)	0.242 (0.016)	0.274 (0.001)
	G3	ASGM	0.265 (0.001)	0.248 (0.001)	0.342 (0.001)	0.331 (0.001)
		BSAM	0.161 (0.019)	0.209 (0.001)	0.224 (0.014)	0.267 (0.001)
0.95	G1	ASGM	0.481 (0.021)	0.427 (0.001)	0.625 (0.015)	0.538 (0.002)
		BSAM	0.369 (0.036)	0.368 (0.002)	0.500 (0.021)	0.455 (0.002)
	G2	ASGM	0.459 (0.017)	0.421 (0.001)	0.603 (0.012)	0.531 (0.002)
		BSAM	0.339 (0.031)	0.363 (0.001)	0.464 (0.018)	0.450 (0.002)
	G3	ASGM	0.444 (0.014)	0.414 (0.001)	0.588 (0.010)	0.524 (0.002)
		BSAM	0.320 (0.028)	0.357 (0.001)	0.441 (0.017)	0.442 (0.002)

Table S7. Reliabilities of genomic breeding values for crossbred performance with a mixed reference population assuming two unrelated breeds and a genetic correlation of 0.3. Reliabilities were computed with (With) and without (Without) availability of genotyping data, based on an across-breed SNP genotype model (ASGM) or on a breed-specific allele substitution effects model (BSAM). The reference population included 4000 breed A animals, and 2000, or 4000, crossbred AB animals. Reference animals were separated from the breed A selection candidates by 1 (G1), 2 (G2), or 3 (G3) generation(s). Results are averages (SD) across replicates.

			6000 animals		8000 animals	
Heritability	Generation	Model	With	Without	With	Without
0.20	G1	ASGM	0.096 (0.001)	0.095 (0.001)	0.147 (0.001)	0.160 (0.001)
		BSAM	0.078 (0.001)	0.075 (0.001)	0.133 (0.001)	0.126 (0.001)
	G2	ASGM	0.089 (0.001)	0.092 (0.001)	0.136 (0.001)	0.157 (0.001)
		BSAM	0.068 (0.001)	0.074 (0.001)	0.117 (0.001)	0.124 (0.001)
	G3	ASGM	0.085 (0.000)	0.090 (0.001)	0.130 (0.001)	0.153 (0.001)
		BSAM	0.062 (0.001)	0.072 (0.001)	0.108 (0.001)	0.120 (0.001)
0.40	G1	ASGM	0.180 (0.002)	0.169 (0.001)	0.270 (0.002)	0.273 (0.002)
		BSAM	0.168 (0.001)	0.136 (0.001)	0.265 (0.001)	0.221 (0.001)
	G2	ASGM	0.167 (0.001)	0.165 (0.001)	0.252 (0.002)	0.268 (0.002)
		BSAM	0.149 (0.001)	0.133 (0.001)	0.238 (0.001)	0.216 (0.002)
	G3	ASGM	0.160 (0.001)	0.162 (0.001)	0.242 (0.002)	0.262 (0.001)
		BSAM	0.137 (0.001)	0.130 (0.001)	0.221 (0.001)	0.211 (0.001)
0.95	G1	ASGM	0.332 (0.003)	0.316 (0.002)	0.505 (0.004)	0.465 (0.002)
		BSAM	0.321 (0.002)	0.260 (0.002)	0.497 (0.001)	0.394 (0.002)
	G2	ASGM	0.313 (0.002)	0.310 (0.002)	0.485 (0.003)	0.459 (0.002)
		BSAM	0.292 (0.002)	0.255 (0.002)	0.462 (0.002)	0.388 (0.002)
	G3	ASGM	0.301 (0.002)	0.304 (0.001)	0.472 (0.003)	0.452 (0.002)
		BSAM	0.273 (0.001)	0.250 (0.002)	0.440 (0.002)	0.381 (0.002)

Table S8. Reliabilities of genomic breeding values for crossbred performance with a mixed reference population assuming two unrelated breeds and a genetic correlation of 0.7. Reliabilities were computed with (With) and without (Without) availability of genotyping data, based on an across-breed SNP genotype model (ASGM) or on a breed-specific allele substitution effects model (BSAM). The reference population included 4000 breed A animals, and 2000, or 4000, crossbred AB animals. Reference animals were separated from the breed A selection candidates by 1 (G1), 2 (G2), or 3 (G3) generation(s). Results are averages (SD) across replicates.

Heritability	Generation	Model	6000 animals		8000 animals	
			With	Without	With	Without
0.20	G1	ASGM	0.210 (0.002)	0.164 (0.001)	0.257 (0.002)	0.220 (0.001)
		BSAM	0.091 (0.003)	0.147 (0.001)	0.145 (0.002)	0.190 (0.001)
	G2	ASGM	0.203 (0.002)	0.160 (0.001)	0.246 (0.002)	0.215 (0.001)
		BSAM	0.082 (0.003)	0.144 (0.001)	0.130 (0.002)	0.187 (0.001)
	G3	ASGM	0.199 (0.002)	0.156 (0.001)	0.240 (0.002)	0.211 (0.001)
		BSAM	0.076 (0.002)	0.141 (0.001)	0.120 (0.002)	0.182 (0.001)
0.40	G1	ASGM	0.300 (0.001)	0.269 (0.002)	0.380 (0.001)	0.351 (0.002)
		BSAM	0.193 (0.004)	0.244 (0.001)	0.286 (0.003)	0.309 (0.002)
	G2	ASGM	0.288 (0.001)	0.265 (0.001)	0.363 (0.001)	0.345 (0.002)
		BSAM	0.175 (0.004)	0.240 (0.002)	0.260 (0.003)	0.305 (0.002)
	G3	ASGM	0.280 (0.001)	0.260 (0.001)	0.353 (0.001)	0.339 (0.002)
		BSAM	0.164 (0.004)	0.235 (0.001)	0.244 (0.003)	0.299 (0.002)
0.95	G1	ASGM	0.467 (0.003)	0.436 (0.002)	0.611 (0.003)	0.542 (0.002)
		BSAM	0.377 (0.006)	0.399 (0.002)	0.537 (0.004)	0.490 (0.002)
	G2	ASGM	0.450 (0.003)	0.431 (0.002)	0.592 (0.002)	0.536 (0.002)
		BSAM	0.350 (0.006)	0.394 (0.002)	0.505 (0.004)	0.485 (0.002)
	G3	ASGM	0.439 (0.003)	0.425 (0.002)	0.580 (0.002)	0.529 (0.002)
		BSAM	0.334 (0.006)	0.388 (0.002)	0.484 (0.004)	0.478 (0.002)