Supplementary Information S1. Algebric Posterior Mean Variance (PMV) approach for gametic variance computation.

Estimation of marker effects:

We consider the following SNP-BLUP model to estimate marker effects in a Training Population (TP):

$$\boldsymbol{y} = \boldsymbol{\mu} + \boldsymbol{X\beta} + \boldsymbol{r}$$

with $\boldsymbol{y}$ the vector of phenotypes of the TP corrected for any fixed effects, $\boldsymbol{\mu}$ the grand mean, $\boldsymbol{\beta}$ a vector of random SNP effects assumed to be normally distributed $N\left(0, \boldsymbol{I}\sigma_\beta^2\right)$, with its matrix of incidence $\boldsymbol{X}$ for SNPs (TP), and $\boldsymbol{r}$ the vector of random residual effects assumed to be normally distributed $N(0, I\sigma_r^2)$.

We can develop the estimates of marker effects as:

$$\widehat{\boldsymbol{\beta}} = \mathrm{E}[\boldsymbol{\beta}|\mathrm{data}] = \mathrm{E}[\boldsymbol{\beta}|\boldsymbol{X}, \boldsymbol{y}] = \mathrm{E}[\boldsymbol{\beta}] + \mathrm{cov}(\boldsymbol{\beta}, \boldsymbol{y})\mathrm{var}(\boldsymbol{y})^{-1}(\boldsymbol{y} - \widehat{\boldsymbol{\mu}})$$

with $\mathrm{cov}(\boldsymbol{\beta}, \boldsymbol{y}) = \mathrm{cov}(\boldsymbol{\beta}, \boldsymbol{X\beta}) = \hat{\sigma}_\beta^2 \boldsymbol{X}$ and $\mathrm{var}(\boldsymbol{y}) = \boldsymbol{X}\hat{\sigma}_\beta^2\boldsymbol{X}' + \hat{\sigma}_r^2$, that leads to:

$$\widehat{\boldsymbol{\beta}} = \boldsymbol{X}'(\boldsymbol{XX}' + \boldsymbol{I}\theta)^{-1}(\boldsymbol{y} - \widehat{\boldsymbol{\mu}}) \quad (1)$$

with $\theta = \frac{\hat{\sigma}_r^2}{\hat{\sigma}_\beta^2}$.

We can then deduce:

$$\mathrm{var}(\boldsymbol{\beta}|\mathrm{data}) = \mathrm{var}(\boldsymbol{\beta}) - \mathrm{cov}(\boldsymbol{\beta}, \boldsymbol{y})\mathrm{var}(\boldsymbol{y})^{-1}\mathrm{cov}(\boldsymbol{y}, \boldsymbol{\beta}) = \sigma_\beta^2 \boldsymbol{I} - \sigma_\beta^2\sigma_\beta^2 \boldsymbol{X}'\left(\boldsymbol{XX}'\hat{\sigma}_\beta^2 + \boldsymbol{I}\hat{\sigma}_r^2\right)^{-1}\boldsymbol{X}$$

that leads to:

$$\mathrm{var}(\boldsymbol{\beta}|\mathrm{data}) = \sigma_\beta^2(\boldsymbol{I} - \boldsymbol{X}'(\boldsymbol{XX}' + \boldsymbol{I}\theta)^{-1}\boldsymbol{X}) \quad (2)$$

Estimation of the exact gametic variance:

We aim now to predict the gametic variance of a cross, $\hat{\sigma}_{P_1\times P_2}^2$ or $\mathrm{var}\left(\left(\boldsymbol{X}_{\boldsymbol{P_1}\times\boldsymbol{P_2}}\right)^{\mathrm{RIL}(k)}\boldsymbol{\beta}|\mathrm{data}\right)$, with $\left(\boldsymbol{X}_{\boldsymbol{P_1}\times\boldsymbol{P_2}}\right)^{\mathrm{RIL}(k)}$ the vector of genotypes for the RIL progeny of cross $P_1 \times P_2$ with k generations.

We assume:

$$\mathrm{E}\left[\left(\boldsymbol{X}_{\boldsymbol{P_1}\times\boldsymbol{P_2}}\right)^{\mathrm{RIL}(k)}\boldsymbol{\beta}|\mathrm{data}\right] = \mathrm{E}\left[\left(\boldsymbol{X}_{\boldsymbol{P_1}\times\boldsymbol{P_2}}\right)^{\mathrm{RIL}(k)}\boldsymbol{\beta}|\boldsymbol{X}_{\boldsymbol{P_1}\times\boldsymbol{P_2}},\boldsymbol{X},\boldsymbol{y}\right]$$

$$= \mathrm{E}\left[\left(\boldsymbol{X}_{\boldsymbol{P_1}\times\boldsymbol{P_2}}\right)^{\mathrm{RIL}(k)}|\boldsymbol{X}_{\boldsymbol{P_1}\times\boldsymbol{P_2}},\boldsymbol{X},\boldsymbol{y}\right]\mathrm{E}\left[\boldsymbol{\beta}|\boldsymbol{X}_{\boldsymbol{P_1}\times\boldsymbol{P_2}},\boldsymbol{X},\boldsymbol{y}\right]$$

$$\mathrm{E}\left[\left(\boldsymbol{X}_{\boldsymbol{P_1}\times\boldsymbol{P_2}}\right)^{\mathrm{RIL}(k)}\boldsymbol{\beta}|\mathrm{data}\right] = 0.5\boldsymbol{X}_{\boldsymbol{P_1}\times\boldsymbol{P_2}}\widehat{\boldsymbol{\beta}} \quad (3)$$

Following (Bernardo 2014; Mohammadi et al. 2015; Lehermeier et al. 2017), an approximation of gametic variance is:

$$\hat{\sigma}^2_{P_1\times P_2} = \widehat{\boldsymbol{\beta}}'\boldsymbol{V}_{\boldsymbol{P_1}\times\boldsymbol{P_2}}\widehat{\boldsymbol{\beta}}$$

with $\boldsymbol{V}_{\boldsymbol{P_1}\times\boldsymbol{P_2}}$ the genotypic variance-covariance matrix for biparental progeny. Diagonal terms of this matrix are 0 if parents carry the same allele at *loci j* and l, or 0.25 if alleles are in coupling phase, that is one parent carries the two beneficial alleles while the other carries deleterious alleles, or -0.25 if the alleles are in repulsion phase), k the number of generations, and c_{jl} the recombination rate between *loci j* and l.

To compute the exact $\mathrm{var}\left(\left(\boldsymbol{X}_{\boldsymbol{P_1}\times\boldsymbol{P_2}}\right)^{\mathrm{RIL}(k)}\boldsymbol{\beta}|\boldsymbol{X}_{\boldsymbol{P_1}\times\boldsymbol{P_2}},\boldsymbol{X},\boldsymbol{y}\right)$, we use the following property:

$\mathrm{var}(a|c) = \mathrm{var}_b(\mathrm{E}[a|b,c]) + \mathrm{E}_b[\mathrm{var}(a|b,c)]$.

With $a = \left(\boldsymbol{X}_{\boldsymbol{P_1}\times\boldsymbol{P_2}}\right)^{\mathrm{RIL}(k)}\boldsymbol{\beta}$, $b = \boldsymbol{\beta}$ and $c = \boldsymbol{X}_{\boldsymbol{P_1}\times\boldsymbol{P_2}},\boldsymbol{X},\boldsymbol{y}$, we obtain**:**

$$\mathrm{var}\left(\left(\boldsymbol{X}_{\boldsymbol{P_1}\times\boldsymbol{P_2}}\right)^{\mathrm{RIL}(k)}\boldsymbol{\beta}\middle|\boldsymbol{X}_{\boldsymbol{P_1}\times\boldsymbol{P_2}},\boldsymbol{X},\boldsymbol{y}\right) = \mathrm{var}_{\boldsymbol{\beta}}\left(\mathrm{E}\left[\left(\boldsymbol{X}_{\boldsymbol{P_1}\times\boldsymbol{P_2}}\right)^{\mathrm{RIL}(k)}\boldsymbol{\beta}|\boldsymbol{\beta},\boldsymbol{X}_{\boldsymbol{P_1}\times\boldsymbol{P_2}},\boldsymbol{X},\boldsymbol{y}\right]\right)$$

$$+\mathrm{E}_{\boldsymbol{\beta}}\left[\mathrm{var}\left(\left(\boldsymbol{X}_{\boldsymbol{P_1}\times\boldsymbol{P_2}}\right)^{\mathrm{RIL}(k)}\boldsymbol{\beta}|\boldsymbol{\beta},\boldsymbol{X}_{\boldsymbol{P_1}\times\boldsymbol{P_2}},\boldsymbol{X},\boldsymbol{y}\right)\right]$$

From equation (3) we deduce the first term:

$$\mathrm{var}_{\boldsymbol{\beta}}\left(\mathrm{E}\left[\left(\boldsymbol{X}_{\boldsymbol{P_1}\times\boldsymbol{P_2}}\right)^{\mathrm{RIL}(k)}\boldsymbol{\beta}|\mathrm{data}\right]\right) = 0.25\boldsymbol{X}_{\boldsymbol{P_1}\times\boldsymbol{P_2}}\mathrm{var}(\boldsymbol{\beta}|\mathrm{data})\boldsymbol{X}'_{\boldsymbol{P_1}\times\boldsymbol{P_2}}$$

From the following two properties, we deduce the second term:

Property 1: $\mathrm{var}(Ma) = a'\mathrm{var}(M)a$

Property 2: $\mathrm{E}[a'Ma|\mathrm{data}] = \mathrm{E}[a|\mathrm{data}]'M\mathrm{E}[a|\mathrm{data}] + \mathrm{trace}\big(M\mathrm{var}(a|\mathrm{data})\big)$

$$\mathrm{E}_{\boldsymbol{\beta}}\left[\mathrm{var}\left(\left(\boldsymbol{X}_{\boldsymbol{P_1}\times\boldsymbol{P_2}}\right)^{\mathrm{RIL}(k)}\boldsymbol{\beta}|\mathrm{data}\right)\right] = \mathrm{E}_{\boldsymbol{\beta}}\left[\widehat{\boldsymbol{\beta}}'\boldsymbol{V}_{\boldsymbol{P_1}\times\boldsymbol{P_2}}\widehat{\boldsymbol{\beta}}\right]$$

$$= \mathrm{E}[\boldsymbol{\beta}|\mathrm{data}]'\boldsymbol{V}_{\boldsymbol{P_1}\times\boldsymbol{P_2}}\mathrm{E}[\boldsymbol{\beta}|\mathrm{data}] + \mathrm{trace}\left(\boldsymbol{V}_{\boldsymbol{P_1}\times\boldsymbol{P_2}}\mathrm{var}(\boldsymbol{\beta}|\mathrm{data})\right)$$

$$= \widehat{\boldsymbol{\beta}}'\boldsymbol{V}_{\boldsymbol{P_1}\times\boldsymbol{P_2}}\widehat{\boldsymbol{\beta}} + \mathrm{trace}\left(\boldsymbol{V}_{\boldsymbol{P_1}\times\boldsymbol{P_2}}\mathrm{var}(\boldsymbol{\beta}|\mathrm{data})\right)$$

The final formula for the exact computation of $\hat{\sigma}^2_{P_1\times P_2}$ is then:

$$\hat{\sigma}^2_{P_1\times P_2} = \widehat{\boldsymbol{\beta}}'\boldsymbol{V}_{\boldsymbol{P_1}\times\boldsymbol{P_2}}\widehat{\boldsymbol{\beta}} + \mathrm{trace}\left\{\boldsymbol{V}_{\boldsymbol{P_1}\times\boldsymbol{P_2}}\mathrm{var}(\boldsymbol{\beta}|\boldsymbol{X},\boldsymbol{y})\right\} + 0.25\boldsymbol{X}'_{\boldsymbol{P_1}\times\boldsymbol{P_2}}\mathrm{var}(\boldsymbol{\beta}|\boldsymbol{X},\boldsymbol{y})\boldsymbol{X}_{\boldsymbol{P_1}\times\boldsymbol{P_2}} \quad (4)$$

In our study we decompose equation (4) into 3 estimators for the variance of gametes, Vg_1, Vg_2 and Vg_3:

$$\left(\hat{\sigma}^2_{P_1\times P_2}\right)_{\mathrm{Vg}_1} = \widehat{\boldsymbol{\beta}}'\boldsymbol{V}_{\boldsymbol{P_1}\times\boldsymbol{P_2}}\widehat{\boldsymbol{\beta}}$$

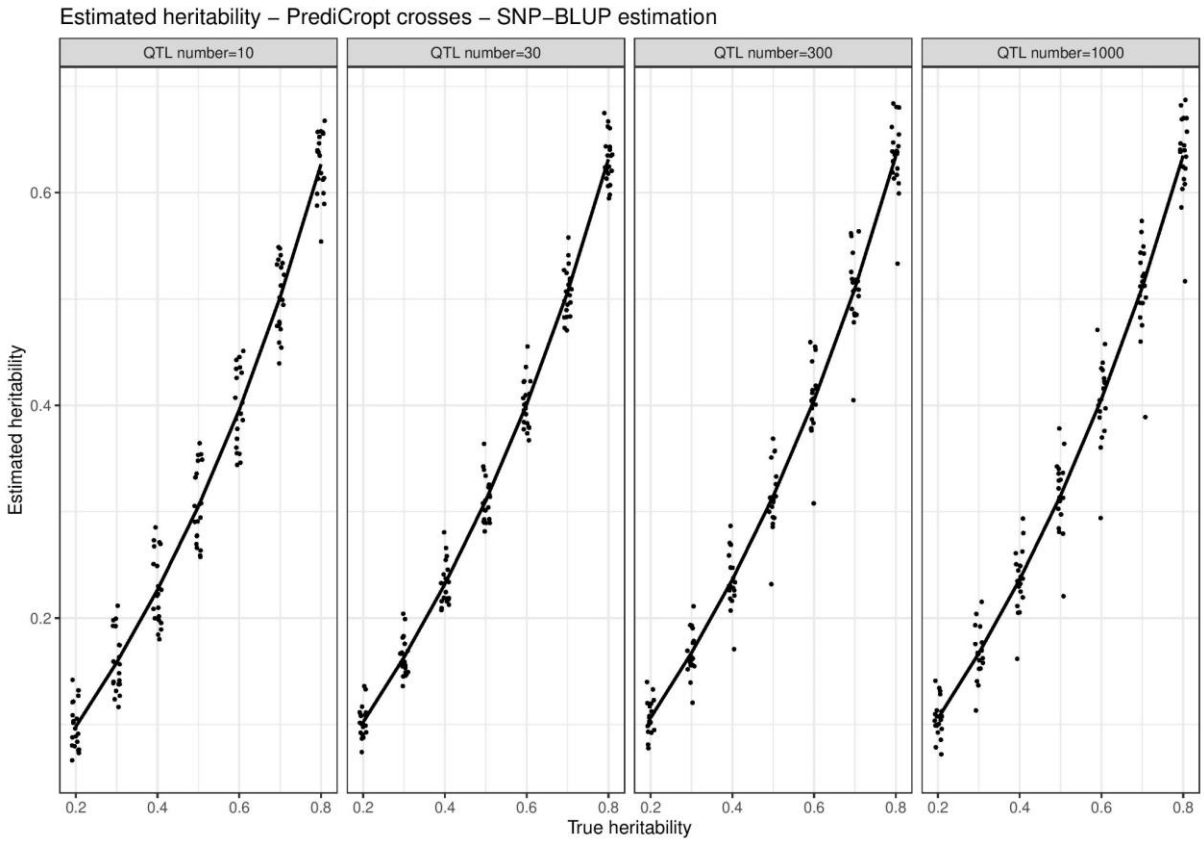
$\left(\hat{\sigma}^2_{P_1\times P_2}\right)_{\mathrm{Vg}_1}$ estimator is the classical estimator where the uncertainty in the estimate of SNP effects measured by $\mathrm{var}(\boldsymbol{\beta}|\boldsymbol{X},\boldsymbol{y})$ is neglected.

$$\left(\hat{\sigma}^2_{P_1\times P_2}\right)_{\mathrm{Vg}_2} = \widehat{\boldsymbol{\beta}}'\boldsymbol{V}_{\boldsymbol{P_1}\times\boldsymbol{P_2}}\widehat{\boldsymbol{\beta}} + \mathrm{trace}\left\{\boldsymbol{V}_{\boldsymbol{P_1}\times\boldsymbol{P_2}}\mathrm{var}(\boldsymbol{\beta}|\boldsymbol{X},\boldsymbol{y})\right\}$$

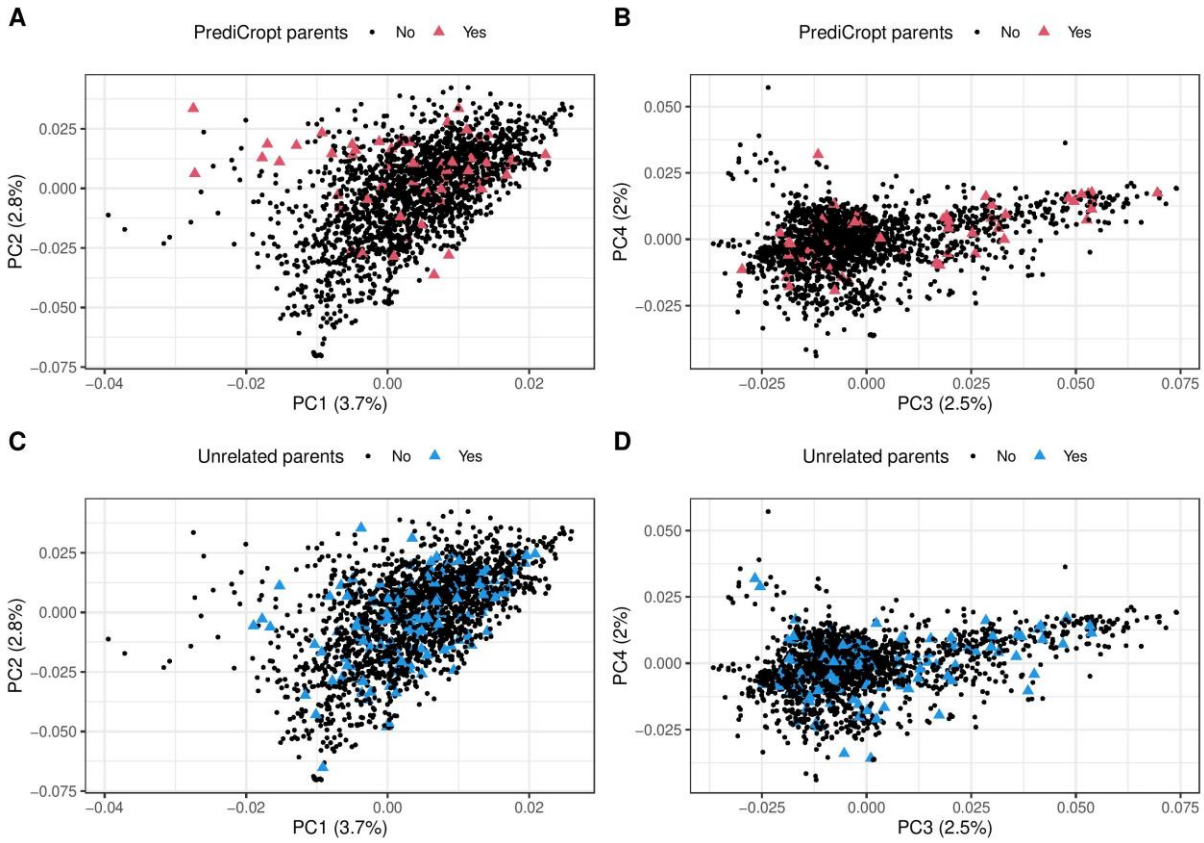
$\left(\hat{\sigma}^2_{P_1\times P_2}\right)_{\mathrm{Vg}_2}$ is an algebraic version of the Posterior Mean Variance (PMV) method described by (Lehermeier et al. 2017), i.e. the average of the variances obtained over L successive samplings in the Markov chain: $\sigma^{2\,(\mathrm{PMV})} = \frac{1}{L}\sum_{s=1}^{L}\boldsymbol{\beta}'_{(s)}\boldsymbol{V}\boldsymbol{\beta}_{(s)}$ where $\boldsymbol{\beta}_{(s)}$ is the value obtained at the s^{th} sampling. For L large $\sigma^{2\,(\mathrm{PMV})} \sim \mathrm{E}_{\boldsymbol{\beta}}\left[\mathrm{var}\left(\boldsymbol{X}_{\boldsymbol{P_1}\times\boldsymbol{P_2}}\boldsymbol{\beta}|\mathrm{data}\right)\right]$.

$$\left(\hat{\sigma}^2_{P_1\times P_2}\right)_{\mathrm{Vg}_3} = \widehat{\boldsymbol{\beta}}'\boldsymbol{V}_{\boldsymbol{P_1}\times\boldsymbol{P_2}}\widehat{\boldsymbol{\beta}} + \mathrm{trace}\left\{\boldsymbol{V}_{\boldsymbol{P_1}\times\boldsymbol{P_2}}\mathrm{var}(\boldsymbol{\beta}|\boldsymbol{X},\boldsymbol{y})\right\} + 0.25\boldsymbol{X}'_{\boldsymbol{P_1}\times\boldsymbol{P_2}}\mathrm{var}(\boldsymbol{\beta}|\boldsymbol{X},\boldsymbol{y})\boldsymbol{X}_{\boldsymbol{P_1}\times\boldsymbol{P_2}}$$

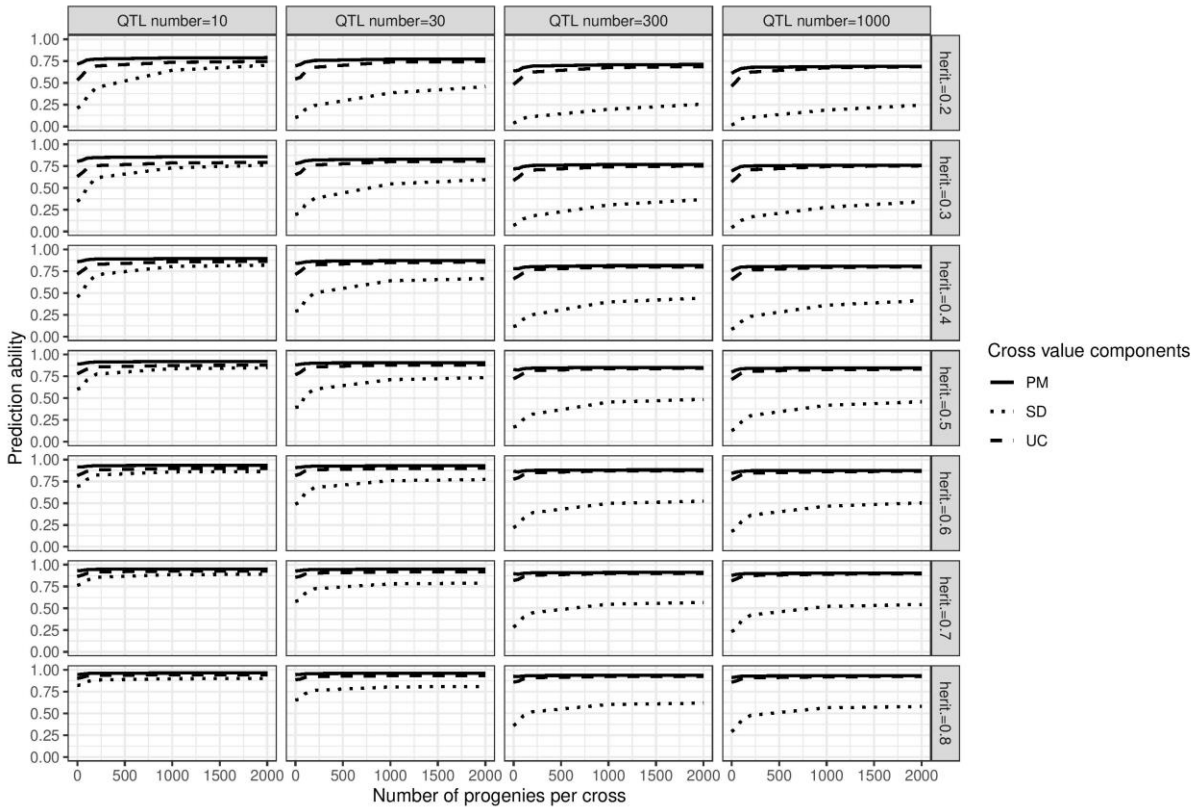
$\left(\hat{\sigma}^2_{P_1\times P_2}\right)_{\mathrm{Vg}_3}$ considers the fact that the uncertainty of the estimation of marker effects is modulated for each sire by his own genomic constitution.



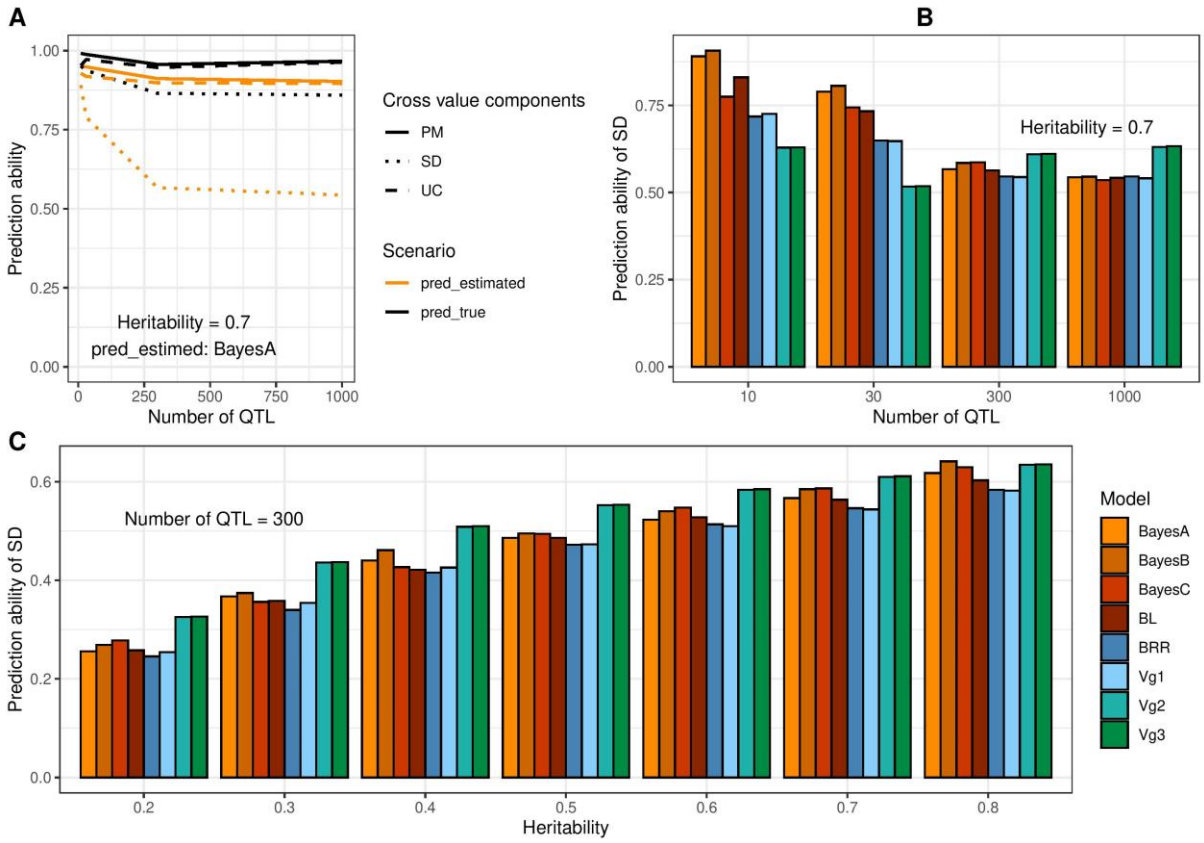
Supplementary Figure S1. Estimated heritability as a function of true heritability in the simulation study. *Variance components were estimated using a SNP-BLUP approach implemented in the rrBLUP R package.*



Supplementary Figure S2. Four Principal Components (PC) decomposition for the parents of the 73 crosses of the 'PrediCropt' (A and B) and 'Unrelated' scenarii (C and D) among the phenotyped training population.



Supplementary Figure S3. Impact of the number of progenies per cross on the prediction ability of the three cross value components, based on simulations. *Marker effects were estimated with 'BayesA' method. Abbreviations: PM: Parental Mean, SD: Standard Deviation, UC: Usefulness Criterion.*



Supplementary Figure S4. Impact of the knowledge of QTL on the prediction ability of the three cross value components (A) and of the genomic selection method on the prediction ability of SD (B and C), based on simulations. *The number of progenies per cross was 2000 progenies per cross. In A, the heritability was 0.7 and marker effects were estimated with 'BayesA' method. The true cross value components (pred_true) were calculated with true marker effects whereas the estimated cross value components (pred_estimated) were calculated with estimated marker effects. In B, the heritability was 0.7. In C, the number of QTL was 300. Abbreviations: PM: Parental Mean, SD: Standard Deviation, UC: Usefulness Criterion.*

Trait	Dataset	Zone	Number of environments (location*year)	Number of means	Number of lines with BLUE values	Number of lines with phenotypes and genotypes
Yield	GEVES	North	548	19,556	471	434
		South	297	8,114	258	237
	INRAE-AO	North	194	26,596	2,539	1,578
		South	94	2,960	596	375
	Both	Both	1,031	57,226	3,241	2,146
Grain protein content	GEVES	North	351	10,807	449	416
		South	240	5,616	257	236
	INRAE-AO	North	136	13,547	2,309	1,515
		South	36	931	264	210
	Both	Both	714	30,901	2,933	2,062
Plant height	GEVES	North	278	9,314	469	432
		South	159	4,231	258	237
	INRAE-AO	North	116	14,709	2,357	1,575
		South	45	1,191	364	242
	Both	Both	551	29,445	3,008	2,126
Heading date	GEVES	North	448	15,281	466	431
		South	215	5,784	257	236
	INRAE-AO	North	168	21,272	2,539	1,578
		South	71	2,277	580	369
	Both	Both	832	44,614	3,237	2,145

Supplementary Table S1. Description of the historical training population for the 4 analyzed traits. *For each trial, we computed spatially adjusted means when coordinates were available and arithmetic means if not. BLUE values were then computed from these means to correct the effect of the environment (location*year).*

North / South	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
2000	38 18	26 (0.72)	5	5	6	6	6	4	3	2	3	2	2	2	2	1							
2001	10 (0.82)	50 16	28 (0.79)	7	6	6	6	4	3	1	2	2	2	2	2	1							
2002	3	9 (0.96)	48 15	26 (0.82)	7	5	5	8	7	4	3	3	3	3	3	2			1				
2003	3	4	10 (0.90)	44 15	24 (0.87)	5	5	8	8	5	3	3	3	3	3	2			1				
2004	2	3	3	8 (0.76)	51 17	27 (0.86)	6	5	4	3	4	3	3	3	3	2			1				
2005	2	3	3	3	12 (0.82)	50 19	29 (0.69)	7	5	4	6	6	6	5	4	3			1				
2006	2	3	3	3	5	11 (0.80)	47 20	25 (0.73)	5	4	6	6	6	5	5	4	2	1	2				
2007	3	4	3	3	3	3	12 (0.85)	52 25	30 (0.67)	5	4	3	3	3	4	3	2	1	2				
2008	2	3	2	3	4	3	3	15 (0.80)	50 26	24 (0.67)	3	2	2	2	2	1			1				
2009	2	3	2	3	4	3	3	3	14 (0.66)	52 27	30 (0.78)	4	3	3	2	2	1	1	2	1		1	1
2010	3	4	3	3	3	3	3	4	3	16 (0.77)	54 34	28 (0.91)	5	5	5	6	3	3	4	2	1	2	2
2011	3	4	3	3	3	3	3	4	3	4	22 (0.87)	55 38	29 (0.62)	5	5	5	2	3	3	1	1	1	1
2012	3	4	3	3	3	3	3	5	4	3	6	22 (0.77)	54 39	27 (0.83)	4	3	1	2	2	1	1	1	
2013	3	4	3	3	3	3	3	5	4	3	5	6	23 (0.89)	52 32	28 (0.87)	4	1	1	3	1	1	1	
2014	2	3	3	3	3	3	3	4	3	3	4	5	6	15 (0.85)	46 33	20 (0.86)	2	1	3	1	2	2	1
2015	1	2	2	2	2	2	2	3	2	1	3	4	4	4	21 (0.89)	42 38	24 (0.50)	3	4	3	3	4	3
2016								2	2	1	2	3	2	2	3	19 (0.73)	49 33	27 (0.25)	6	4	5	6	4
2017								2	2	1	2	2	1	1	2	2	16 (0.69)	44 27	21 (0.80)	3	4	6	4
2018											1	1			1	4	3	12 (0.91)	38 30	18 (0.49)	2	4	4
2019											1	1			3	6	3	1	19 (0.71)	34 29	18 (0.82)	6	6
2020											1	1			3	5	3	2	3	13 (0.77)	41 32	26 (0.87)	6
2021											1	1			2	4	3	2	2	3	22 (0.78)	43 33	23 (0.89)
2022											1	1			3	5	3	2	3	4	5	16 (0.90)	25 18

Supplementary Table S2. Number of lines for yield in GEVES dataset per year and in common between years, and correlation between years. *Correlations are provided in parenthesis for consecutive years only. North dataset is above the diagonal and South, below. An empty cell means 0.*

North / South	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
2000	144	46 (0.61)	24	15	7	5	4	2	2	2	2	2	2	2	2	2	1	1	2	1	1	1	1
2001	8 (0.09)	166	59 (0.74)	29	16	13	5	2	2	3	3	2	2	2	2	1	1		1				
2002	5	13 (0.90)	184	59 (0.54)	27	18	7	4	4	6	5	3	3	3	3	2	1	1	2	1	1	1	1
2003	3	6	10 (0.82)	185	57 (0.70)	24	11	5	5	6	6	4	4	4	4	3	1	1	2	1	1	1	1
2004	3	4	5	8 (0.94)	181	52 (0.78)	21	11	8	7	7	5	5	5	5	4	1	1	2	1	1	1	1
2005	3	6	6	6	9 (0.88)	164	56 (0.86)	24	11	8	8	5	5	5	5	4	1	1	2	1	1	1	1
2006	3	5	4	4	7	11 (0.81)	161	59 (0.27)	24	11	9	5	6	5	5	5	2	1	2	1	1	1	1
2007	2	3	3	3	3	4	7 (0.83)	178	73 (0.52)	29	14	7	8	6	6	5	2	1	2	1	1	1	1
2008	2	3	3	3	3	3	4	10 (0.80)	174	57 (0.72)	29	13	11	8	8	7	4	1	2	1	1	1	1
2009	2	2	2	2	3	3	4	8	14 (0.62)	172	55 (0.71)	23	13	8	8	6	5	2	3	2	1	1	1
2010	1	1	1	1	1	1	2	3	5	13 (-0.07)	174	67 (0.65)	32	17	13	11	6	4	3	2	1	1	1
2011	1	1	1	1	1	1	1	2	2	3	14 (0.10)	178	61 (0.43)	31	21	16	8	4	3	2	1	1	1
2012	1	1	1	1	1	1	1	2	2	2	4	10 (0.59)	181	66 (0.54)	39	17	9	5	3	2	1	1	1
2013	1	1	1	1	1	1	2	3	3	3	3	4	14 (0.33)	176	84 (0.74)	38	20	9	7	4	1	2	1
2014	1	2	2	2	2	2	3	3	3	2	2	2	6	16 (0.86)	176	77 (0.81)	37	18	8	6	1	2	1
2015	1	2	2	2	2	2	2	2	2	1	1	2	3	8	19 (0.78)	183	79 (00.52)	37	15	7	2	3	2
2016												1	2	5	12	22 (0.83)	157	67 (0.41)	24	12	4	2	1
2017													1	1	6	12	23 (0.34)	178	67 (0.69)	23	9	5	4
2018															2	7	10	25 (0.64)	154	40 (0.50)	10	5	4
2019	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	8	8	10	14 (0.69)	180	45 (0.51)	18	12
2020	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	6	6	8	9	25 (0.23)	172	56 (0.55)	20
2021	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	3	3	13	26 (0.57)	144	36 (0.67)
2022	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	10	15	27 (0.46)	120

Supplementary Table S3. Number of lines for yield in INRAE-AO dataset per year and in common between years, and correlation between years.

Correlations are provided in parenthesis for consecutive years only. North dataset is above the diagonal and South, below. An empty cell means 0.

North / South	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
2000	36	24 (0.55)	5	5	6	5	5	3	2	2	3	2	2	2	2	1							
2001	10 (0.85)	49	28 (0.38)	6	5	4	4	2	1	1	2	2	2	2	2	1							
2002	3	9 (0.72)	48	26 (0.73)	7	4	4	6	5	4	3	3	3	3	3	2			1				
2003	3	4	10 (0.94)	43	24 (0.95)	4	4	6	5	4	3	3	3	3	3	2			1				
2004	2	3	3	8 (0.96)	47	27 (0.92)	6	4	3	3	4	3	3	3	3	2			1				
2005	2	3	3	3	12 (0.91)	47	26 (0.88)	4	3	4	6	6	6	5	4	3			1				
2006	2	3	3	3	5	11 (0.80)	44	22 (0.73)	3	4	6	6	6	5	5	4	2	1	2				
2007	3	4	3	3	3	3	12 (0.61)	47	27 (0.89)	5	4	3	3	3	4	3	2	1	2				
2008	2	3	2	3	4	3	3	15 (0.59)	46	24 (0.72)	3	2	2	2	2	1			1				
2009	2	3	2	3	4	3	3	3	14 (0.84)	50	29 (0.90)	3	3	3	2	2	1	1	2	1			
2010	3	4	3	3	3	3	3	4	3	16 (0.89)	54	28 (0.91)	5	5	5	6	3	3	4	2	1	1	1
2011	3	4	3	3	3	3	3	4	3	4	20 (0.76)	52	29 (0.82)	5	5	5	2	3	3	1	1	1	1
2012	3	4	3	3	3	3	3	5	4	3	4	21 (0.88)	51	27 (0.83)	4	3	1	2	2	1	1	1	
2013	3	4	3	3	3	3	3	5	4	3	4	5	23 (0.94)	52	28 (0.85)	4	1	1	3	1	1	1	
2014	2	3	3	3	3	3	3	4	3	3	4	5	6	15 (0.94)	44	20 (0.89)	2	1	3	1	2	2	1
2015	1	2	2	2	2	2	2	3	2	1	3	4	4	4	21 (0.97)	42	24 (0.70)	3	4	3	3	3	2
2016								2	2	1	2	3	2	2	3	19 (0.83)	48	26 (0.41)	6	4	5	5	3
2017								2	2	1	2	2	1	1	2	2	16 (0.85)	42	20 (0.84)	3	4	5	3
2018											1	1			1	4	3	12 (0.91)	38	18 (0.61)	2	3	2
2019											1	1			3	6	3	1	18 (0.83)	34	18 (0.83)	5	4
2020											1	1			3	5	3	2	2	13 (0.93)	38	25 (0.81)	6
2021											1	1			2	4	3	2	2	3	22 (0.92)	42	22 (0.88)
2022											1	1			2	4	3	2	2	3	5	16 (0.92)	22

Supplementary Table S4. Number of lines for grain protein content in GEVES dataset per year and in common between years, and correlation between years. *Correlations are provided in parenthesis for consecutive years only. North dataset is above the diagonal and South, below. An empty cell means 0.*

North / South	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
2000	143		24	15	7	5	4	2	2	2	2	2	2	2	2	1	1	1	2	1	1	1	1
2001		9																					
2002			64	27 (0.85)	14	11	3	3	3	4	4	3	3	3	3	1	1	1	2	1	1	1	1
2003				185	57 (0.80)	24	11	5	5	6	6	4	4	4	4	2	1	1	2	1	1	1	1
2004					181	52 (0.62)	21	11	8	7	7	5	5	5	5	2	1	1	2	1	1	1	1
2005		2				164 17	56 (0.85)	24	11	8	8	5	5	5	5	2	1	1	2	1	1	1	1
2006		2				10 (0.86)	161 28	59 (0.72)	24	11	9	5	6	5	5	2	2	1	2	1	1	1	1
2007								178	73 (0.72)	29	14	7	8	6	6	2	2	1	2	1	1	1	1
2008									174	57 (0.80)	29	13	11	8	8	2	4	1	2	1	1	1	1
2009		2				3	4			172 41	55 (0.86)	23	13	8	8	1	5	2	3	2	1	1	1
2010		1				1	2			9 (0.83)	174 23	67 (0.86)	32	17	13	4	6	4	3	2	1	1	1
2011		1				1	1			3	8 (0.28)	178 22	61 (0.72)	31	21	7	8	4	3	2	1	1	1
2012		1				1	1			2	3	5 (-0.28)	181 30	66 (0.73)	39	8	9	5	3	2	1	1	1
2013		1				1	2			3	3	3	14 (0.50)	176 16	84 (0.90)	28	20	9	7	4	1	2	1
2014		1				1	3			2	2	2	6	8 (0.44)	176 34	35 (0.78)	37	18	8	6	1	2	1
2015																40	17 (0.87)	8	7	4	2	3	2
2016												1	2	2	6		157 26	67 (0.64)	24	12	4	2	1
2017													1	1	2		14 (0.61)	178 28	67 (0.79)	23	9	5	4
2018																	7	13 (0.91)	154 28	40 (0.91)	10	5	4
2019		1				1	1			1	1	1	1	1	1		6	8	9 (0.98)	180 28	45 (0.86)	18	12
2020		1				1	1			1	1	1	1	1	1		4	6	6	11 (0.98)	172 28	56 (0.83)	20
2021																	1	2	3	4	16 (0.84)	144 22	36 (0.84)
2022																	1	1	1	2	9	13 (0.86)	120 32

Supplementary Table S5. Number of lines for grain protein content in INRAE-AO dataset per year and in common between years, and correlation between years. *Correlations are provided in parenthesis for consecutive years only. North dataset is above the diagonal and South, below. An empty cell means 0.*

North / South	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
2000	38	26 (0.94)	5	5	6	5	6	4	2	2	3	2	2	2	2	1							
2001	10 (0.93)	50	28 (0.95)	7	6	4	6	3	1	1	2	2	2	2	2	1							
2002	3	9 (0.96)	48	26 (0.94)	7	4	5	7	5	4	3	3	3	3	3	2			1				
2003	3	4	10 (0.93)	44	24 (0.97)	4	5	7	6	5	3	3	3	3	3	2			1				
2004	2	3	3	8 (0.89)	51	27 (0.97)	6	5	3	3	4	3	3	3	3	2			1				
2005	2	3	3	3	12 (0.96)	47	26 (0.98)	5	3	4	6	6	6	5	4	3			1				
2006	2	3	3	3	5	11 (0.92)	47	25 (0.95)	3	4	6	6	6	5	5	4	2	1	2				
2007	3	4	3	3	3	3	12 (0.89)	32	28 (0.94)	5	4	3	3	3	3	2			1				
2008	2	3	2	3	4	3	3	15 (0.88)	47	24 (0.94)	3	2	2	2	2	1			1				
2009	2	3	2	3	4	3	3	3	14 (0.85)	52	30 (0.97)	4	3	3	2	2	1	1	2	1		1	
2010	3	4	3	3	3	3	3	4	3	16 (0.97)	54	28 (0.95)	5	5	5	6	3	3	4	2	1	2	1
2011	3	4	3	3	3	3	3	4	3	4	22 (0.94)	55	29 (0.87)	5	5	5	2	3	3	1	1	1	1
2012	3	4	3	3	3	3	3	5	4	3	6	22 (0.92)	54	27 (0.95)	4	3	1	2	2	1	1	1	
2013	3	4	3	3	3	3	3	5	4	3	5	6	23 (0.85)	52	28 (0.94)	4	1	1	3	1	1	1	
2014	2	3	3	3	3	3	3	4	3	3	4	5	6	6 (0.89)	46	20 (0.93)	2	1	3	1	2	2	1
2015	1	2	2	2	2	2	2	3	2	1	3	4	4	4	21 (0.94)	42	24 (0.93)	3	4	3	3	4	2
2016								2	2	1	2	3	2	2	3	19 (0.85)	49	27 (0.82)	6	4	5	6	3
2017								2	2	1	2	2	1	1	2	2	16 (0.91)	44	21 (0.95)	3	4	6	3
2018											1	1			1	4	3	12 (0.96)	38	18 (0.94)	2	4	2
2019											1	1			3	6	3	1	19 (0.91)	34	18 (0.92)	6	4
2020											1	1			3	5	3	2	3	13 (0.78)	41	26 (0.96)	6
2021											1	1			2	4	3	2	2	3	22 (0.89)	43	22 (0.42)
2022											1	1			2	4	3	2	2	3	5	16 (0.77)	22

Supplementary Table S6. Number of lines for plant height in GEVES dataset per year and in common between years, and correlation between years.

Correlations are provided in parenthesis for consecutive years only. North dataset is above the diagonal and South, below. An empty cell means 0.

North / South	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
2000	144	46 (0.72)	24	15		5	4	2	2	2	2	2	2	2	2	2	1	1	2	1	1	1	1
2001	26	166	58 (0.37)	29		13	5	2	2	3	3	2	2	2	2	1	1		1				
2002	13 (0.93)	24	64	27 (0.80)		11	3	3	3	4	4	3	3	3	3	2	1	1	2	1	1	1	1
2003	6	10 (0.88)	21	185		24	11	5	5	6	6	4	4	4	4	3	1	1	2	1	1	1	1
2004	4	5	8 (0.92)	26																			
2005	4	5	5	9 (0.93)	18	164	56 (0.92)	24	11	8	8	5	5	5	5	4	1	1	2	1	1	1	1
2006	4	4	4	4	7	11 (0.78)	28	161	59 (0.86)	24	11	9	5	6	5	5	5	2	1	2	1	1	1	1
2007	3	3	3	3	3	4	7 (0.67)	26	178	73 (0.90)	29	14	7	8	6	6	5	2	1	2	1	1	1	1
2008	3	3	3	3	3	3	4	10 (0.67)	47	174	57 (0.87)	29	13	11	8	8	7	4	1	2	1	1	1	1
2009	2	2	2	2	3	3	4	8	14 (0.74)	41	172	55 (0.91)	23	13	8	8	6	5	2	3	2	1	1	1
2010	1	1	1	1	1	1	2	3	5	9 (0.86)	23	174	67 (0.84)	32	17	13	11	6	4	3	2	1	1	1
2011	1	1	1	1	1	1	1	2	2	3	8 (0.89)	22	178	61 (0.88)	31	21	16	8	4	3	2	1	1	1
2012	1	1	1	1	1	1	1	2	2	2	3	5 (0.97)	30	181	66 (0.82)	39	17	9	5	3	2	1	1	1
2013	1	1	1	1	1	2	3	3	3	3	3	3	14 (0.62)	16	176	84 (0.87)	38	20	9	7	4	1	2	1
2014	2	2	2	2	2	3	3	3	2	2	2	6	8 (0.87)	34	176	77 (0.93)	37	18	8	6	1	2	1
2015	2	2	2	2	2	2	2	2	2	1	1	2	3	4	11 (0.93)	25	183	79 (0.87)	37	15	7	2	3	2
2016												1	2	2	6	13 (0.84)	26	157	67 (0.88)	24	12	4	2	1
2017													1	1	2	8	14 (0.63)	28	178	67 (0.93)	23	9	5	4
2018																5	7	13 (0.92)	28	154	40 (0.90)	10	5	4
2019		1	1	1	1	1	1	1	1	1	1	1	1	1	1	4	6	8	9 (0.93)	28	180	45 (0.84)	18	12
2020		1	1	1	1	1	1	1	1	1	1	1	1	1	1	4	4	6	6	11 (0.59)	28	172	56 (0.87)	20
2021																1	1	2	3	4	16 (0.69)	28	144	36 (0.88)
2022																1	1	1	1	2	9	17 (0.66)	32	120

Supplementary Table S7. Number of lines for plant height in INRAE-AO dataset per year and in common between years, and correlation between years.

Correlations are provided in parenthesis for consecutive years only. North dataset is above the diagonal and South, below. An empty cell means 0.

North / South	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
2000	38	26 (0.97)	5	5	6	6	6	4	2	2	3	2	2	2	2	1							
2001	10 (0.97)	50	28 (0.98)	7	6	6	6	4	1	1	2	2	2	2	2	1							
2002	3	9 (0.94)	48	26 (0.96)	7	5	5	8	5	4	3	3	3	3	3	2			1				
2003	3	4	10 (0.96)	44	24 (0.97)	5	5	8	6	5	3	3	3	3	3	2			1				
2004	2	3	3	8 (0.92)	36	15 (0.99)	6	5	3	3	4	3	3	3	3	2			1				
2005						49	28 (0.80)	6	3	4	6	6	6	5	4	3			1				
2006	2	3	3	3	5		47	25 (0.90)	3	4	6	6	6	5	5	4	2	1	2				
2007	3	4	3	3	3		3 (1.00)	52	28 (0.97)	5	4	3	3	3	4	3	2	1	2				
2008	2	3	2	3	4		3	15 (0.81)	47	24 (0.97)	3	2	2	2	2	1			1				
2009	2	3	2	3	4		3	3	14 (0.95)	52	30 (0.98)	4	3	3	2	2	1	1	2	1		1	
2010	3	4	3	3	3		3	4	3	16 (0.90)	54	28 (0.97)	5	5	5	6	3	3	4	2	1	2	1
2011	3	4	3	3	3		3	4	3	4	22 (0.95)	55	29 (0.97)	5	5	5	2	3	3	1	1	1	1
2012	3	4	3	3	3		3	5	4	3	6	22 (0.88)	54	27 (0.96)	4	3	1	2	2	1	1	1	
2013	3	4	3	3	3		3	5	4	3	5	6	23 (0.94)	52	28 (0.97)	4	1	1	3	1	1	1	
2014	2	3	3	3	3		3	4	3	3	4	5	6	6 (0.99)	46	20 (0.97)	2	1	3	1	2	2	1
2015	1	2	2	2	2		2	3	2	1	3	4	4	4	21 (0.95)	42	24 (0.97)	3	4	3	3	4	2
2016								2	2	1	2	3	2	2	3	19 (0.93)	49	27 (0.89)	6	4	5	6	3
2017								2	2	1	2	2	1	1	2	2	16 (0.55)	44	21 (0.96)	3	4	6	3
2018											1	1			1	4	3	12 (0.97)	38	18 (0.99)	2	4	2
2019											1	1			3	6	3	1	19 (0.92)	34	18 (0.97)	6	4
2020											1	1			3	5	3	2	3	13 (0.91)	41	26 (0.97)	6
2021											1	1			2	4	3	2	2	3	22 (0.93)	43	22 (0.96)
2022											1	1			2	4	3	2	2	3	5	16 (0.89)	22

Supplementary Table S8. Number of lines for heading date in GEVES dataset per year and in common between years, and correlation between years.

Correlations are provided in parenthesis for consecutive years only. North dataset is above the diagonal and South, below. An empty cell means 0.

North / South	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
2000	144	46 (0.89)	24	15	7	5	4	2	2	2	2	2	2	2	2	2	1	1	2	1	1	1	1
2001	26	166	59 (0.93)	29	16	13	5	2	2	3	3	2	2	2	2	1	1		1				
2002	13 (0.97)	24	184	59 (0.88)	27	18	7	4	4	6	5	3	3	3	3	2	1	1	2	1	1	1	1
2003	6	10 (0.95)	21	185	57 (0.86)	24	11	5	5	6	6	4	4	4	4	3	1	1	2	1	1	1	1
2004	4	5	8 (0.88)	26	181	52 (0.76)	21	11	8	7	7	5	5	5	5	4	1	1	2	1	1	1	1
2005	4	5	5	9 (0.88)	18	164	56 (0.92)	24	11	8	8	5	5	5	5	4	1	1	2	1	1	1	1
2006	4	4	4	7	11 (0.95)	28	161	59 (0.80)	24	11	9	5	6	5	5	5	2	1	2	1	1	1	1
2007	3	3	3	3	4	7 (0.94)	26	178	73 (0.93)	29	14	7	8	6	6	5	2	1	2	1	1	1	1
2008	3	3	3	3	3	4	10 (0.97)	47	174	57 (0.80)	29	13	11	8	8	7	4	1	2	1	1	1	1
2009	2	2	2	3	3	4	8	14 (0.89)	64	172	55 (0.95)	23	13	8	8	6	5	2	3	2	1	1	1
2010	1	1	1	1	1	1	2	3	5	13 (0.47)	59	174	67 (0.87)	32	17	13	11	6	4	3	2	1	1
2011	1	1	1	1	1	1	1	2	2	3	14 (0.90)	42	178	61 (0.94)	31	21	16	8	4	3	2	1	1
2012	1	1	1	1	1	1	1	2	2	2	4	10 (0.77)	30	181	66 (0.92)	39	17	9	5	3	2	1	1
2013	1	1	1	1	1	2	3	3	3	3	3	4	14 (0.96)	35	176	84 (0.88)	38	20	9	7	4	1	2
2014	2	2	2	2	2	3	3	3	2	2	2	6	16 (0.81)	176	52	77 (0.94)	37	18	8	6	1	2	1
2015	2	2	2	2	2	2	2	2	2	1	1	2	3	8	19 (0.89)	45	183	79 (0.95)	37	15	7	2	3
2016												1	2	5	12	22 (0.79)	157	49	67 (0.94)	24	12	4	2
2017													1	1	6	12	23 (0.91)	178	65	67 (0.97)	23	9	5
2018															2	7	10	25 (0.97)	154	46	40 (0.95)	10	5
2019		1	1	1	1	1	1	1	1	1	1	1	1	1	1	8	8	10	14 (0.70)	180	60	45 (0.94)	18
2020		1	1	1	1	1	1	1	1	1	1	1	1	1	1	6	6	8	9	25 (0.76)	172	52	56 (0.95)
2021		1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	3	3	13	26 (0.80)	144	48
2022		1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	10	15	27 (0.94)	120

Supplementary Table S9. Number of lines for heading date in INRAE-AO dataset per year and in common between years, and correlation between years. *Correlations are provided in parenthesis for consecutive years only. North dataset is above the diagonal and South, below. An empty cell means 0.*

Organism	Type of data	Location or group	Raw 2020	Raw 2021	Raw 2022	Clean Yield	Clean Grain protein content	Clean Plant height	Clean Heading date
FD	Plots	CAP	457	327	0	782	784	784	784
		HOU	459	364	301	1,124	1,123	1,124	1,124
		Parents	210	178	94	481	481	482	482
		Progenies	706	513	207	1,425	1,426	1,426	1,426
		Total	916	691	301	1,906	1,907	1,908	1,908
	Lines	Parents	14	18	28	29	29	29	29
		Progenies	666	473	207	1,139	1,139	1,139	1,139
		Total	680	491	235	1,168	1,168	1,168	1,168
INRAE	Plots	AUZ	419	0	820	1,236	408	1,239	1,239
		CLE	0	800	804	1,591	789	1,604	1,604
		LUS	420	834	1,003	2,257	1,246	2,257	2,255
		MON	660	802	1,008	2,270	1,283	2,294	2,294
		Parents	93	508	549	1,141	591	1,142	1,142
		Progenies	1,406	1,928	3,086	6,213	3,135	6,252	6,250
		Total	1,499	2,436	3,635	7,354	3,726	7,394	7,392
	Lines	Parents	2	52	74	74	52	74	74
		Progenies	818	1,735	2,698	4,426	2,383	4,452	4,451
		Total	820	1,787	2,772	4,500	2,435	4,526	4,525
Both	Adjusted phenotypes	Total				7,867	4,638	7,907	7,905
	BLUE	Total				5,658	3,596	5,684	5,683

Supplementary Table S10. Description of the experimental data for the 4 analyzed traits.

*Abbreviations for the protocol's locations are the following: CAP: Cappelle, HOU: Houville, AUZ: Auzeville, CLE: Clermont-Ferrand, LUS: Lusignan, MON: Mons. Clean data is after discussion with partners concerning the quality of the observations. BLUE values were computed from spatially adjusted clean observations to correct the effect of the environment (location*year).*

P1	P2	Yield				Grain protein content				Plant height				Heading date			
		Nb progenies	Mean	SD	Observed UC	Nb progenies	Mean	SD	Observed UC	Nb progenies	Mean	SD	UC	Nb progenies	Mean	SD	Observed UC
2	78	22	93.7	4.7	103.1	18	11.3	0.8	12.9	22	87.8	5.2	98.1	22	132.9	1.7	135.1
3	51	26	85.1	9.5	99.7	21	12.4	0.9	13.8	26	88.9	21.7	126.8	25	138.6	4.9	144.0
5	107	69	86.9	5.8	98.7	52	11.8	0.9	13.6	73	91.0	11.5	112.1	73	136.8	4.0	144.4
7	18	37	88.1	8.7	100.9	37	11.7	0.6	12.8	37	89.0	6.5	101.9	37	135.2	4.6	142.3
7	41	82	92.4	8.3	107.2	82	11.7	0.6	12.7	82	99.4	8.0	115.6	82	136.7	3.5	143.0
7	50	24	84.8	7.8	97.3	24	11.4	0.5	12.3	24	91.2	6.4	102.4	24	140.1	3.1	146.7
7	55	26	82.1	9.2	97.0	26	12.1	0.7	13.7	26	89.9	17.2	115.4	26	137.5	6.9	151.6
7	79	44	84.3	8.8	99.1	34	11.8	1.1	15.2	44	85.0	8.3	103.1	44	135.8	4.1	143.6
7	84	34	82.8	8.6	96.1	34	11.9	0.7	13.2	34	83.2	16.2	111.5	34	137.6	5.7	150.6
7	85	60	85.5	6.0	94.8	60	11.4	0.4	12.2	60	91.5	5.2	102.1	60	136.1	3.4	143.1
7	88	10	89.1	10.8	99.5	12	11.5	0.5	12.2	13	95.4	14.7	122.9	13	135.1	4.5	143.7
7	100	36	89.0	6.3	100.4	36	11.4	0.7	12.6	36	94.1	5.9	104.1	36	138.7	7.3	146.4
7	106	19	84.6	8.5	99.1	19	11.9	0.7	13.7	19	92.2	18.4	123.8	19	137.1	5.2	146.4
8	37	68	84.4	6.5	95.0	53	12.0	1.0	14.4	68	90.6	15.5	114.9	68	139.0	3.5	146.5
8	58	59	84.8	5.5	95.0	48	12.4	0.9	14.5	59	88.0	6.5	100.0	59	132.1	2.9	136.7
8	105	62	89.0	5.9	98.7	47	11.7	0.8	12.9	62	95.2	10.9	115.5	62	135.4	3.7	143.5
12	2	49	86.9	6.3	98.1	38	11.4	0.6	12.5	49	86.2	5.6	96.8	49	132.9	3.3	139.7
12	7	31	91.3	7.9	105.5	22	11.6	0.8	12.9	31	87.3	10.3	114.0	31	133.5	4.6	142.6
12	88	60	89.6	8.2	104.6	46	11.3	0.8	13.1	60	86.0	7.5	102.2	60	132.8	2.7	138.3
13	6	40	87.4	6.3	98.9	0				40	99.9	7.8	113.3	40	141.0	3.3	146.5
15	8	84	78.8	10.0	92.7	83	12.8	0.7	14.1	84	98.2	10.7	117.3	84	134.7	5.2	145.7
16	20	43	79.1	6.8	90.1	43	11.9	0.5	13.1	44	102.5	11.1	124.6	44	140.9	3.1	145.6
18	35	60	84.6	6.9	96.7	0				60	93.9	10.3	115.9	60	138.2	5.1	145.9
18	106	60	87.4	7.4	100.6	46	11.3	0.8	13.1	60	86.9	15.6	116.2	60	134.7	3.0	142.2
19	82	64	82.9	8.4	94.7	0				64	91.2	7.1	105.1	64	133.7	3.2	142.1
21	50	73	84.5	5.5	93.2	53	12.1	0.9	13.8	73	94.6	14.3	115.9	73	139.2	2.0	142.8
25	50	68	85.8	5.0	94.2	54	11.7	1.0	13.8	68	96.8	11.1	117.8	68	135.2	3.9	141.3
26	24	59	83.8	8.9	97.7	0				60	97.2	11.9	116.3	60	141.4	3.8	146.4
28	81	65	83.1	7.9	95.8	64	12.9	0.9	14.7	66	86.8	10.9	105.8	66	133.5	3.5	139.2
30	62	76	83.4	5.1	93.4	76	12.5	0.5	13.6	76	95.3	5.5	105.0	76	133.2	2.9	139.6
33	4	35	82.1	7.5	95.7	0				35	101.3	8.9	115.9	35	145.3	4.0	151.1
36	106	48	90.1	4.7	98.7	39	11.1	0.8	13.1	48	89.2	6.7	100.9	48	134.7	2.8	141.4
37	7	63	79.6	9.0	94.8	0				63	96.6	16.1	119.6	63	143.5	2.1	147.4
39	46	53	81.1	8.0	94.9	0				53	98.8	15.3	128.6	53	139.4	4.4	147.9
40	88	8	89.5	4.9	96.2	5	11.4	0.9	12.6	8	87.5	5.8	92.9	8	132.1	1.5	135.3
42	7	72	90.7	6.5	104.4	0				72	90.2	5.8	100.5	72	138.3	3.9	145.5
42	50	63	89.8	5.2	100.7	63	11.6	0.4	12.6	63	87.0	7.2	103.3	63	137.1	3.0	143.1
42	55	43	85.3	7.6	102.4	0				44	94.6	7.7	109.8	44	135.5	4.5	144.5
42	68	67	85.9	8.2	100.0	0				67	96.2	13.6	117.7	67	136.2	4.5	147.1
42	102	75	88.6	6.6	101.1	0				75	89.6	5.4	98.8	75	138.7	3.5	145.9
45	48	84	92.9	6.4	105.3	84	11.3	0.4	12.1	84	92.4	5.1	102.4	84	138.6	2.8	143.3
47	29	84	89.5	5.6	99.4	84	11.6	0.4	12.5	84	91.2	5.2	101.4	84	134.6	2.3	139.7
50	92	60	91.1	5.6	100.2	60	11.1	0.4	11.9	60	89.7	5.7	100.2	60	139.4	1.5	142.3
52	10	39	87.9	9.4	101.6	0				40	94.4	6.7	105.1	40	143.1	3.8	148.5
52	73	60	87.7	11.1	109.4	0				60	93.5	6.7	107.8	60	141.5	3.2	146.5
52	108	59	91.0	6.5	104.6	0				60	91.5	6.3	105.1	60	140.8	3.8	147.4
54	10	49	80.7	8.0	95.8	0				50	98.0	10.1	113.9	50	144.3	2.4	148.3
54	52	60	86.4	9.4	105.0	0				60	97.7	9.8	112.9	60	141.1	4.2	148.1
54	73	50	83.9	7.8	96.7	0				50	99.6	7.8	111.9	50	141.3	2.1	145.0
54	108	50	81.9	7.5	94.7	0				50	99.1	11.2	119.9	50	143.5	2.6	148.1
55	56	59	90.6	8.1	107.6	0				59	86.8	6.8	101.1	59	129.6	2.9	136.4
55	75	13	89.7	6.9	98.1	8	11.2	0.6	11.9	13	84.8	3.4	92.2	13	132.3	1.6	135.1
55	101	61	82.2	7.6	95.3	0				63	97.1	15.3	123.3	63	136.6	6.1	146.3
57	78	25	93.6	6.1	104.7	21	10.9	0.7	12.3	25	83.8	5.3	93.3	25	132.4	2.1	134.9
58	102	49	84.4	7.6	96.1	0				49	90.3	7.8	106.9	49	132.4	4.3	140.9
59	38	60	80.1	8.4	92.8	0				60	87.0	6.1	98.4	60	137.7	4.5	144.9
60	27	59	85.7	7.4	98.4	0				59	99.0	11.1	117.4	59	136.8	3.6	143.9
60	84	41	91.4	5.8	101.1	32	11.5	0.8	12.7	43	93.0	6.5	106.2	43	135.0	2.2	137.9
62	1	72	85.8	6.4	97.0	53	12.3	0.9	14.4	73	95.8	13.8	116.7	73	137.1	4.0	144.5
62	76	56	89.0	7.8	105.2	0				56	89.6	12.7	109.6	56	135.5	2.6	141.6
62	107	68	86.6	5.7	95.9	50	11.8	0.8	13.3	68	96.5	14.2	118.0	68	136.6	4.1	142.2
63	78	22	93.9	4.3	101.0	19	10.6	0.6	11.6	22	86.2	5.1	96.7	22	132.8	1.8	135.7
64	34	75	83.5	7.8	96.0	58	12.3	0.9	14.1	75	87.1	6.2	98.1	75	139.0	3.9	146.1
64	67	64	86.1	4.7	95.2	47	12.4	0.9	14.0	64	93.0	12.0	112.5	64	135.6	1.8	139.2
65	7	57	86.1	11.8	102.8	57	11.6	0.7	13.3	57	91.4	7.8	105.1	57	140.6	3.9	148.8
65	46	60	84.0	7.7	100.9	0				60	89.5	5.3	98.9	60	141.7	3.8	147.9
65	101	50	86.0	10.0	97.0	49	11.6	0.6	12.8	50	92.4	9.2	108.2	50	140.0	2.1	143.5
66	44	85	87.4	11.1	101.0	85	11.6	0.6	13.1	85	88.6	4.9	97.5	85	137.6	3.5	143.1
69	23	65	83.6	6.1	96.0	51	11.7	1.1	13.9	65	94.9	9.1	111.9	65	136.5	4.3	143.0
70	96	81	84.0	8.0	96.6	81	12.6	0.7	14.2	81	93.2	6.8	105.0	81	136.4	3.8	143.7
71	32	51	84.7	4.3	94.2	39	11.8	1.1	13.5	51	91.2	4.0	99.6	51	133.5	3.4	140.3
71	69	68	86.7	8.3	97.8	52	11.1	1.0	12.6	68	92.1	12.0	115.0	68	131.5	6.4	141.6
72	17	26	80.6	7.9	93.0	18	12.3	0.9	14.0	26	88.5	17.7	119.6	26	140.8	1.6	142.6
72	94	18	83.7	3.6	92.5	12	11.9	0.6	13.0	18	97.2	8.0	120.1	18	142.3	2.3	146.5
73	10	49	84.4	11.3	103.4	0				49	94.7	5.3	106.1	49	143.3	2.9	147.9
74	21	61	90.7	4.9	98.7	47	11.7	0.7	13.5	61	88.2	5.3	97.7	61	137.4	3.2	143.4
74	64	67	86.1	7.0	96.0	48	12.3	0.8	14.1	67	89.8	5.9	101.0	67	137.3	2.3	142.0
74	71	68	88.3	6.0	98.1	49	11.7	0.7	13.3	70	90.0	5.0	99.2	70	134.8	4.7	143.3
74	89	64	90.0	4.7	99.9	51	11.4	0.7	13.0	65	92.4	5.3	102.7	65	132.8	1.6	135.5
80	9	86	84.4	7.4	98.1	86	11.8	0.4	12.8	86	90.3	6.0	102.0	86	139.7	2.0	142.8

81	53	122	86.5	5.6	97.1	122	12.8	0.7	14.1	122	91.3	9.1	107.5	122	135.1	2.3	140.0
84	91	60	89.9	6.8	99.5	60	11.4	0.4	12.2	60	92.4	4.2	101.6	60	135.1	1.3	137.7
85	31	59	84.1	7.8	96.9	0				60	93.2	12.1	116.7	60	134.6	4.1	144.0
85	49	81	86.4	6.4	96.6	81	11.6	0.4	12.4	81	90.3	4.3	97.9	81	137.9	2.9	143.6
86	14	60	88.1	6.8	97.9	60	11.5	0.5	12.5	60	87.8	4.8	97.0	60	136.2	2.0	139.4
87	11	60	88.2	6.3	99.1	60	11.8	0.4	12.5	60	88.5	4.5	97.5	60	136.2	1.3	138.6
88	2	8	92.5	8.2	102.2	6	11.3	0.7	12.7	8	86.3	7.0	98.2	8	134.0	1.9	135.9
90	5	50	89.2	5.0	100.0	40	11.5	0.5	12.8	50	90.4	5.8	102.1	50	135.9	2.0	138.9
90	36	31	88.9	4.9	96.5	31	11.9	0.6	12.9	31	88.0	4.2	95.1	31	133.7	2.5	137.1
95	102	59	80.6	7.8	92.8	0				59	90.6	12.7	109.9	59	142.1	2.8	146.5
97	93	53	89.0	5.6	99.5	53	11.7	0.4	12.4	53	91.1	5.0	100.8	53	133.3	1.6	136.0
98	25	70	87.0	5.2	95.5	53	11.6	0.8	13.1	70	85.7	6.2	96.9	70	136.7	3.5	142.9
99	61	60	88.2	6.2	100.9	60	11.2	0.5	12.2	60	86.9	5.8	96.9	60	139.5	1.3	142.4
101	22	37	84.8	6.3	96.8	37	12.5	0.7	13.8	37	92.5	13.7	112.6	37	139.9	3.6	145.0
101	60	17	83.3	6.9	92.5	16	12.2	0.9	14.5	17	89.0	14.2	118.8	17	138.7	4.4	144.9
102	43	60	88.1	5.6	96.3	60	11.4	0.5	12.3	60	89.9	5.5	100.4	60	139.8	1.5	142.3
103	7	23	85.6	10.5	99.0	20	11.8	1.2	15.0	23	95.0	15.8	126.0	23	137.5	5.2	145.1
103	83	54	92.5	6.9	105.6	40	11.2	0.8	12.4	54	87.8	6.3	97.9	54	134.2	1.9	138.4
104	77	83	91.9	4.9	99.6	83	11.3	0.4	12.0	83	91.3	4.8	98.8	83	135.2	2.2	139.3
105	76	66	88.0	5.6	99.1	52	11.7	1.0	13.3	69	91.8	11.6	113.7	69	136.6	2.2	141.1
105	89	65	90.6	6.1	102.4	51	10.8	0.9	12.7	65	90.3	5.1	100.5	65	132.0	2.1	135.4
107	50	75	86.4	5.6	95.3	61	11.5	0.8	13.4	75	85.4	4.9	97.1	75	139.4	1.3	141.9

Supplementary Table S11. Descriptive statistics of the experimental data for the 4 analyzed traits.

Abbreviations: P1: parent 1, P2: parent 2, Nb: number of, SD: standard deviation, UC: usefulness criterion.

Trait	Year		2020		2021		2022
		Site	CAP	HOU	CAP	HOU	HOU
Yield	**2020**	**CAP**		53	3	3	85
		HOU	0.55		3	3	84
	2021	**CAP**	0.54	0.83		58	89
		HOU	-0.58	-0.20	0.51		89
	2022	**HOU**	0.13	0.11	0.18	0.29	
Grain protein content	**2020**	**CAP**		53	3	3	85
		HOU	0.55		3	3	84
	2021	**CAP**	0.54	0.83		58	89
		HOU	-0.58	-0.20	0.51		89
	2022	**HOU**	0.13	0.11	0.18	0.29	
Plant height	**2020**	**CAP**		53	3	3	85
		HOU	0.78		3	3	84
	2021	**CAP**	1.00	0.95		58	89
		HOU	0.74	0.56	0.67		89
	2022	**HOU**	0.80	0.63	0.73	0.70	
Heading date	**2020**	**CAP**		53	3	3	85
		HOU	0.82		3	3	84
	2021	**CAP**	0.78	0.70		58	89
		HOU	0.80	0.72	0.88		89
	2022	**HOU**	0.79	0.92	0.92	0.90	

Supplementary Table S12. Number of lines in common (above diagonal) and correlations (below diagonal) between sites for the 4 analyzed traits in Florimond-Desprez protocol.

*Abbreviations for the protocol's locations are the following: CAP: Cappelle, HOU: Houville. Pearson's correlations were computed from spatially adjusted clean observations to correct the effect of the environment (location*year).*

Trait	Year		2020			2021			2022			
		Site	AUZ	LUS	MON	CLE	LUS	MON	AUZ	CLE	LUS	MON
Yield	2020	AUZ		45	132	6	6	7	7	2	9	5
		LUS	0.51		132	41	41	35	40	16	34	37
		MON	0.15	0.53		29	33	32	29	16	29	28
	2021	CLE	0.17	0.37	0.39		101	93	81	66	96	103
		LUS	0.61	0.32	0.47	0.36		86	88	64	72	72
		MON	0.91	0.81	0.59	0.47	0.48		91	125	206	203
	2022	AUZ	0.64	0.42	0.54	0.46	0.53	0.55		54	63	58
		CLE	1.00	0.55	0.18	0.33	0.50	0.28	0.64		140	145
		LUS	0.85	0.64	0.08	0.53	0.60	0.59	0.74	0.55		163
		MON	0.71	0.48	0.61	0.52	0.64	0.45	0.68	0.38	0.50	
Grain protein content	2020	AUZ		45	128	7	6	7				
		LUS	0.58		131	41	40	35				
		MON	0.59	0.70		29	32	32				
	2021	CLE	0.62	0.54	0.53		100	93				
		LUS	0.26	0.62	0.61	0.75		86				
		MON	0.06	0.80	0.63	0.39	0.51					
Plant height	2020	AUZ		46	132	7	6	7	7	2	10	5
		LUS	0.91		132	41	41	35	40	16	34	37
		MON	0.84	0.85		29	33	32	29	16	29	28
	2021	CLE	0.93	0.79	0.80		102	94	83	66	96	105
		LUS	0.76	0.84	0.87	0.81		87	88	64	72	72
		MON	0.94	0.56	0.79	0.76	0.83		91	125	208	204
	2022	AUZ	0.98	0.93	0.92	0.53	0.77	0.83		54	63	58
		CLE	1.00	0.86	0.74	0.27	0.52	0.58	0.63		140	146
		LUS	0.94	0.86	0.69	0.66	0.82	0.82	0.76	0.71		165
		MON	0.98	0.90	0.91	0.69	0.85	0.84	0.78	0.80	0.83	
Heading date	2020	AUZ		46	132	7	6	7	7	2	10	5
		LUS	0.91		131	41	41	34	40	16	34	36
		MON	0.53	0.86		29	33	32	29	16	29	28
	2021	CLE	0.90	0.88	0.79		102	94	83	66	96	105
		LUS	0.90	0.91	0.88	0.91		87	88	64	72	72
		MON	0.85	0.96	0.91	0.91	0.95		91	125	208	204
	2022	AUZ	0.99	0.94	0.85	0.88	0.94	0.90		54	63	58
		CLE	1.00	0.88	0.67	0.92	0.92	0.92	0.91		140	146
		LUS	0.83	0.95	0.87	0.84	0.90	0.92	0.91	0.94		165
		MON	0.95	0.94	0.92	0.91	0.93	0.94	0.94	0.96	0.96	

Supplementary Table S13. Number of lines in common (above diagonal) and correlations (below diagonal) between sites for the 4 analyzed traits in INRAE protocol. *Abbreviations for the protocol's locations are the following: AUZ: Auzeville, CLE: Clermont-Ferrand, LUS: Lusignan, MON: Mons. Pearson's correlations were computed from spatially adjusted clean observations to correct the effect of the environment (location*year).*