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VRNturing into the unknown:

Dissecting the role of *VRN2* in climate adaptation

Dominique Hirsz

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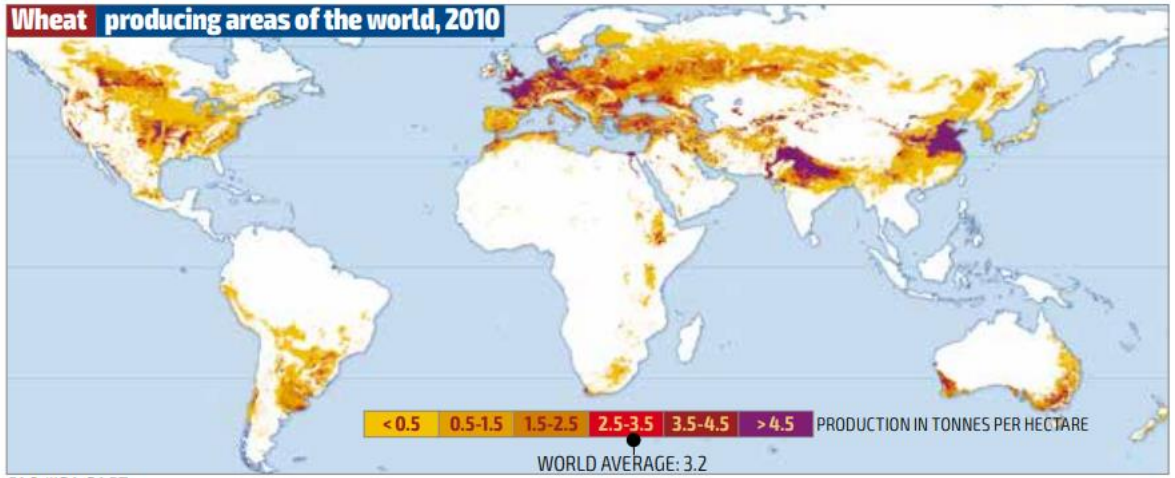
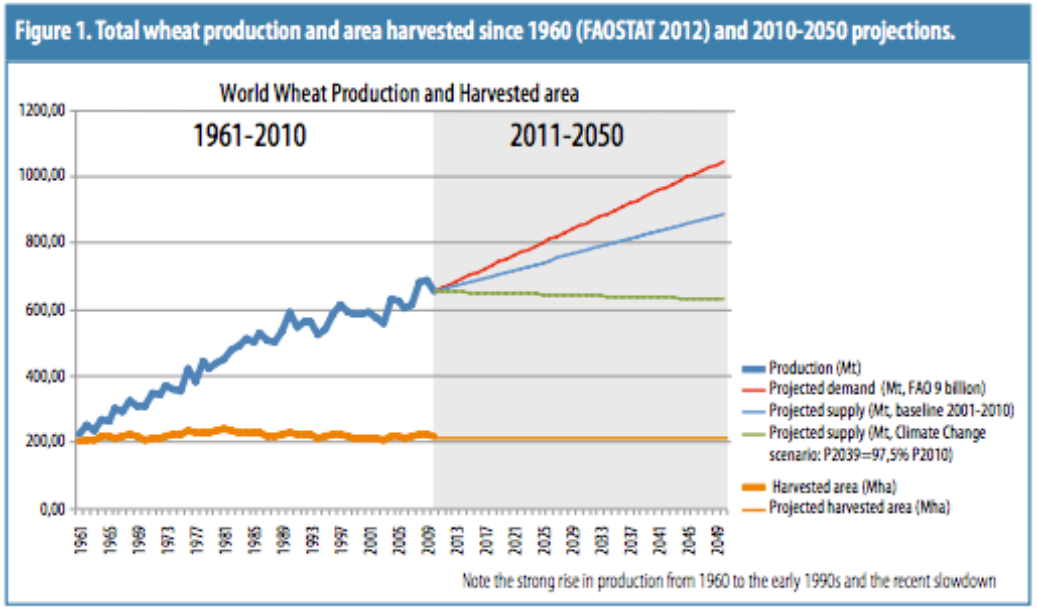
Climate change

- Wheat is the most widely cultivated cereal crop due to well-adapted varieties:
  - Spring wheat vs winter wheat
  - Photoperiod insensitivity
- The most vulnerable cereal to the effects of climate change
  - Each 1°C increase is expected to reduce yield by 4-20% depending on the region



FAO/IISA GAEZ



FAO, 2012

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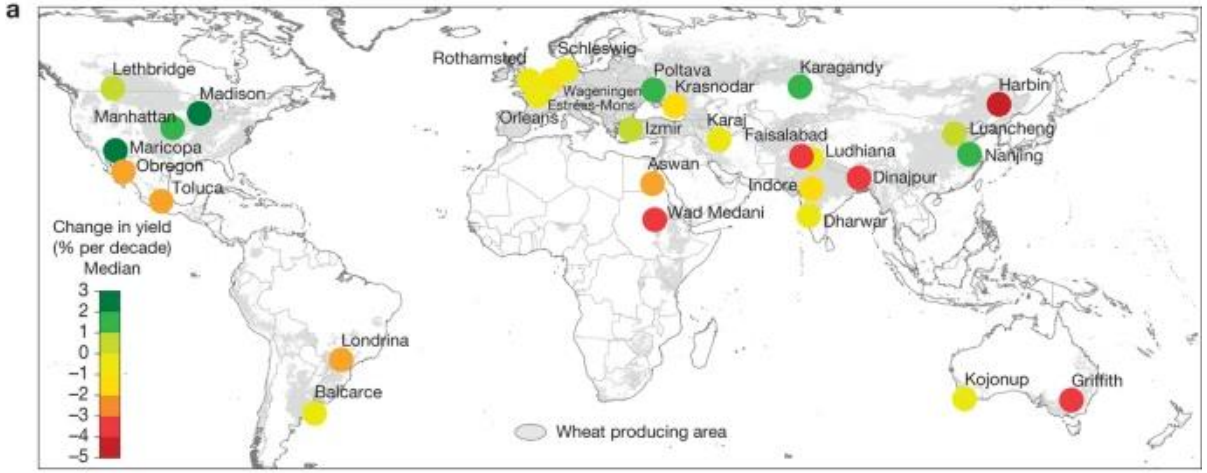
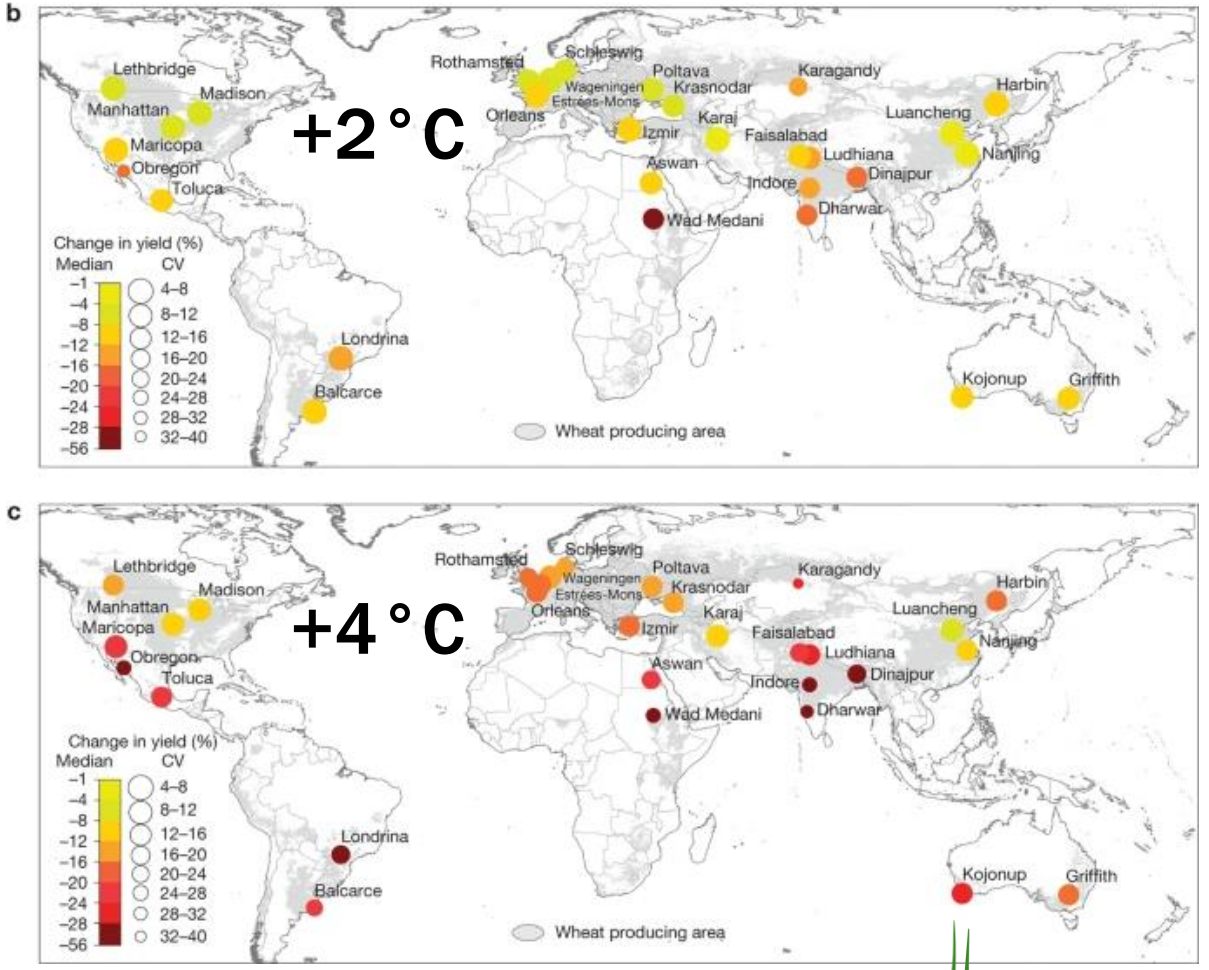
The impacts of climate change on wheat production

Grain trend yields from 1981 - 2010



Relative predicted grain yield for:



Asseng et al., 2015

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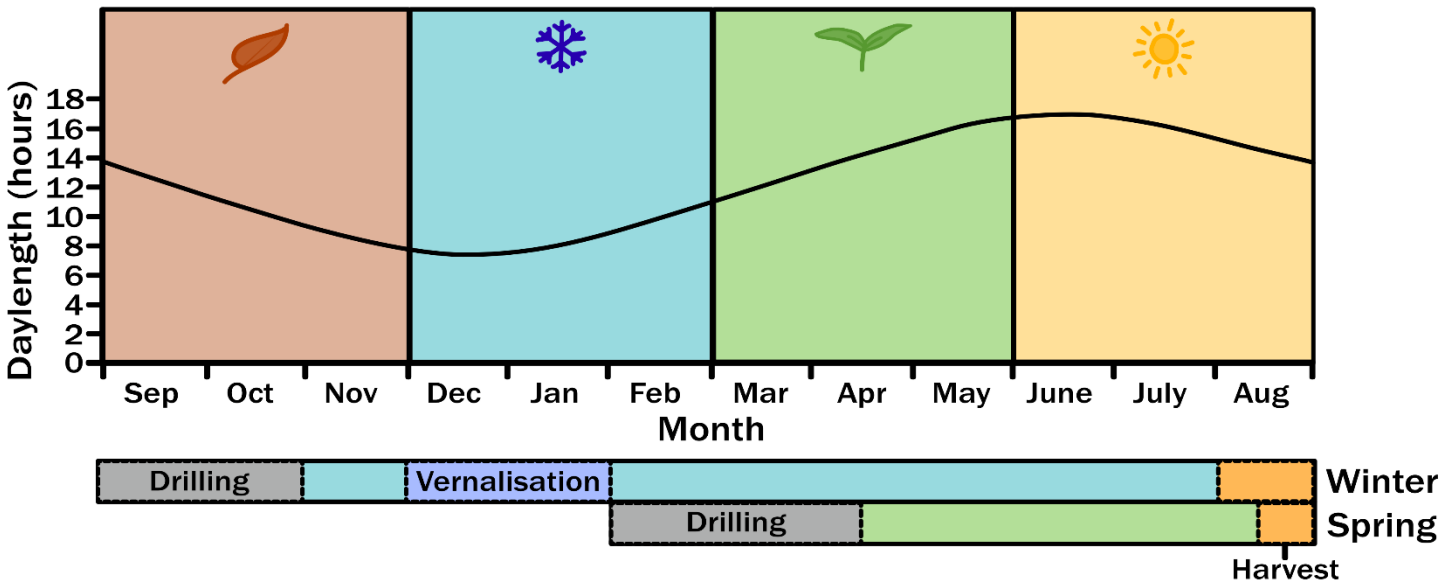
Growth habit in cereals

- Spring growth – delayed drilling date, vernalisation not required to flower
- Winter growth – autumn drilling, requires vernalisation to flower
- Facultative (spring) – flexible drilling date, vernalisation responsive but not required to flower



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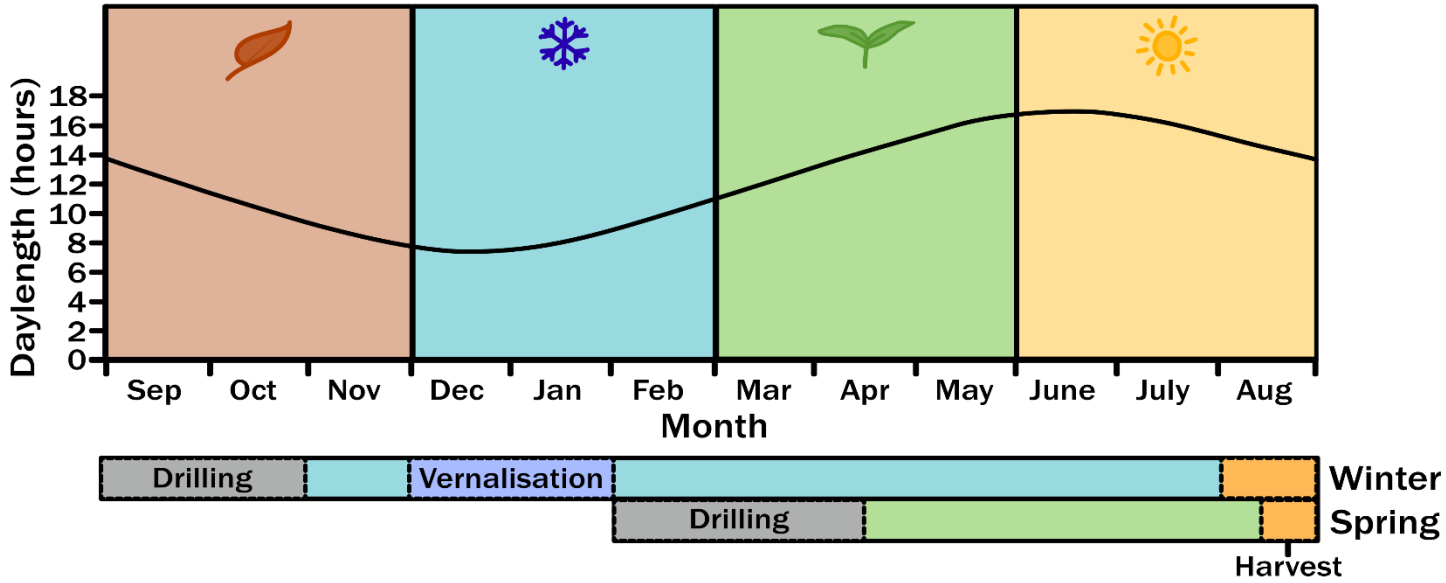
What is vernalisation?

The requirement for an extended cold exposure in winter varieties of plants to enable flowering



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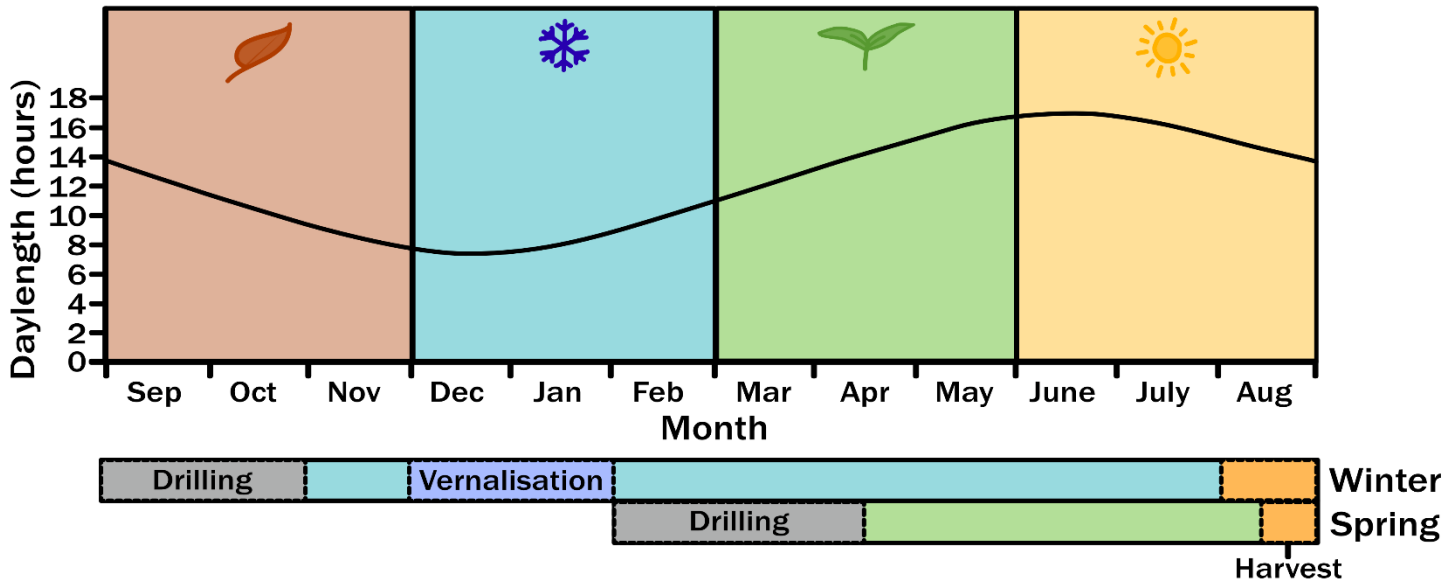
Why work with winter wheat?

- Higher yields as flowering occurs at lower temperatures and there is more time for grain filling
- Higher protein quality than spring – necessary for higher quality flour which is essential for some baked goods (eg bread)
- Ground coverage over winter



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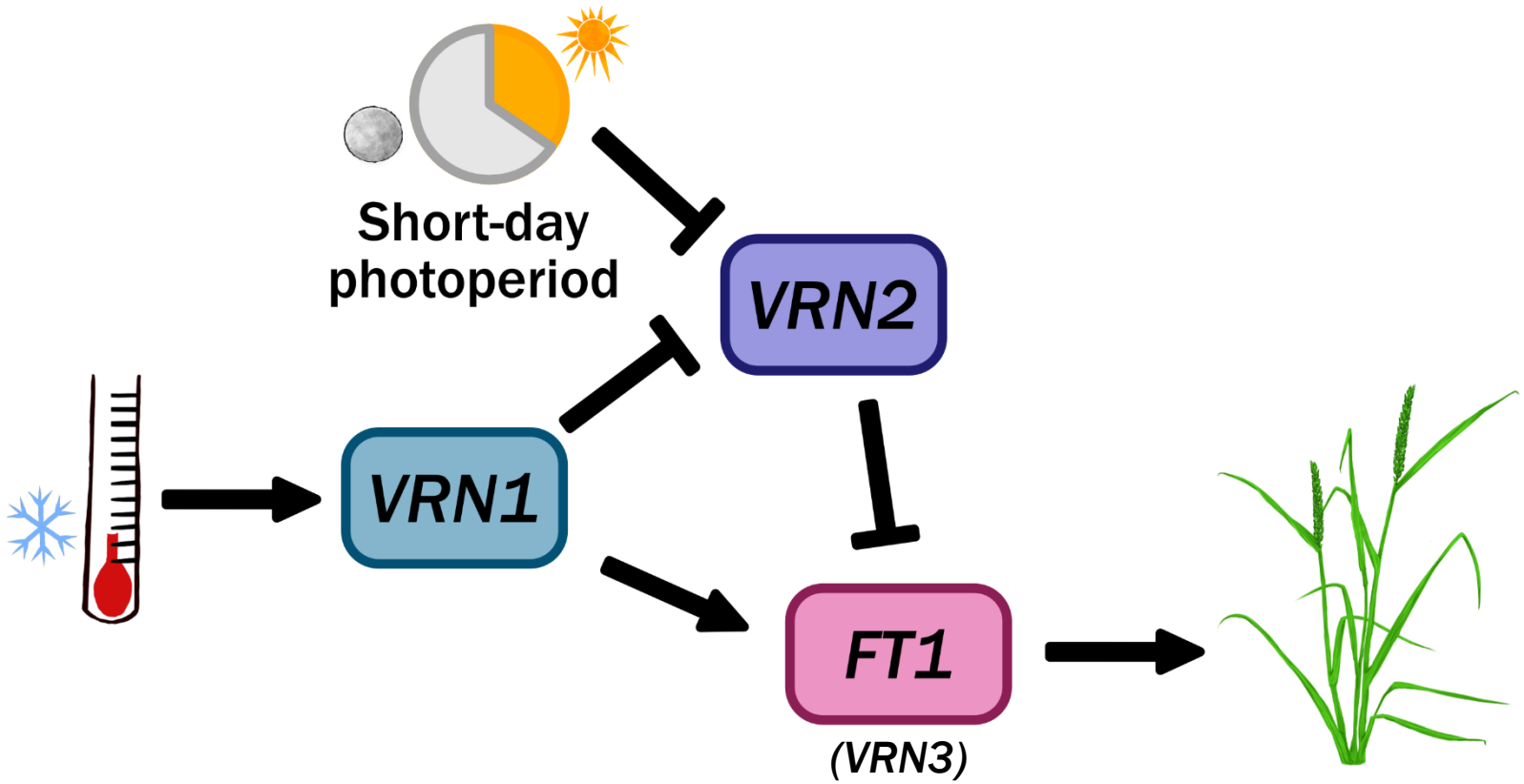
The vernalisation pathway in cereals



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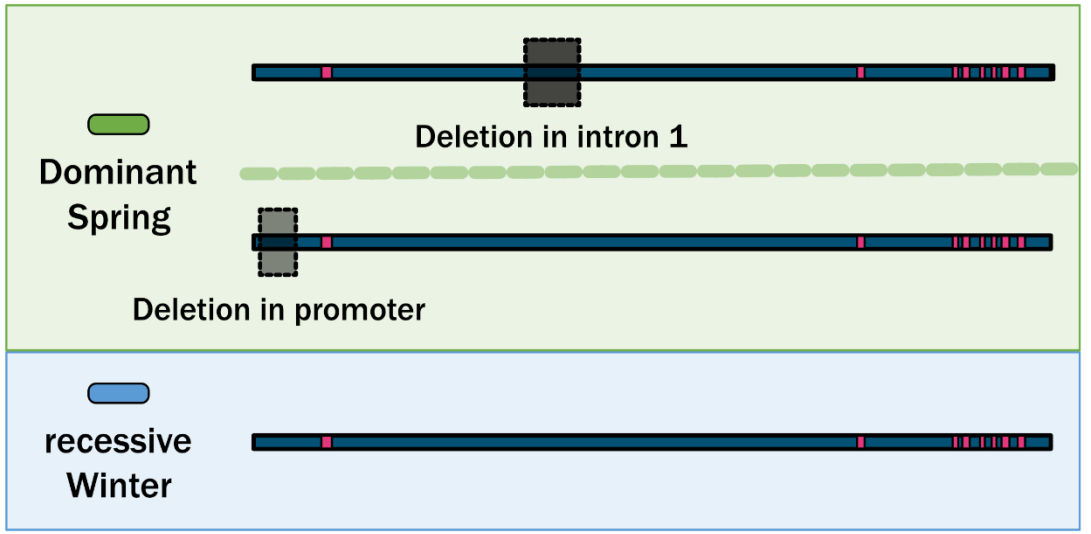
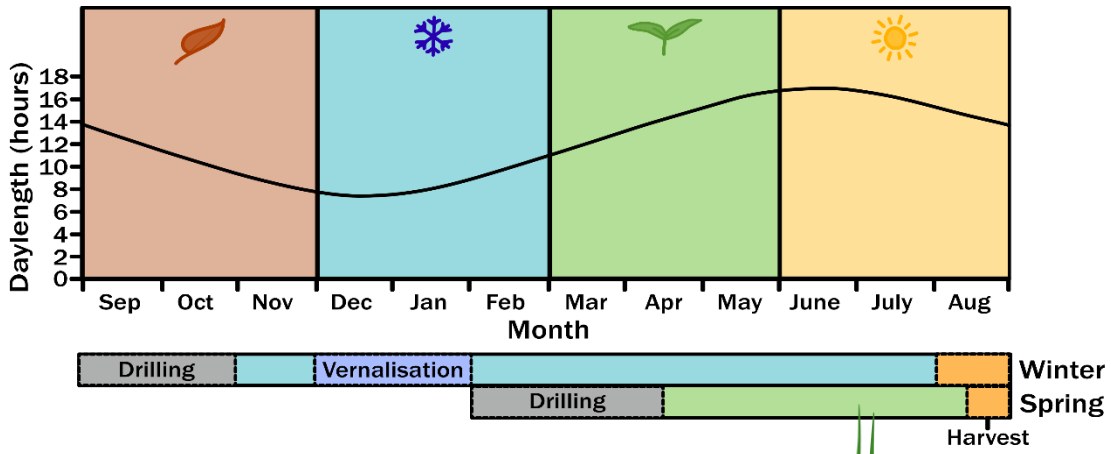
Genetic variation underpins growth habit in cereals

	VRN-A1	*VRN-B1*	*VRN-D1*
Spring	Dominant	recessive	recessive
Winter	recessive	recessive	recessive
Facultative (spring)	recessive	Dominant	recessive
	recessive	recessive	Dominant





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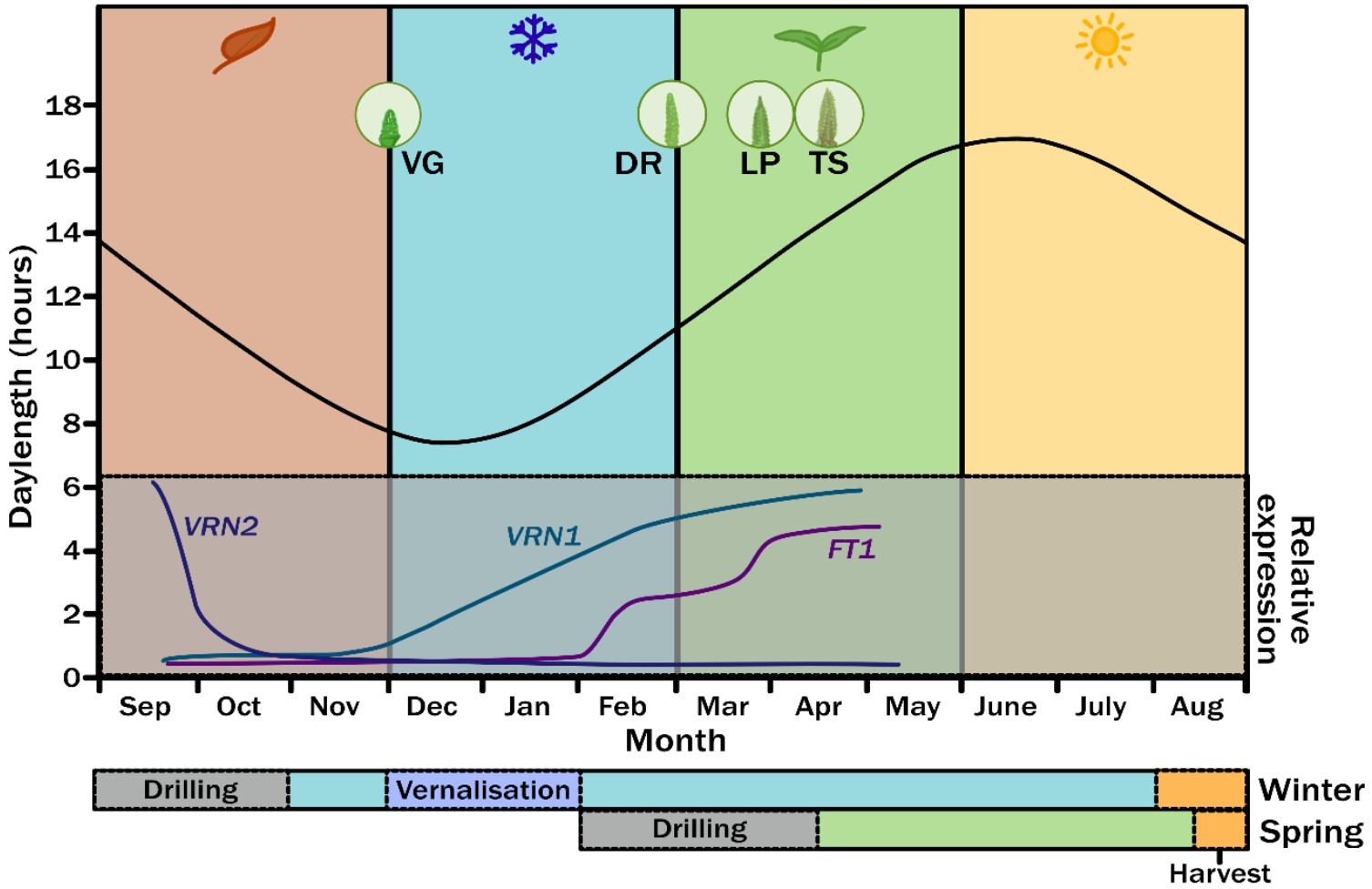
Genetic variation underpins growth habit in cereals

- *VRN1* underpins growth habit
- *VRN2* (hexaploid) fine tunes vernalisation and provides adaptive benefit
  - Understand the effect of specific alleles



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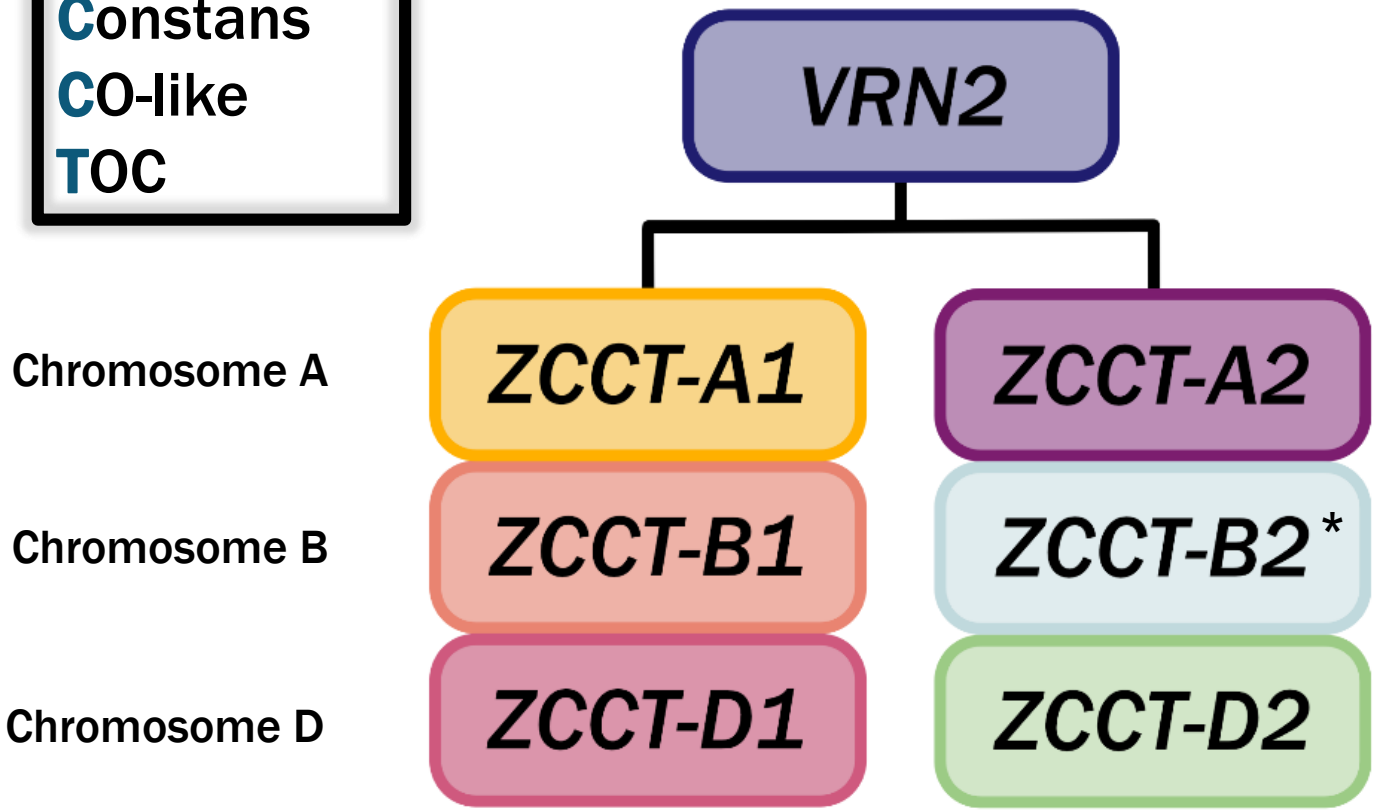
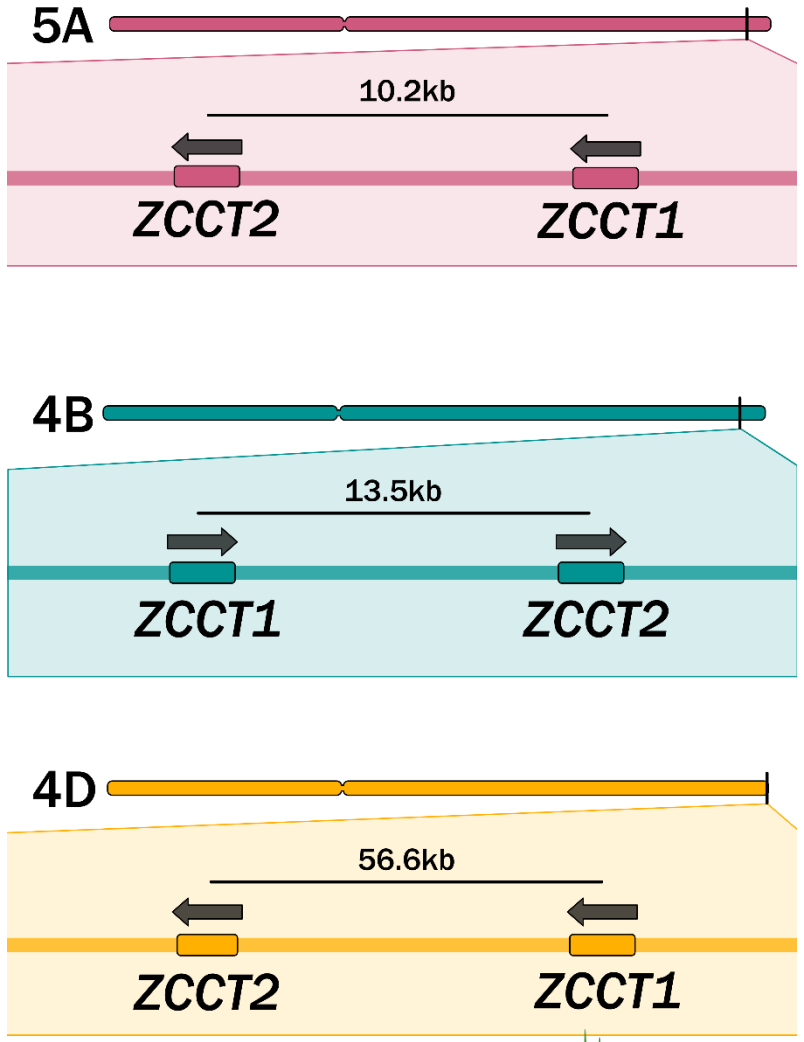
VRN2 loci is formed of *ZCCT1* and *ZCCT2*

Zinc finger
Constans
CO-like
TOC



*not present in the reference sequence



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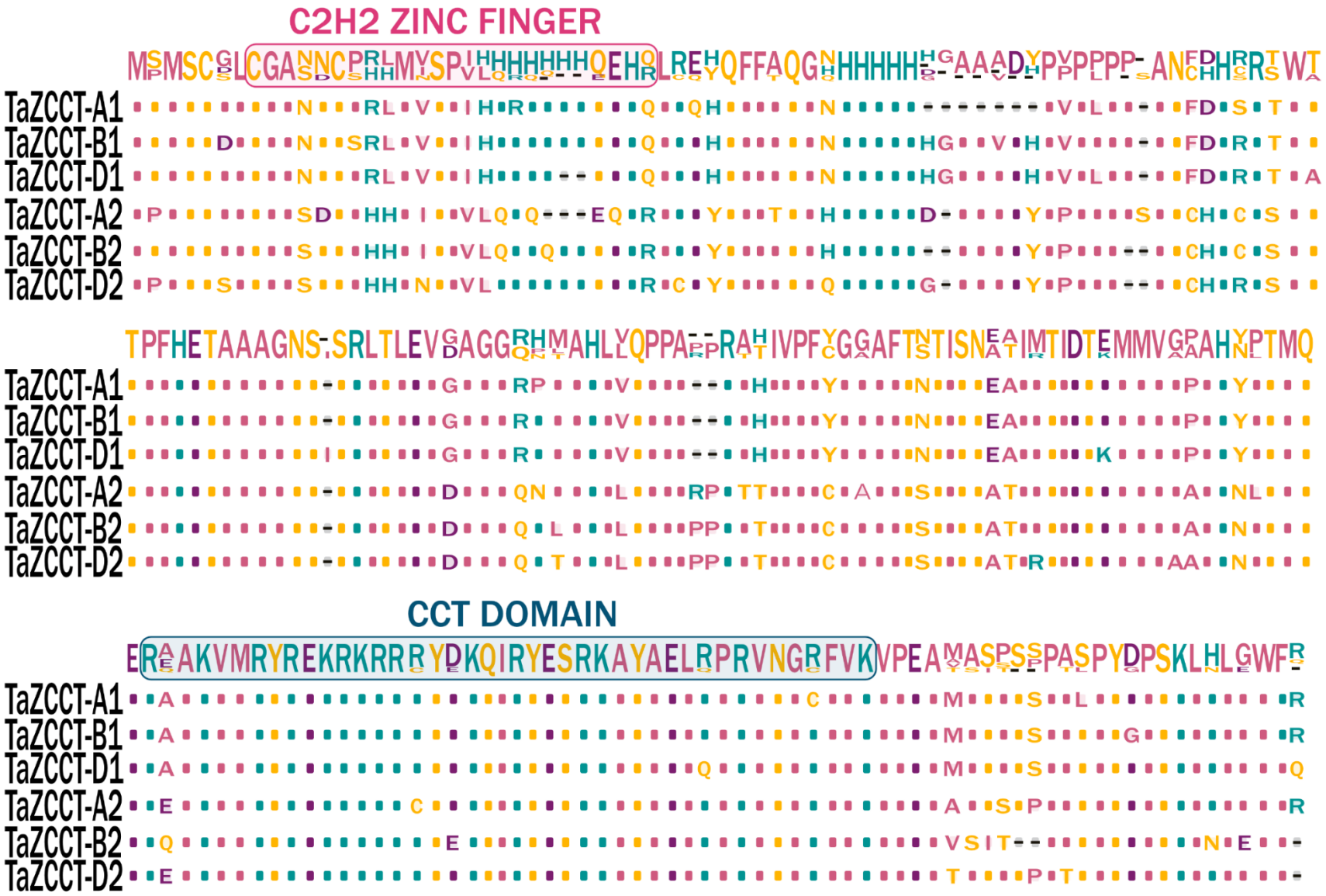
The CCT domain is well conserved



Zinc finger
Constans
CO-like
TOC

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Key Questions

- Is there an **additional** adaptive role for *VRN2?*

- Are all *ZCCTs* equal?

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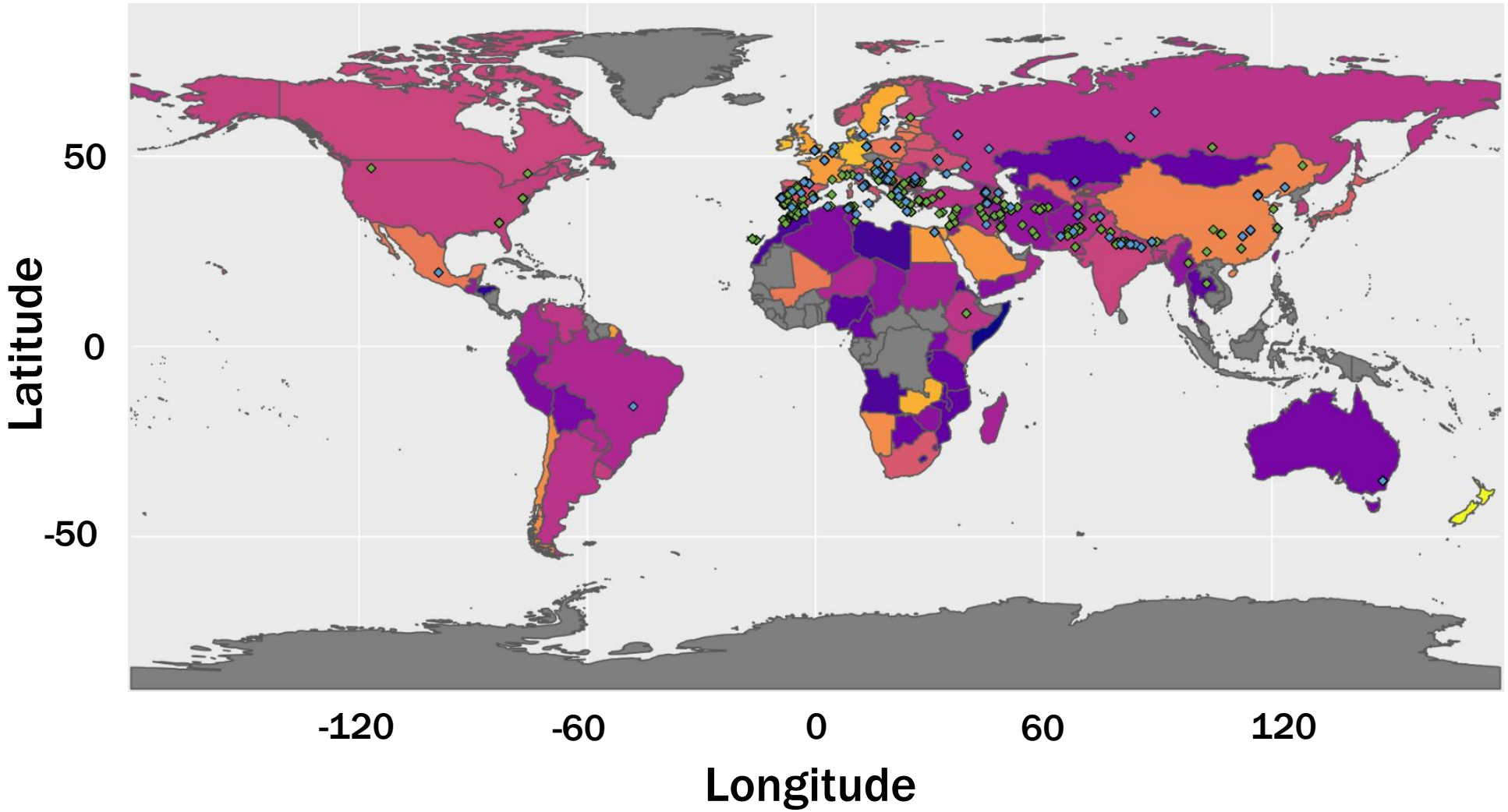
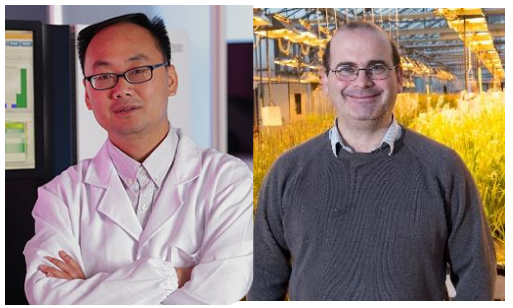
Natural variation in the Watseq Collection





Simon Griffiths, JIC
Shifeng Cheng, AGIS

Cheng et al., 2024

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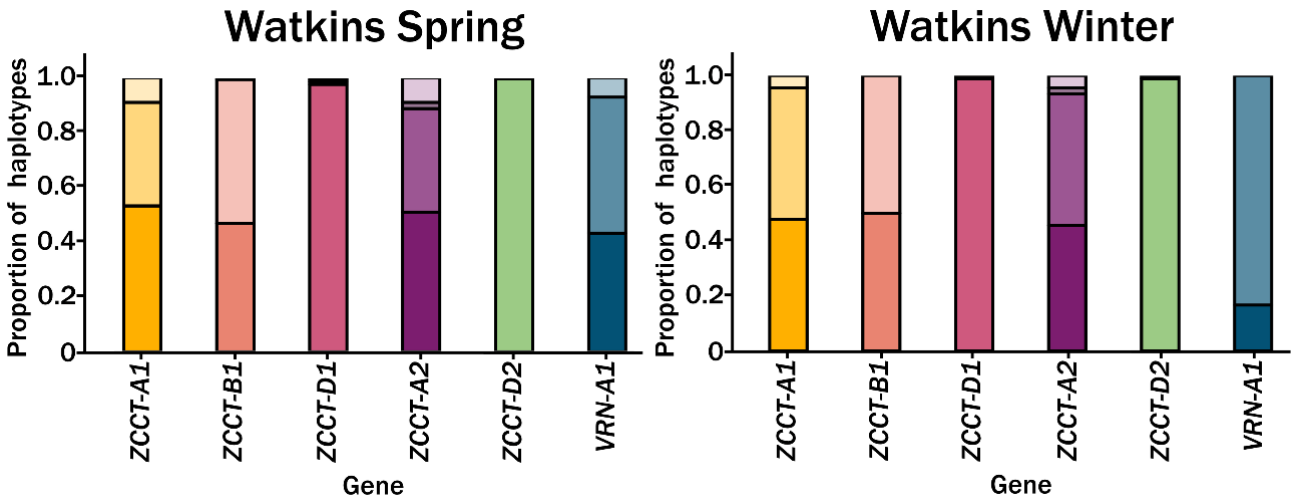
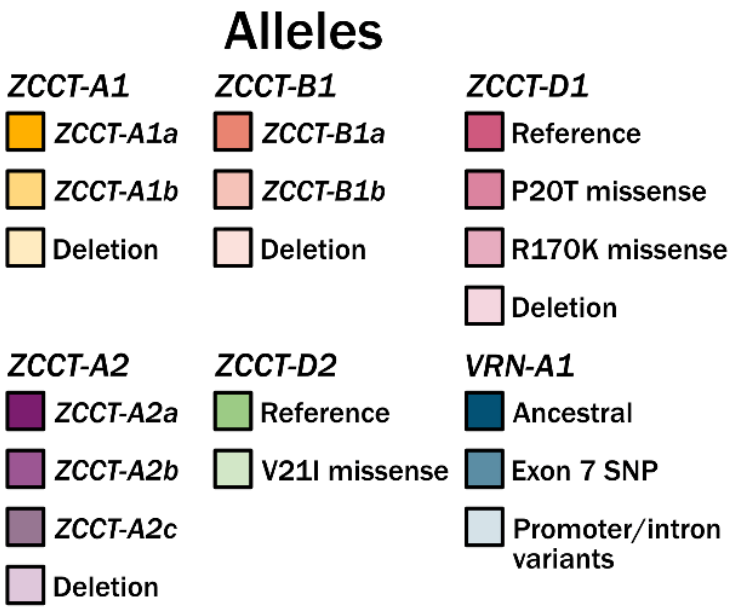
Natural variation in the Watseq Collection





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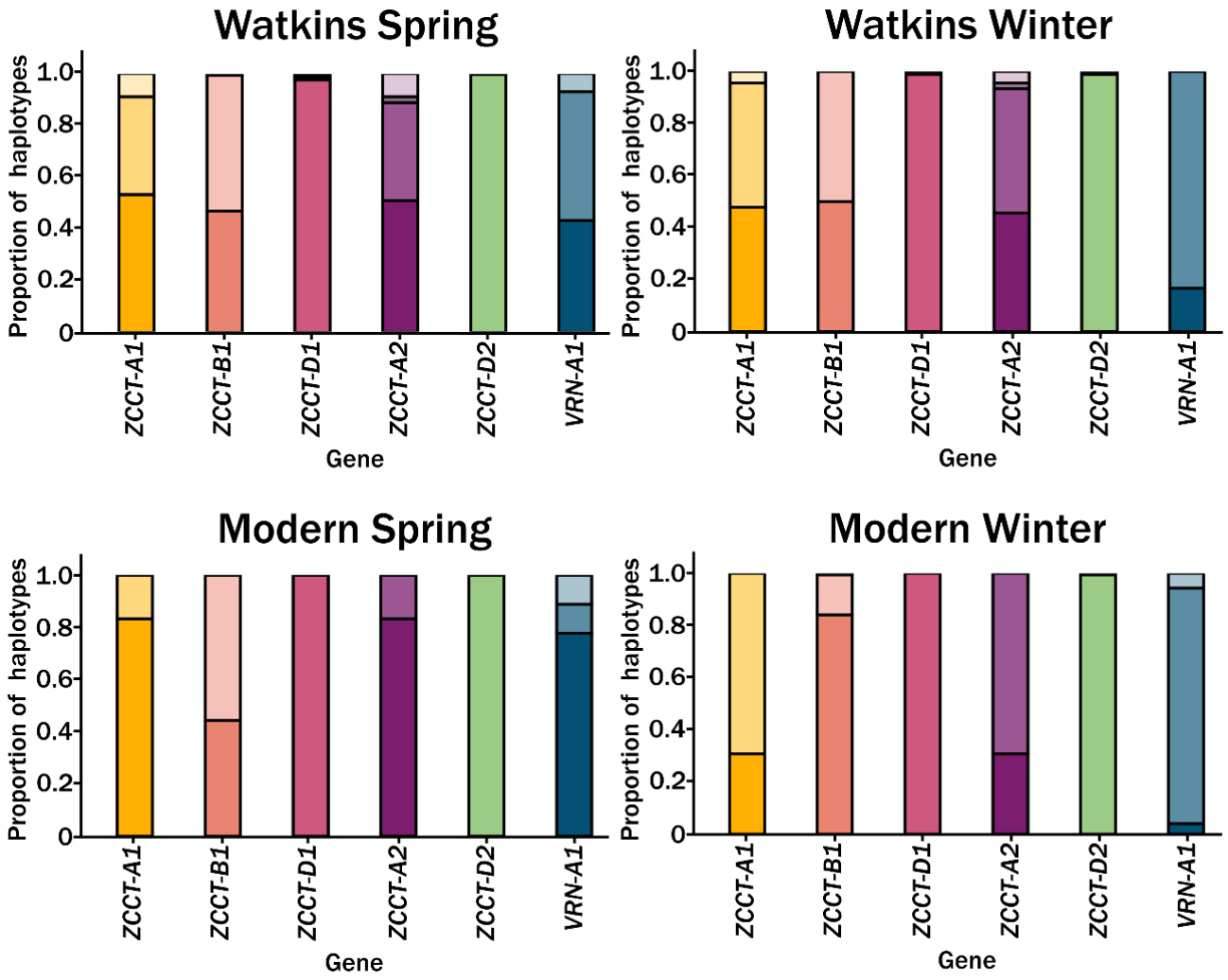

Alleles

ZCCT-A1
- ZCCT-A1a
- ZCCT-A1b
- Deletion

ZCCT-B1
- ZCCT-B1a
- ZCCT-B1b
- Deletion

ZCCT-D1
- Reference
- P20T missense
- R170K missense
- Deletion

ZCCT-A2
- ZCCT-A2a
- ZCCT-A2b
- ZCCT-A2c
- Deletion

ZCCT-D2
- Reference
- V21I missense

VRN-A1
- Ancestral
- Exon 7 SNP
- Promoter/intron variants

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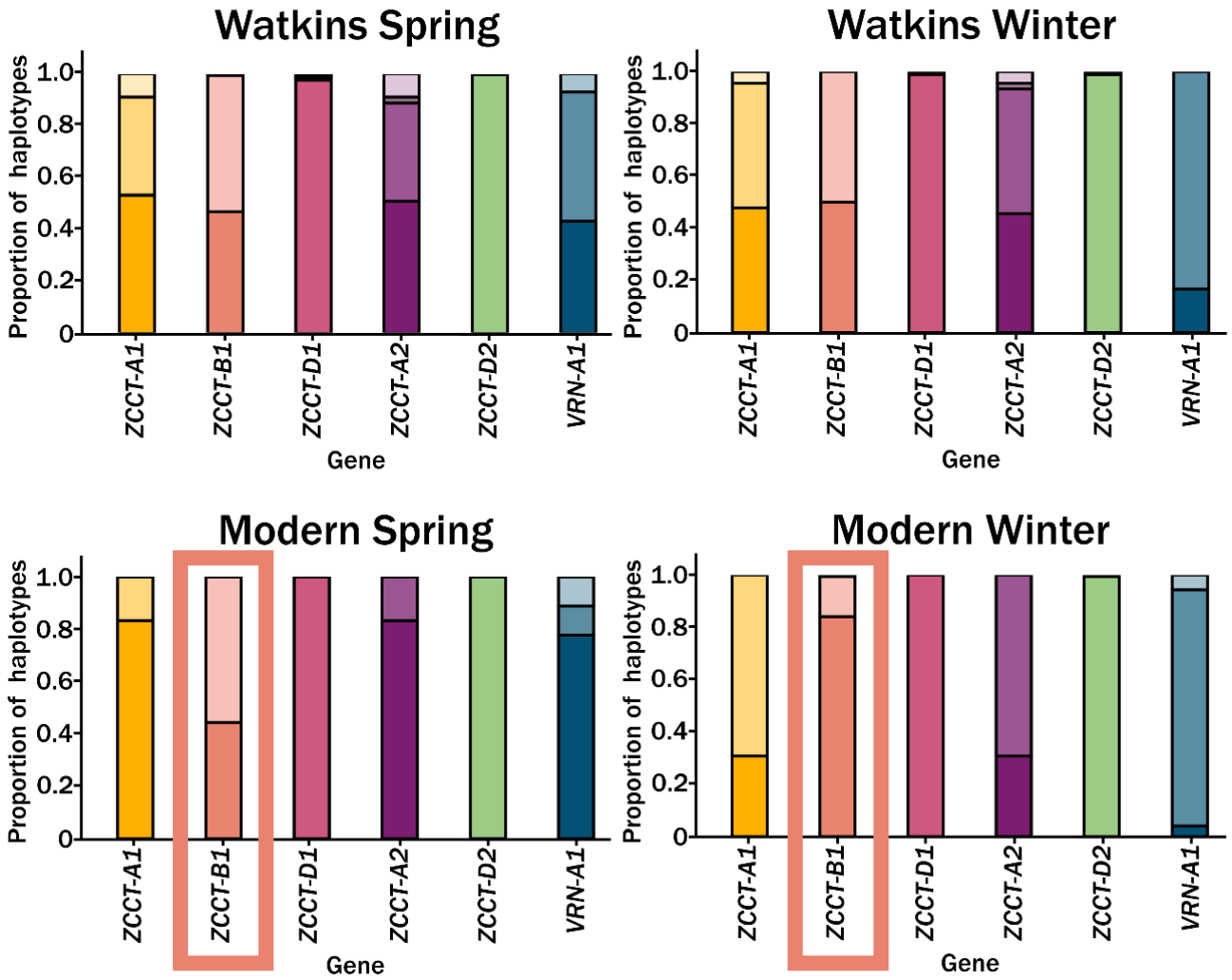
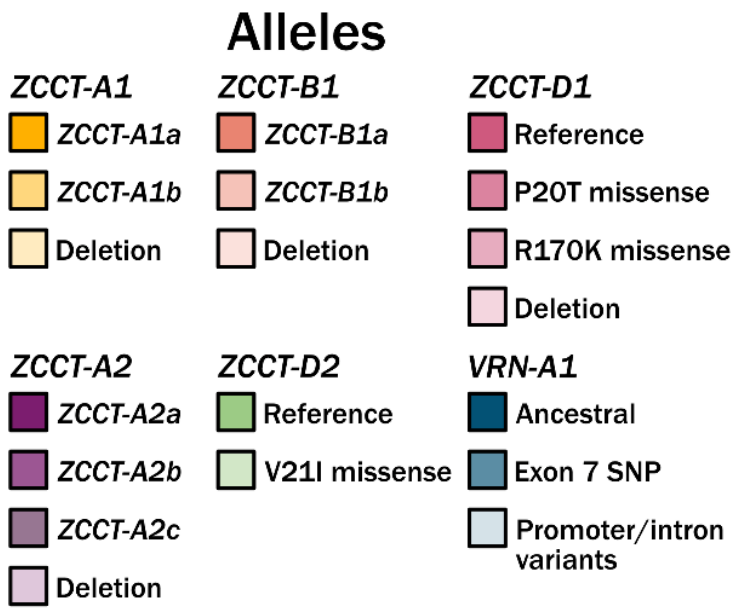
Natural variation in the Watseq Collection





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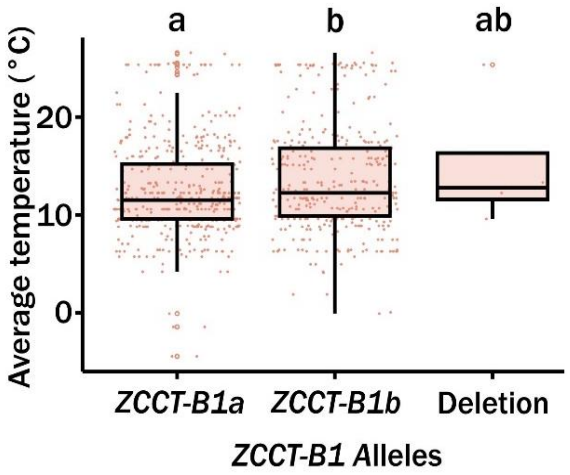
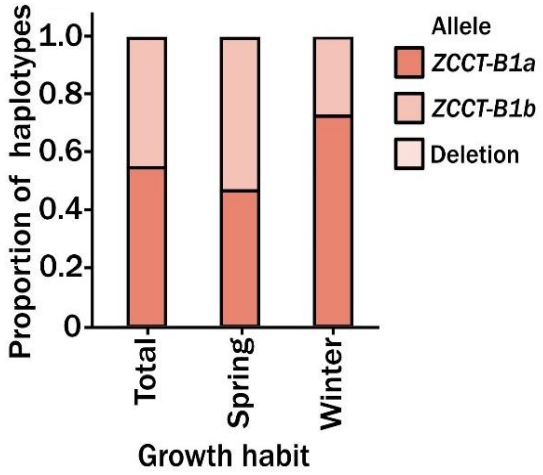
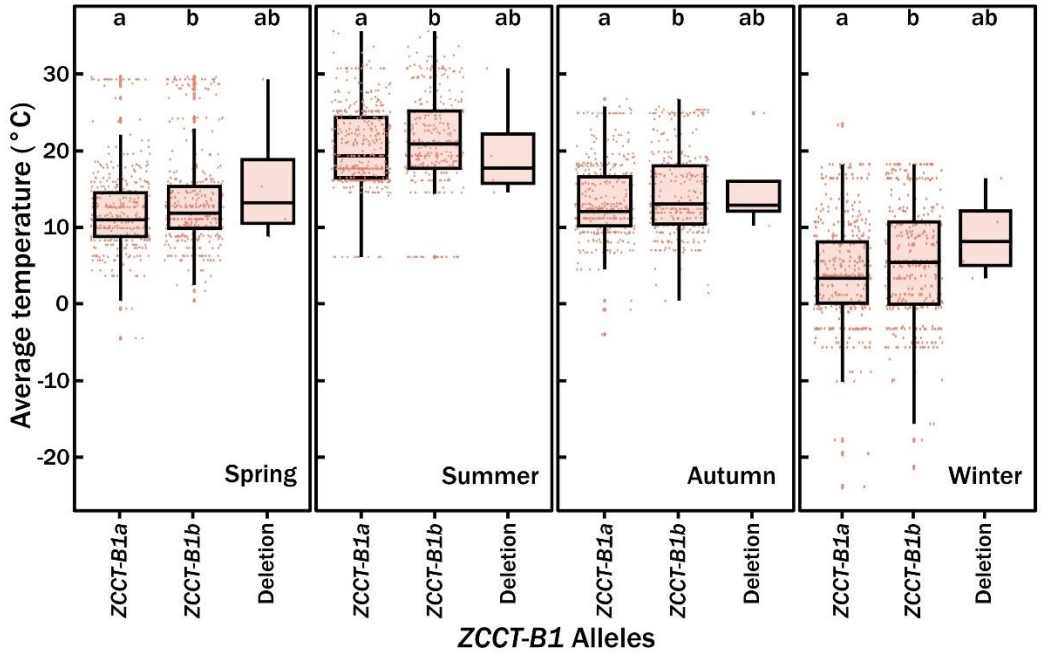
Different alleles of *ZCCT-B1* have been selected for depending on temperature







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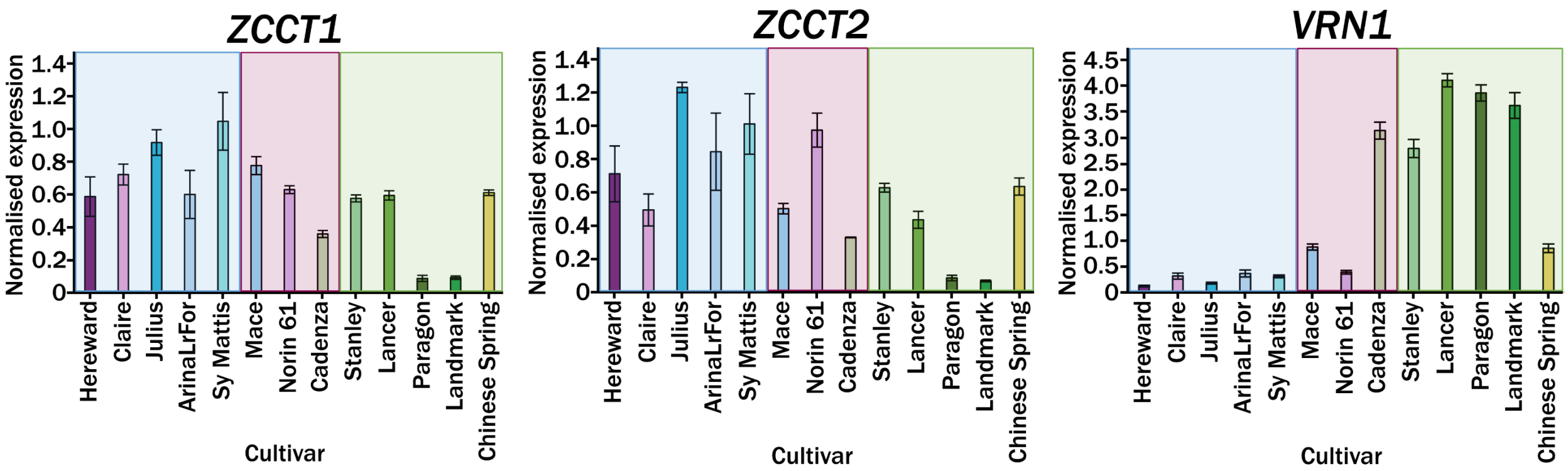
ZCCT expression is variable across cultivars



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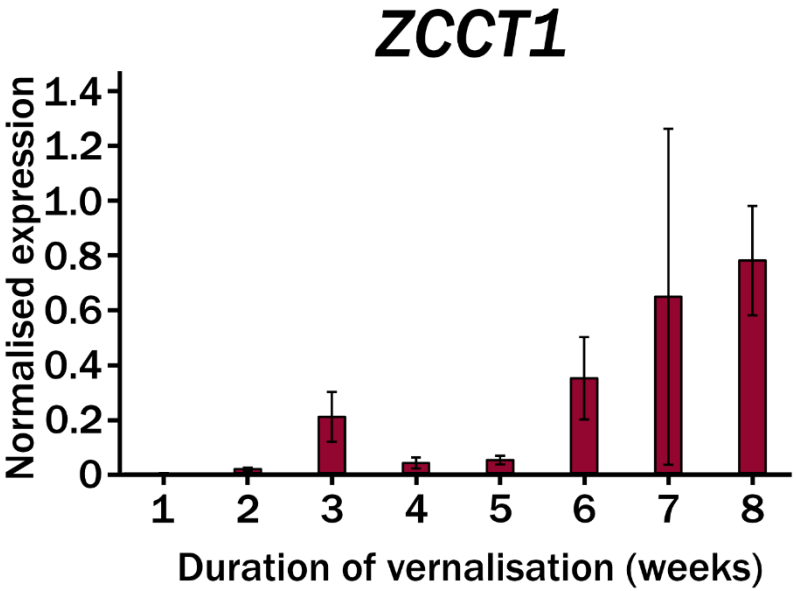
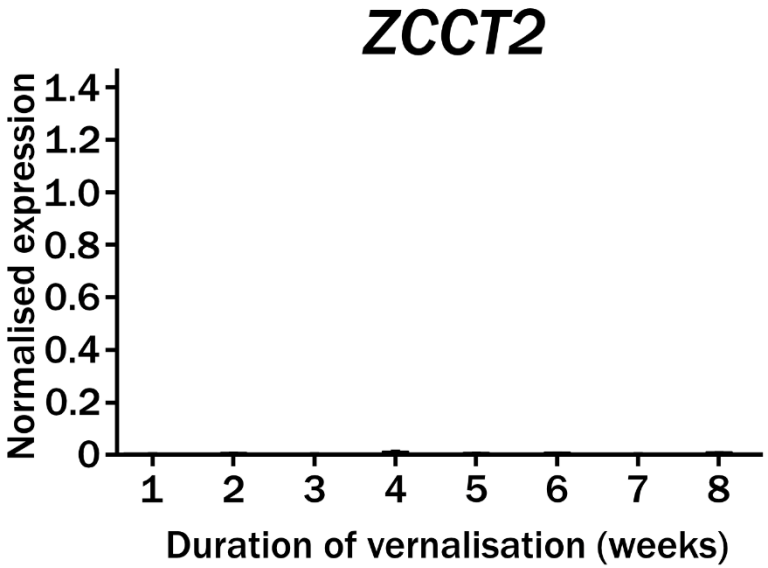
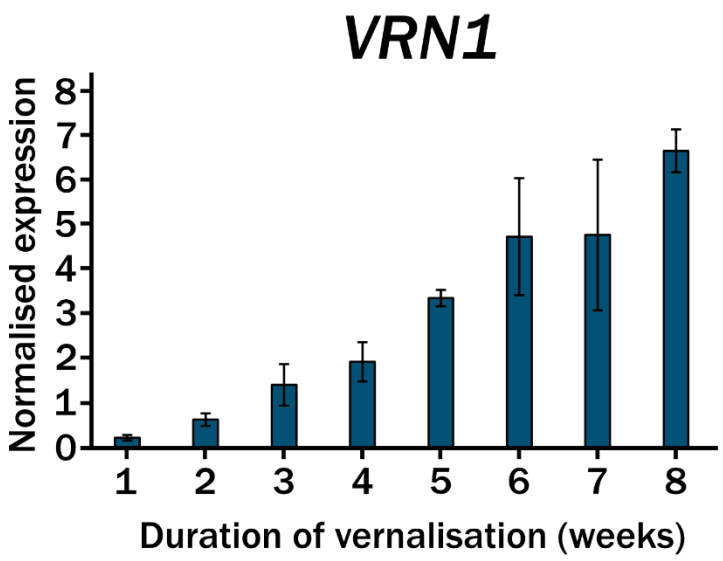
ZCCT1 and *ZCCT2* are expressed differently during vernalisation







Indi Lacey

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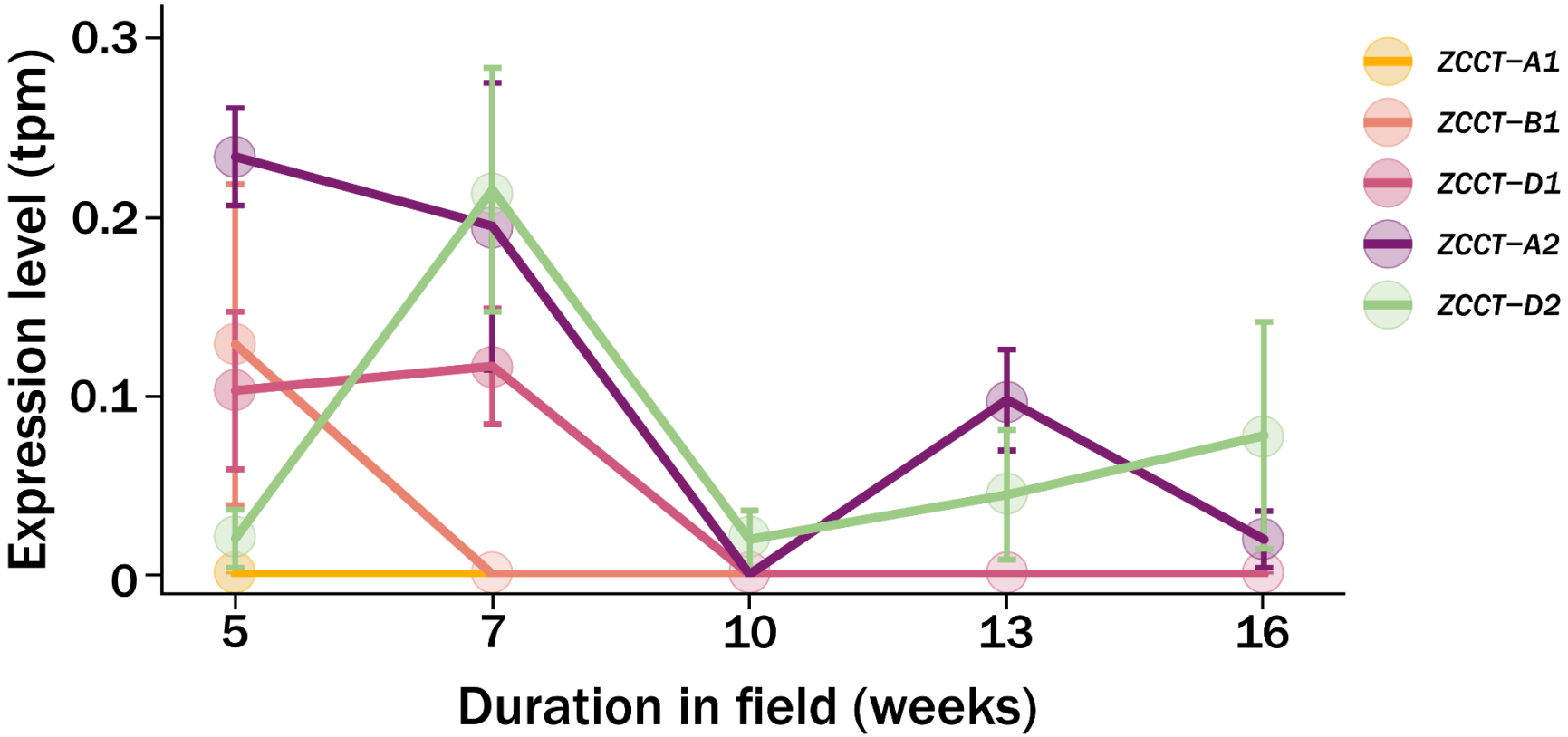
VRN1 and *VRN2* expression during vernalisation in the field



Kate O'Connor

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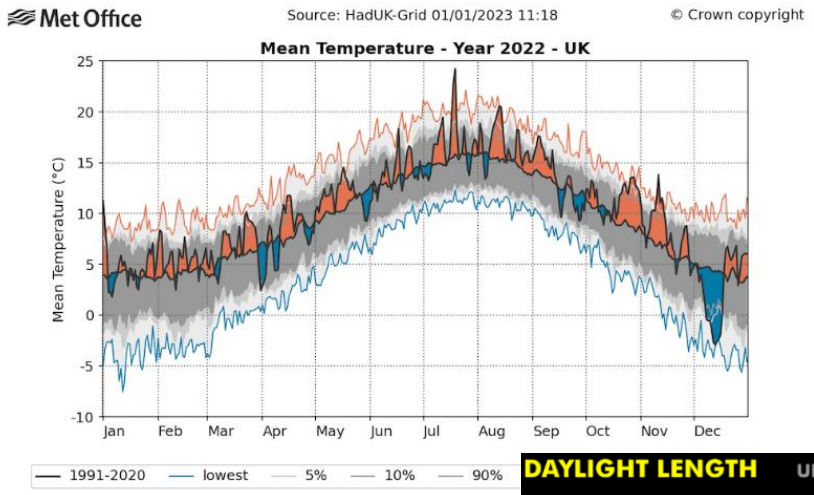
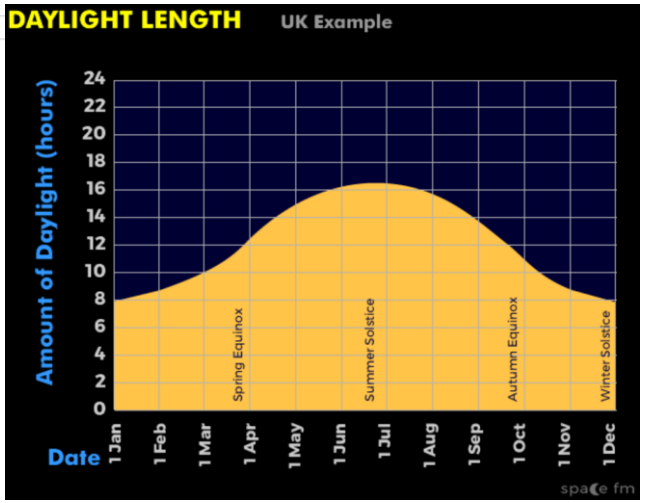
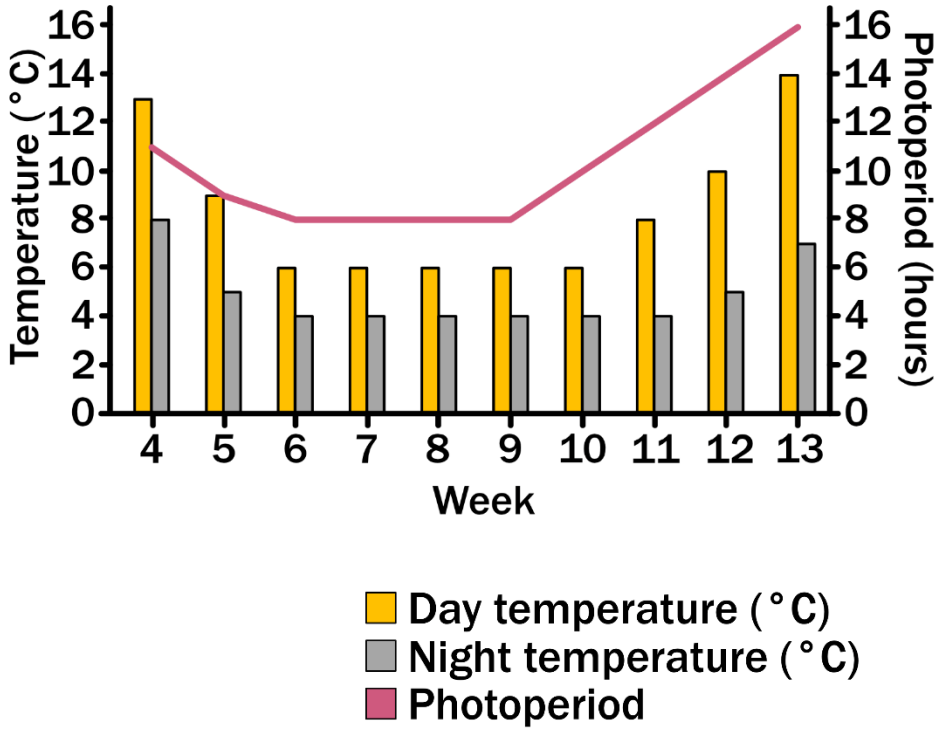
Condensing All Seasons INto One (CASINO): environmental conditions







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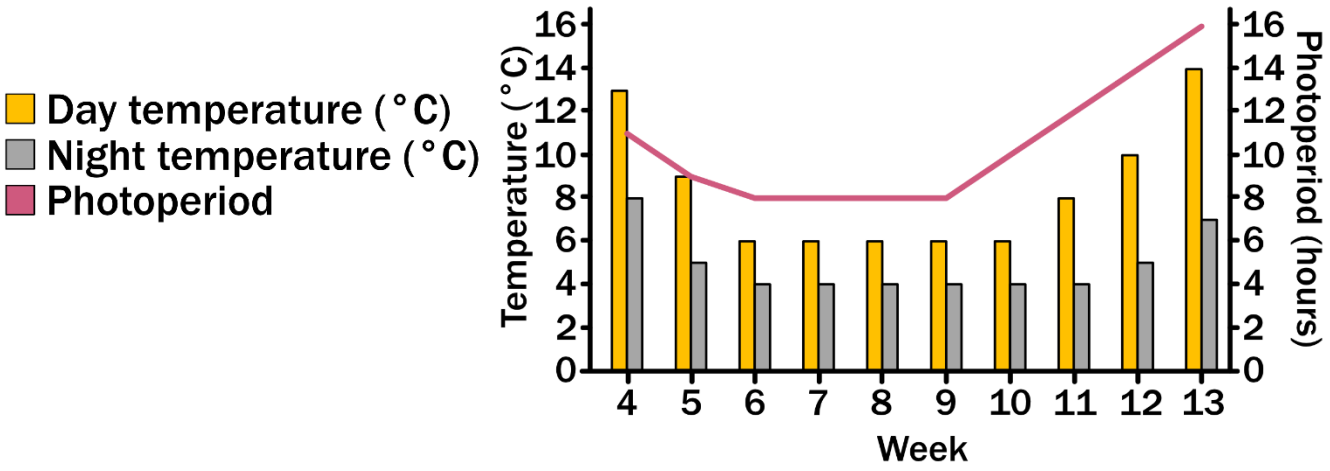
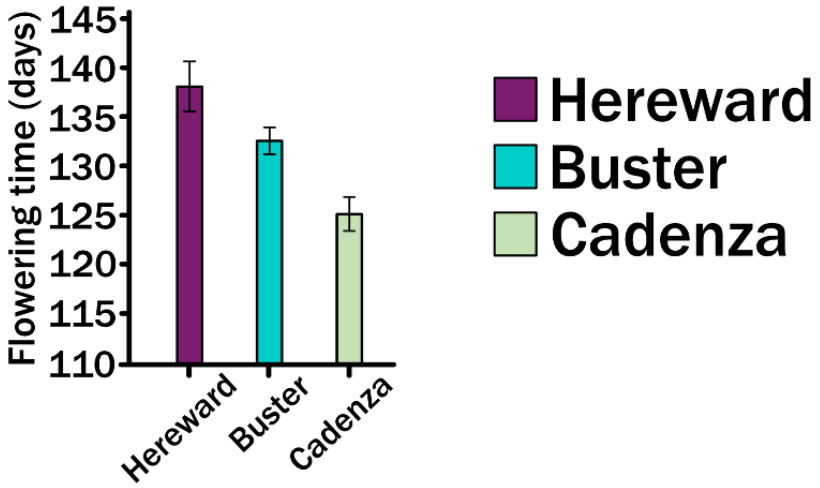
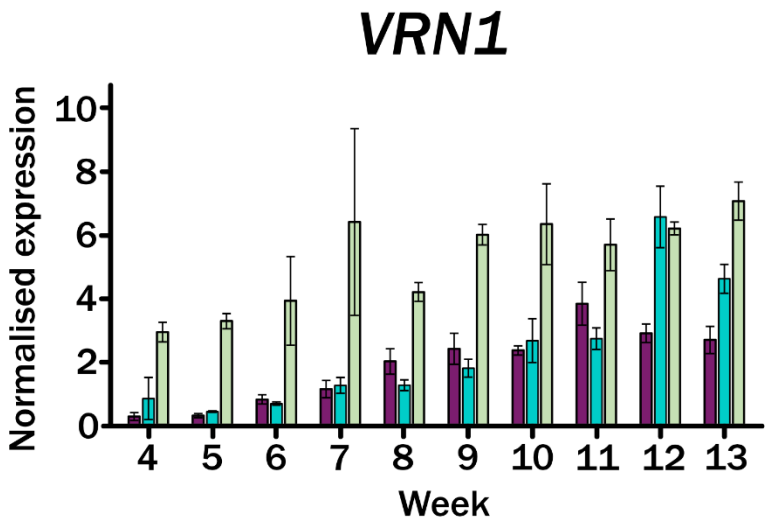
VRN1 expression increases during vernalisation







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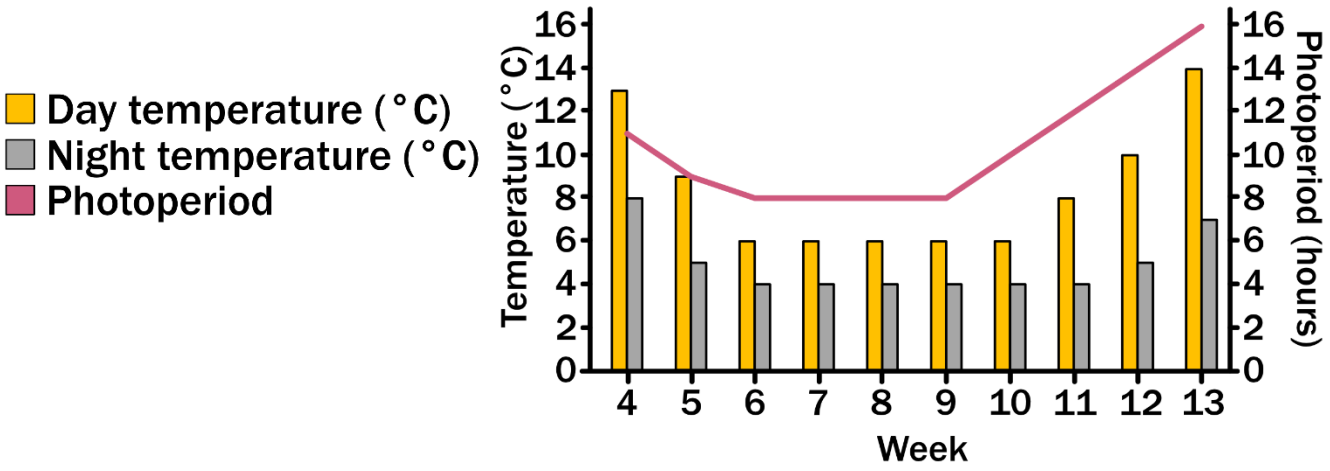
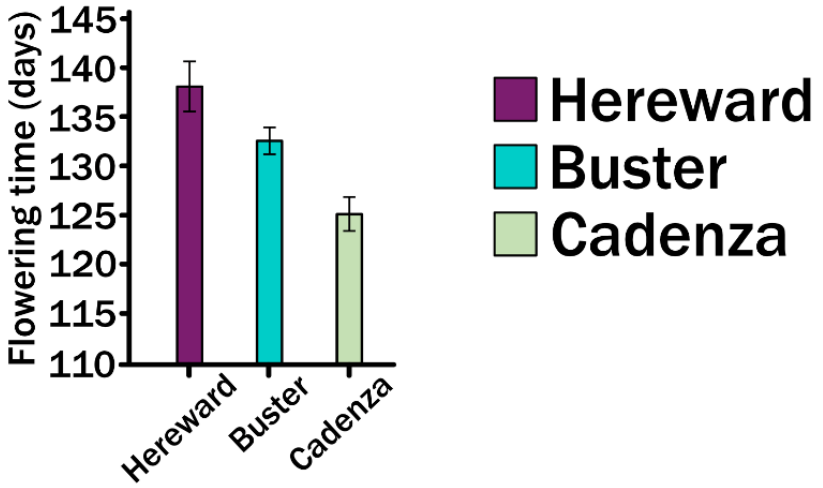
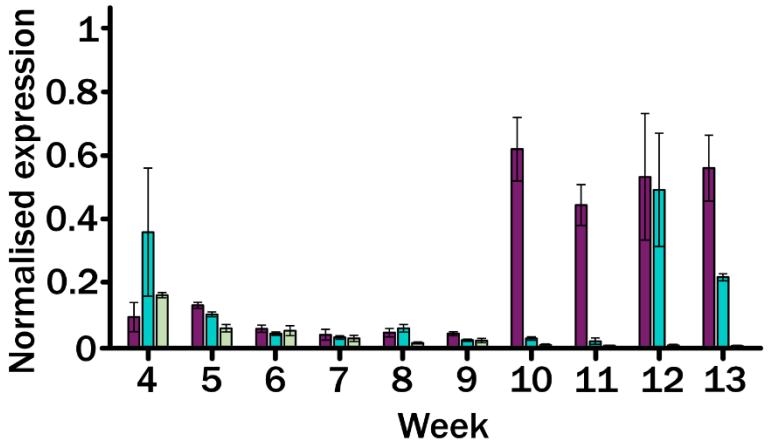
ZCCT1 expression increases post-vernalisation

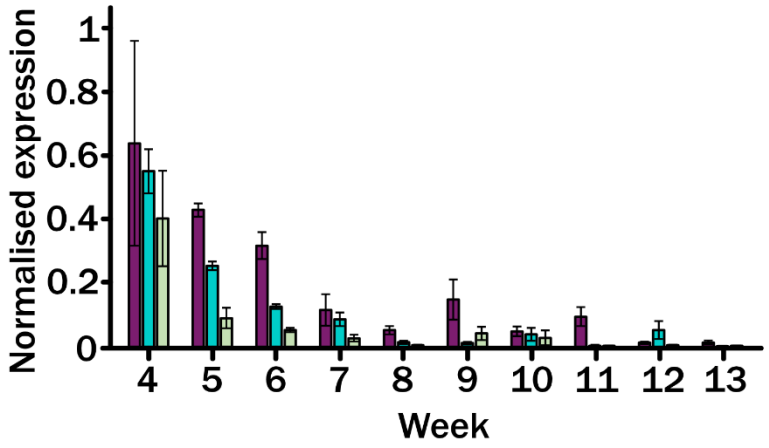




ZCCT1



ZCCT2



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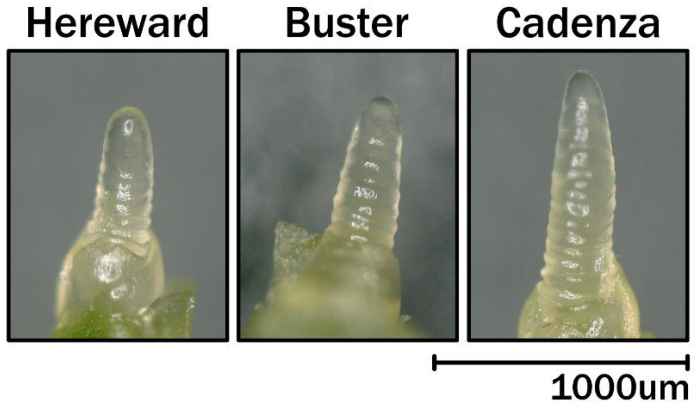
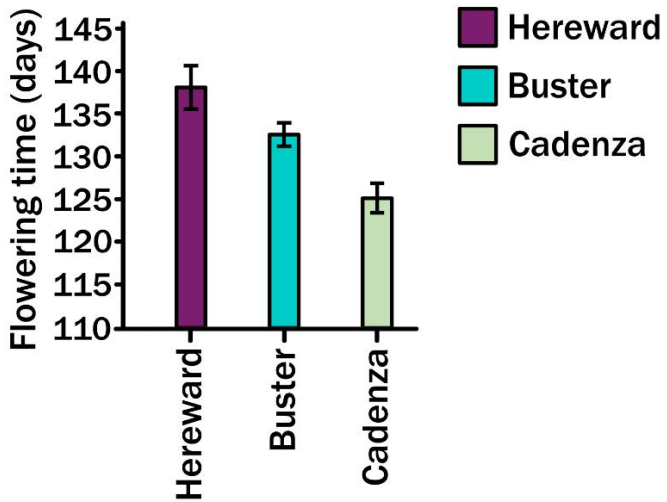
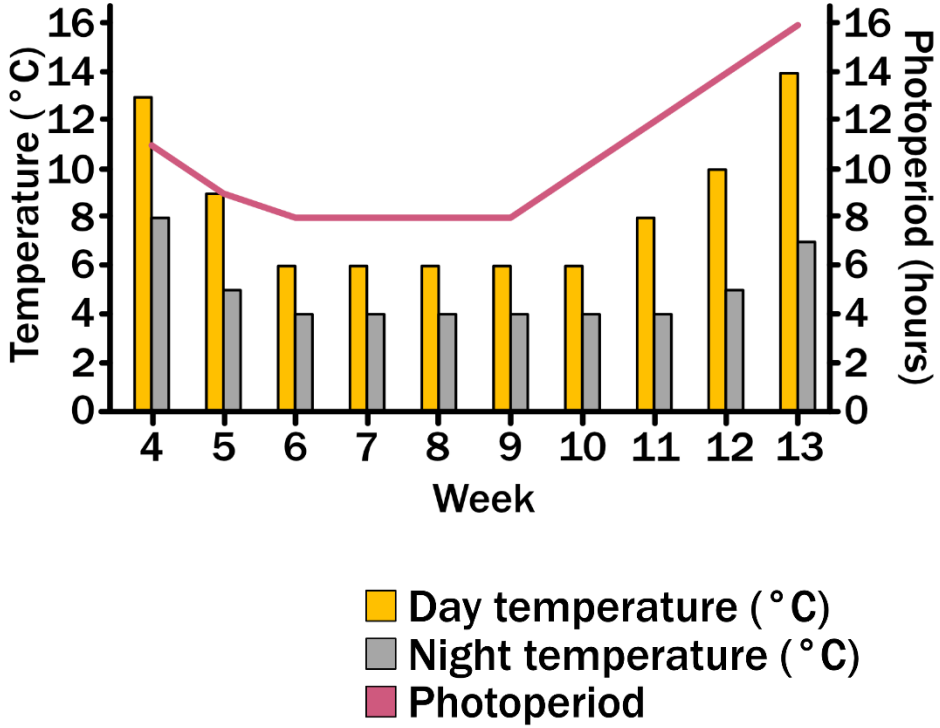
All cultivars flowered despite the late expression of *ZCCT1*







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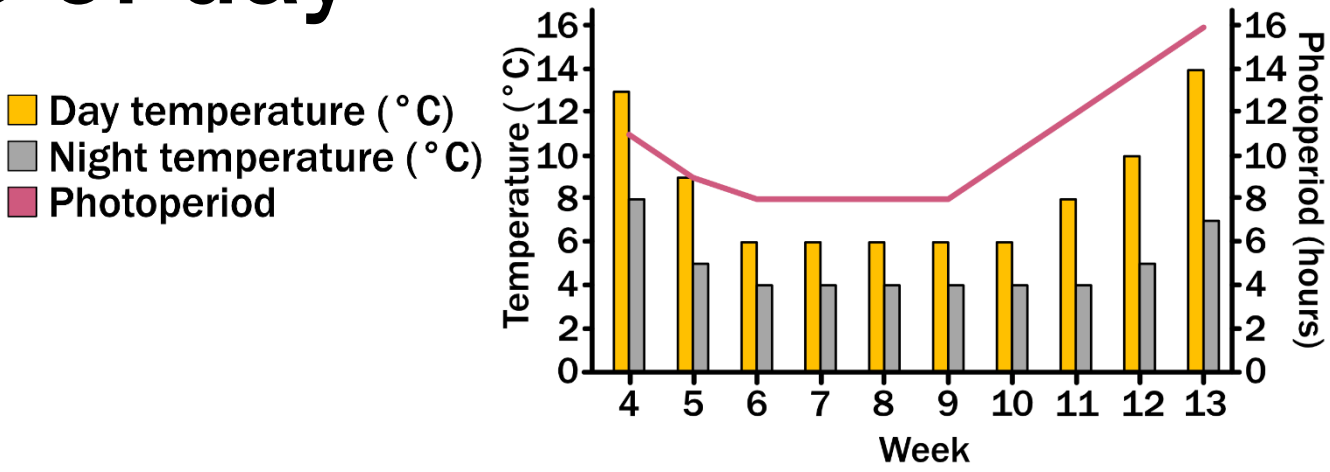
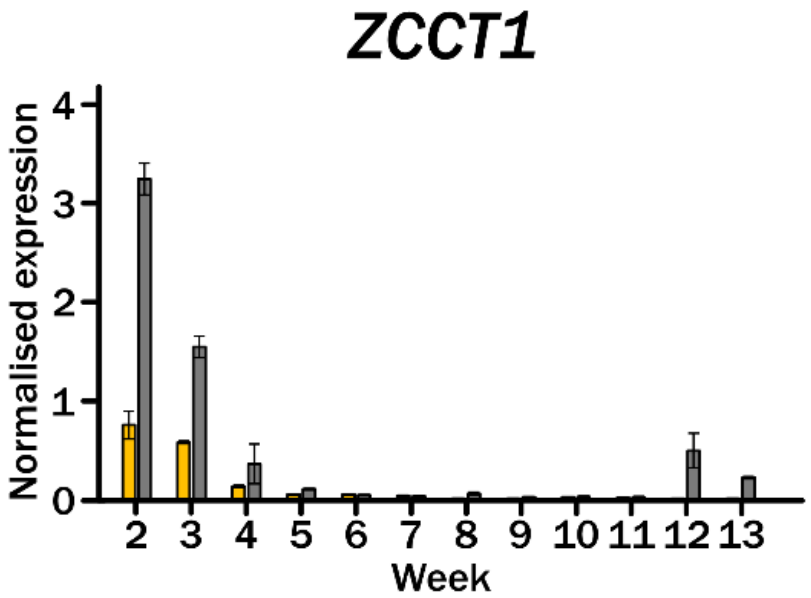
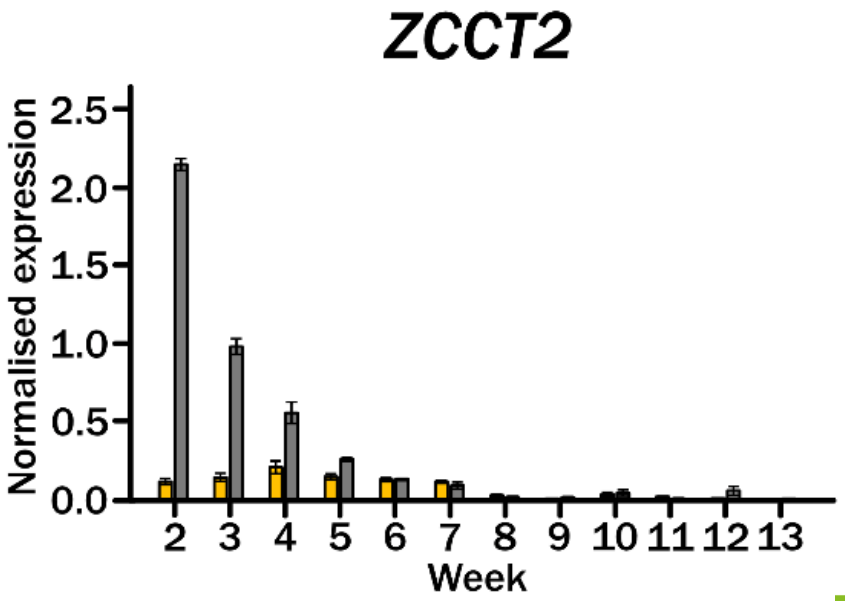
ZCCT expression patterns vary depending on time of day







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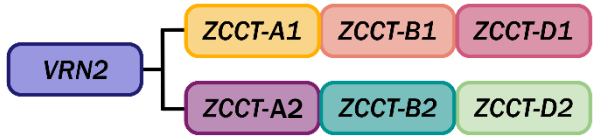
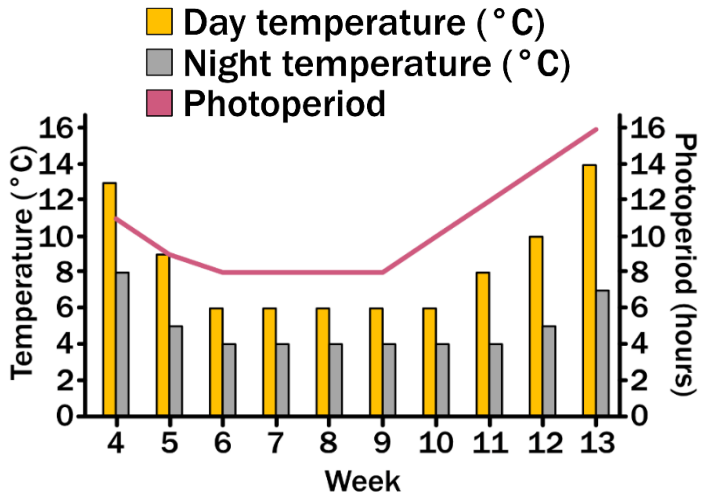
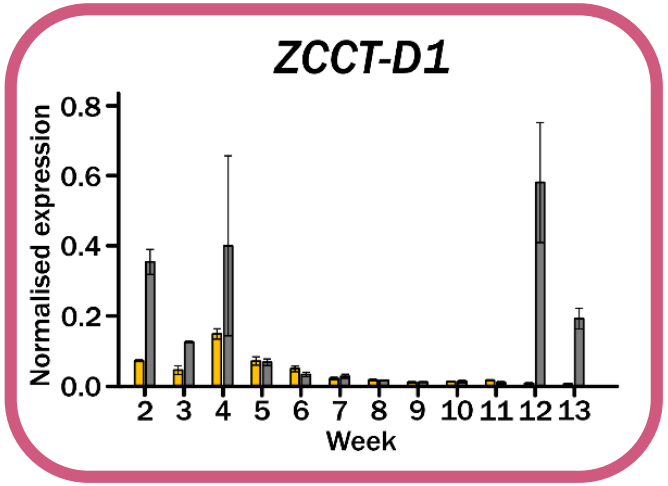
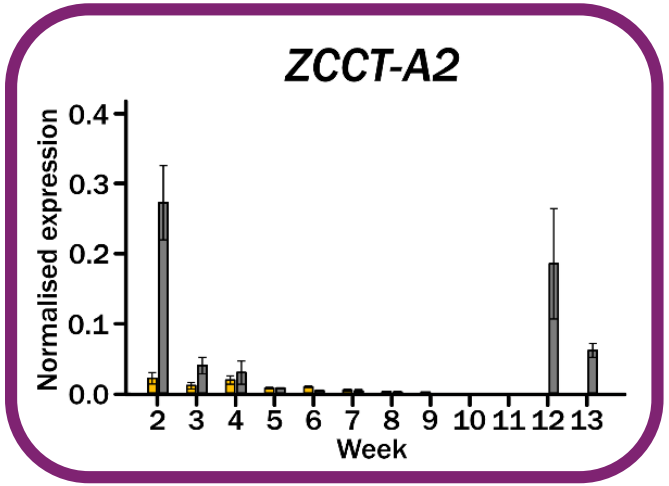
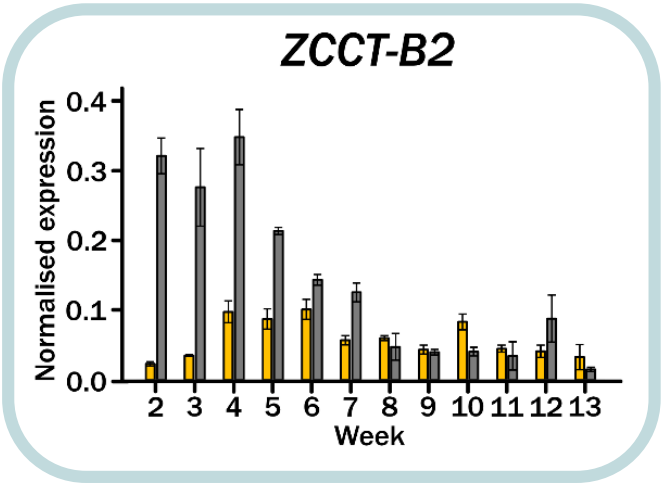
Different *ZCCT* genes show varying expression patterns

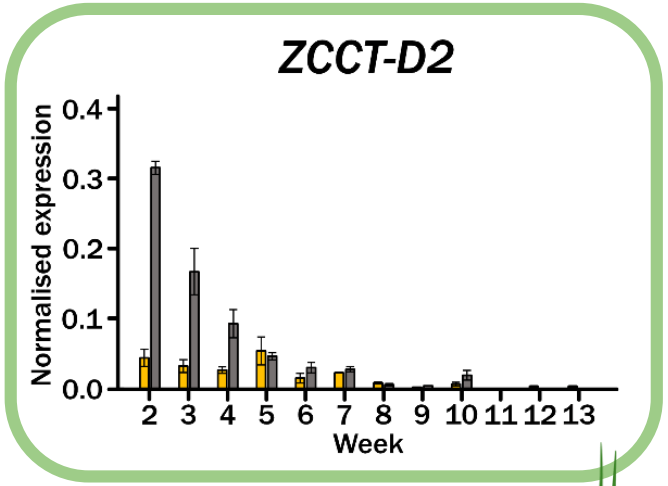












Dawn timepoint
Dusk timepoint

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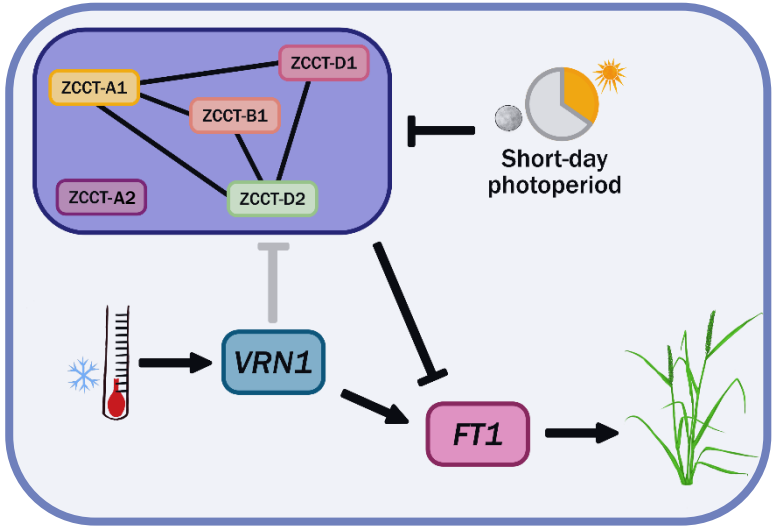
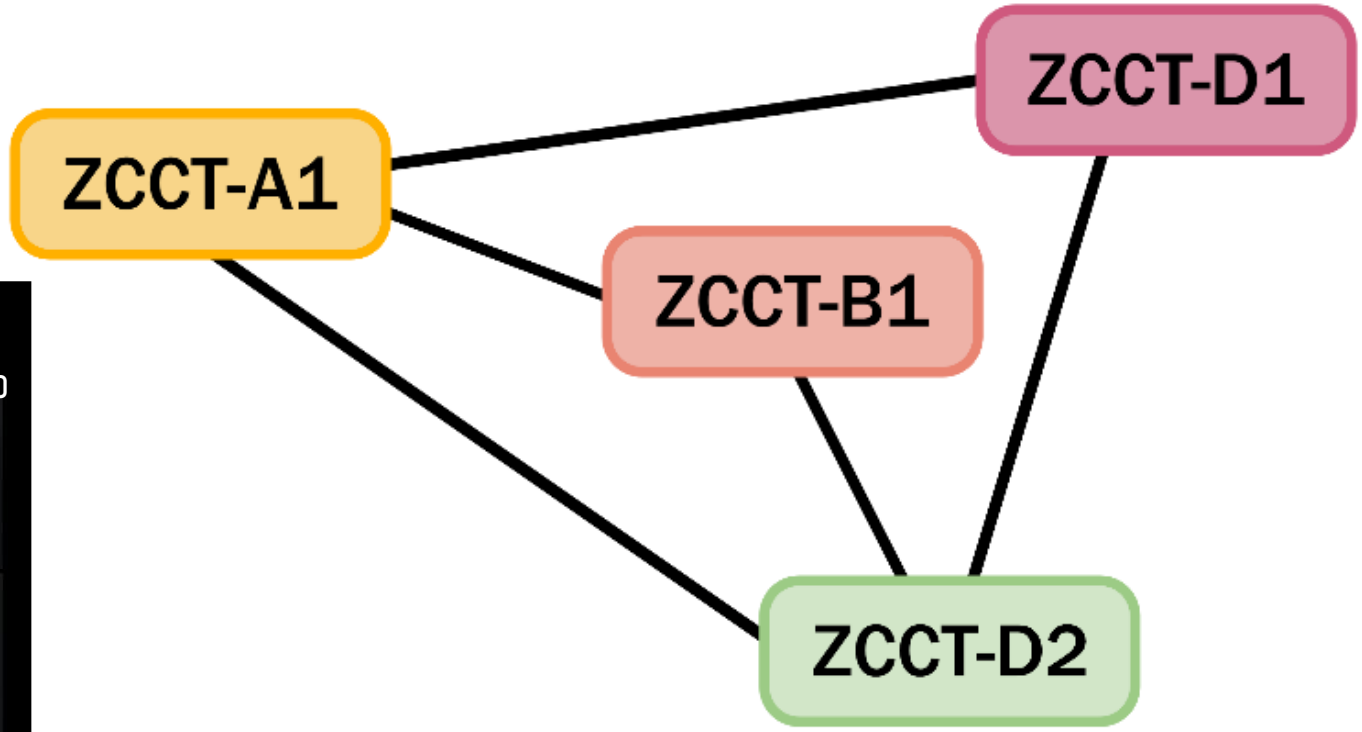
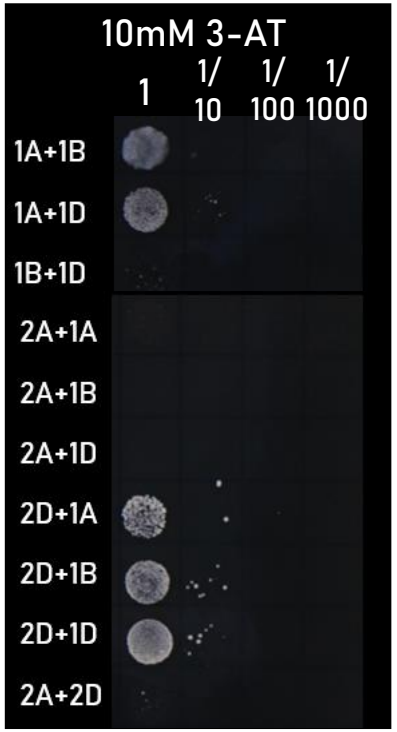
ZCCT proteins form different heterodimers



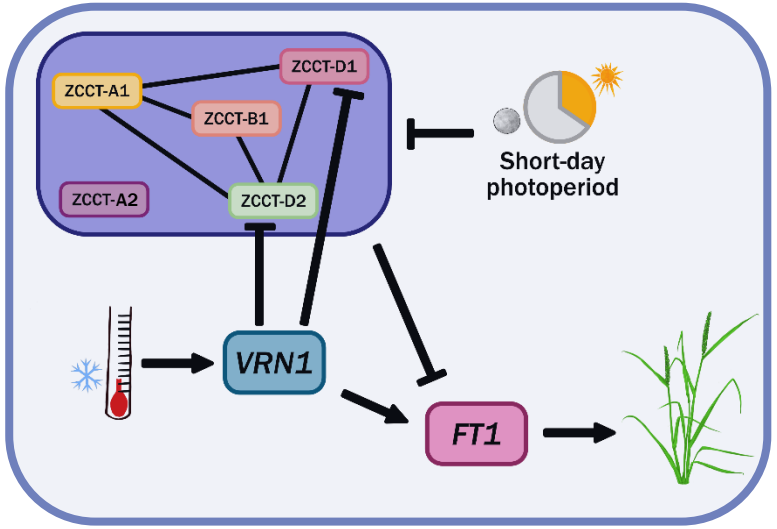


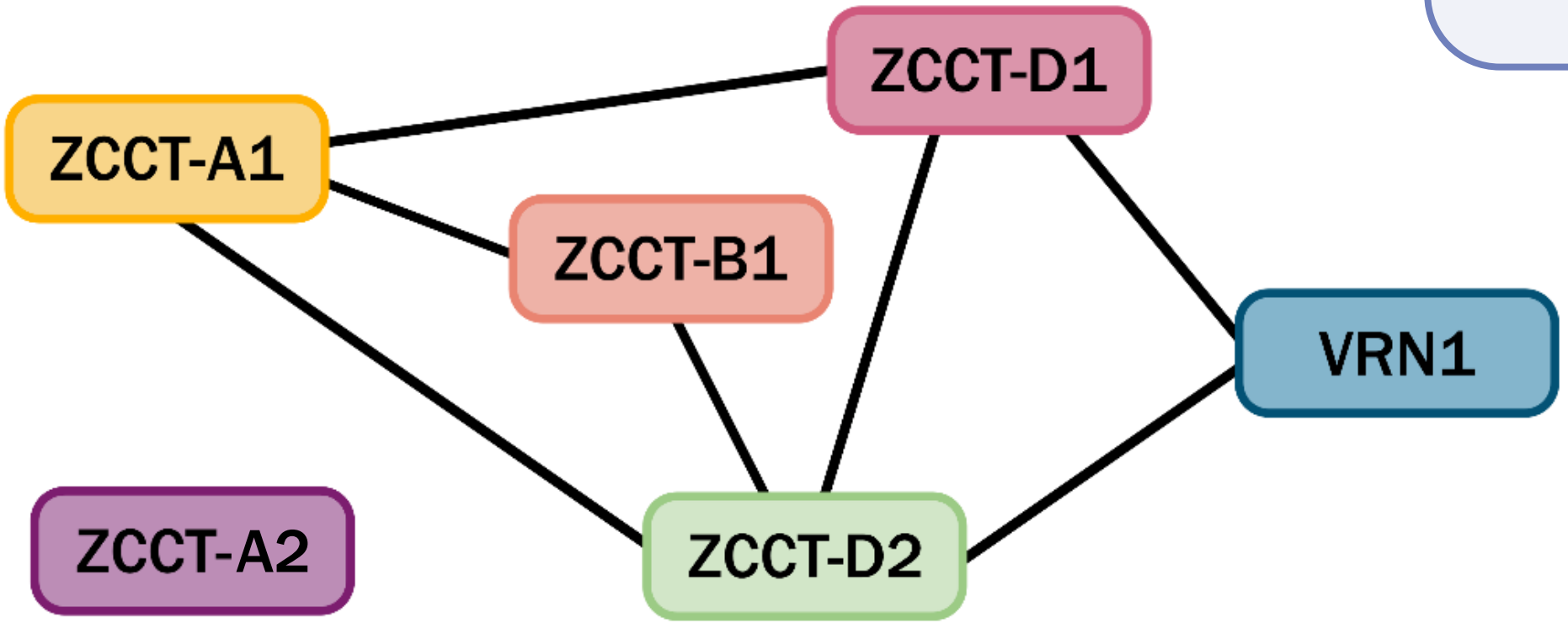
ZCCT-A2

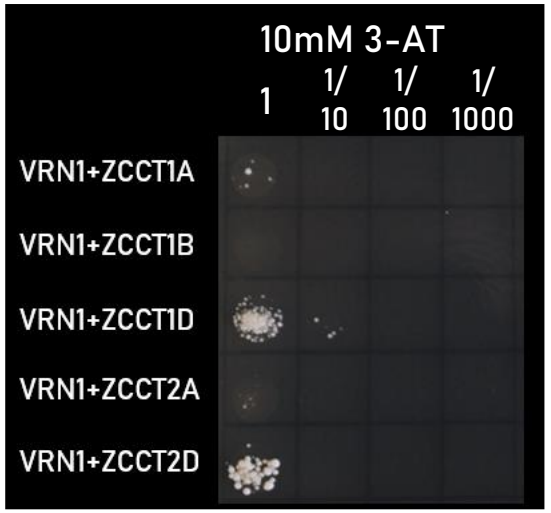


IPK LEIBNIZ-INSTITUT

VRN1 does not interact with all the ZCCTs

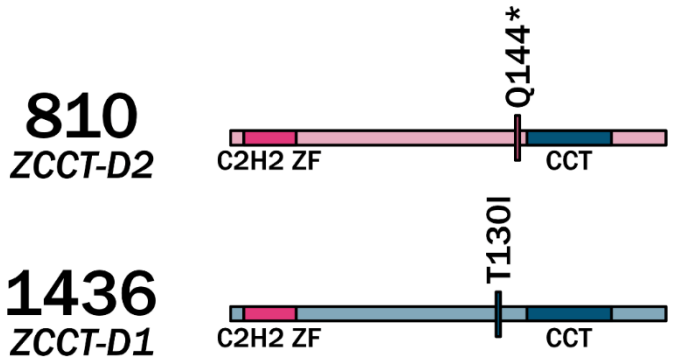


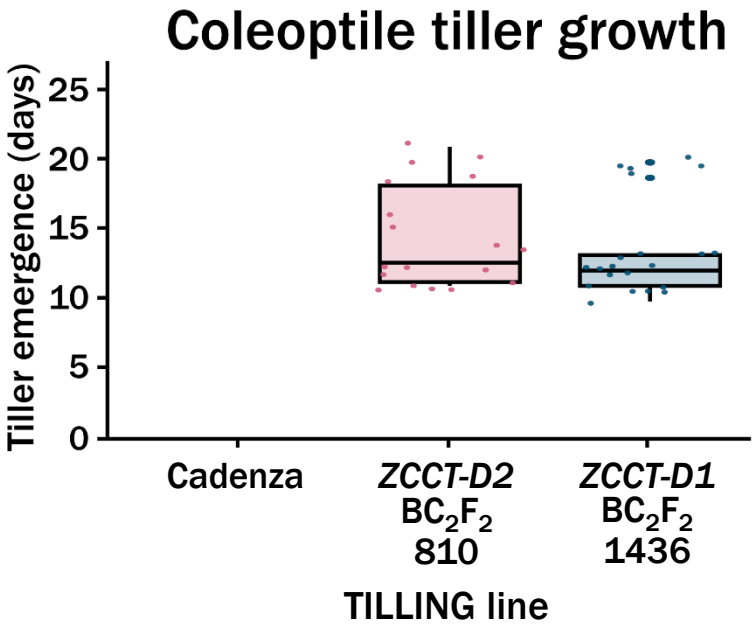


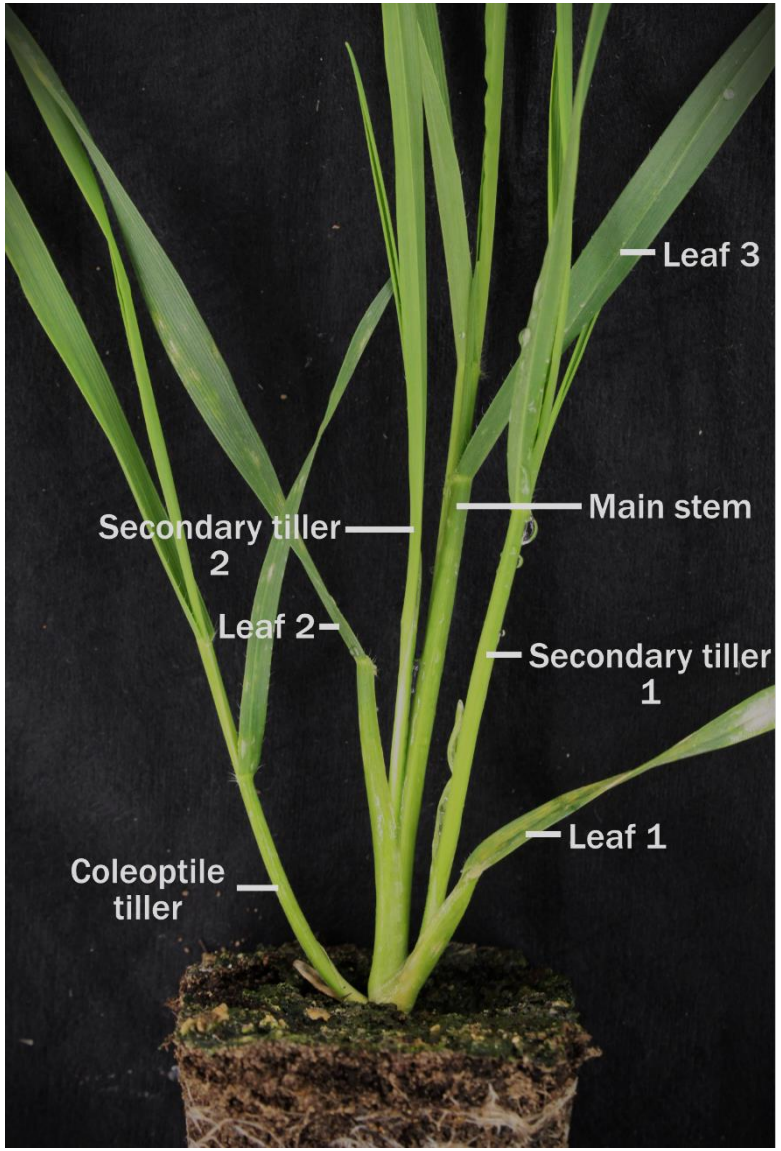


IPK LEIBNIZ-INSTITUT

ZCCT mutants have an increased number of coleoptile tillers

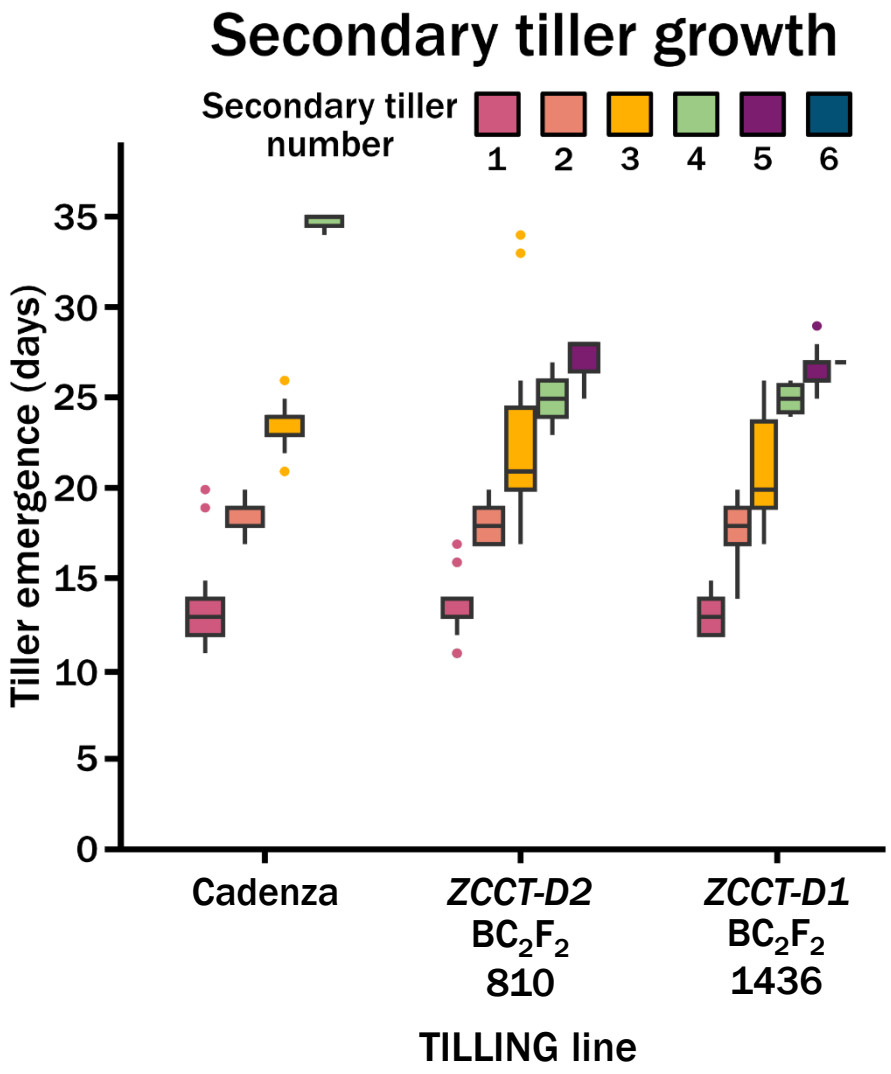


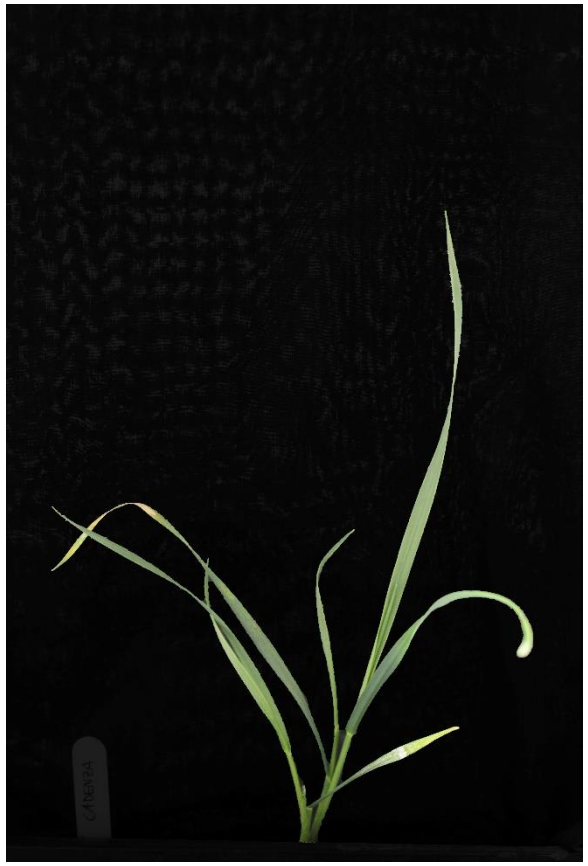




IPK LEIBNIZ-INSTITUT

ZCCT mutants have increased early tillering



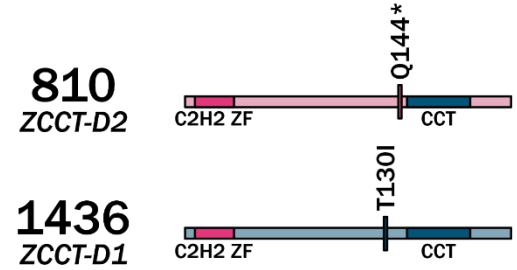


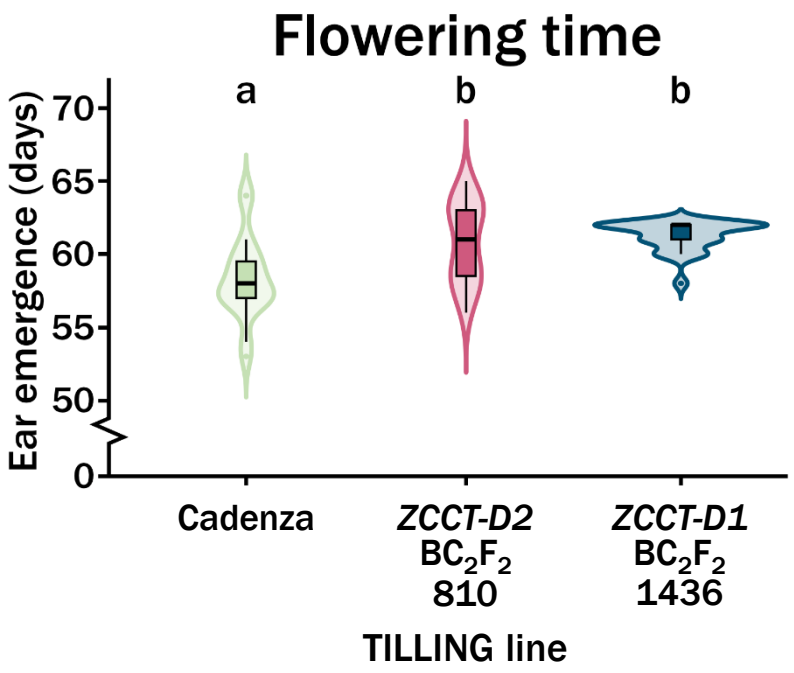
Cadenza

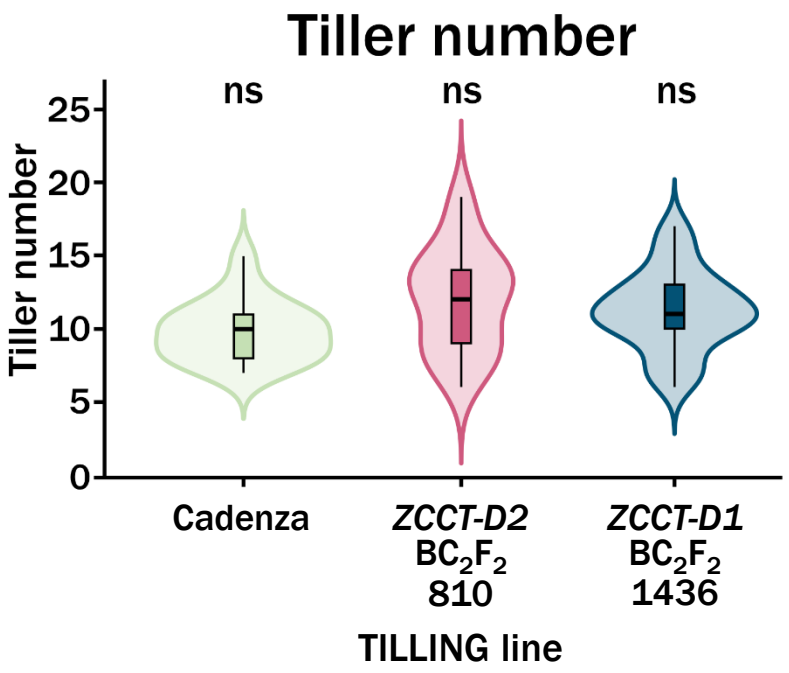
ZCCT-D2
(BC_2F_2 810)

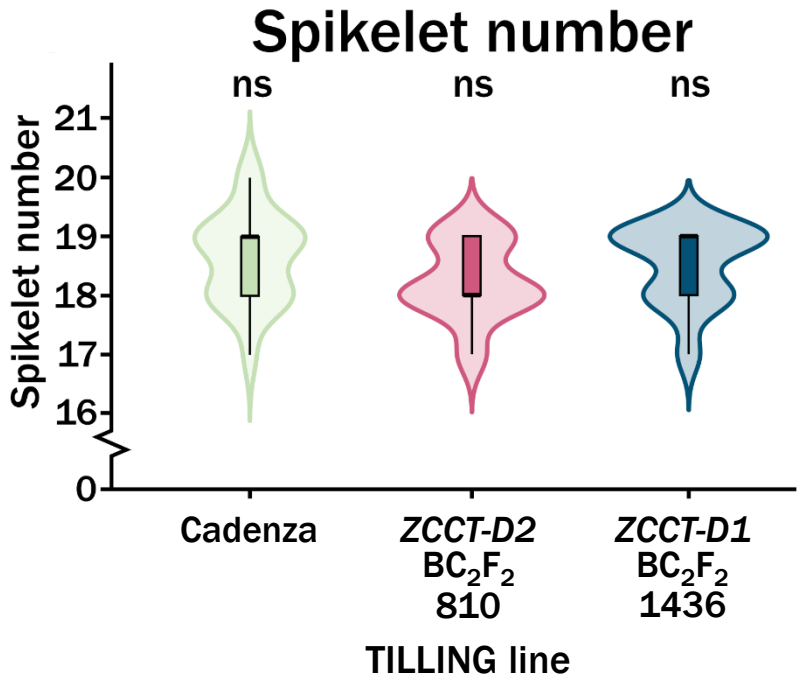
IPK LEIBNIZ-INSTITUT

ZCCT mutants have a slight delay in flowering time









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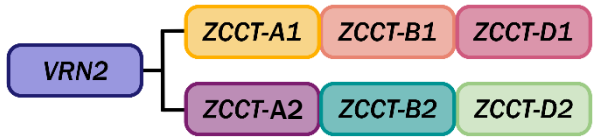
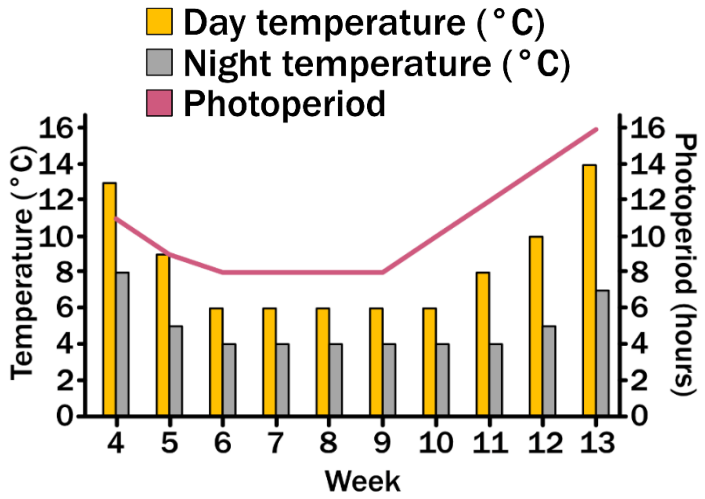
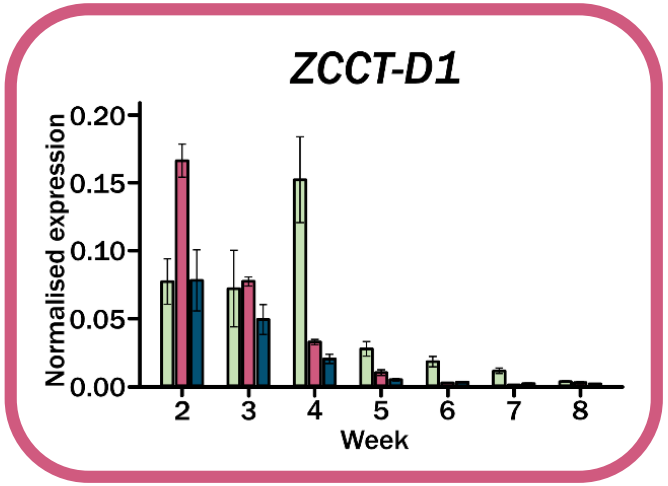
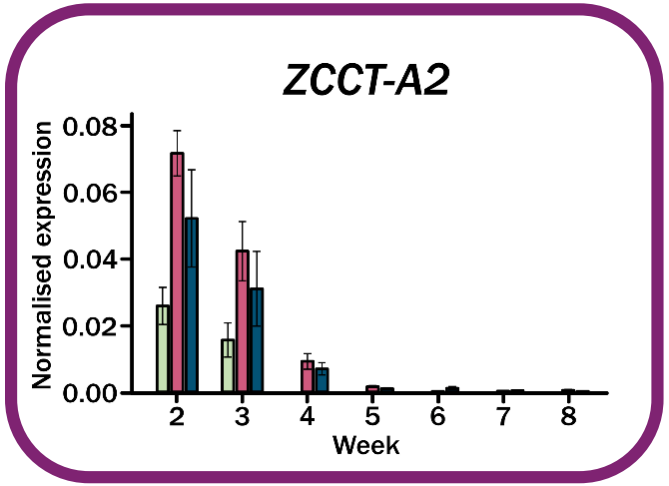
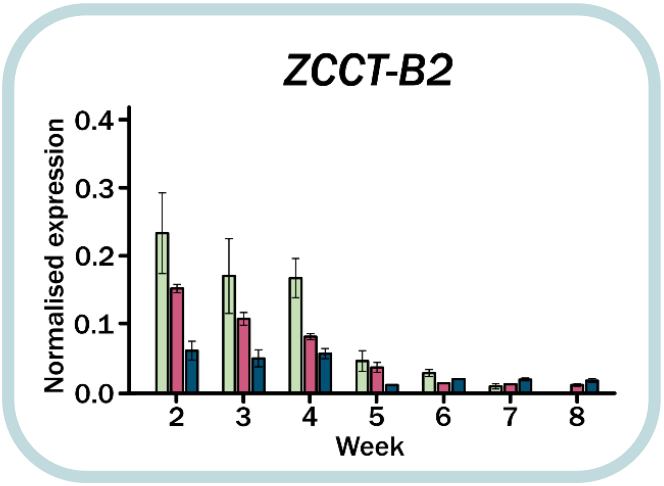
Mutants in *ZCCT-D1* and *ZCCT-D2* show increased expression of *ZCCT-A2*

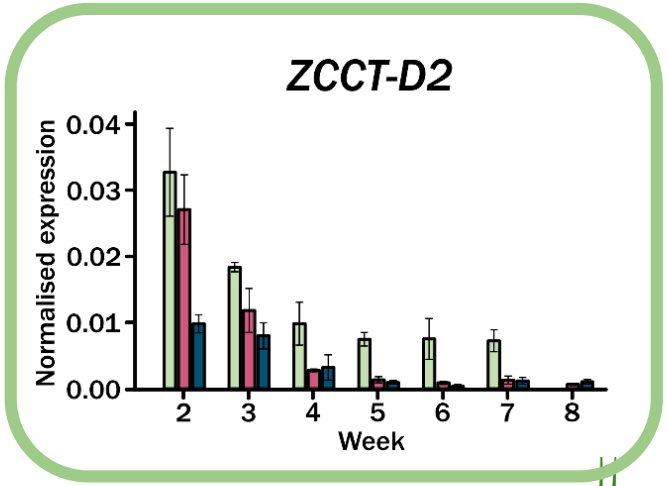












Cadenza
ZCCT-D2 (810)
ZCCT-D1 (1436)

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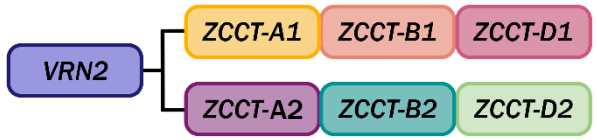
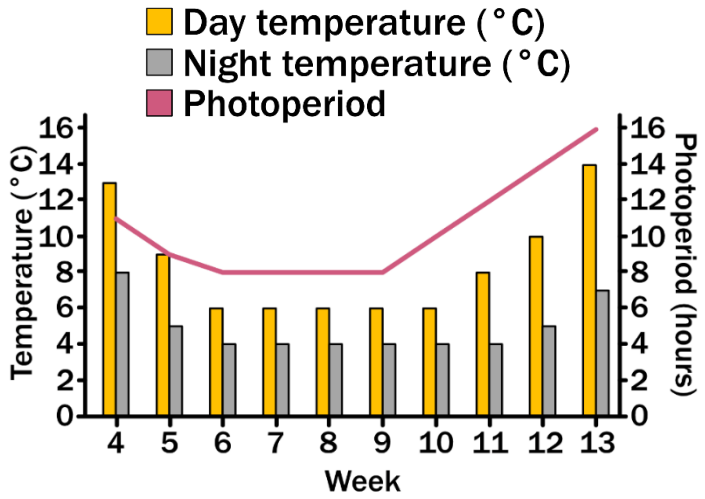
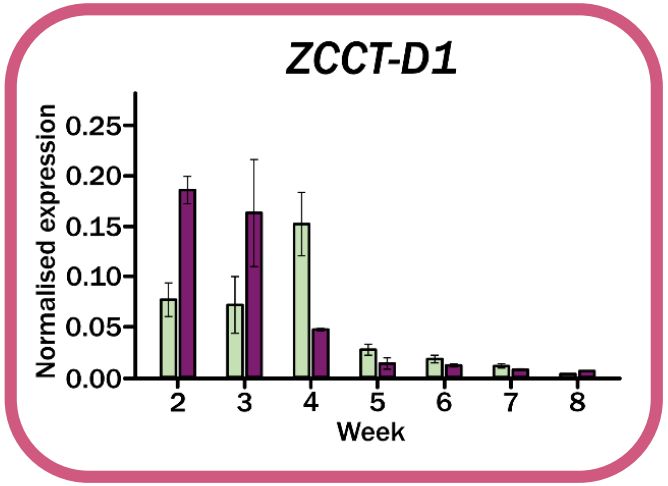
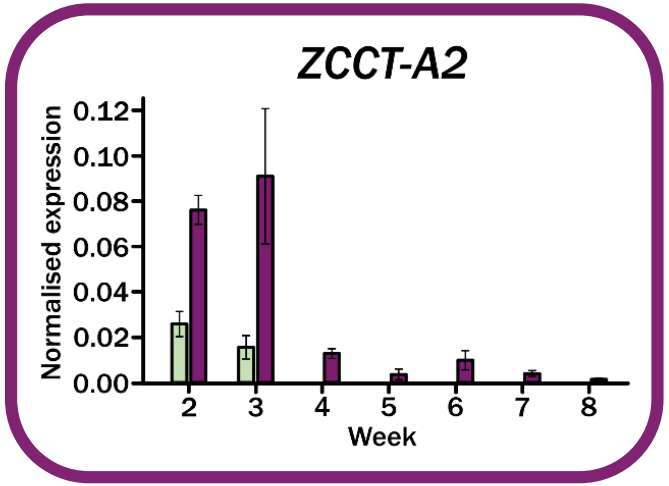
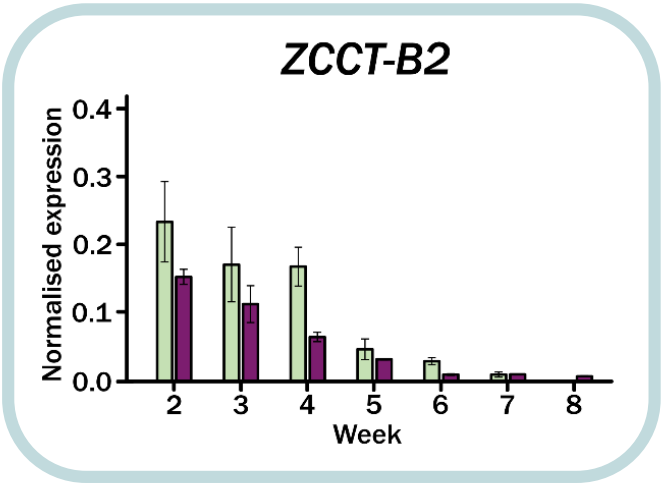
Transgenic overexpression of *ZCCT-A2* also alters expression of *ZCCT-D1*

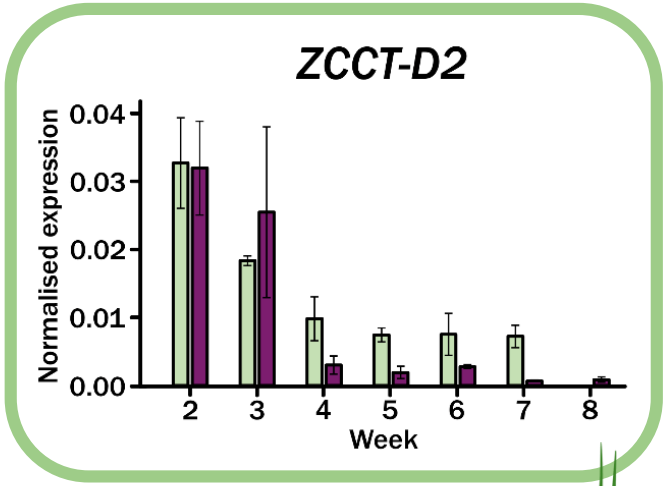












Cadenza
ZCCT-A2-OE (CTA175.2)

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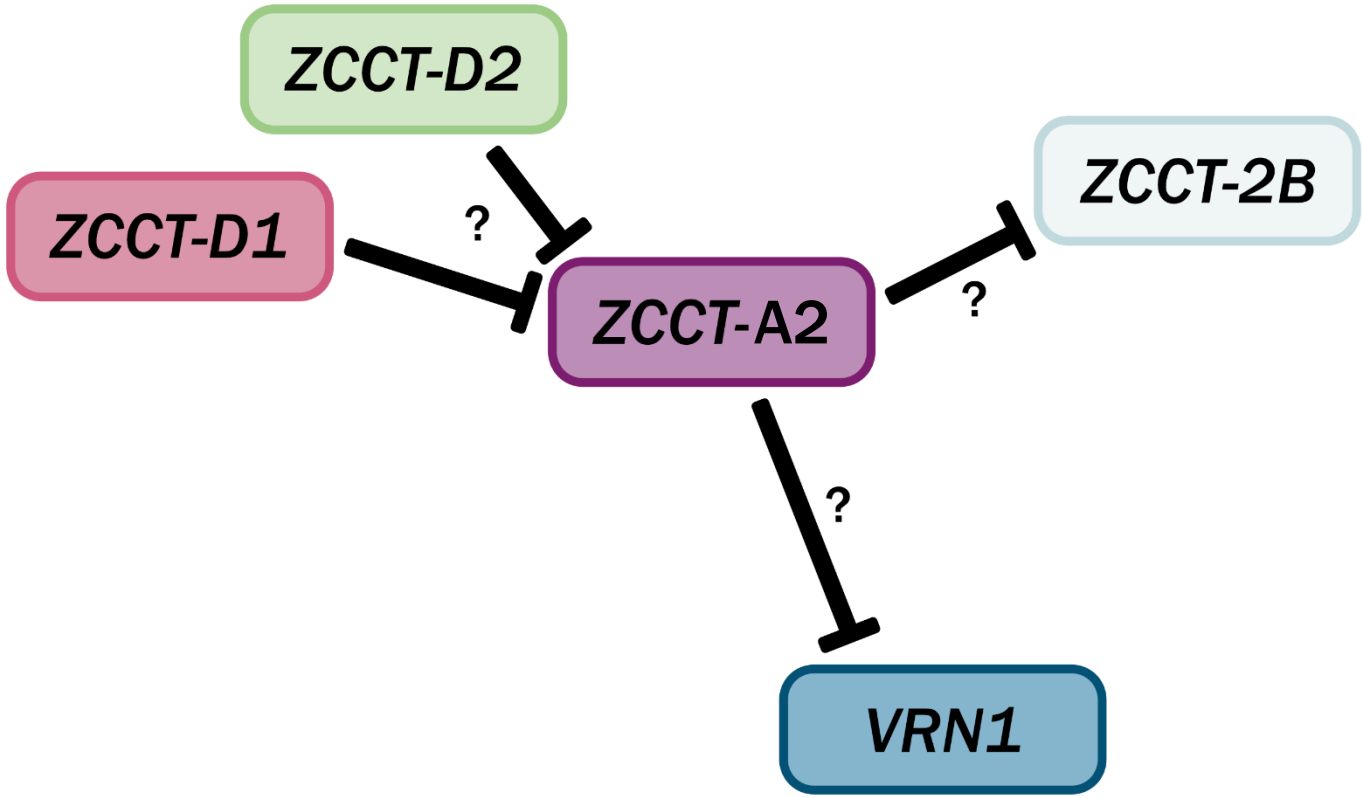
The *ZCCT* genes may regulate each other as a network



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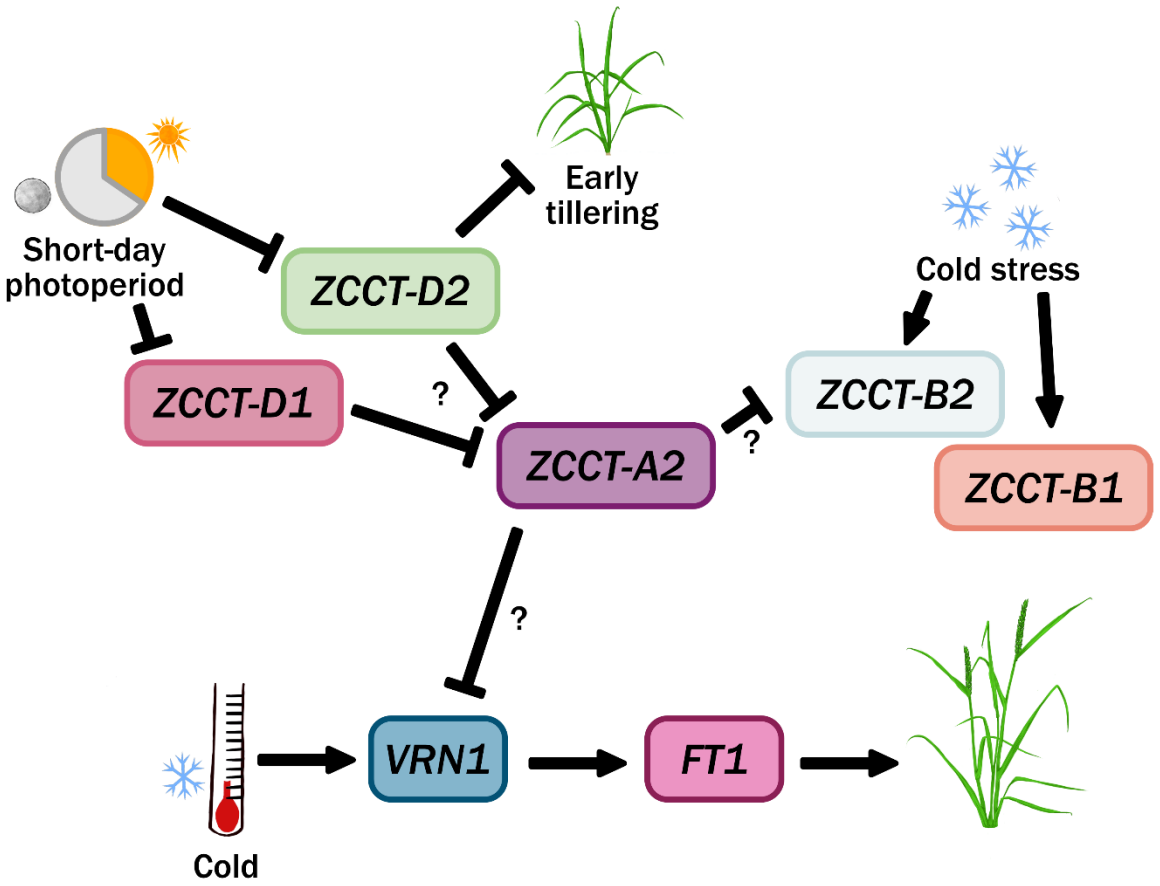
Conclusions

- *VRN2* expression patterns are not always reflective of a vernalisation-responsive floral repressor
- There is potentially an additional developmental role for *VRN2*
- Not all *ZCCT* genes are behaving the same and likely form a regulatory network



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Acknowledgements

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