Barley adaptation. Lessons learned from landraces will help to cope with climate change

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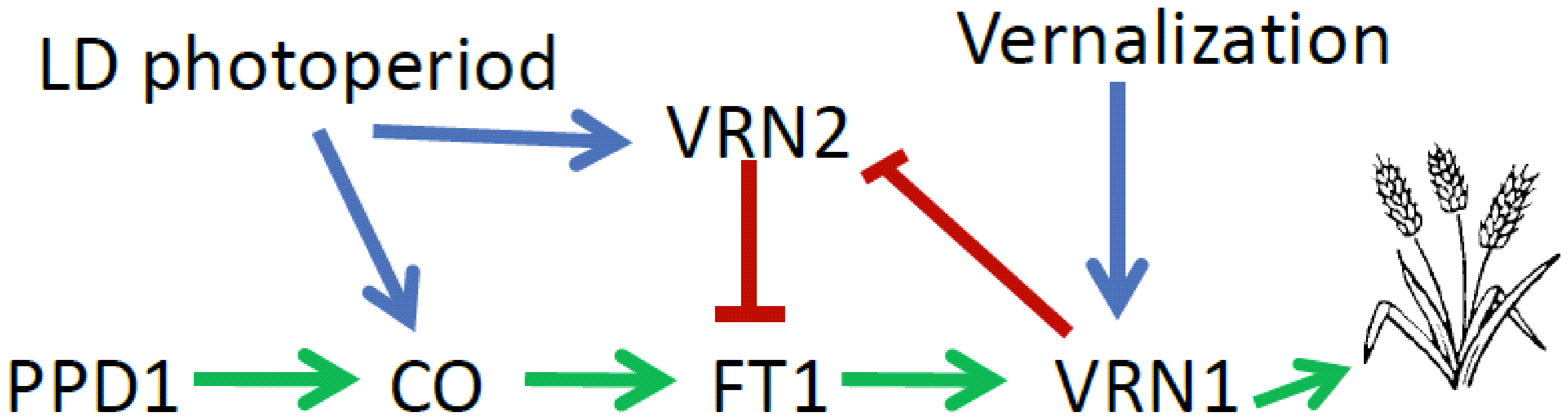
After domestication, crop expansion until current situation required adaptation to:

- **TEMPERATURE, especially cold in temperate climates**
- **DAYLENGTH**

- **What do we know about the genes driving this adaptation process?**
- **Have we explored in full the genetic diversity of these genes?**
- **What are their agronomic effects?**
- **Can we apply this knowledge to improve plant breeding for climate change scenarios?**



Simplified flowering time pathway in wheat, Nitcher, Distelfeld and Dubcovsky, 2012

Three genes control variation in requirement for vernalization

VRNH1	• 5HL, MADS box transcription factor, *HvBM5A*. • High similarity to *Arabidopsis* meristem identity genes *APETALA1*, *CAULIFLOWER*, and *FRUITFULL.* • Dominant alleles reduce vernalization requirement.
VRNH2	• 4HL, Putative zinc finger and CCT domain, HvZCCTa,b. • No clear homologous in *Arabidopsis.* • Recessive allele reduce vernalization requirement.
VRNH3	• 7HS, RAF kinase inhibitor-like protein, *HvFT1*. • Homologous to *FLOWERING LOCUS T* (*FT*) gene of *Arabidopsis.* • Dominant allele reduce vernalization requirement.

Takahashi & Yasuda (1971); Yan et al. (2003, 2004, 2006)

Two genes control response to photoperiod

PPDH1

- 2HS, Pseudo-response regulator, *HvPRR7*
- Dominant allele, sensitive to long photoperiod, accelerates flowering.

PPDH2

- 1HL, Candidate Phosphatidylethanolamine binding protein, *HvFT3*
- Dominant allele, presence of the gene, affects flowering under short photoperiod.

Turner et al. (2005) Science; Faure et al. (2007) Genetics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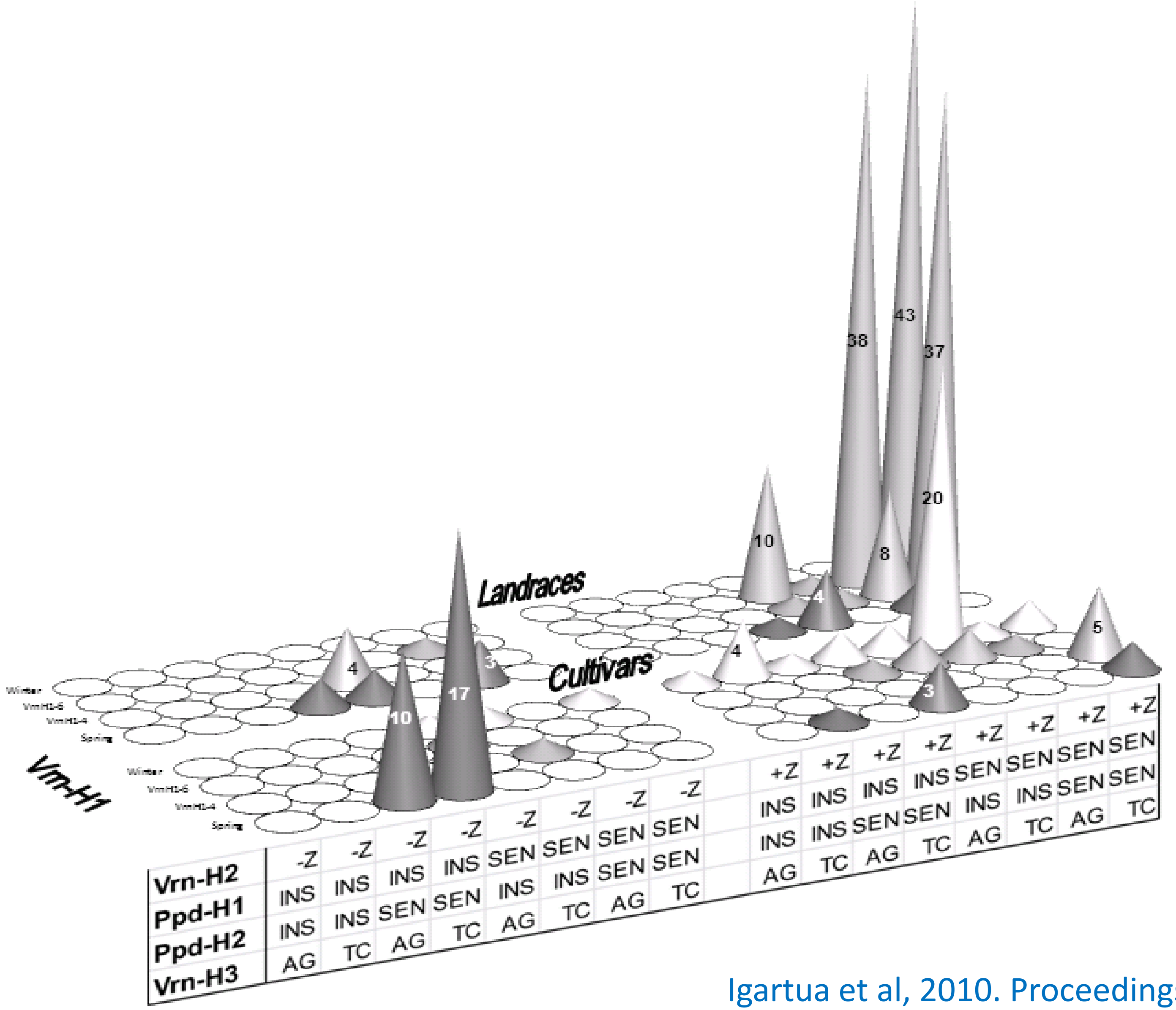
http://www.eead.csic.es/EEAD/barley/index.php

Frequencies of loci in SBCC and reference European cultivars



Igartua et al, 2010. Proceedings 10th IBGS

Frequencies of loci in SBCC and reference European cultivars

Locus, allele	6-row landraces	2-row landraces	Winter cultivars	Spring cultivars	Facultative cultivars
PpdH1	148	8	36	2	6
ppdH1	0	3	12	31	0
PpdH2	127	9	13	32	2
ppdH2	21	2	35	1	4
VrnH2	144	3	48	6	0
vrnH2	4	8	0	27	6
vrnH1	0	0	33	0	3
VrnH1-4	50	1	5	0	1
VrnH1-6	93	1	7	0	1
Others	0	0	3	0	1
VrnH1	5	9	0	33	0

Modified from Igartua et al, 2010. Proceedings 10th IBGS

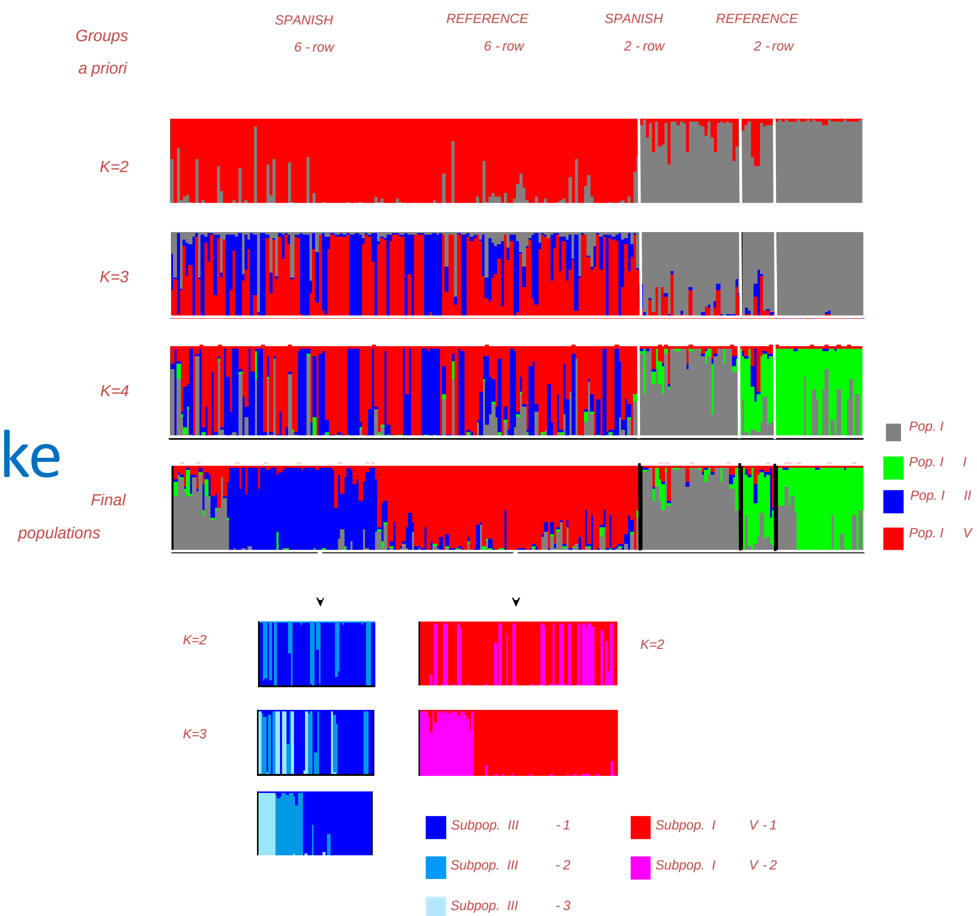
Population structure in the SBCC. Four populations:

– 2-row

– 6-row European-like

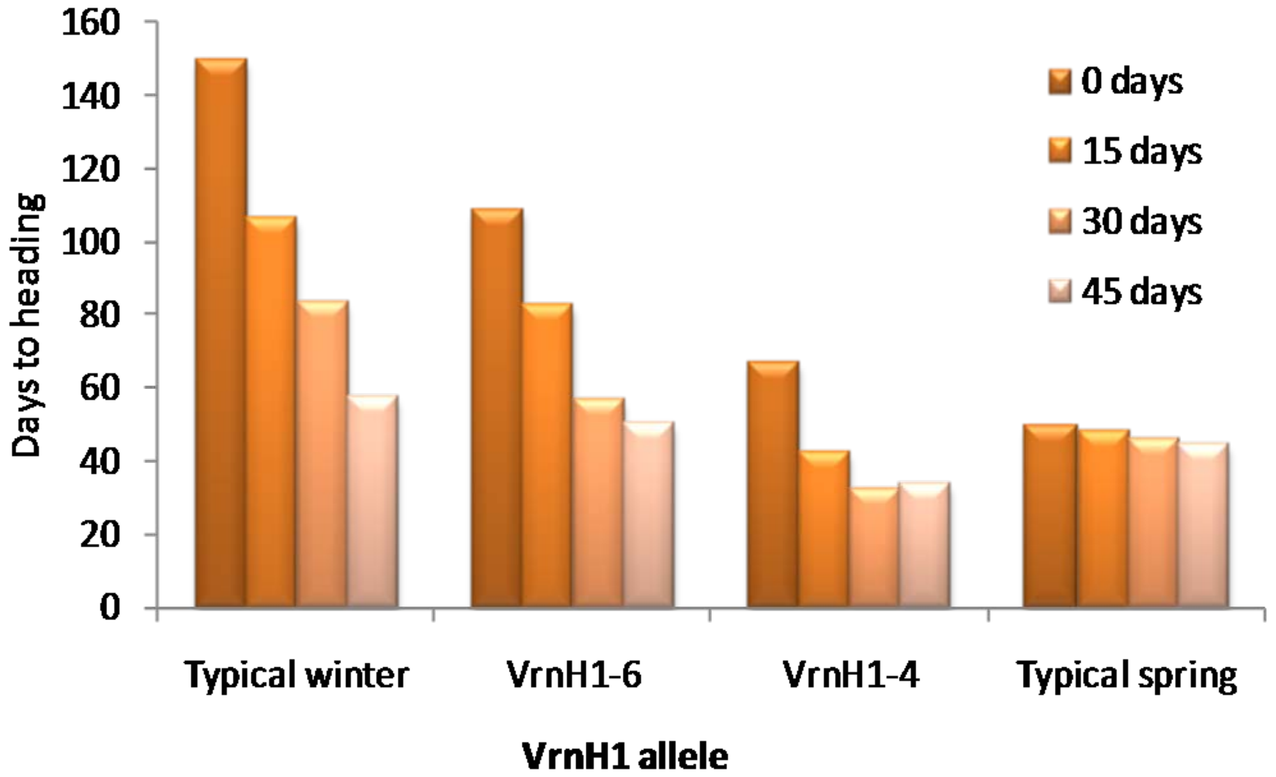
– 6-row Spanish

– 6-row Spanish



Yahiaoui et al, 2008. TAG

Allelic series in VrnH1. Vernalization effect



Casao et al. 2011, J Exp Bot

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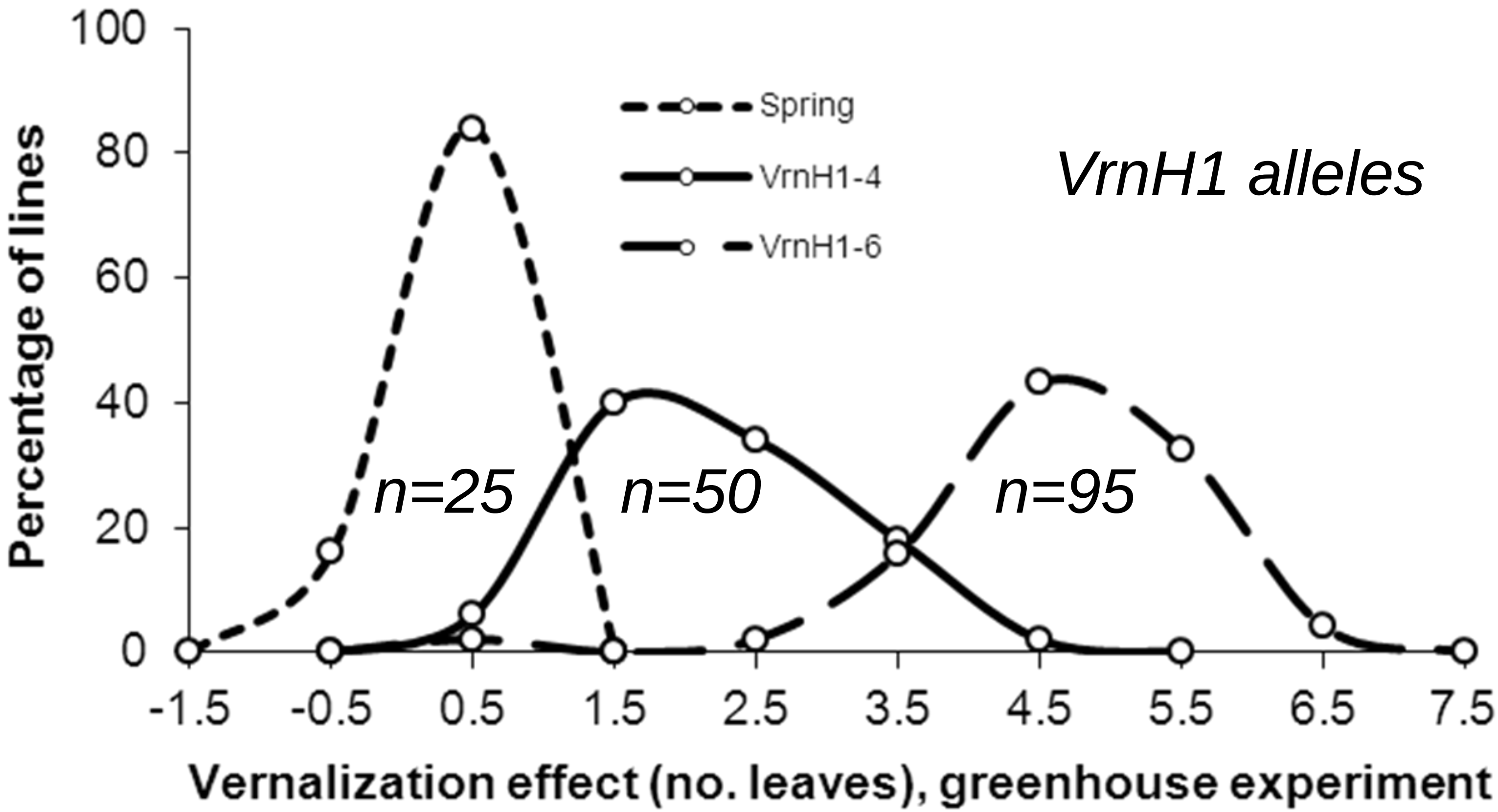
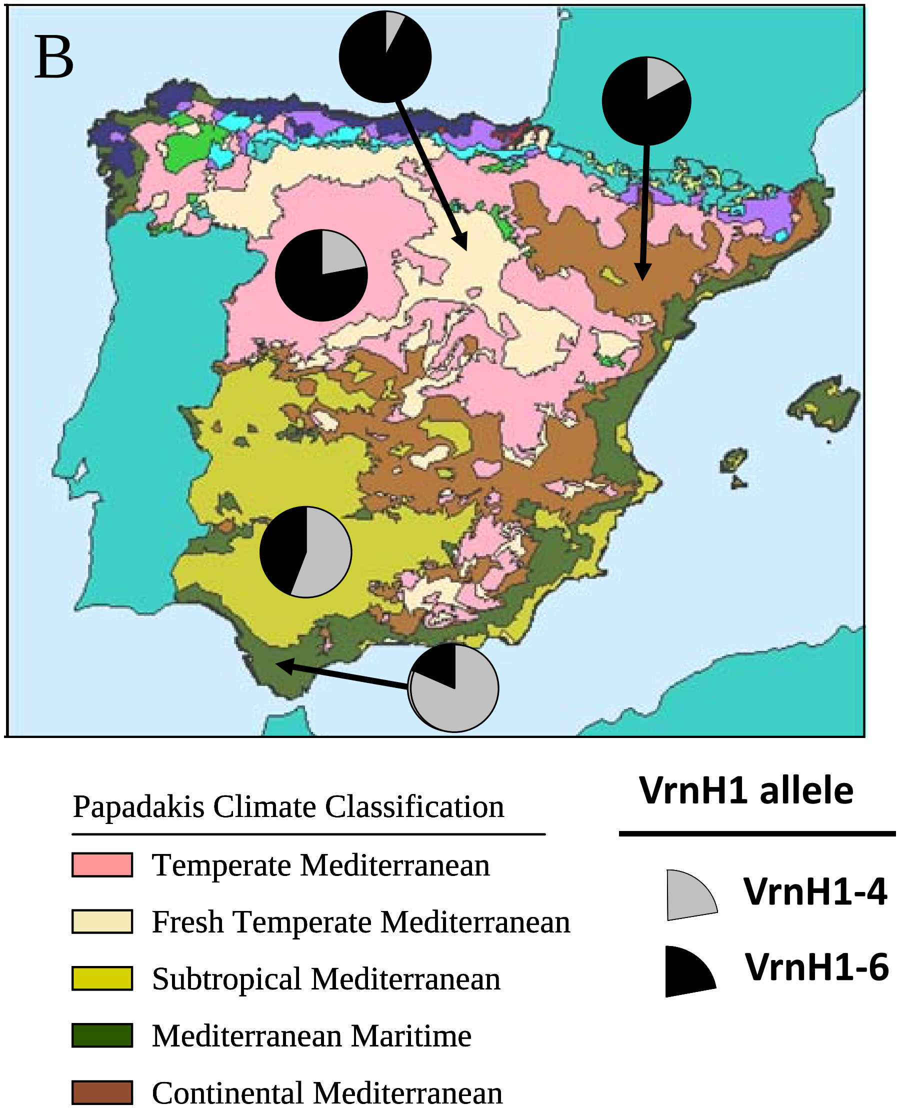
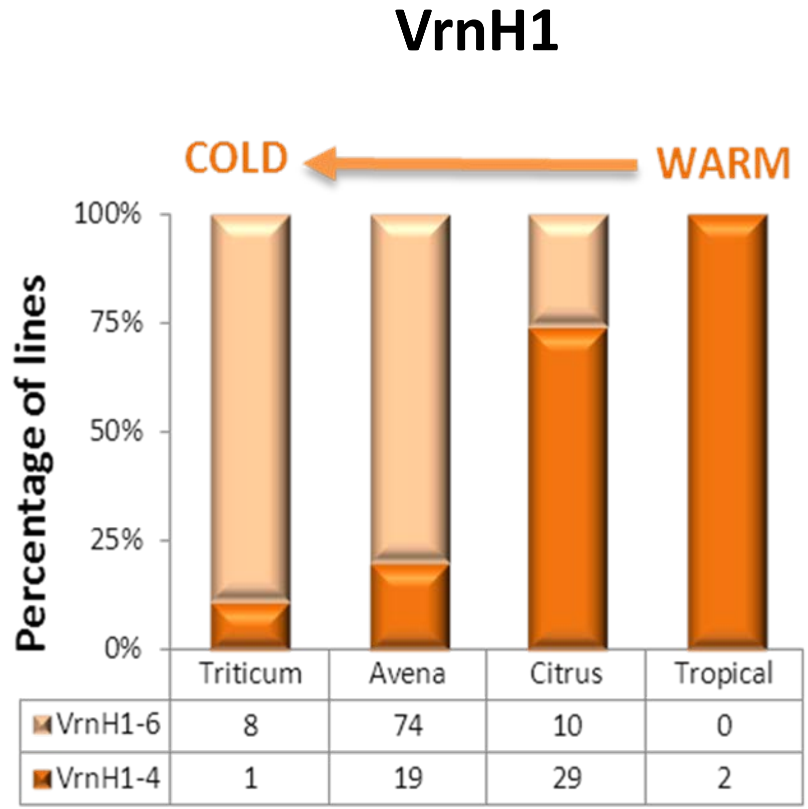


Igartua et al, 2010. Proceedings 10th IBGS

VrnH1 distribution associated with geographical features



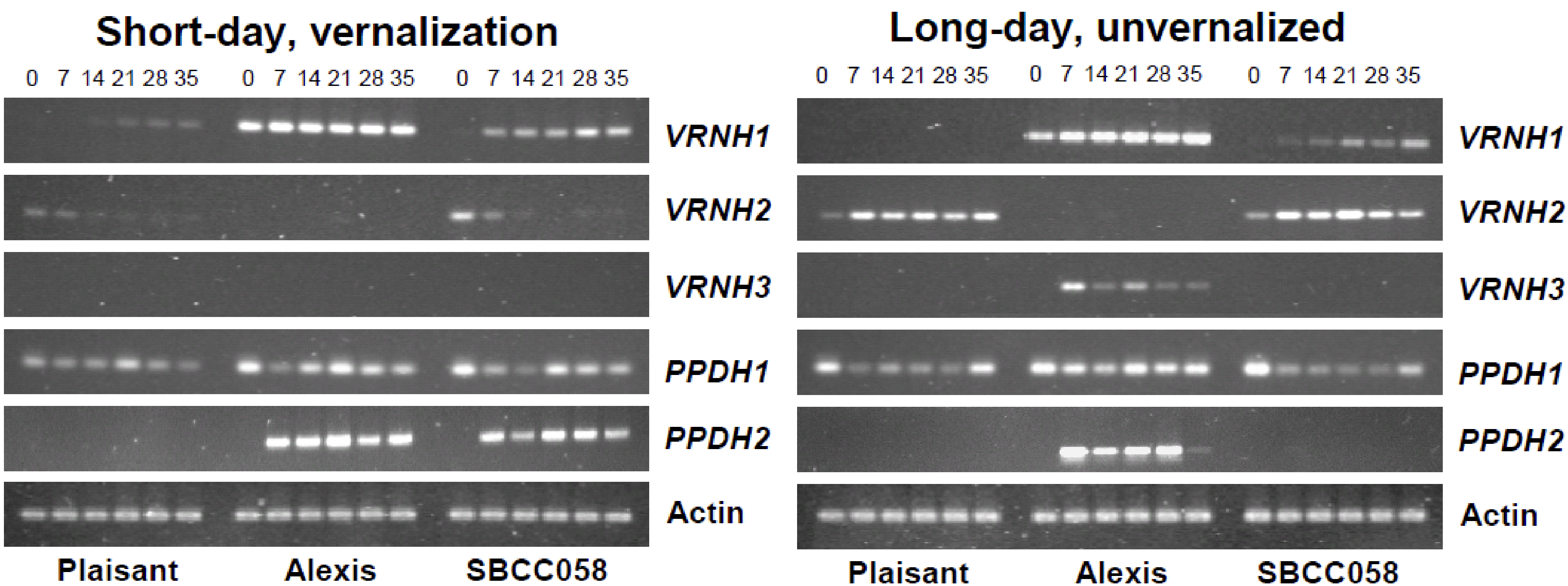


	Triticum	Avena	Citrus	Tropical
VrnH1-6	8	74	10	0
VrnH1-4	1	19	29	2

VrnH1 allele distribution over type of winter

Igartua et al, 2012. Proceedings 11th IBGS

VrnH1, expression pattern

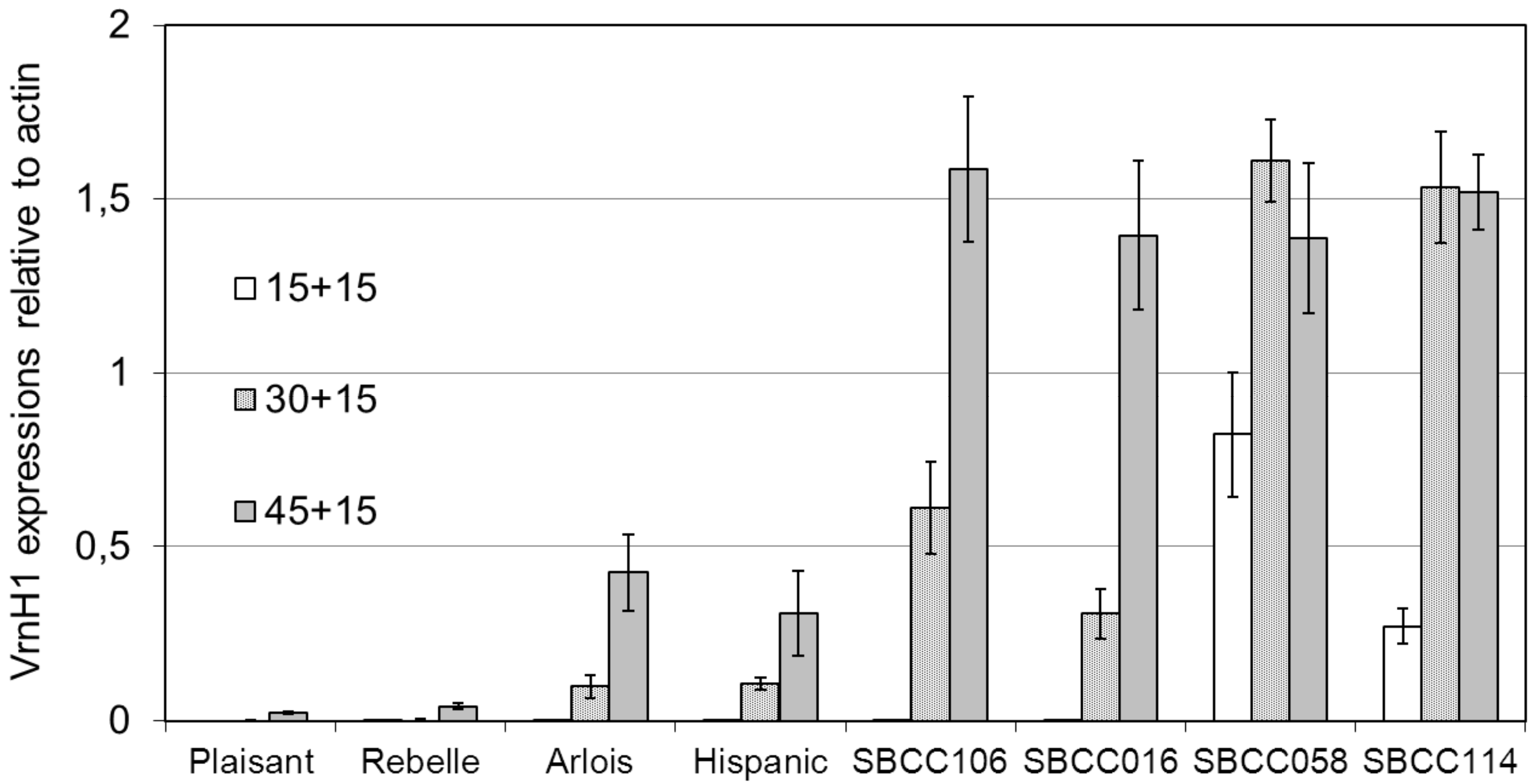


vrnH1, winter | VrnH1, spring | VrnH1-4, intermediate

vrnH1, winter | VrnH1, spring | VrnH1-4, intermediate

Casao et al. 2011, J Exp Bot

VrnH1, expression pattern



---------- vrnH1, winter -----------   ---- VrnH1-6 ---- ---- VrnH1-4 ----

Modified from Casao, Karsai et al. 2011, BMC Plant Biol

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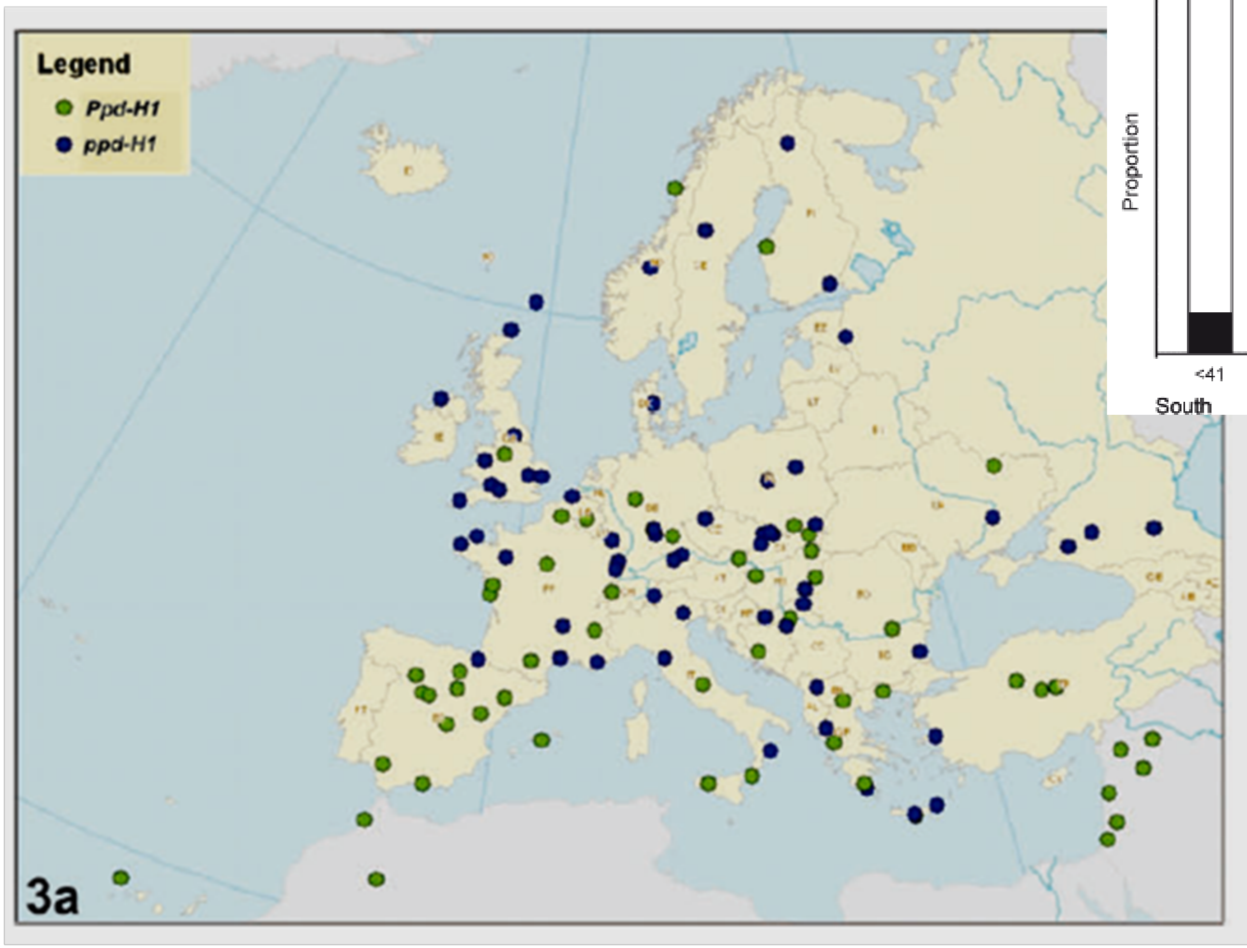
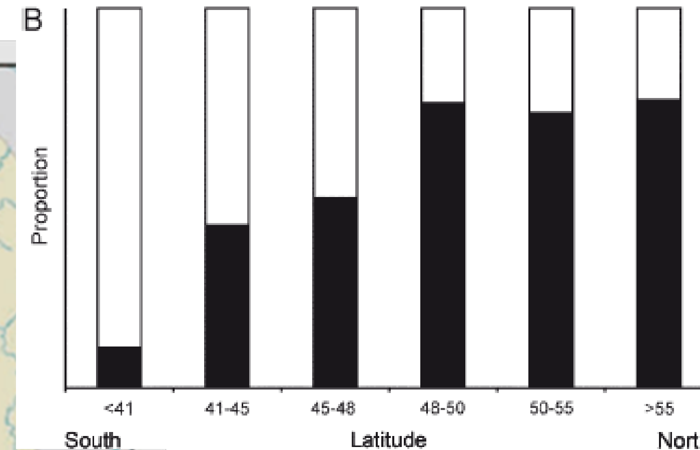
PpdH1 distribution associated with geographical features

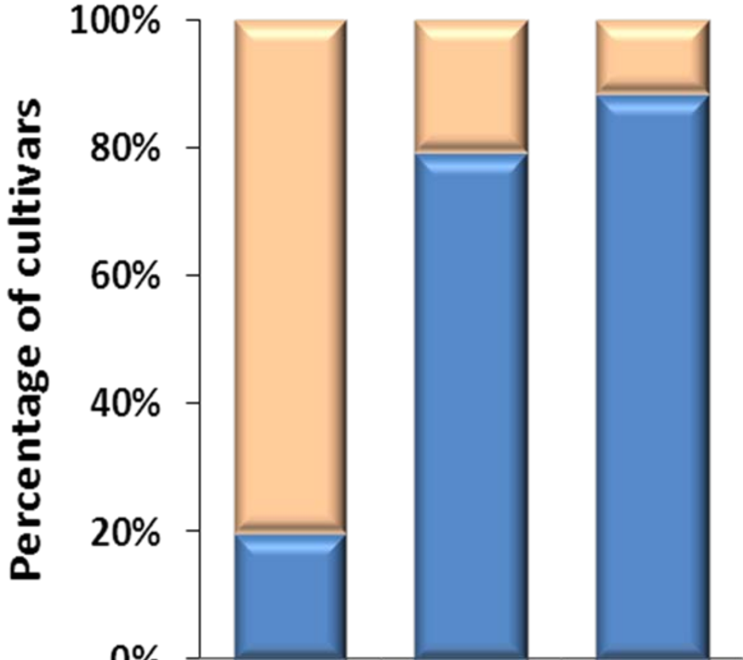




Cockram et al. 2007. J Exp Bot, 58:1231-1244

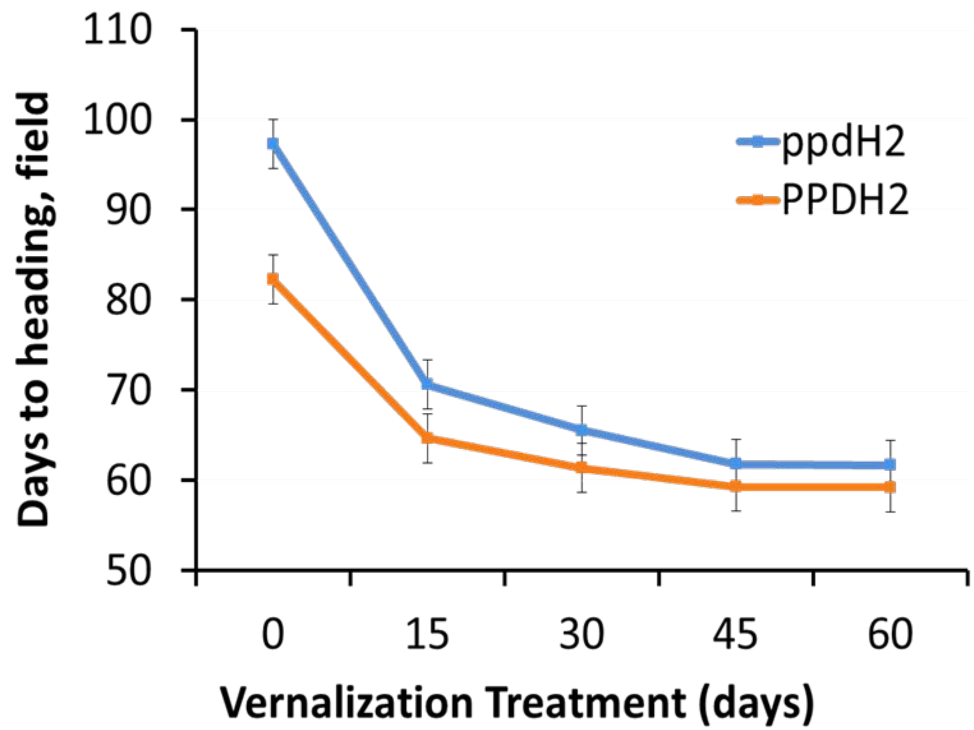
PpdH2 distribution associated with latitude. Phenotypic effect

PpdH2, winter barleys



	<44° N	44°-50° N	>50° N
PpdH2	16	11	6
ppdH2	4	42	46

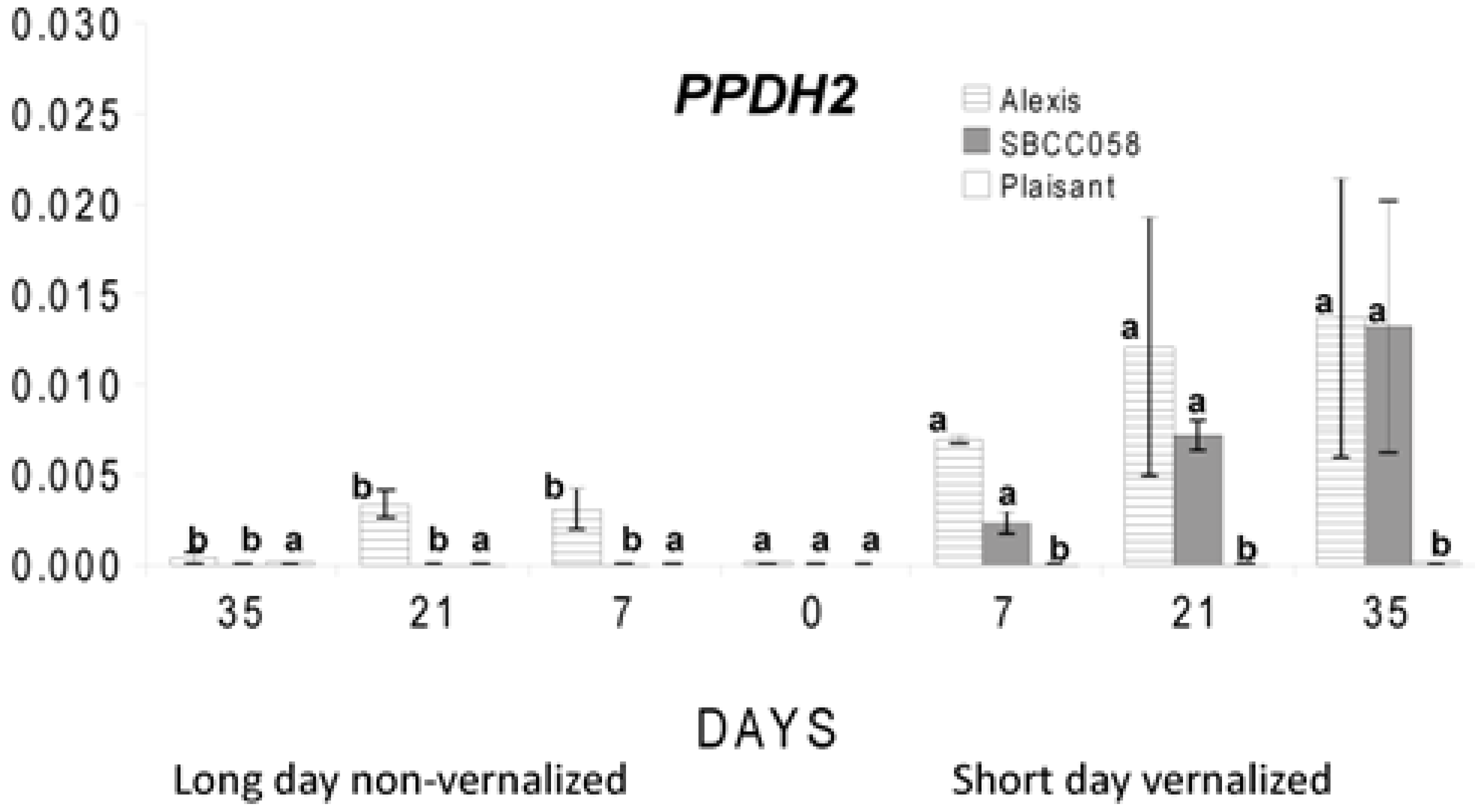
Latitude



Casao, Karsai et al. 2011, BMC Plant Biology

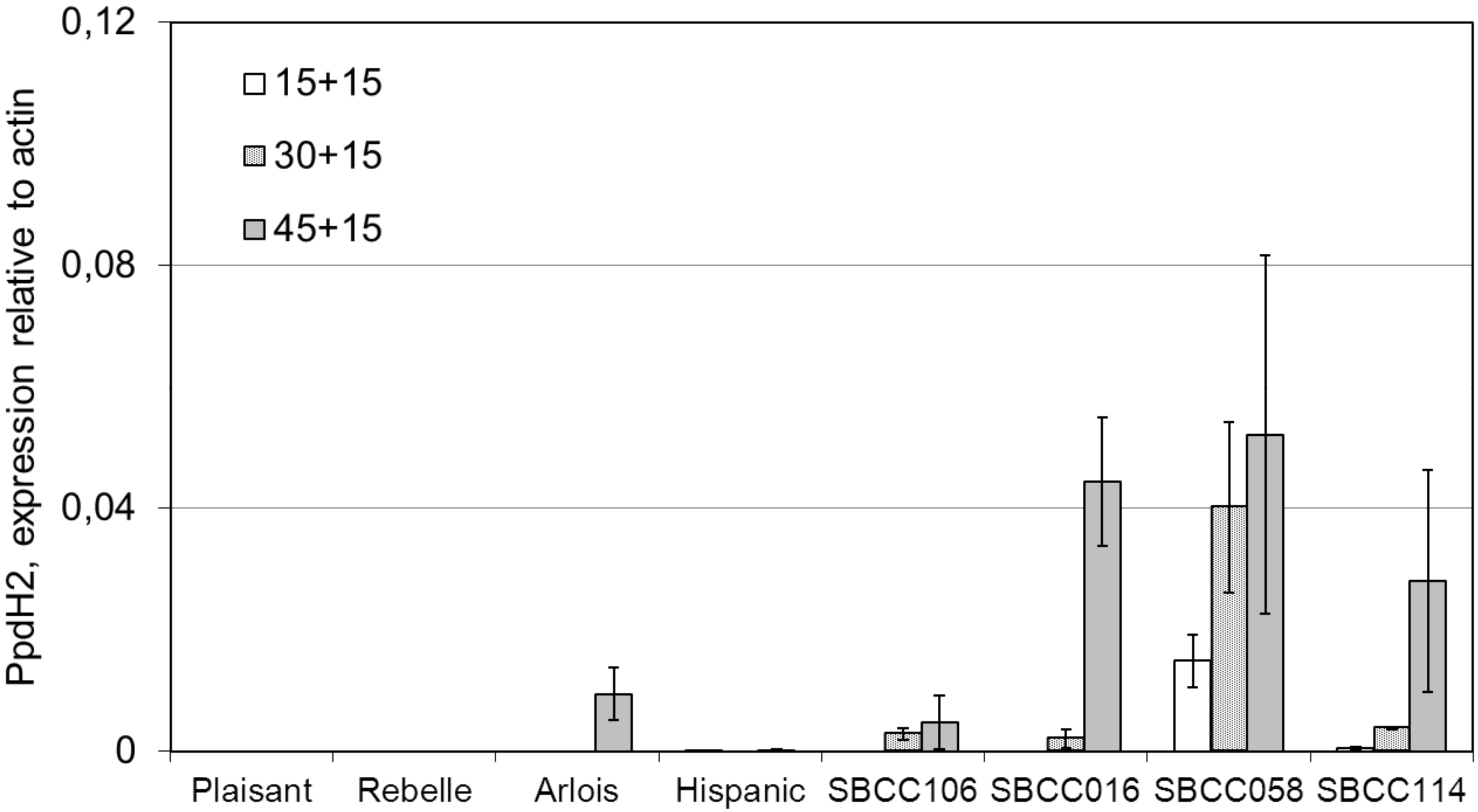
PpdH2, expression pattern in SD and LD

Alexis: VrnH1, spring, PpdH2
SBCC058: VrnH1-4, PpdH2
Plaisant: vrnH1, ppdH2



Casao et al. 2011, J Exp Bot

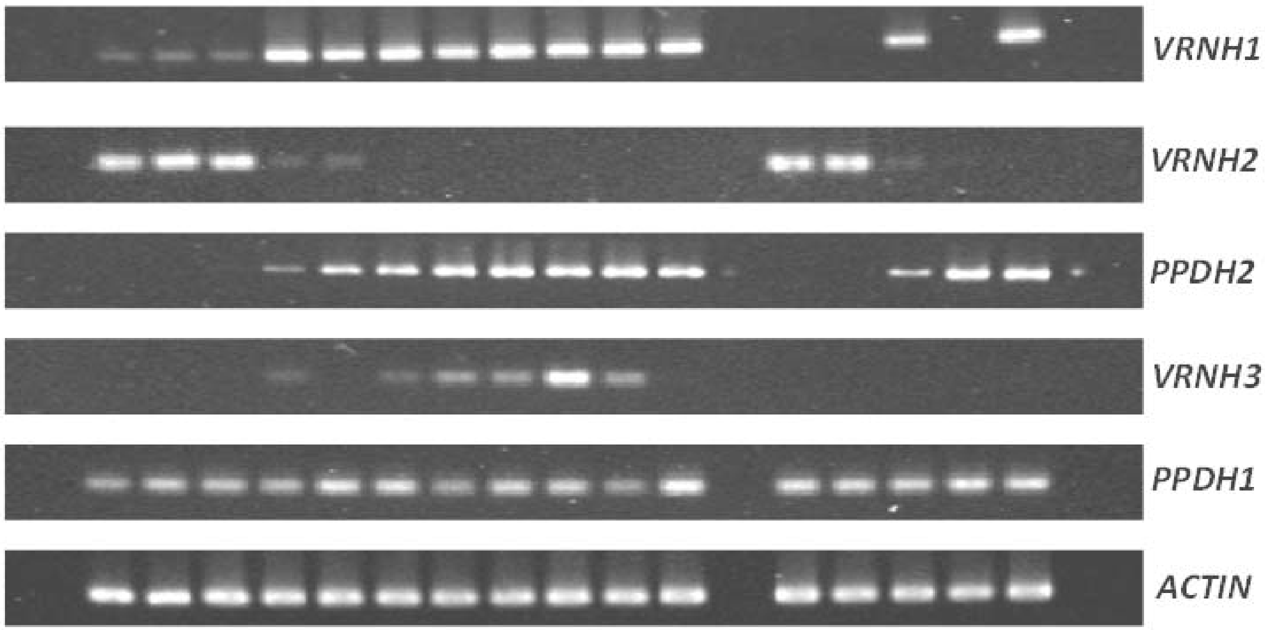
PpdH2, expression pattern across VrnH1 allelic series



---------- vrnH1, winter ----------- ---- VrnH1-6 ---- ---- VrnH1-4 ----

Modified from Casao, Karsai et al. 2011, BMC Plant Biol

PpdH2, expression pattern

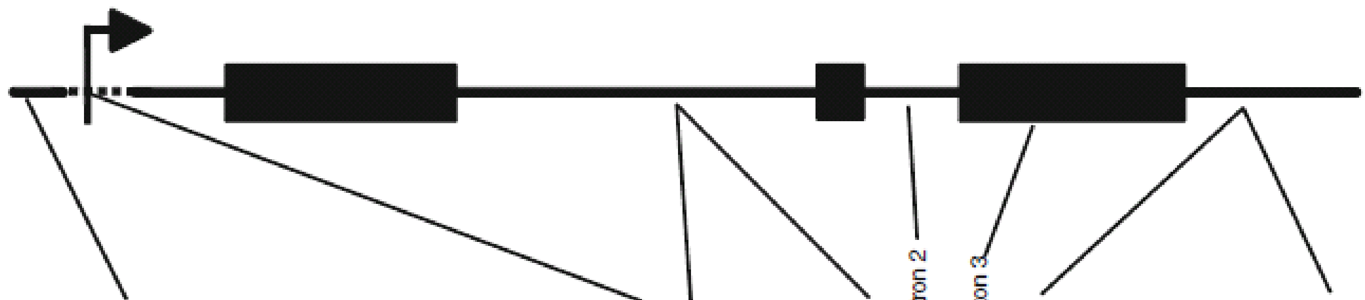


	Pané	DH385	DH426	DH412	DH414	DH364	DH416	DH424	DH427	DH429	Alexis	Mogador	DH1855	DH1829	DH1819	Beka
VRNH1	P	P	P	A	A	A	P	A	A	A	A	M	M	B	M	B
VRNH2	P	P	P	P	P	P	A	A	A	A	A	M	M	M	B	B
PPDH2[1]	-	-	-	-	-	-	-	-	-	-	-	M	B	B	B	B
VRNH3[2]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PPDH1[3]	P	P	A	P	A	P	P	P	A	P	A	-	-	-	-	-

Casao et al. 2011, J Exp Bot

VrnH3, polymorphisms

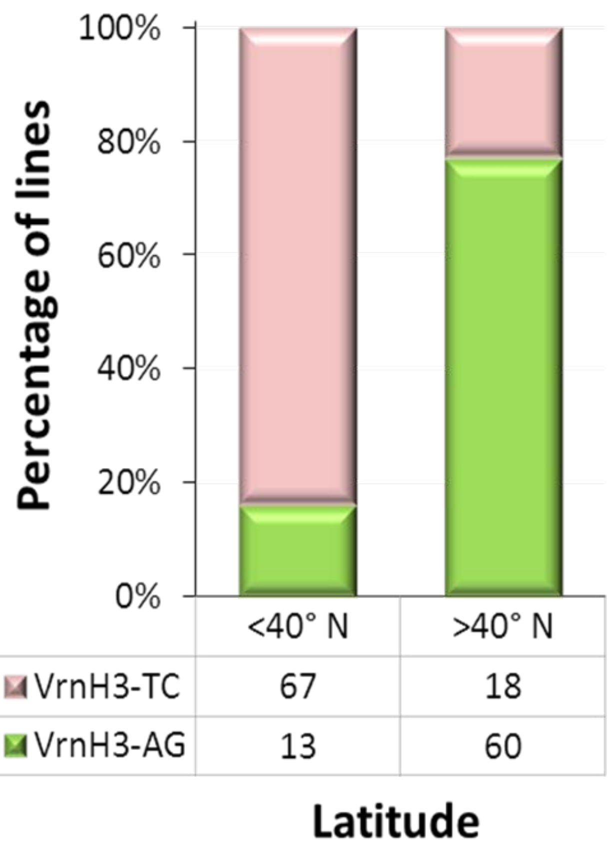
VrnH3

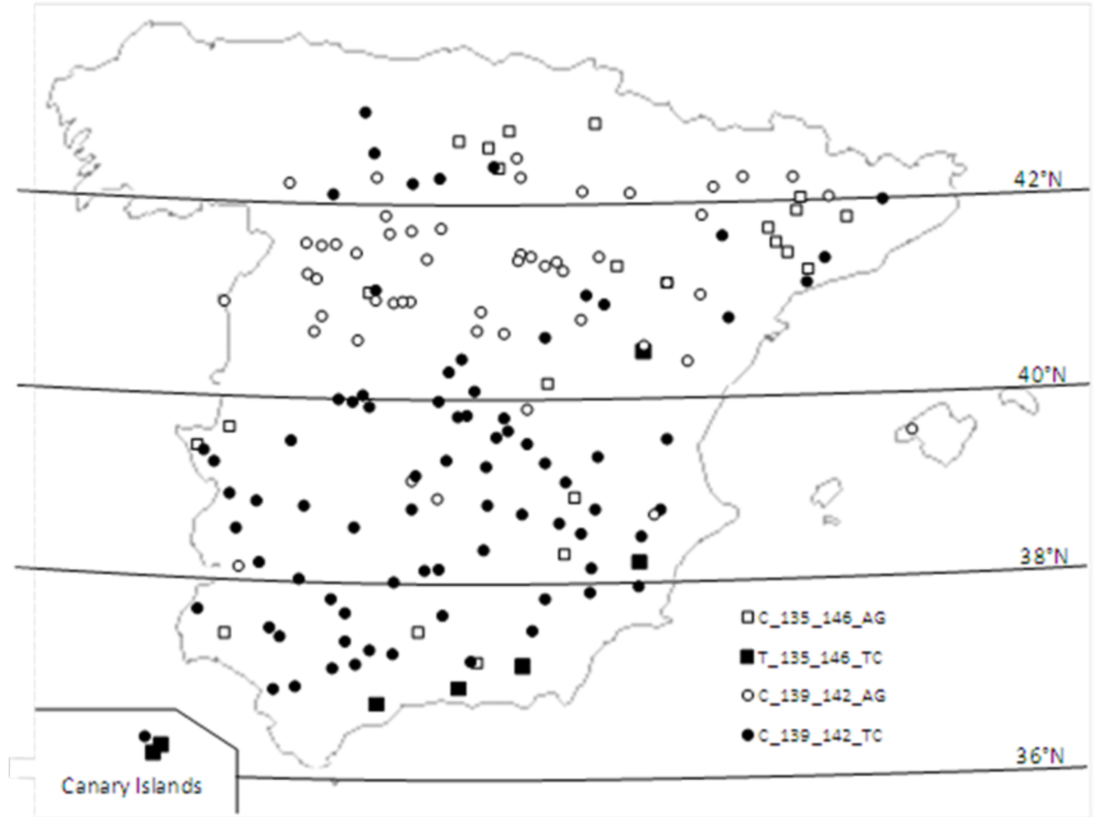


Growth habit	Genotype	Promoter 2349	2355	2375	2468	2526	2584	2628	2636	2685	2736	2747	2824	2908	2927	2935	2940	Intron 1 3328	3340	3343	3467	3547	3661	Intron 2 (GT)n	Exon 3 4078	3' untranslated 4255	4361	4448	4601	4714	4732	4770	4782	4881
W	**Iqri**	T	C	C	C	ind	A	C	G	G	-	C	C	-	C	G	T	A	T	C	A	T	C	11	G	T	C	C	G	T	C	A	A	A
W	*H.spontaneum*	C	C	G	G	ind	A	T	G	G	G	G	C	-	C	G	T	G	C	C	G	T	C	8	G	C	T	A	A	G	T	A	C	G
W	Calicuchima-sib	T	C	C	C	ind	A	C	G	G	-	C	C	-	C	G	T	A	T	C	A	T	C	11	G	T	C	C	G	T	C	A	A	A
W	Kompolti korai	T	C	C	C	ind	A	C	G	G	-	C	C	-	C	G	T	A	T	C	A	T	C	11	G	T	C	C	G	T	C	A	A	A
F	Dicktoo	T	C	C	C	ind	A	C	G	G	-	C	C	-	C	G	T	A	T	C	A	T	C	11	A	T	C	C	G	T	C	A	A	A
W	SBCC106	T	C	C	C	ind	A	C	G	G	-	C	C	-	C	G	T	A	T	C	A	T	C	11	G									
W	**Esterel**	T	C	C	C	ind	A	C	G	G	-	C	C	-	C	G	T	A	T	C	A	T	C	11	G									
W	**SBCC016**	T	C	C	C	ind	A	C	G	G	-	C	C	-	C	G	T	A	T	C	A	A	G	8	G									
W	Dairokkaku	C	C	G	G	-	G	C	A	C	G	G	T	ind	T	C	C	A	C	C	A	T	C	8	G	C	T	A	A	T	T	A	C	G
W	SBCC145	C	C	G	G	-	G	C	A	C	G	G	T	ind	T	C	C	A	C	C	A	T	C	8	G									
W	Strider	C	C	G	G	-	G	C	A	C	G	G	T	ind	T	C	C	A	C	T	A	A	G	8	G	T	T	C	A	T	T	G	A	A
S	**BGS213**	C	C	G	G	-	G	C	A	C	G	G	T	ind	T	C	C	A	C	C	A	A	G	8	G	T	T	C	A	T	T	G	A	A
S	SBCC154	T	C	C	C	ind	A	C	G	G	-	C	C	-	C	G	T	A	T	C	A	A	G	8	G									
S	Beatrix	T	C	C	C	ind	A	C	G	G	-	C	C	-	C	G	T	A	T	C	A	T	C	11	G									
S	Triumph	T	C	C	C	ind	A	C	G	G	-	C	C	-	C	G	T	A	T	C	A	T	C	11	G	T	C	C	G	T	C	A	A	A
S	Tammi	C	C	G	G	-	G	C	A	C	G	G	T	ind	T	C	C	A	C	C	A	A	G	8	G	T	T	C	A	T	T	G	A	A
S	Morex	C	C	G	G	-	G	C	A	C	G	G	T	ind	T	C	C	A	C	C	A	A	G	8	G									
S	Stander	C	G	G	G	-	G	C	A	C	G	G	T	ind	T	C	C	A	C	C	A	A	G	8	G	T	T	C	A	T	T	G	A	A

Casas et al. 2011, Theor Appl Genet

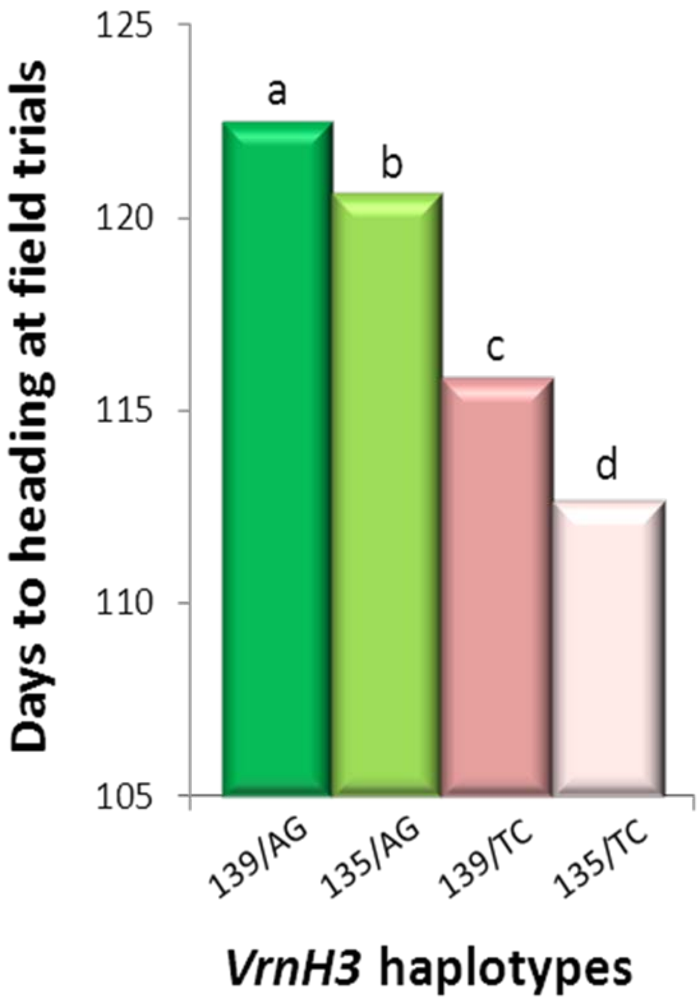
VrnH3 distribution associated with latitude





Adapted from Casas et al. 2011, Theor Appl Genet

VrnH3, phenotypic effect



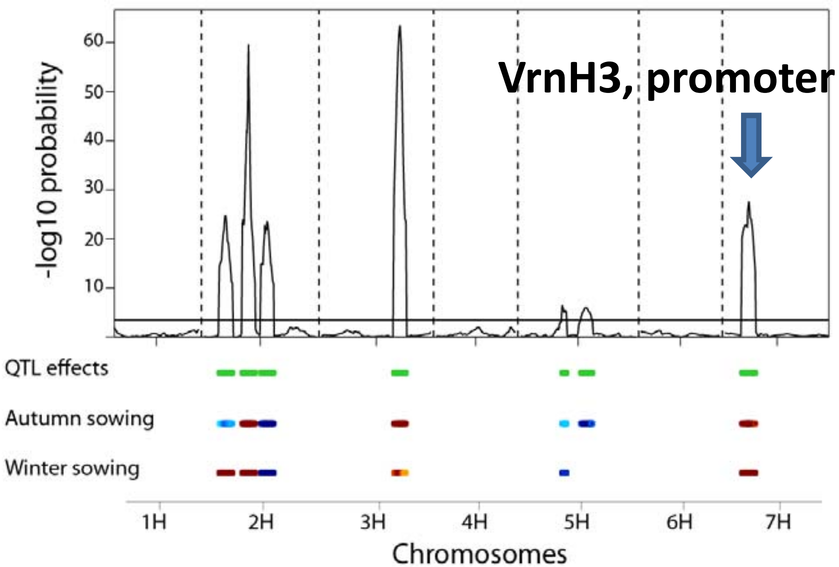
135-139: polymorphism at the promoter
AG-TC: polymorphism at the first intron

Association study, effect of VrnH3 (HvFT1) alleles on flowering date in field trials of the Spanish Barley Core Collection

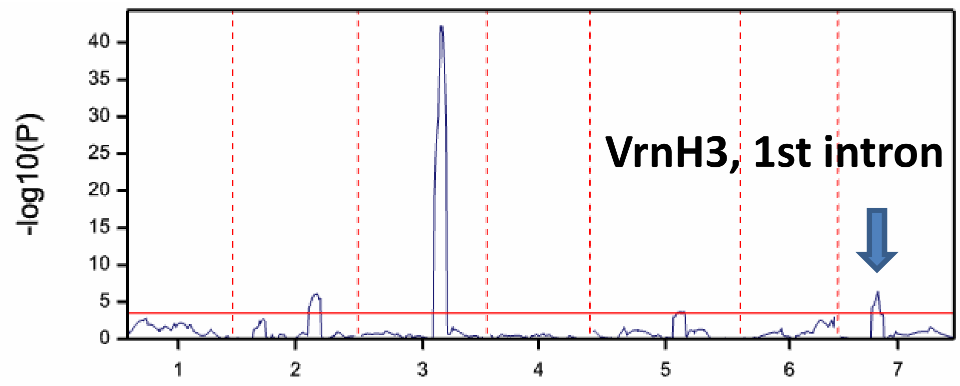
Adapted from Casas et al. 2011, Theor Appl Genet

VrnH3 validation, QTL search in biparental populations

SBCC145 x Beatrix

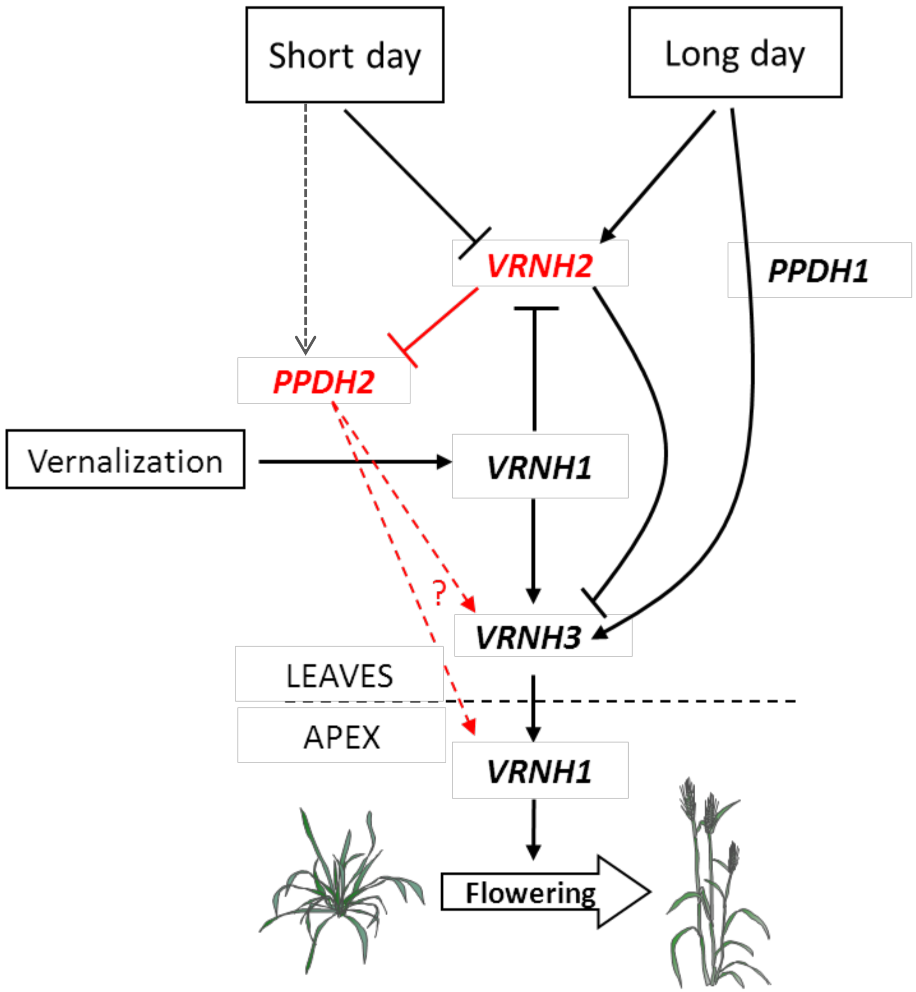


SBCC154 x Beatrix



VrnH3. Three alleles confronted in two populations with one common parent. Effect of the polymorphisms at the promoter and first intron apparently confirmed with markers developed within the gene.

Ponce-Molina et al., 2012, Crop Sci



Based on Trevaskis et al. (2007) and Higgins et al. (2010), including findings in Casao et al J Exp Bot, 2011 and BMC Plant Biol, 2011

Conclusions

• Most Spanish barley landraces are winter types with reduced vernalization requirement to match crop growth to the most favorable seasonal conditions. We propose that, under Mediterranean conditions, there are three safety mechanisms in place to secure that flowering occurs at an appropriate time, and to avoid early summer heat:

• first, intermediate *VrnH1* alleles, adapted to the prevalent winter temperature conditions;

• then, the presence of a functional *PPDH2* allele accelerates the promotion to flowering of winter cultivars under field conditions, especially when the vernalization requirement has not been fulfilled

• finally, the presence of long day sensitivity (provided by the sensitive *PPDH1* allele) gives a final boost towards flowering before temperatures rise too high.

• Other genes such as *VrnH3* or *Eam6* allow fine tuning to local temperatures

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