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Cantin, Celia M.; Wang, Xin-Wei; Almira, María; [et al.]. «Inheritance and QTL analysis of chilling and heat requirements for flowering in an interspecific almond x peach (Texas x Earlygold) F2 population». *Euphytica*, Vol. 216, issue 3 (March 2020), art. 51. DOI 10.1007/s10681-020-02588-9

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1 **Inheritance and QTL analysis of chilling and heat requirements for flowering in an**
2 **interspecific almond x peach (Texas x Earlygold) F₂ population**

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16

17 **Abstract**

18 Blooming in temperate fruit species is triggered by chilling and heat requirements (CR and
19 HR), with a wide range of requirements within the same species. CR for flower bud dormancy
20 release has become a limiting factor for geographical adaptation of fruit trees in warmer
21 regions. The present study investigated the genetic basis of CR and HR to break dormancy and
22 flowering time (FT) in an almond x peach F₂ progeny. FT, HR and CR were evaluated over two
23 consecutive years (2015/2016 and 2016/2017). Seven out of the eight identified quantitative
24 trait loci (QTLs) were found in both periods of analysis. They affected eight traits, and included

25 a consistent QTL for breaking dormancy, CR and HR. Two of them, affecting FT and HR for
26 FT (GDHF), colocalized in G1, and the remaining QTLs, affecting chilling and heat
27 requirements, both influenced by dormancy breaking (DB), were located in G6. These results
28 indicate that factors not related to DB affect flowering time in this population. Implications of
29 the results in peach breeding are discussed.

30

31 **Keywords:** chilling requirements, heat requirements, peach, flowering.

32

33 **Introduction**

34 Flowering, an essential and complex developmental process in plants ([Castède et al., 2015](#))
35 , is regulated by a number of external signals and internal elements (Hanke *et al.*, 2007). Its
36 correct completion is fundamental for the commercial production of seeds and fruits ([Zhang](#)
37 [and Taylor, 2011](#)).

38 In fruit tree orchards, there must be synchronization between flowering phenology and
39 climatic conditions ([Castède et al., 2015](#)). As flowering is crucial for sexual reproduction, buds
40 of perennial species in temperate regions become dormant (cease growth) during the winter
41 months to survive. Endodormancy requires a certain amount of chilling for the transition to
42 ecodormancy, whereas ecodormancy, requires a certain amount of heat to start the flowering
43 process ([Castède et al., 2015](#)). Consequently, dormancy and flowering are linked, and breeders
44 must select cultivars whose CR and flowering time match local climatic conditions ([Bielenberg](#)
45 [et al., 2015](#)). However, it has been demonstrated that global warming can advance or delay
46 flowering and/or fruiting of temperate fruit trees (Heide, 1993; [Ramirez and Kallarackal, 2015](#);
47 [Rivero et al., 2016](#); [Woznicki, et al. 2019](#)), having an unknown and undesired effect on the
48 productivity of fruit crop species. Globally, the temperature has increased by approximately

49 0.6°C over the past 100 years ([Walther, 2002](#)). The forecast is for this trend to continue, with
50 studies already having observed the decrease in winter chill and the resulting changes in
51 phenological events ([Menzel et al., 2005](#); [Menzel et al., 2006](#)).

52 The *Prunus* genus, within the Rosaceae family, is characterized by species that grow in
53 areas with well-marked seasons and are adapted to survive cold winters and dry summers
54 ([Dirlewanger et al., 2012](#)). Various models have been proposed to measure the accumulation of
55 CR in deciduous fruit-growing areas ([Albuquerque et al., 2008](#)). The effect and genetic basis
56 of HR on flowering is not yet well understood and studies on this topic are scarce. Previous
57 studies in *Prunus* have suggested that CR has a stronger effect on flowering time than HR
58 (Couvillon and Erez, 1985; [Campoy et al., 2012](#); [Albuquerque et al., 2008](#); [Okie and](#)
59 [Blackburn, 2011](#); [Sanchez-Perez et al., 2012](#)). In this genus, as in most woody perennials, the
60 physiology and biochemistry of the flowering process is poorly understood ([Dirlewanger et al.,](#)
61 [2012](#); [Woznicki et al., 2019](#)). Recent reports suggest that intrinsic and environmental signaling
62 interact and dynamically affect the extent of bud dormancy ([Castède et al., 2015](#); [Woznicki et](#)
63 [al., 2019](#)). Peach (*Prunus persica* (L.) Batsch) is an economically important species that
64 provides an excellent system for the genetic analysis of CR and FT due to the ample variation
65 for both traits among peach cultivars (CR between 50 to 1,050 h) ([Zhebentyayeva et al., 2014](#)).
66 Both CR and FT are inherited as quantitative traits ([Fan et al., 2010](#); [Hauagge and Cummins,](#)
67 [1991](#)), but their molecular regulation is not yet fully understood. Some quantitative trait loci
68 (QTLs) associated with FT have been found in *Prunus* species (reviewed in Salazar et al.,
69 2014): almond ([Sanchez-Perez et al., 2012](#); [Silva et al., 2005](#)); peach ([Dirlewanger et al., 2012](#);
70 [Bielenberg et al., 2015](#)); almond x peach ([Donoso et al., 2015](#)); apricot ([Campoy et al., 2013](#);
71 [Dirlewanger et al., 2012](#); [Kitamura et al., 2018](#)); sweet cherry ([Dirlewanger et al., 2012](#); [Calle](#)
72 [et al., 2020](#)) and sour cherry ([Wang et al., 2000](#)). The separate effect of CR and HR on FT has

73 only been reported in a few studies in peach ([Fan et al., 2010](#)), apricot ([Olukolu et al., 2009](#))
74 and cherry (Castède et al. [2014](#)). Since these traits can only be evaluated 2-3 years after seed
75 germination in most *Prunus*, the identification of genetic markers linked with CR, HR and FT
76 would be a valuable tool to select genotypes at the seedling stage and make the breeding
77 process much more efficient ([Bielenberg et al., 2015](#)).

78 In this work, we studied an F₂ c n o q p f " z " r g c e j " r t q i g p { " * V z G . " "
79 ÷ G c t n { ivøpefl at IRTA and used as the *Prunus* reference map ([Dirlewanger et al.,](#)
80 [2004](#)), for which a high-density linkage map was available (Donoso et al. 2015). The main
81 goals were to study the inheritance of CR, HR and FT, and to test the existing chill unit (CU)
82 models in Gimènells, Lleida (Spain) (latitude 0°23'E /longitude 41°39'N), with a temperate
83 semi-arid climate, to identify which of them fits best with the climatic conditions in one of the
84 major areas of peach and almond production in the world.

85

86 **Materials and methods**

87 *Plant material*

88 The *Prunus* reference interspecific almond x peach F₂ progeny (T x E), obtained by selfing
89 c " j { d t k f " k p f k x k f w c n " * ÷ O D " 3 0 5 9 ø + " h t q o " c " e t q u u "
90 (Donoso et al. 2015), and its parents was used for this study (Tables S1 and S2). From the
91 original progeny of 111 hybrids, we phenotyped the 72 trees that were still alive. Trees of T x E
92 are at the IRTA Experimental Station of Lleida in Gimènells (Spain) grafted on ÷ I c t p g o ø "
93 (Felipe 2009) rootstocks. Standard agricultural practices were applied.

94

95 *Phenotyping*

96 The parents, hybrid and TxE offspring were evaluated over two seasons (2015/2016 and
97 2016/2017, that we refer to as 2016 and 2017, respectively) following a forcing protocol
98 widely used in temperate fruit trees (Campoy et al. 2011). Traits phenotyped were chilling
99 requirement (CR), flowering time (FT), and heat requirement (HR). Three one-year-old
100 fruiting branches for each individual were randomly collected once a week from November
101 1st until chilling requirements were reached. At least 30 flower buds were collected from
102 the three branches for each sampling date. The bases of the branches were placed in water
103 in a growth chamber at 25°C, under white fluorescent tubes with a 16 h:8 h, light:dark
104 photoperiod to force floral bud break (Ruiz et al., 2007; Sánchez-Pérez et al., 2012). After 7
105 d, the phenological stage of the flower buds was observed. The date of dormancy breaking
106 (DB) was established when 50% of flower buds were at phenological growth stage 53
107 according to the international Biologische Bundesanstalt, Bundessortenamt et Chemische
108 Industrie (BBCH) scale (Meier et al., 1994; Albuquerque et al., 2008). Three chill models
109 were then used to calculate chilling accumulation from October 1st until dormancy release,
110 corresponding to the CR. The flowering time (FT) was scored as the number of Julian days
111 when 50% of flowers were open. Also, the length of the period between DB and FT was
112 calculated as the number of Julian days. For each genotype, the whole tree was observed by the same person every 1 or 2 days during
113 the flowering period. A scheme of the traits evaluated can be found in Figure 1.

115

116 *Weather data*

117 Hourly temperatures from October 1st to flowering time for both years were obtained from
118 the Gimènells weather station of the Generalitat de Catalunya, in the same area as the studied
119 population (<https://ruralcat.gencat.cat>).

120

121 *Chilling and forcing models*

122 For this study, we used the Chill Hours (CH), Utah (CU) and Dynamic (CP) Models. The
123 Chill Hours Model (CH) (Weinberger, 1950) is the oldest and simplest model, which considers
124 all hours with temperatures between 0 and 7°C as effective for chill accumulation. The Utah
125 Model (Richardson et al., 1974), which measures chill in Chill Units (CU), contains a weighted
126 function attributing chilling efficiencies to different temperature ranges, including negative
127 contributions by high temperatures, and it is particularly used in cooler areas of temperate
128 zones (Dennis et al., 2003). The Dynamic Model (Erez and Couvillon, 1987) was developed
129 for warmer areas. It considers that dormancy cessation occurs in two steps, the first being
130 reversible and the second irreversible, and CR are calculated as chill portions (CP). It adopts a
131 process-based concept of chill accumulation: an intermediate chill product is first formed
132 through bud exposure to low temperatures, and once a critical amount of this intermediate has
133 accumulated, it is transformed into a Chill Portion (CP). The CP is then retained until the end
134 of the chilling period (Erez and Fishman, 1998). As with the Utah model, temperatures have
135 different effects on dormancy, but the temperature ranges differ in the two models
136 ([Alburquerque et al., 2008](#); [Byrne, 2003](#)).

137 To describe heat accumulation during the later stages of tree dormancy, we used the model
138 proposed by Richardson et al. (1974), which calculates Growing Degree Hours (GDH) between
139 dormancy release and flowering date. According to this model, heat builds up when hourly
140 temperatures are between 4.5°C and 36°C (at different rates depending on the maximum
141 temperature), with maximum accumulation at an optimal temperature (25°C). Additionally, we
142 also calculated GDH between 1st October and flowering date (GDHF).

143

144 *Chilling and heat requirements*

145 Chilling and heat accumulation were calculated for the two consecutive dormancy seasons
146 (2016 and 2017) with the hourly temperatures measured in the field. Chill was computed
147 according to the Chill Hours (CH), Utah (CU) and Dynamic (CP) models and heat according to
148 the GDH Model. Correlations between chilling and heating requirements and blooming were
149 determined using Partial Least Squares (PLS) regression (Luedeling and Gassner, 2012). Since
150 heat cannot have an effect after bloom, the flowering time was considered as the end of the
151 forcing period. CR and HR were estimated as the sum of all daily chill and heat accumulated
152 during the chilling and forcing periods. Heat accumulation was calculated as the number of
153 GDH from DB to FT, and the length of this period of heat accumulation was also recorded (GDHF).

156

157 *QTL analysis*

158 For QTL analysis, we used the TxE genetic map described by Donoso et al. (2015), which
159 was constructed using 1,948 molecular markers (SNPs and SSRs), covering a total genetic
160 distance of 472.1 cM. The interval mapping method with the MapQTL 6.0 software package
161 (Van Ooijen et al. 2009) was used for QTL analysis of the phenotyped traits. QTLs were
162 considered consistent when the LOD \times 3.0 in both seasons, or with a LOD \times 3.0 one year and
163 LOD \times 2.0 the other year. QTLs were considered as major QTLs when they explained more
164 than 20% of phenotypic variation in both years of study (Tanksley, 1993). QTL positions were
165 drawn using the MapChart 2.1 software (Voorrips 2002).

166 Gene action was estimated following the guidelines of Tanksley (1993) with the ratio, d/a ,
 167 between the additive, where $a = (A - B)/2$, and dominance $d = H - [(A + B)/2]$ effects, with H,
 168 A and B the average phenotypic values of the heterozygous, almond homozygous and peach
 169 homozygous genotypes, respectively. Based on the d/a ratio, QTLs were classified as
 170 underdominant ($d/a < -1.25$; U), dominant for the peach allele ($-1.25 < d/a < -0.75$; DP),
 171 partially dominant for the peach allele ($-0.75 < d/a < -0.25$; PD), additive ($-0.25 < d/a < 0.25$;
 172 A), partially dominant for the almond allele ($0.25 < d/a < 0.75$; AD), dominant for the almond
 173 allele ($0.75 < d/a < 1.25$; DA) and overdominant ($d/a > 1.25$; O).

174

175 **Results**

176 *Temperature and chilling accumulation*

177 Maximum and minimum daily temperatures during the consecutive years studied in
 178 Gimenells (Lleida) are shown in Supplementary Fig. S1. Higher maximum and minimum
 179 temperatures were registered during the winter in 2016, meaning a warmer winter compared to
 180 the following year. However, warmer maximum temperatures were registered at the end of the
 181 winter in 2017, reaching 25°C at the beginning of March.

182 Chilling accumulation was very similar over the winter in both seasons (Fig. 3) using the
 183 CU model and the CP model, but the accumulated CH was higher in 2017. Spearman
 184 correlations between models were very high for both seasons (Fig. 4).

185

186 *Chill requirements to break dormancy*

187 The range of CR for dormancy breaking (DB) for the parental lines [\div O D " 3 (H) 5 9 \emptyset
 188 \div V g z (E) and \div G c t n (E)] was between 42 and 64 CP. Of these, Ec t n { had the \emptyset
 189 lowest CR (42 and 45 CP for consecutive years), whereas the requirements for H (60 and 59

190 CP) and $T_g z c$ (54 and 64 CP) were similar. There was transgressive segregation for CR, with
191 values from 33 to 71 CP (579 - 1434 CU; 484 - 1327 CH) averaged for two years (Table 1). CR
192 data for the F_2 population showed normal distributions in the two years (Fig. 4), with CR
193 skewed in both years to high CR. Data for each individual is given in supplementary material
194 (Table S1 and S2).

195 In most genotypes, CR were similar for both years evaluated, showing high correlations
196 between them (Table 1). The date of DB was, in general, earlier in 2016 than in 2017, with the
197 earliest on 16th Dec and 14th Dec, whereas the latest was on 4th Feb and 2nd Feb (2016 and
198 2017, respectively).

199

200 *Heat requirements for flowering*

201 The range of HR for flowering among the parents was 3,575 to 6,170 GDH, whereas in the
202 segregating population it was 2,681 to 7,105 GDH (averaged for the two years) (Figure 4). $\div O D$ "
203 3 0 5 had the lowest HR of the parents, and was similar to $T_g z c$ whereas $E c t n$ { had n f ø
204 the highest. Within the segregating population, most genotypes had similar HR for both
205 consecutive years, showing a high correlation ($r^2 = 0.78$) between years (Table 1). Date of
206 flowering (FT) was, in general, earlier in 2016 than in 2017, with the exception of only three
207 genotypes. The parental lines ($\div O D 3 0 5 9 \phi . "$ $\div V g z c$ showed very similar FT in n { i q n
208 both years. Correlation between years for FT was lower than for other traits ($r^2 = 0.39$) (Table
209 1). The earliest FT was on 21st Feb and 3rd March, and the latest 15th and 12th March (2016 and
210 2017, respectively). The number of days between DB to FT in the segregating population
211 (JD), which is the period for heat accumulation, ranged from 27 to 77 days (averaged for the
212 two years), and there was a high correlation between both seasons ($r^2 = 0.86$). HR showed a

213 bimodal distribution in 2017, whereas it was a single peak in 2016 (Fig. 4). There were single
214 peaks for FT in both years, although it was slightly skewed to late bloom in 2017.

215

216 *Correlations between traits*

217 Highly unipolar chilling accumulation models were used to estimate chilling accumulation for both seasons (Supplementary Table S1). Similarly,
218 correlations between DB and these three models were very high (Table 1). Correlations between seasons were very high for most of the traits ($r^2 = 0.78-0.89$), with lower
219 values for FT and GDHF ($r^2 = 0.39$ and $r^2 = 0.47$, respectively) (Table 1). Flowering time (FT)
220 showed a high correlation with GDHF. Correlation between FT and CR and HR traits was low
221 for both years of study.

222 Heat requirements (GDH) were highly and negatively correlated with CR and DB (Table 1
223 and Fig. 5), which means that the lower the CR, the higher the HR. As expected, HR was
224 highly correlated with the number of days for heat accumulation was highly and negatively correlated with CR and DB.

225

226 *QTL analysis*

227 Data from the eight traits under study (DB, CH, CP, CU, FT, GDH, GDHF, L) were used
228 for QTL analysis. One consistent QTL per trait was identified (Table 2). QTLs were located in
229 G1 for FT and GDHF, and in G6 for DB, the CR models (CH, CU and CP), GDH and L (Fig. S2).

230 For dormancy breaking (DB), the LOD for the QTL from G6 was 3.4 in 2016 and 3.4 in
231 2017 and explained 18.4 and 18.1 % of the phenotypic variance, respectively. The homozygote
232 for the peach allele increased the date of DB by 15 days compared to the almond homozygote
233

237 in 2016 and by almost two days in 2017. In 2017, while both homozygous classes had similar
238 values, there was an increase of 13 days for the heterozygous individuals. Very similar results
239 were obtained for L F " c n v j L Q D for the QTL, as G6 was less than 2.0 (1.8) in 2017 and
240 therefore was not considered.

241 For CR data similar results were obtained with the three models, although the most
242 significant QTLs were obtained using the dynamic model, while the least was for the Utah
243 model. For the dynamic model, a QTL was identified at the proximal end of G6 with a LOD
244 score of 3.4 in 2016 and 3.2 in 2017, explaining, respectively, 18.4% and 17.4 % of the
245 phenotypic variance. The confidence interval for G6 QTLs spans the genomic region Pp06: 0-
246 4.001.078 where 702 genes have been annotated. In 2016, the individuals with the homozygous
247 peach allele needed 10 CP more to reach DB than those with the homozygous almond allele. In
248 2017, this difference was only four CP, but 10 with heterozygous individuals.

249 In the same region of G6 we c n u q " k f g p v k h k g f " c " S V in 2016, it " I F J
250 explaining between 16.8% and 19.9% of the phenotypic variance respectively. For FT we
251 identified a QTL at the beginning of G1 in 2017 (LOD 3.9; $R^2 = 21\%$), but with a LOD score of
252 2.2 in 2016 ($R^2 = 11.5\%$). The confidence interval spans the genomic region Pp01:0-
253 10.521.046 bp, where 1584 have been annotated. The peach allele in homozygosis increased
254 the FT by five days in 2016 and three in 2017, compared to the homozygous almond allele. In
255 the same region, we also detected a QTL for GDHF in both years, with LOD values of 3.9 and
256 3.1 respectively.

257

258 **Discussion**

259 *Phenotypic data of chilling and heat requirements*

260 It is usually assumed that almond flowers before peach. It is interesting to note that in our
261 case, ÷ V g z a late flowering almond cultivar and ÷ G c t n, (an early flowering peach,
262 flower at the same time even though they have different CR and HR. The CR of the progeny
263 are in the range of those reported for peach and almond from other Mediterranean areas
264 ([Benmoussa et al., 2017](#); [Campoy et al., 2012](#); [Ruiz et al., 2007](#)). However, it must be noted
265 that TxE is an interspecific population, and therefore results are not fully comparable to single
266 species populations studies. The range observed in the TxE population exemplifies the
267 difficulties for growing certain peach and almond cultivars in warm regions where annual chill
268 accumulation is decreasing due to global warming. A large variation in the HR within the
269 studied progeny was also found.

270 The performance of chill accumulation models vary in different climate conditions, as
271 observed in peach ([Balandier et al., 1993](#); [Erez et al., 1990](#); [Erez et al., 2000](#); [Perez et al., 2008](#))
272 and other *Prunus* species ([Alburquerque et al., 2003](#); [Alburquerque et al., 2008](#); [Egea et al.,](#)
273 [2003](#); [Ruiz et al., 2007](#)).

274 In Lleida (Spain) the CR calculated using the three models were very well correlated and
275 with DB, and therefore could be used for the calculation of CR in this climatic area, as for
276 peach ([Fan et al., 2010](#)) and apricot ([Campoy et al., 2012](#)) in colder climates. This correlation
277 could be due to the lack of long periods of warm and fluctuating temperatures, so that chilling
278 accumulation based on different models all steadily increased in a similar way through the two
279 seasons. Substantial differences among the many models used have been observed in moderate
280 mild climates ([Erez et al., 1990](#); [Erez et al., 2000](#)) since some of them, such as the Utah model,
281 were developed in a cold area and are not appropriate for warmer areas.

282 The variability of chill accumulation between years was lower with the Dynamic model
283 than when the calculations were done with the Utah and the hours-below 7°C models. This may

284 be explained by the homogenizing effect of the Dynamic model, which takes into account the
285 synergistic effect between moderate and low temperatures for breaking dormancy ([Fishman et](#)
286 [al., 1987](#)). Other authors have previously reported similar results in apricot ([Campoy et al.,](#)
287 [2012](#); [Ruiz et al., 2007](#)), suggesting that the Dynamic model is optimal for the climatic
288 conditions of Lleida and other areas of the Ebro Valley in Northern Spain.

289

290 *Correlations among endodormancy and ecodormancy traits*

291 V j g " j k i j " p g i c v k x g " e q t tang GDH vs. CR (CH, CP and CU) d g v y g
292 indicate that genotypes with lower CR required a longer period of heat accumulation to bloom.
293 This has been also found in peach ([Li et al., 2016](#)) and apricot ([Campoy et al., 2012](#)). Li et al.
294 (2016) reported a decrease of 16 days per 200 accumulated CHs, up to a threshold of approx.
295 950 CHs. Overall, these results suggest that in cultivars with low CRs, GDH accumulation just
296 after CR fulfillment is less effective than in cultivars with higher CRs, and therefore they need
297 more time to accomplish their HR.

298 A similar result was found for the correlation between DB and CR (CH, CU, and CP)
299 against HR (GDH). Similar high correlations have been found in peach ([Fan et al., 2010](#); [Li et](#)
300 [al., 2016](#); [Pawasut et al., 2004](#); [Scorza and Okie, 1990](#)) and apricot ([Ruiz et al., 2007](#)). We
301 found a high level of variability among the progeny regarding HR, which disagrees with
302 Linsley-Noakes and Allan (1994) who reported no differences in HRs between three nectarine
303 cultivars with different CR. These results suggest the existence of different heat requirements
304 among genotypes and a major genetic contribution in the control of this trait, or that this trait is
305 not being measured accurately because the physiological base is not yet well understood. The
306 first hypothesis is in line with the model for Douglas fir ([Harrington et al., 2010](#)), which
307 proposes a variable threshold for the efficiency of chill and heat temperatures. However, other

308 authors have reported contradictory results ([Couvillon and Erez, 1985](#); [Guerriero et al., 2006](#);
309 [Kotowski et al., 1980](#)), which may be due to the different climate of the cited studies. There is
310 no consensus in the literature about whether there is a clear relationship between CR and HR.

311 No significant correlation was found between HR (GDH) and FT, in agreement with other
312 authors in peach ([Fan et al., 2010](#)) and apricot ([Campoy et al., 2012](#)). This result indicates that
313 GDH is not as important as CR for determining flowering time. However, a high correlation
314 was found between FT and GDHF which could indicate the importance of warm temperature
315 before dormancy breaking on the flower bud formation and development, as reported
316 previously for plum (Woznicki et al., 2019) The fact that $r_{FT, CR}$ is a low CR cultivar
317 might also explain this result. Also Li et al. (2016) found that both the days to full bloom date
318 and HR were negatively correlated with CH, which may indicate that less accumulated CHs
319 could lengthen the days to full bloom date and increase the heat requirement. Together, the
320 results indicate that CR is a major factor determining flowering time, although not the only one.
321 Indeed, it is unclear in the literature whether heat accumulation for floral or vegetative bud
322 break starts before or after the release of endodormancy. Recent reports have shown a positive
323 correlation between August-September temperature and the amount and time of flowering in
324 the following spring on plum (Døving 2009; Woznicki et al., 2019) and sweet cherry (Døving
325 et al., 2011). We also found a low correlation between FT and CR. This is contrary to what has
326 been shown by other authors in peach and almond populations (Castède et al., 2014; Sánchez-
327 Pérez et al., 2012; Fan et al., 2010). However, there is no previous literature on CR for
328 interspecific populations. We believe that this distortion to the expected results is due to the
329 existence of two different species in the progeny. Indeed, in the Figure 3 can be observed that
330 $r_{FT, CR}$ is a low CR cultivar $r_{FT, CR}$ is a low CR cultivar $r_{FT, CR}$ is a low CR cultivar $r_{FT, CR}$ is a low CR cultivar
331 significant lower CR than T.

332

333 *Genetic control of endodormancy and ecodormancy traits*

334 We have identified one genomic region controlling endodormancy and ecodormancy traits
335 (CR and GDH) located in G6 and another one controlling FT in G1, that have not been
336 previously identified in other *Prunus* populations. The interspecific nature of the TxE
337 population might explain some of the differences observed with previous data obtained in
338 single species mapping populations. Data for GDHF, a trait highly correlated to FT, also
339 detected a QTL in G1 co-locating with that of FT, indicating either that GDHF is not related to
340 HR but a different way of measuring FT, or that warm temperatures during the winter
341 dormancy period, and not only after the fulfillment of the CR, are important for determining
342 FT. The latter hypothesis would support the high negative correlation, observed in this and
343 other studies, between CR and HR ([Fan et al., 2010](#); [Pawasut et al., 2004](#); [Ruiz et al., 2007](#);
344 [Scorza and Okie, 1990](#)), since the longer the period for chill accumulation, the higher amount
345 of GDHF likely to be accumulated.

346 Consistent QTLs across years for CR, HR and FT have been described in various *Prunus*
347 progenies. In peach, Fan et al. (2010) identified QTLs for CR, HR and FT at the latter end of
348 G1, where the evergrowing gene (*Evg*) maps (Bielenberg et al. 2008), and for CR and FT in G4
349 and G7, where QTLs for FT have been found in various *Prunus* crops (Dirlewanger et al.
350 2012). In similar positions of G1 and G4, QTLs for CR and/or FT have been detected by
351 Bielenberg et al. (2015) in peach, by Sánchez-Pérez et al. (2012) in almond and by Quilot et al.
352 (2004) in an advanced backcross between *P. persica* cultivars and *P. Davidiana*. For sweet
353 cherry, a consistent QTL in G4 for CR and FT has also been detected by Castède et al. (2014).
354 In all cases, the QTLs for CR coincided in map position with those of FT and produced effects
355 of similar magnitude and gene action, suggesting CR as a major cause for the FT phenotype.

356 Where HR was studied (Fan et al. 2010, Castède et al. 2014, Sánchez Pérez et al 2012), the
357 QTLs were detected at the same positions as those of CR and FT, or were not consistent over
358 the two years and had effects generally opposite to those of the QTLs detected for CR. This
359 suggests that HR is a minor or irrelevant factor in the determination of FT, that its measurement
360 as GDH is inefficient, or both. Our results support these observations as we found that HR and
361 CR detected the same QTL in both years studied. On the other hand, we did not find common
362 QTLs for CR and FT, indicating that FT was mainly determined by factors other than those we
363 measured. A possible explanation for this is that the TxE offspring, from the cross between two
364 cultivars from different species with low CR, had a lower level of variation for CR than other
365 mapping populations studied. In the cold-winter conditions of Lleida, chilling requirements
366 could have been rapidly met, resulting in a narrower distribution of variability than the
367 parameters used measured with low efficiency. In agreement with our results, a QTL for FT
368 was previously found in G1 in the TxE progeny in 2012 and 2013 (Donoso et al. 2016). Here,
369 we also identified a peak with LOD of 2.9 in 2016 for FT in G6 but it was not considered as an
370 stable QTL as it had a $LOD < 2$ in 2017 (results not shown). This does not discount that the CR
371 may be involved in FT variability, with apparently minor effects, although the population size
372 used could have been insufficient to detect them with a significant threshold.

373

374 **Conclusions**

375 All the models for the estimation of CR (Utah, Dynamic and Hours-below 7°) worked well
376 for the area of study, characterized by short but cold winters, with warm falls and springs.
377 However, the Dynamic model seems the most appropriate as it reduced the year-to-year
378 variation observed in the population. The results indicate that, although CR appears to have a
379 more important role than HR in determining flowering time, neither factor had a major effect

380 on this trait under the conditions of this research. For HR, the warm temperatures during
381 endodormancy (not only after endodormancy release) may have also influenced flowering time.
382 In summary, our data supports FT as a quantitatively inherited character with a strong genotype
383 x environment component that is affected by both chilling and heat requirements. The observed
384 variation in the CRs within the population studied highlights the importance and feasibility of
385 breeding for low CRs in a new scenario of low chill accumulation due to global warming.

386

387 **Acknowledgements**

388 This project was supported in part by funding from the Spanish Ministry of Economy
389 and Competitiveness (MINECO/FEDER projects AGL2015-68329-R and RTA2015-
390 00050-00-00, Severo Ochoa Program for Centres of Excellence in R&D 201-2019 SEV-
391 2015-0533) and from the CERCA Programme-Generalitat de Catalunya.

392

393 **Tables**

394 Table 1. Pearson’s correlation coefficients for seasons 2016 and 2017 between dormancy
 395 break (DB), flowering time (FT), chilling requirements for DB [Chill Hours (CH), Chill
 396 Units (CU) and Chill Portions (CP)] and HR for blooming [Total Growing Degree hours
 397 from 1st October to FT (GDHF), Growing Degree Hours (GDH) and number of days (JD)
 398 from DB to FT]. R g c t u correlation coefficients between seasons 2016 and 2017 are
 399 indicated in the diagonal.

		2015-2016							
		DB	CH	CU	CP	FT	GDHF	GDH	ΛJD
2016-2017	DB	0.89	0.87	0.88	0.89	0.21	0.16	-0.81	-0.81
	CH	0.90	0.89	0.89	0.90	0.22	0.16	-0.81	-0.81
	CU	0.86	0.84	0.85	0.86	0.21	0.16	-0.78	-0.81
	CP	0.87	0.86	0.87	0.88	0.22	0.16	-0.80	-0.81
	FT	-0.11	-0.07	-0.10	-0.11	0.39	0.54	0.38	0.25
	GDHF	-0.29	-0.26	-0.28	-0.28	0.32	0.47	0.50	0.40
	GDH	-0.88	-0.84	-0.87	-0.83	-0.13	-0.05	0.84	0.81
	ΛJD	-0.87	-0.84	-0.86	-0.87	-0.06	-0.02	0.83	0.86

400

401 X c n w g u " k p " d q n f " c t g " u k i p k h k e c p v " c v " r Ö 2 0 2 2 3 0

402

403 Table 2. Summary of consistent QTLs identified with the TxE map including trait name,
 404 QTL names, LOD score of the maximum peak, position of the maximum peak, closest
 405 marker, and parameters of percentage of explained phenotypic variance (R^2), additivity (a),
 406 dominance/additivity (d/a) and inferred gene action (GA). DB, dormancy break; FT,
 407 flowering time; CH, chill hours; CU, chill units; CP, chill portions; GDHF, growing degree
 408 hours to flowering= " L F . " p w o d g t " q h " f c { u " h t q o " F D " v q " H V 0

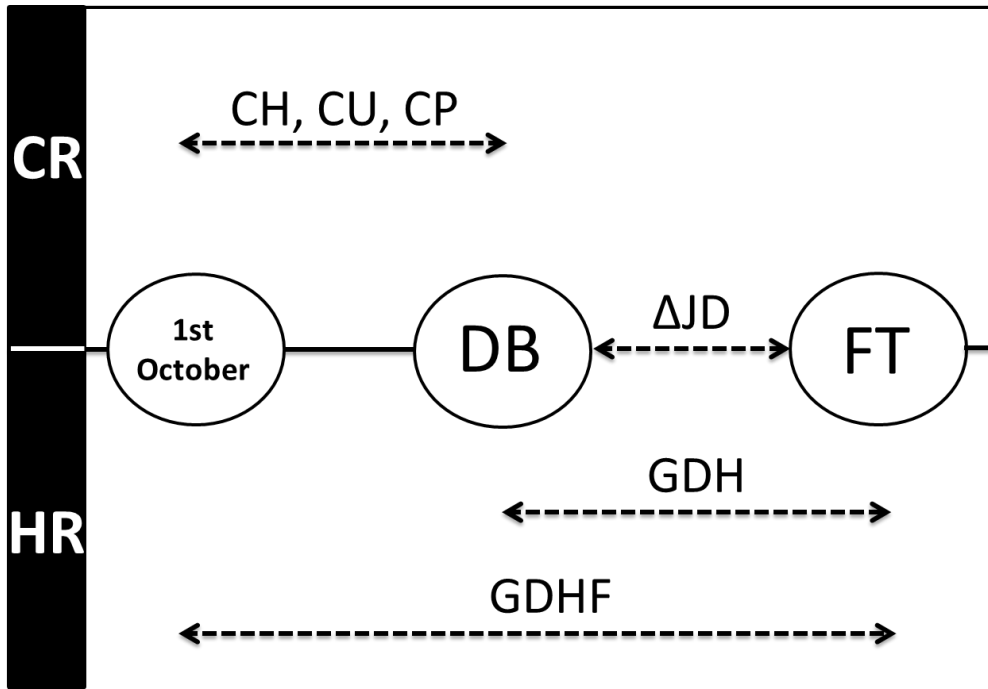
Trait	QTL name	LG	Position (cM)	Closest marker	LOD	R^2	a^a	d/a^b	GA ^c
DB-2015	qDB6	G6	2,4	SNP_IGA_6138	3,4	18,4	-7,5	-0,7	PD
DB-2016	qDB6	G6	2,4	SNP_IGA_6138	3,3	18,1	-0,9	-14,6	U
CH-2015	qCH6	G6	2,4	SNP_IGA_6138	3,2	17,3	-95,9	-0,6	PD
CH-2016	qCH6	G6	2,4	SNP_IGA_6138	3,2	17,4	-31,4	-7,0	U
CU-2015	qCU6	G6	2,4	SNP_IGA_6138	3,2	17,2	-129,0	-0,7	PD
CU-2016	qCU6	G6	2,4	SNP_IGA_6138	2,9	16,1	-2,0	-81,3	U
CP-2015	qCP6	G6	2,4	SNP_IGA_6138	3,4	18,4	-5,5	-0,7	PD
CP-2016	qCP6	G6	2,4	SNP_IGA_6138	3,2	17,4	-0,3	-26,9	U
FT-2015	qFT1	G1	9,8	SNP_IGA_2325	2,2	11,5	-2,5	0,4	AD
FT-2016	qFT1	G1	1,4	SNP_IGA_2006	3,9	21	-1,7	0,2	A
GDHF-2015	qGDHF1	G1	5	SNP_IGA_1052	3,9	19,9	-324,8	0,1	A
GDHF-2016	qGDHF1	G1	1,9	SNP_IGA_2670	3,1	16,8	-144,3	0,1	A
GDH-2015	qGDH6	G6	2,4	SNP_IGA_6138	3	16,3	452,4	-1,2	DP
GDH-2016	qGDH6	G6	2,4	SNP_IGA_6138	3,5	19,9	82,8	-13,6	U
409 Δ JD-2015	q Δ JD6	G6	3	SNP_IGA_6127	3,6	18,9	5,8	-1,1	DP

410 ^aAdditive effects: $a = (A - B)/2$, where A and B are the average phenotypic values for the
 411 homozygotes of the almond and peach alleles, respectively.

412 ^bDominance $d = H - [(A + B)]$

413 ^cGene action. U underdominance, DP dominance for peach allele, PD partial dominance for peach
 414 allele, A additivity, AD partial dominance for almond allele

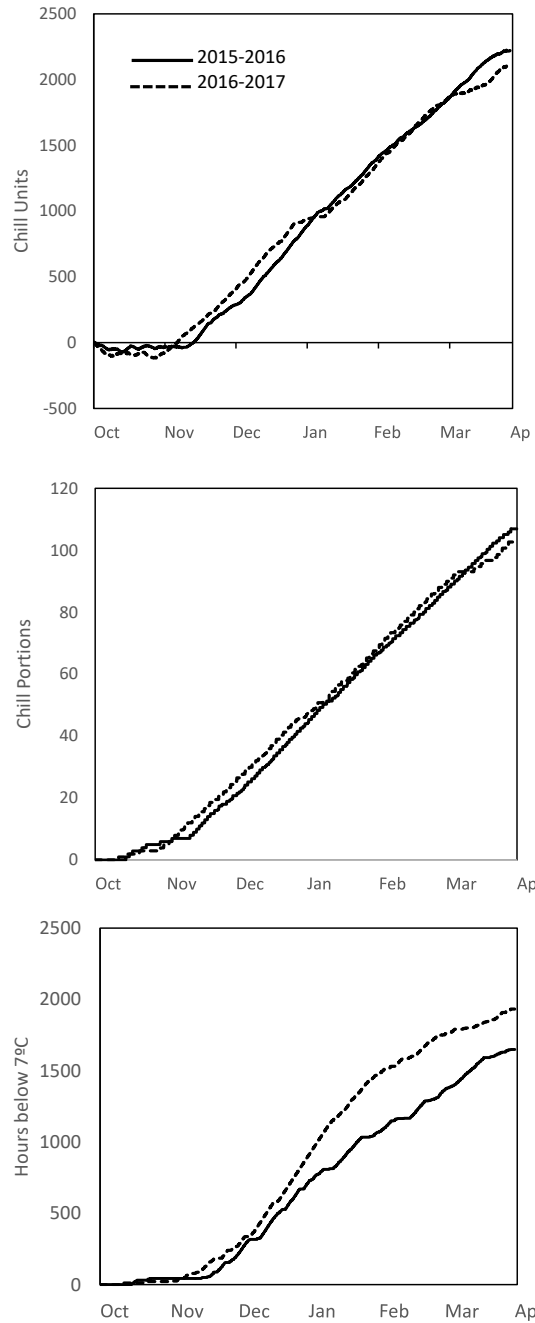
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417

418 Fig. 1. Scheme of the different traits used in this study. CR: Chilling requirement; HR: Heat
 419 requirements; CH: Chill hours; CU: Chill units; CP: Chill portions; DB: Dormancy break;
 420 FT: Flowering time; GDH: Growing Degree Hours; GDHF: Growing Degree Hours to
 421 flowering; Δ JD: Number of Julian days between DB and FT.

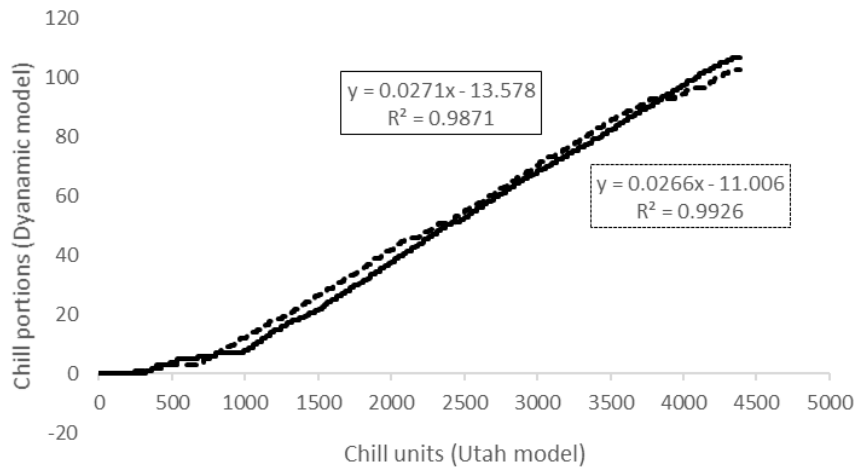
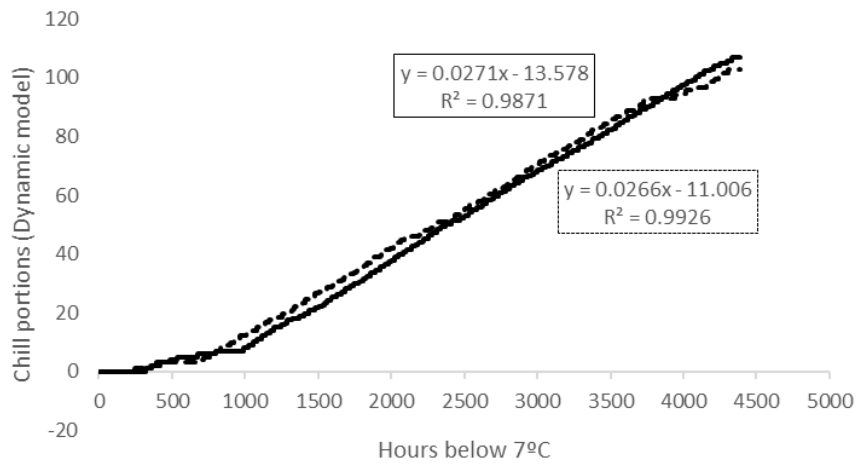
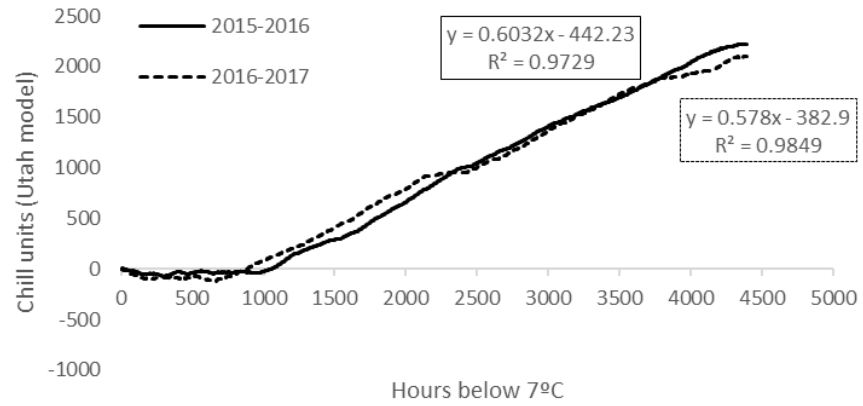
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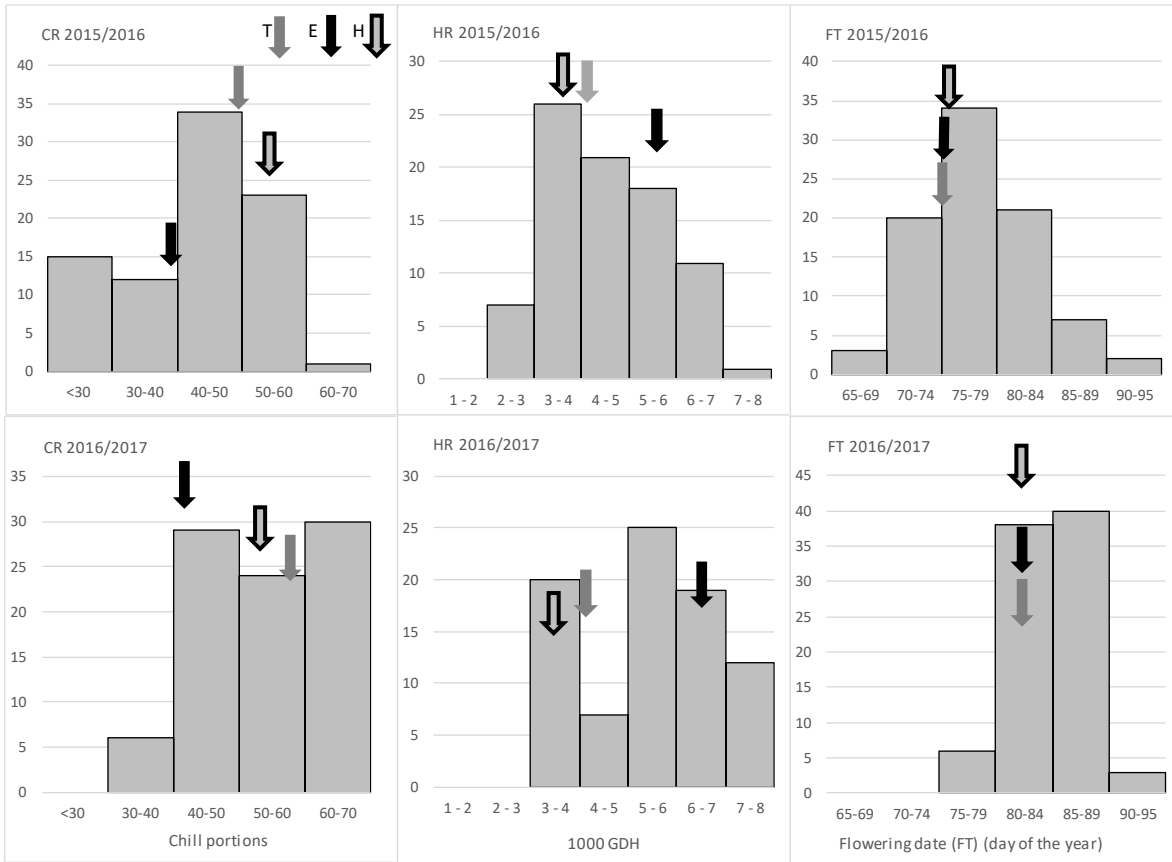
424 Fig. 2. Progression of chill accumulation in the period October-April in 2016 and 2017 in
 425 Gimenezs (Lleida). Results are expressed in Chill Units (Utah model) (upper), Chill Portions
 426 (Dynamic model) (centre) and Chill Hours (hours below 7°C) (lower).

427



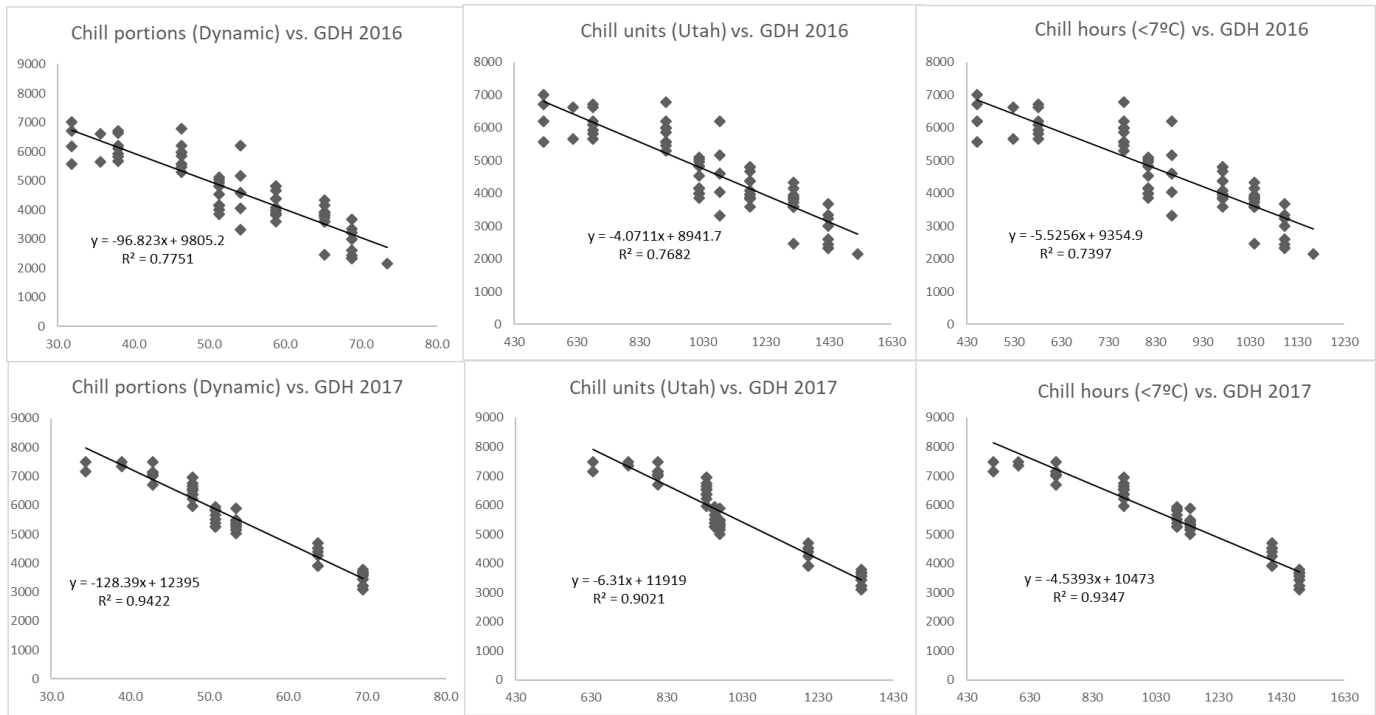
428

429 Fig.3. R-squared regression among CR for breaking dormancy estimated by the Utah, Dynamic
 430 and Chill hours models in Gimenez (Lleida, Spain) for 2016 and 2017. All correlations were
 431 significant ($p < 0.01$).



432

433 Fig. 4. Distribution of phenological traits in the TxE population: chilling requirements (CR) in
 434 chill portions, heat requirements (HR) in growing degree hours (GDH), and flowering times
 435 (FT) as a function of the parental lines are indicated by arrows (T, Texas; E,
 436 Earlygold; H, MB 1.37).



437

438 Fig. 5. Linear regression (R-squared) between chilling requirements (CR) and heat
 439 requirements in the TxE population for 2015-2016 (above) and 2016-2017 (below). CR are
 440 expressed in chill portions (Dynamic model), chill units (Utah model) and chill hours (hours
 441 below 7°C). Heat requirements (HR) are expressed in growing degree hours (GDH).

442

443 **SUPPLEMENTARY DATA**

444 Table S1. Date for dormancy breaking and chilling accumulation (in chill hours, chill units and
445 chill portions) for all the genotypes in the population TxE for the two consecutive years
446 studied. Yearly values, mean values (ave) and coefficient of variation (cv) are shown.

447

Genotype	BD		CH				CU				CP			
	2015-2016	2016-2017	2015-2016	2016-2017	ave	cv	2015-2016	2016-2017	ave	cv	2015-2016	2016-2017	ave	cv
1	11-Jan	2-Jan	814	930	872	82.0	1018	936	977	58.3	51	48	50	2.4
3	4-Jan	2-Jan	763	930	847	118.1	914	936	925	15.6	46	48	47	1.1
5	19-Jan	2-Feb	1039	1488	1264	317.5	1319	1345	1332	18.4	65	70	67	3.1
6	24-Dec	24-Dec	582	714	648	93.3	680	806	743	89.1	38	43	40	3.5
10	4-Jan	11-Jan	763	1140	952	266.6	914	970	942	40.0	46	53	50	5.0
11	21-Dec	19-Dec	528	594	561	46.7	618	728	673	77.4	36	39	37	2.4
12	4-Feb	2-Feb	1104	1488	1296	271.5	1429	1345	1387	59.0	69	70	69	0.6
14	21-Jan	9-Jan	972	1098	1035	89.1	1180	958	1069	157.0	59	51	55	5.6
15	11-Jan	9-Jan	814	1098	956	200.8	1018	958	988	42.8	51	51	51	0.3
16	21-Dec	24-Dec	528	714	621	131.5	618	806	712	132.9	36	43	39	5.1
17	21-Jan	11-Jan	972	1140	1056	118.8	1180	970	1075	148.1	59	53	56	3.8
20	11-Jan	2-Jan	814	930	872	82.0	1018	936	977	58.3	51	48	50	2.4
21	24-Dec	2-Jan	582	930	756	246.1	680	936	808	180.7	38	48	43	7.0
22	29-Jan	2-Feb	1039	1488	1264	317.5	1319	1345	1332	18.4	65	70	67	3.1
23	15-Jan	2-Jan	864	930	897	46.7	1084	936	1010	104.7	54	48	51	4.4
25	11-Jan	2-Jan	814	930	872	82.0	1018	936	977	58.3	51	48	50	2.4
30	21-Jan	9-Jan	972	1098	1035	89.1	1180	958	1069	157.0	59	51	55	5.6
31	21-Jan	11-Jan	972	1140	1056	118.8	1180	970	1075	148.1	59	53	56	3.8
34	29-Jan	2-Feb	1039	1488	1264	317.5	1319	1345	1332	18.4	65	70	67	3.1
37	15-Jan	9-Jan	864	1098	981	165.5	1084	958	1021	89.1	54	51	52	2.3
39	4-Feb	2-Feb	1104	1488	1296	271.5	1429	1345	1387	59.0	69	70	69	0.6
40	4-Jan	2-Jan	763	930	847	118.1	914	936	925	15.6	46	48	47	1.1
41	11-Jan	11-Jan	814	1140	977	230.5	1018	970	994	33.9	51	53	52	1.5
43	11-Jan	11-Jan	814	1140	977	230.5	1018	970	994	33.9	51	53	52	1.5
44	29-Jan	26-Jan	1039	1400	1220	255.3	1319	1206	1262	80.3	65	64	64	0.9
46	21-Jan	2-Feb	972	1488	1230	364.9	1180	1345	1262	117.0	59	70	64	7.6
47	29-Jan	2-Feb	1039	1488	1264	317.5	1319	1345	1332	18.4	65	70	67	3.1
49	29-Jan	26-Jan	1039	1400	1220	255.3	1319	1206	1262	80.3	65	64	64	0.9
53	21-Jan	2-Feb	972	1488	1230	364.9	1180	1345	1262	117.0	59	70	64	7.6
55	29-Jan	2-Feb	1039	1488	1264	317.5	1319	1345	1332	18.4	65	70	67	3.1
56	4-Feb	2-Feb	1104	1488	1296	271.5	1429	1345	1387	59.0	69	70	69	0.6
59	24-Dec	24-Dec	582	714	648	93.3	680	806	743	89.1	38	43	40	3.5
61	11-Jan	11-Jan	814	1140	977	230.5	1018	970	994	33.9	51	53	52	1.5
63	29-Jan	26-Jan	1039	1400	1220	255.3	1319	1206	1262	80.3	65	64	64	0.9
69	4-Jan	24-Dec	763	714	739	34.6	914	806	860	76.0	46	43	45	2.5
72	15-Jan	2-Jan	864	930	897	46.7	1084	936	1010	104.7	54	48	51	4.4
73	15-Jan	26-Jan	864	1400	1132	379.0	1084	1206	1145	86.3	54	64	59	6.9
74	4-Jan	11-Jan	763	1140	952	266.6	914	970	942	40.0	46	53	50	5.0
83	16-Dec	24-Dec	452	714	583	185.3	524	806	665	199.8		43	37	7.8
84	21-Jan	2-Feb	972	1488	1230	364.9	1180	1345	1262	117.0	59	70	64	7.6
85	29-Jan	2-Feb	1039	1488	1264	317.5	1319	1345	1332	18.4	65	70	67	3.1
90	24-Dec	2-Jan	582	930	756	246.1	680	936	808	180.7	38	48	43	7.0
91	11-Jan	11-Jan	814	1140	977	230.5	1018	970	994	33.9	51	53	52	1.5
95	2-Nov	2-Feb	1165	1488	1327	228.4	1523	1345	1434	125.5	73	70	71	2.7
97	29-Jan	2-Feb	1039	1488	1264	317.5	1319	1345	1332	18.4	65	70	67	3.1
98	4-Jan	24-Dec	763	714	739	34.6	914	806	860	76.0	46	43	45	2.5
100	16-Dec	16-Dec	452	515	484	44.5	524	634	579	78.1	32	34	33	1.8
105	4-Jan	2-Jan	763	930	847	118.1	914	936	925	15.6	46	48	47	1.1
106	29-Jan	2-Feb	1039	1488	1264	317.5	1319	1345	1332	18.4	65	70	67	3.1
108	16-Dec	16-Dec	452	515	484	44.5	524	634	579	78.1	32	34	33	1.8
117	11-Jan	11-Jan	814	1140	977	230.5	1018	970	994	33.9	51	53	52	1.5
118	21-Jan	11-Jan	972	1140	1056	118.8	1180	970	1075	148.1	59	53	56	3.8
120	21-Jan	11-Jan	972	1140	1056	118.8	1180	970	1075	148.1	59	53	56	3.8
122	16-Dec	19-Dec	452	594	523	100.4	524	728	626	144.2	32	39	35	5.0
125	4-Jan	2-Jan	763	930	847	118.1	914	936	925	15.6	46	48	47	1.1
128	15-Jan	26-Jan	864	1400	1132	379.0	1084	1206	1145	86.3	54	64	59	6.9
133	4-Jan	2-Jan	763	930	847	118.1	914	936	925	15.6	46	48	47	1.1
150	4-Feb	26-Jan	1104	1400	1252	209.3	1429	1206	1317	157.7	69	64	66	3.5
152	15-Jan	11-Jan	864	1140	1002	195.2	1084	970	1027	80.3	54	53	54	0.5
153	21-Jan	9-Jan	972	1098	1035	89.1	1180	958	1069	157.0	59	51	55	5.6
165	29-Jan	2-Feb	1039	1488	1264	317.5	1319	1345	1332	18.4	65	70	67	3.1
166	4-Feb	2-Feb	1104	1488	1296	271.5	1429	1345	1387	59.0	69	70	69	0.6
172	4-Feb	26-Jan	1104	1400	1252	209.3	1429	1206	1317	157.7	69	64	66	3.5
194	21-Jan	9-Jan	972	1098	1035	89.1	1180	958	1069	157.0	59	51	55	5.6
199	11-Jan	11-Jan	814	1140	977	230.5	1018	970	994	33.9	51	53	52	1.5
202	24-Dec	14-Dec	582	515	549	47.4	680	634	657	32.5	38	34	36	2.5
211	11-Jan	2-Jan	814	930	872	82.0	1018	936	977	58.3	51	48	50	2.4
215	24-Dec	2-Jan	582	930	756	246.1	680	936	808	180.7	38	48	43	7.0
218	11-Jan	11-Jan	814	1140	977	230.5	1018	970	994	33.9	51	53	52	1.5
226	21-Jan	9-Jan	972	1098	1035	89.1	1180	958	1069	157.0	59	51	55	5.6
239	4-Jan	24-Dec	763	714	739	34.6	914	806	860	76.0	46	43	45	2.5
241	29-Jan	26-Jan	1039	1400	1220	255.3	1319	1206	1262	80.3	65	64	64	0.9

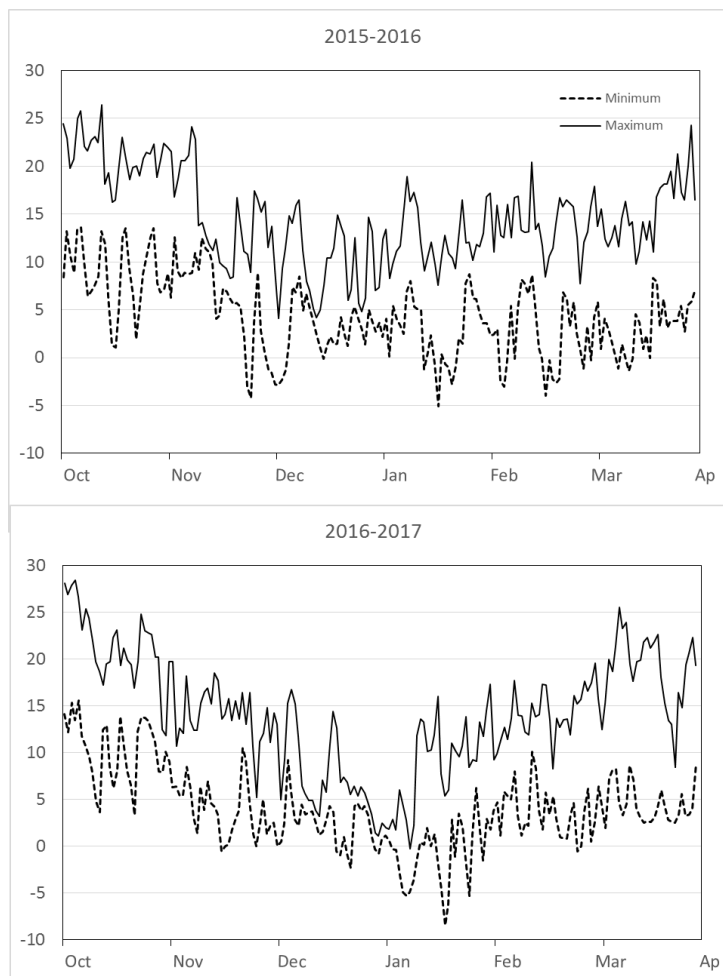
449 Table S2. Heat requirements in growing degree hours (GDH), flowering dates (FT) and days
450 from dormancy breaking to FT (JD) for all the genotypes in the population TxE for the two
451 consecutive years studied. Yearly values, mean values (ave) and coefficient of variation (cv)
452 are shown. Only genotypes with two years measurements are shown.

Genotype	FT		GDH				Δ/D			
	2015-2016	2016-2017	2015-2016	2016-2017	Ave	cv	2015-2016	2016-2017	Ave	cv
1	5-Mar	11-Mar	5034	6641	5837	1137	54	69	62	10.6
3	3-Mar	9-Mar	5855	6508	6181	462	59	67	63	5.7
5	7-Mar	11-Mar	3937	3783	3860	109	38	38	38	0.0
6	1-Mar	11-Mar	6194	7139	6667	668	68	78	73	7.1
10	4-Mar	9-Mar	5987	5444	5716	384	60	58	59	1.4
11	3-Mar	9-Mar	6613	7349	6981	521	73	81	77	5.7
12	25-Feb	3-Mar	2329	3099	2714	544	21	35	28	9.9
14	27-Feb	7-Mar	3829	5658	4743	1293	37	58	48	14.8
15	24-Feb	3-Mar	3991	5253	4622	892	44	54	49	7.1
16	23-Feb	5-Mar	5656	6705	6181	742	64	72	68	5.7
17	3-Mar	8-Mar	4375	5361	4868	697	42	57	50	10.6
20	3-Mar	7-Mar	4816	6362	5589	1093	52	65	59	9.2
21	24-Feb	3-Mar	5663	5956	5810	207	62	61	62	0.7
23	10-Mar	10-Mar	5156	6553	5855	988	55	67	61	8.5
25	24-Feb	7-Mar	3991	6362	5176	1676	44	65	55	14.8
30	8-Mar	10-Mar	4807	5849	5328	737	47	60	54	9.2
31	28-Feb	9-Mar	3885	5444	4664	1103	38	57	48	13.4
34	3-Mar	9-Mar	3588	3650	3619	44	34	35	35	0.7
37	3-Mar	9-Mar	4591	5804	5197	858	48	59	54	7.8
39	3-Mar	3-Mar	2999	3099	3049	71	28	30	29	1.4
40	1-Mar	7-Mar	5561	6362	5961	566	57	65	61	5.7
41	25-Feb	5-Mar	4146	5144	4645	706	45	54	50	6.4
43	25-Feb	6-Mar	4146	5230	4688	766	45	55	50	7.1
44	6-Mar	10-Mar	3874	4253	4063	268	37	43	40	4.2
46	27-Feb	10-Mar	3829	3695	3762	94	37	36	37	0.7
47	3-Mar	6-Mar	3588	3436	3512	108	34	33	34	0.7
49	5-Mar	10-Mar	3806	4512	4159	499	36	43	40	4.9
53	29-Feb	6-Mar	3976	3436	3706	382	39	33	36	4.2
55	5-Mar	8-Mar	3806	3567	3686	169	36	35	36	0.7
56	29-Feb	8-Mar	3347	3567	3457	155	25	35	30	7.1
59	5-Mar	10-Mar	6706	7051	6878	244	72	76	74	2.8
61	25-Feb	7-Mar	4146	5298	4722	814	45	55	50	7.1
63	12-Mar	12-Mar	4338	4703	4520	258	43	45	44	1.4
69	26-Feb	10-Mar	5294	7051	6172	1242	53	76	65	16.3
72	27-Feb	5-Mar	4045	6208	5126	1529	43	62	53	13.4
73	21-Feb	8-Mar	3321	4383	3852	752	37	41	39	2.8
74	1-Mar	10-Mar	5561	5490	5525	51	57	58	58	0.7
84	10-Mar	10-Mar	3588	3695	3642	76	50	36	43	9.9
85	3-Mar	9-Mar	3588	3650	3619	44	34	35	35	0.7
91	6-Mar	10-Mar	5102	5490	5296	274	55	58	57	2.1
95	6-Mar	4-Mar	2144	3218	2681	759	24	31	28	4.9
98	3-Mar	10-Mar	5456	7490	6473	1438	59	76	68	12.0
105	22-Feb	12-Mar	5987	6744	6365	535	49	69	59	14.1
106	1-Mar	4-Mar	2467	3218	2843	531	32	31	32	0.7
108	1-Mar	5-Mar	6719	7490	7105	545	76	80	78	2.8
117	23-Feb	4-Mar	3859	5012	4436	815	43	53	48	7.1
118	6-Mar	10-Mar	4661	5490	5075	586	45	58	52	9.2
120	8-Mar	10-Mar	4807	5490	5148	483	47	58	53	7.8
122	24-Feb	10-Mar	6188	7483	6835	915	70	81	76	7.8
125	7-Mar	11-Mar	6204	6641	6422	309	63	68	66	3.5
128	7-Mar	10-Mar	6204	4512	5358	1196	52	43	48	6.4
133	4-Mar	10-Mar	5987	6553	6270	400	60	67	64	4.9
152	3-Mar	8-Mar	4591	5361	4976	544	48	56	52	5.7
153	3-Mar	12-Mar	4375	5372	4873	705	42	62	52	14.1
165	4-Mar	4-Mar	3720	3218	3469	355	35	31	33	2.8
166	25-Feb	8-Mar	2329	3567	2948	875	21	34	28	9.2
172	11-Mar	4-Mar	2600	3915	3258	930	37	38	38	0.7
194	1-Mar	10-Mar	4081	5504	4793	1006	40	60	50	14.1
199	4-Mar	9-Mar	4948	5444	5196	351	53	57	55	2.8
202	25-Feb	5-Mar	5819	7156	6487	946	63	80	72	12.0
211	1-Mar	7-Mar	4522	6362	5442	1301	50	65	58	10.6
215	29-Feb	10-Mar	6089	6553	6321	328	67	67	67	0.0
218	25-Feb	5-Mar	4146	5144	4645	706	45	54	50	6.4
226	29-Feb	3-Mar	3976	5253	4614	903	39	54	47	10.6
239	15-Mar	11-Mar	6791	7139	6965	246	72	77	75	3.5
241	10-Mar	3-Mar	4154	3915	4034	169	42	37	40	3.5

454

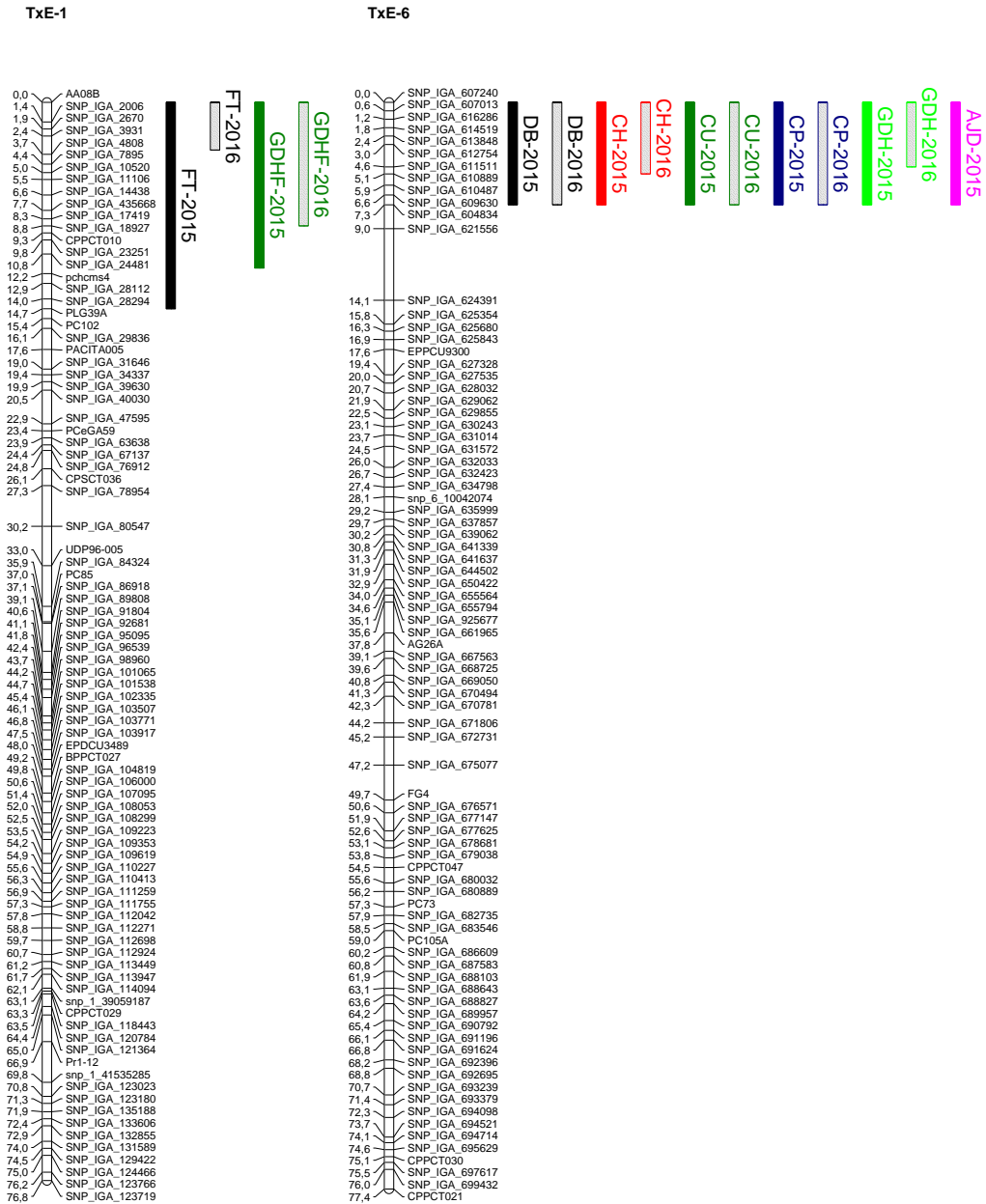
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458 Fig. S1. Maximum and minimum daily temperatures registered in the period October-April in
459 2016 and 2017 in Gimenells (Lleida).



460

461 Fig. S2. Map of the G1 and G6 of the TxE population with the positions of the consistent QTLs
 462 mapped in this work. Bars of QTLs indicate the LOD-1 intervals and are named with the trait
 463 and the year of evaluation. Abbreviations: FT, flower time; GDHF, total growing degree hours;
 464 DB, dormancy breaking; CU, chill units; CP, chill portions; GDH, growing degree hours; \hat{e} JD,
 465 days from dormancy breaking to FT.

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