Differences on flowering phenology under Mediterranean and Subtropical environments for two representative olive cultivars

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ABSTRACT

Olive flowering phenology is highly affected by climatic conditions. Climatic models have been developed to forecast flowering date on olive mainly based on temperature. These models have used flowering datasets collected from trees growing under Mediterranean climatic conditions. In most of the cases, in those conditions, chilling requirements are rapidly fulfilled. In other cases, artificial modifications of the climatic conditions has been practiced by using growth chambers. In the present work, we compare the flowering phenology of 'Picual' and 'Arbequina' olive cultivars in Mediterranean conditions of Andalucía, Southern Spain with those in Tenerife, Canary Island with Sub-Tropical climate. The climatic conditions of Tenerife respect to Andalucía promoted an earlier flowering date but, more importantly, a much longer flowering period. This is mainly produced by an asynchronous flowering bud burst that will generate negative impacts on yield and quality. Quite likely those differences on flowering phenology between Andalucía and Tenerife climatic conditions are mainly caused by the lack of winter chilling in Tenerife locations. Based on those results, we propose that future works studying the effect of lack of winter chilling on olive should include the length of the flowering period as a parameter to be modeled. Besides, studies on natural climatic conditions with warm winters, as the one here reported, are needed to really assess the effect of winter chilling on olive.

Keywords: asynchrony, climate change, flowering period, forecasting, winter chilling

1. Introduction

Flowering is a critical reproductive stage for the final yield in many plant species (Díez-Palet et al., 2019), being highly influenced by climatic conditions (Rodríguez et al., 2019). This included olive (Hartmann and Porlingis, 1957; Navas-Lopez et al., 2019), an evergreen fruit species typical from Mediterranean climate. For that reason, climatic models have been developed to forecast the flowering date in olive, mainly based on air temperature (De Melo-Abreu et al., 2004; Gabaldón-Leal et al., 2017). Those studies concluded that, in the absence of characteristic climatic conditions for olive growing, specially lack of winter chilling, flowering will not occur (Aybar et al., 2015). This is important taken into account the expansion of olive growing outside the Mediterranean climate, as the case of Argentina (Torres et al., 2017) or Australia (Kailis and Sweeney, 2002). Those models are also used to forecast the influence the projections of temperature increase provided by the climate models (Lorite et al., 2018).

The development of phenological models requires high quality experimental data with observations collected in a wide range of weather conditions. However, most of the studies regarding olive flowering phenology have been performed using data gathered in Mediterranean climatic conditions (De Melo-Abreu et al., 2004) or artificial environments (Benlloch-González et al., 2018; Gabaldón-Leal et al., 2017). But few reports have studied flowering phenology using non-Mediterranean natural environments data (Aybar et al., 2015).

In this sense, Tenerife, in the Canary Islands, is one of the non-Mediterranean locations where olive has been grown from some time now (Medina et al., 2018). It is situated 4° above the Tropic of Cancer in the Atlantic Ocean and close to the African coast. The sub-Tropical climate of this island represents a convenient natural scenario to study the influence of natural non-Mediterranean climatic conditions on olive flowering phenology, particularly the lack of the low winter temperatures that are typical of the Mediterranean climate (El Yaacoubi et al., 2014).

Therefore, the objective of the present work is to compare olive flowering phenology in three locations of Andalucía, Southern Iberian Peninsula having typical Mediterranean climate, with other three locations in Tenerife having Sub-Tropical climatic conditions. Cultivars 'Picual' and 'Arbequina', two of the most widely planted in the world, were used for this comparison. Differences on flowering behavior among locations was discussed under the hypothesis of differences on winter chilling.

2. Materials and Methdos

2.1. Plant material and location

This study was carried out in commercial orchards of six different locations with a wide range of weather conditions. Three of them, namely Canales Altas, El Viso and Los Tomillos, are in the Southeast of Tenerife, Canary Islands, with a Sub-tropical climate (Fig. 1) at 630, 410 and 200 m.a.s.l. respectively. The other three are in Andalucía, Southern Iberian Peninsula; Úbeda and Baena located in typical olive growing areas with a Mediterranean climate, and Gibraleón, with milder temperatures from November to February. They are located at 748, 405 and 26 m.a.s.l. respectively. All orchards were grown with typical olive growing management aimed at maximizing productivity. Tenerife locations were irrigated with 3.000 m^3/year, Úbeda and Gibraleón with 1.500 m^3/year and Baena was maintained in dry farming. Air temperature was recorded in each field by weather stations (Pessl Instrument iMetos).

2.2. Flowering phenology

For each location and year, four trees of 'Arbequina' and 'Picual' cultivars, aged from 7 to 9 years and with significant amount flowering were chosen for the study to avoid the potential effect of yield on phenology. Amount of flowering was evaluated following a previously reported methodology (Navas-Lopez et al., 2019) in a 0-3 scale (0 = no flowering, 1 = less than 33% of the canopy having flowers, 2 = from 33 to 66 % of the canopy flowered and 3 = more than 66% of the canopy flowered). Phenology was evaluated in three consecutive years from 2016 to 2018 except 'Picual' at El Viso in 2016 and Los Tomillos in 2017 and 2018. The international standardized BBCH numerical scale for olive (Sanz-Cortés et al., 2002) was used. Observations started when stage 53 appeared (inflorescence buds open and lower cluster development are visible) and ended when stage 69 was the most common in the tree (end of flowering, fruit set, non-fertilized ovaries fallen). Twice a week, the earliest, most common and latest stages were recorded for each tree and location after visually inspection of the whole canopy, as standard protocol on olive (Navas-Lopez et a., 2019; Vuletin-Selak et al., 2013).

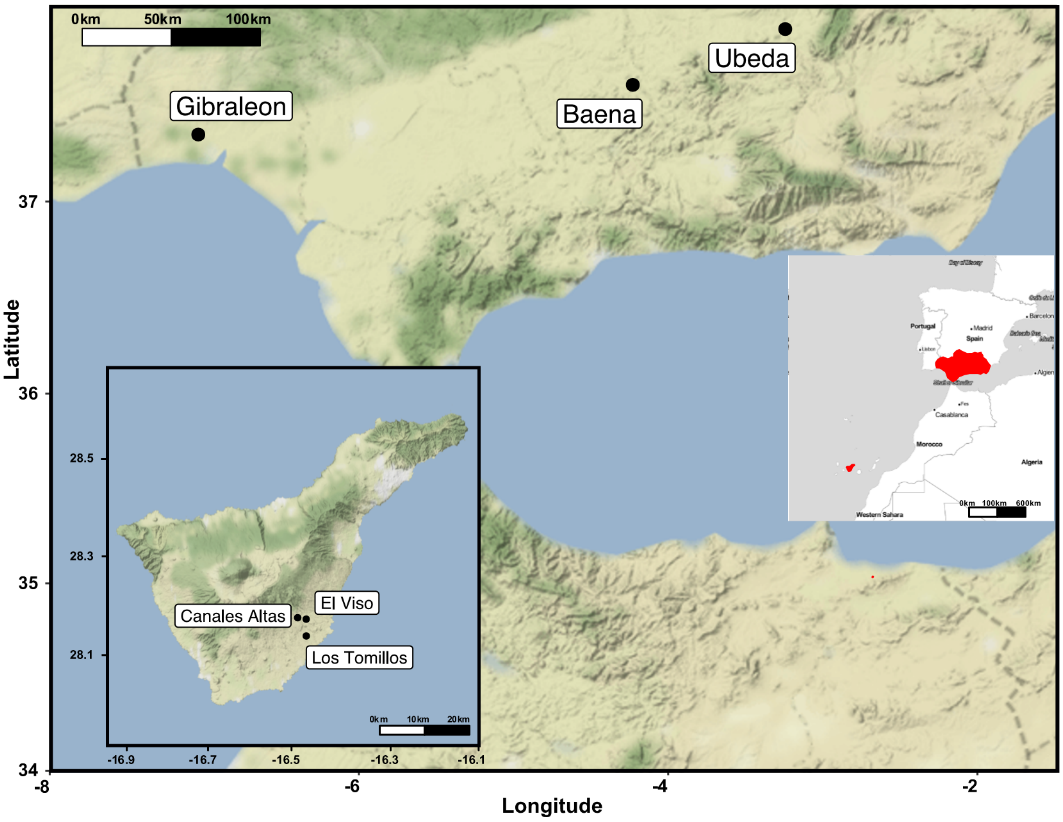

Fig. 1. Location of phenological sampling sites in Tenerife (Canary Islands) and in Andalusia (Southern Iberian Peninsula).

All of these data were used to calculate three phenological parameters as previously reported (Navas-Lopez et al., 2019):

- Length of flowering period (FP): Number of days from the first time for stage 61 (first flower open) to appear as earliest stage, until the first time for stage 68 (majority of petals fallen) to appear as most common stage.
- Length of full bloom period (FBP): Number of days from the first time for stage 61 to appear as most common, until last time for stage 65 (full bloom, at least 50% of flowers open) as most common.
- Full bloom date (FB): Average of the starting and ending date of the FBP, expressed as Julian date.

2.3 Statistical analysis

Analysis of variance was performed to evaluate the relative influence of location, year and their interaction on the variability of phenological parameters by each of the two cultivars studied. It was not possible to perform a joint analysis of both cultivars as there was not a randomize design for them in each location. Comparison of means was used to test differences among locations, years and location-year, when significant. The analysis was performed with R software (R development Core Team, 2016).

For assessing the chill accumulation throughout the crop season, chill portions (CP) were calculated using the Dynamic Model (Fishman et al., 1987), based on hourly temperature datasets, beginning 1st October of each season (Pope et al., 2014; Jarvis-Shean et al., 2015) until summer.

Thermal time or growing degree day (GDD) considered the accumulated daily mean temperatures higher than a base temperature. Following De Melo-Abreu et al. (2004) the base temperature was set at 9.1ºC. Due to the early flowering dates observed in some locations, the thermal time accumulation was calculated from 1st October of the year before flowering.

3. Results

Air temperatures in Tenerife (Canales Altas, El Viso and Los Tomillos) were milder than in Andalucía (Úbeda, Baena and Gibraleón), i.e., higher temperatures in autumn and winter and lower in spring (Fig. 2). In fact, the daily temperature range was much narrow in Tenerife than in Andalucía. Gibraleón was the location in Andalucía with milder winter temperatures, while Canales Altas was the location in Tenerife with lower temperatures and higher range of variation. The winter of 2016 was the mildest of the studied years while 2018 was the coolest. And the spring of 2017 was the hottest of the three recorded. Annual rainfall in Tenerife was lower than in Andalucía in every location and year (Supplementary data).

According to differences on air temperature, chill portion (CP) accumulation in Andalucía, was much higher than in Tenerife (Figure 3 and 4). Two Andalucía locations, Baena and Úbeda, showed an almost identical CP pattern in the three seasons considered (Figure 3). Gibraleón, the other Andalucía location, showed a lower CP accumulation. From the three Tenerife locations, Canales Altas showed a CP accumulation similar to Gibraleón but somewhat delayed, especially in 2015-2016 and 2016-2017 winters. In Los Tomillos and El Viso CP accumulation was very low. On the contrary, growing degree day (GDD) accumulation was much higher in the three Tenerife locations than in the Andalucía ones (Figure 4). Again, Canales Altas showed the closest pattern to Gibraleón, especially in 2016-2017 and 2017-2018.

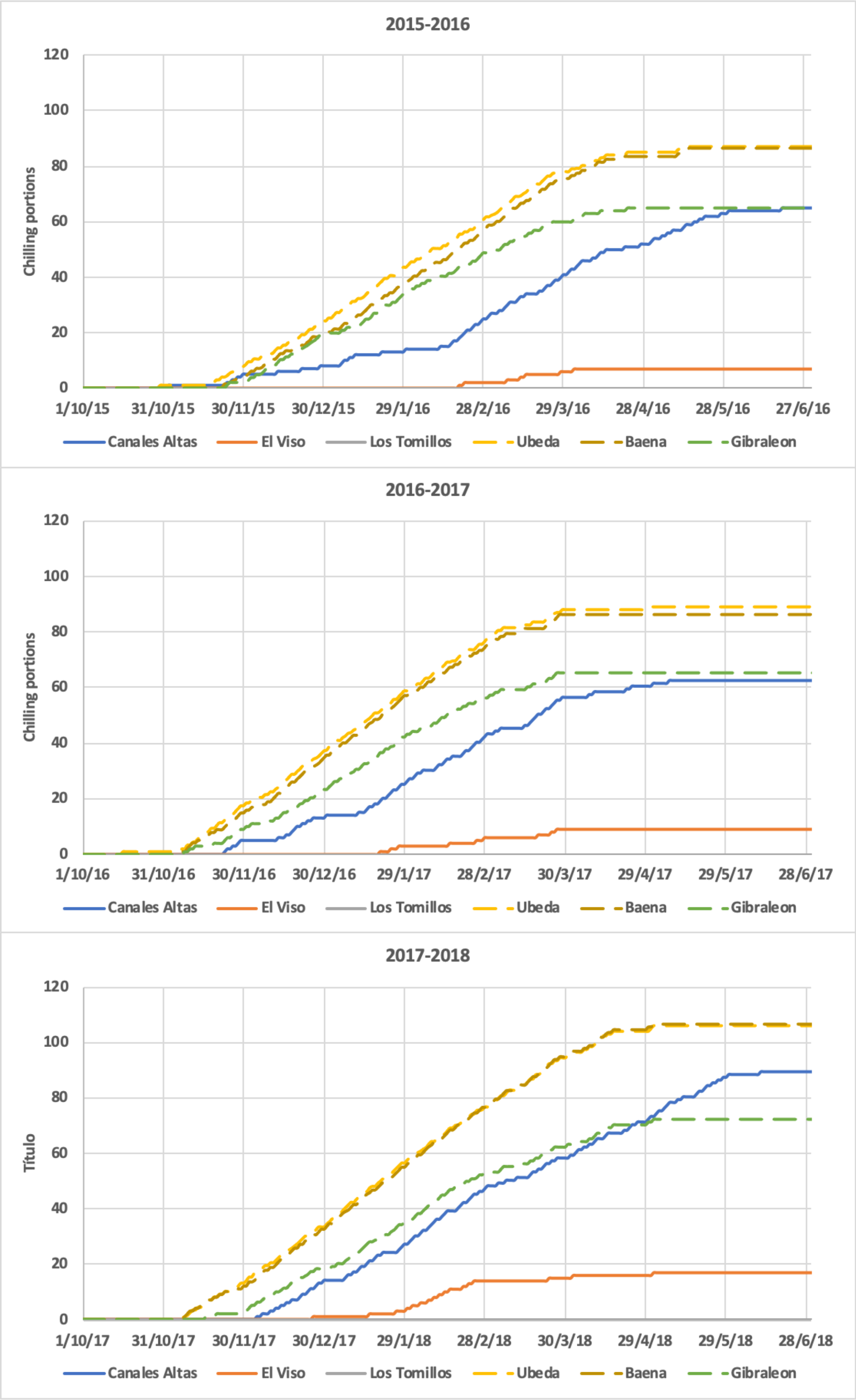

Fig. 3. Variation of the chill portion accumulation with time in the three Andalucía (Úbeda, Baena and Gibraleón) and Tenerife (Canales Altas, El Viso and Los Tomillos) locations in 2016, 2017 and 2018.

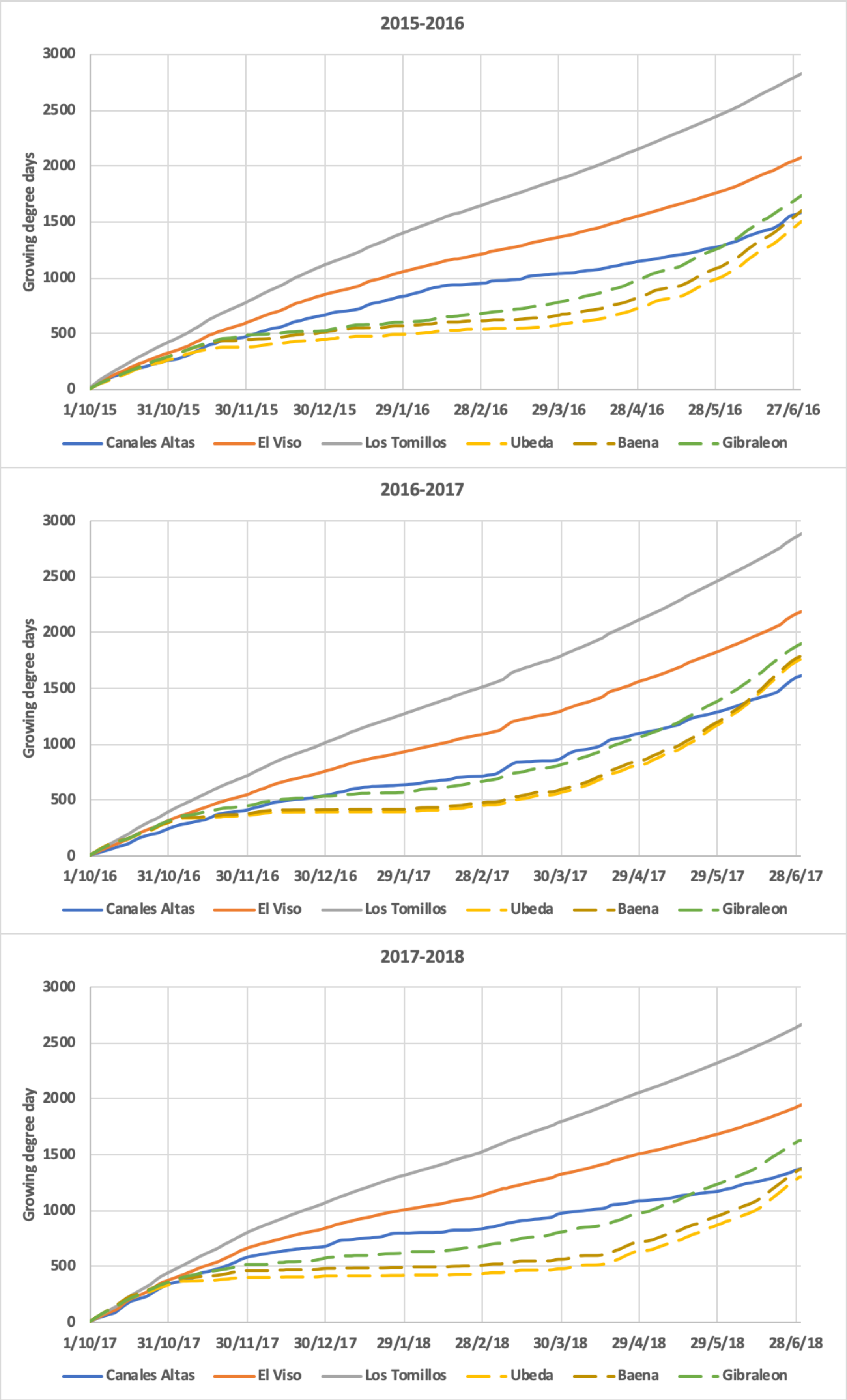

Fig. 4. Variation of the growing degree days accumulation with time in the three Andalucía (Úbeda, Baena and Gibraleón) and Tenerife (Canales Altas, El Viso and Los Tomillos) locations in 2016, 2017 and 2018.

Total variance of the two flowering period parameters studied showed similar distribution for both 'Arbequina' and 'Picual' (Table 1). For FP, location and year*location were the main contributors to the total variance while for FPB year*location has greater effect that the individual factors. On the contrary, different distribution of variance components between cultivars was observed for FB. The main effect was location in the case of 'Arbequina' and year in the case of 'Picual'. All the effects were significant except year for FBP in 'Arbequina'. Error term generally allocated low percentage of the total variance, thus indicating low variance among trees of each elementary plot. The only exception was FPB in Arbequina.

Table 1

Percentage of variance of location, year and their interaction for the flowering period (FP in days), full flowering period (FBP in days) and full bloom time (FB in Day of the Year) in 'Arbequina' and 'Picual'. Values in bold indicate significant differences for this source of variation at p<0.01.

	'Arbequina'				'Picual'			
	df[1]	FP	FBP	FB	df	FP	FBP	FB
Year	2	**5,65**	2,41	**18,55**	2	**3,88**	**10,10**	**53,34**
Location	5	**54,04**	**3,05**	**47,16**	5	**46,41**	**16,93**	**28,86**
Year*Location	7	**33,40**	**42,67**	**28,74**	7	**48,26**	**55,84**	**17,31**
Error	42	6,91	51,87	5,54	40	1,45	17,14	0,49

[1] df = degrees of freedom

Table 2

Comparison of means of length of flowering period (FP, in days), length of full flowering period (FBP, in days) and full bloom date (FB, in Day of Year) in ‘Arbequina’ by location, year and their interaction. Different letters indicate significant differences (p< 0.01) among means within each of those three groups of data.

	FP								FBP								FB							
	2016		2017		2018		AVERAGE		2016		2017		2018		AVERAGE		2016		2017		2018		AVERAGE	
Úbeda	12.5	f	8.5	f	11.0	f	10.7	d	5.5	cde	2.0	e	4.8	de	4.1	b	144.3	ab	127.0	cd	150.1	a	140.44	a
Baena	16.5	f	14.7	f	10.7	f	14.0	d	9.5	cde	6.3	cde	5.8	cde	7.2	ab	141.5	ab	120.6	de	147.1	a	136.41	a
Gibraleón	53.3	cd	18.0	f	14.2	f	28.1	c	31.3	ab	5.0	cde	5.8	cde	14.1	ab	111.3	ef	121.8	cde	131.1	c	122.42	b
Canales Altas	130.0	a	52.5	cd	55.7	cd	79.4	a	20.0	bc	15.0	cd	18.0	bc	17.7	a	134.0	bc	86.3	ij	129.8	cd	116.67	b
Los Tomillos	67.0	bc	36.2	e	64.8	bc	56.0	b	6.5	cde	10.0	cde	37.0	a	17.8	a	123.8	cd	77.0	j	89.0	hi	96.58	c
El Viso	46.0	de	47.7	de	73.0	b	55.6	b	6.0	cde	10.5	cde	18.8	bc	11.8	ab	106.0	fg	98.3	gh	90.9	hi	98.37	c
Average	54.3	a	30.7	b	38.2	b			12.3		8.4		15.0				127.5	a	103.6	b	122.9	a		

Table 3

Comparison of means of flowering period (FP), full flowering period (FBP) and full bloom time (FB) in ‘Picual’ by location year and their interaction. Different letters indicate significant differences (p< 0.01) among means within each of those three group of data.

	FP								FBP								FB							
	2016		2017		2018		AVERAGE		2016		2017		2018		AVERAGE		2016		2017		2018		AVERAGE	
Úbeda	10.0	f	6.0	f	8.3	f	7.7	c	4.0	cd	2.0	d	3.5	d	3.0	b	145.0	bc	126.0	e	151.6	a	140.0	a
Baena	14.3	ef	20.3	de	10.0	ef	14.8	c	7.8	cd	8.0	cd	4.3	cd	6.7	b	143.1	c	121.3	f	147.8	ab	137.4	a
Gibraleón	27.5	cd	14.3	ef	13.5	ef	16.8	c	17.5	b	6.7	cd	3.0	d	7.4	b	126.3	e	120.6	f	131.5	d	126.7	b
Canales Altas	142.5	a	27.8	cd	60.0	b	76.8	a	39.5	a	12.0	bc	7.0	cd	19.5	a	143.3	c	113.8	g	135.3	d	130.7	b
Los Tomillos	29.0	cd	NA		NA		29.0	b	6.0	cd	NA		NA		6.0	b	141.0	c	NA		NA		141.0	a
El Viso	NA		37.5	c	37.8	c	37.6	b	NA		6.8	cd	12.3	bc	9.5	b	NA		108.1	h	114.1	g	111.1	c
Average	51.1	a	21.5	b	25.9	b			16.0	a	7.1	b	6.0	b			140.8	a	117.8	c	136.0	b		

Among the six locations considered, the three in Tenerife showed the longest FP, with Canales Altas having significant higher values than the other two (Tables 2 and 3). For the three Andalucía locations, Gibraleón showed higher FP than the other two but only for ‘Arbequina’. FBP showed very low differences among locations, with Tenerife having slightly higher values than Andalucía, again only for ‘Arbequina’. In relation of full bloom date (FB), three groups with significant differences were found: Úbeda and Baena; Canales Altas and Gibraleón; Los Tomillos and El Viso, with late, intermediate and early date, respectively.

Among the three years studied, 2016 showed the highest values for FB, being 2017 and 2018 very similar. The same happened to FPB but only in ‘Picual’. FB variation across years was similar in ‘Arbequina’ and ‘Picual’, with the lowest values in 2017.

It is also remarkable the significant effect of the location by year interaction (Tables 3 and 4). In fact, the FP of Canales Altas 2016 was much higher than the rest of the year by location combinations, for both ‘Arbequina’ and ‘Picual’. The rest of the FP values were higher in ‘Arbequina’ than in ‘Picual’. High values were also found for FP in 2018 for the three locations in Tenerife. FBP was very high in Canales Altas 2016, specially for ‘Picual’, being the highest in Los Tomillos 2018 and Gibraleón 2016 for ‘Arbequina’. FP and FBP in Gibraleón in 2016 was greater than in the rest of locations and years in Andalucía. The highest values of FB were found in Úbeda and Baena 2016 and 2018, being much lower in 2017.

In general, the flowering started and ended later in Andalucía locations than in Tenerife ones (Figs. 5 and 6). Among Andalucía locations, Gibraleón was the earliest one followed by Baena and Úbeda. The behavior of ‘Arbequina’ and ‘Picual’ was very similar in Andalucía. Only in Gibraleón 2016 the flowering period was much longer in ‘Arbequina’ than in ‘Picual’. In Tenerife, the flowering phenology observed was much more extended than in Andalucía, as previously stated; and higher differences between ‘Picual’ and ‘Arbequina’ were found. The very long flowering period found in Canales Altas 2016 included two full flowering periods, in the same trees, at different dates. This also happened in Los Tomillos 2018 in ‘Arbequina’. In ‘Picual’, FP started later than in ‘Arbequina’ and flowering periods were shorter.

The variation of the average most advanced, common and delayed phenology stage across the flowering season was also very different in Andalucía and Tenerife (Figs. 7 and 8). In Andalucía 2016, Úbeda showed very small differences between those three parameters, being a bit higher in Gibraleón, specially for ‘Arbequina’. On the contrary, for locations in Tenerife, differences among those three parameters were very wide. Again ‘Arbequina’ showed some higher differences than ‘Picual’ specially in Los Tomillos (Figs. 7 and 8). Similar pattern of variation was found in 2017 and 2018 (data not shown).

It is remarkable that the most common phenology stage in Tenerife was not always increasing with time at should be expected. For example, in ‘Arbequina’, Canales Altas 2016, the most common phenology stage in day 41 was 69 while in day 83 was 53 (Fig. 8). This decrease was caused by the blooming of new flowering buds that were still dormant at the first date. This is what caused the above-mentioned occurrence of two full flowering periods in the same tree and year. In general, the erratic behavior of the flowering phenology in Tenerife was caused by the asynchronous bud blooming observed in both ‘Arbequina’ and ‘Picual’ (Fig. 9). In fact, in some flowering branches, up to 9 different phenology stages were found (data not shown). Besides, those different stages were randomly distributed thorough the branch without following a common pattern.

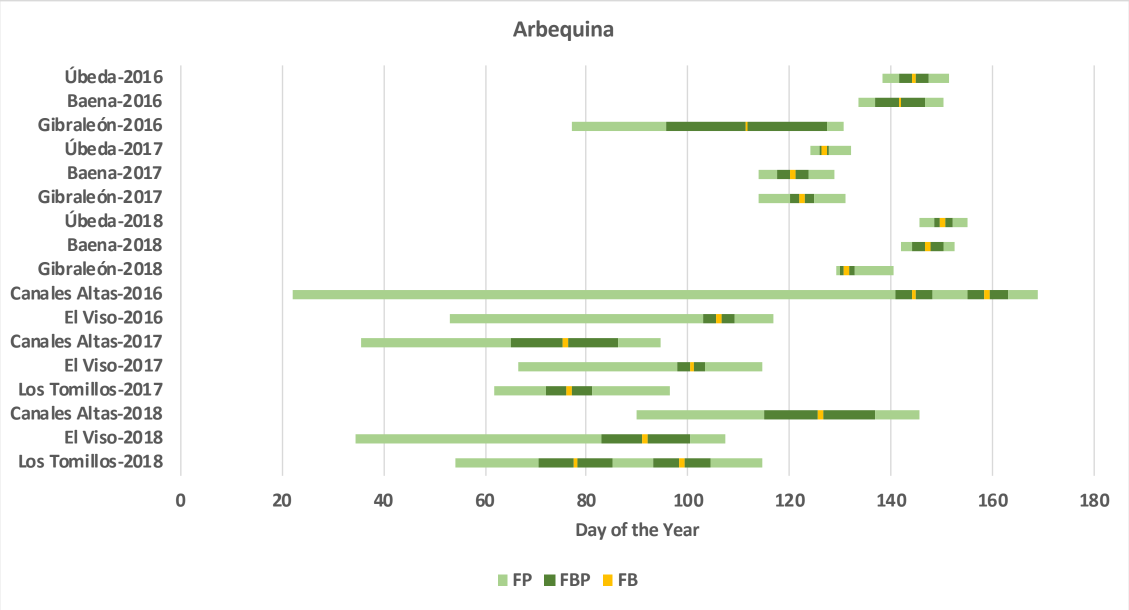

Fig. 5. Means of flowering period in days (FP in light green), full flowering period in days (FBP, in dark green) and full bloom time in Day of the Year (FB in yellow) in 'Arbequina' in the three Andalucía (Úbeda, Baena and Gibraleón) Tenerife (Canales Altas, El Viso and Los Tomillos) locations in 2016, 2017 and 2018.

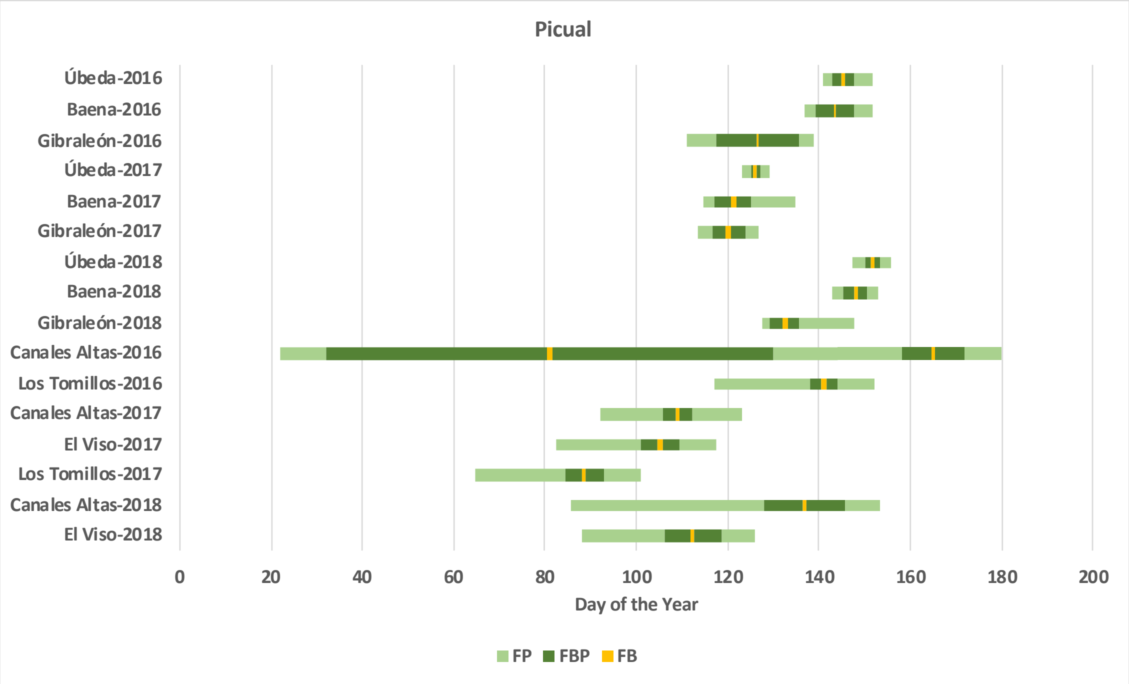

Fig. 6. Means of flowering period in days (FP in light green), full flowering period in days (FBP, in dark green) and full bloom date in Day of the Year (FB in yellow) in 'Picual' in the three Andalucía (Úbeda, Baena and Gibraleón) Tenerife (Canales Altas, El Viso and Los Tomillos) locations in 2016, 2017 and 2018.

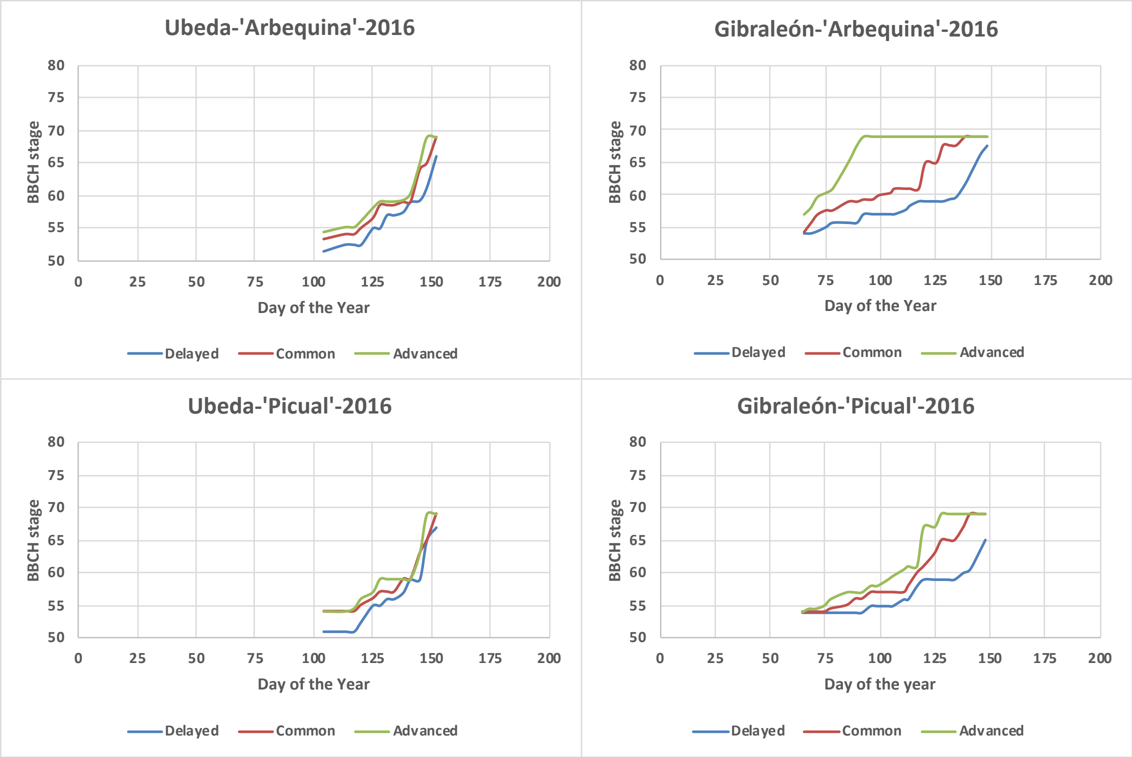

Fig. 7. Variation of the average most delayed, common and advanced flowering stage (BBCH scale) in 'Arbequina' and 'Picual' across the flowering period (Julian day) in two Andalusian locations, Úbeda and Gibraleón in 2016.

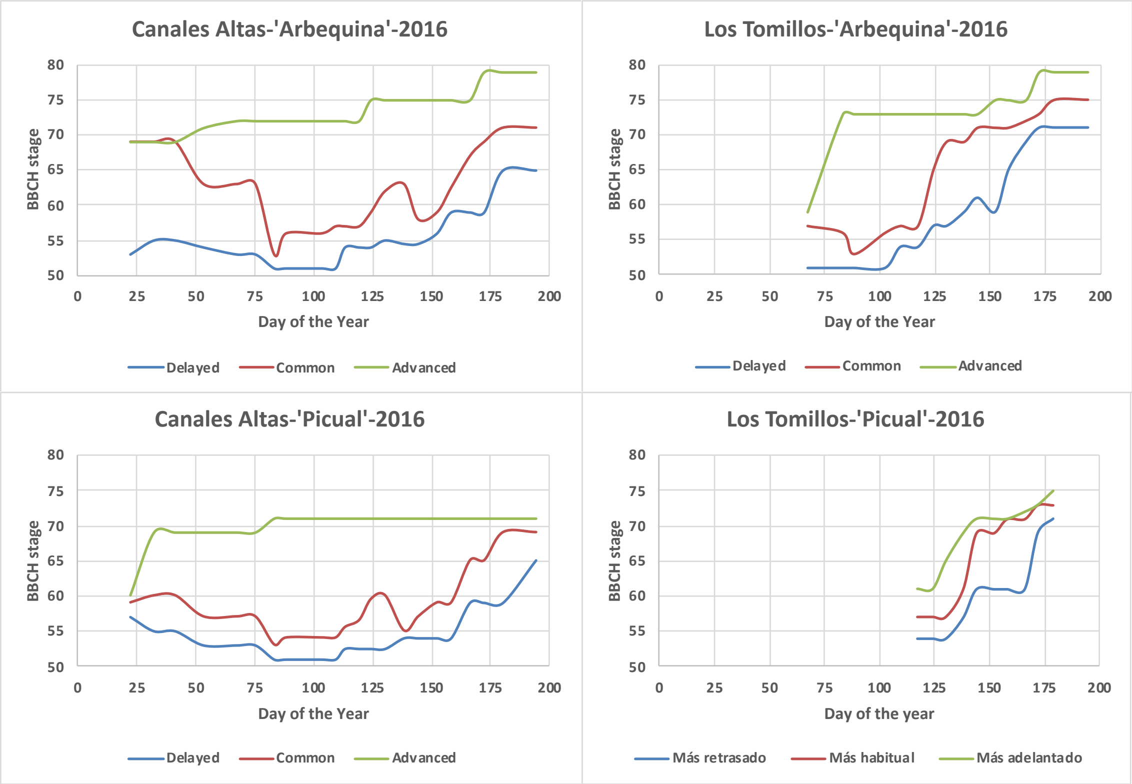

Fig. 8. Variation of the average most delayed, common and advanced flowering stage (BBCH scale) in 'Arbequina' and 'Picual' across the flowering period (Julian day) in the two Tenerife locations, Canales Altas and Los Tomillos in 2016.

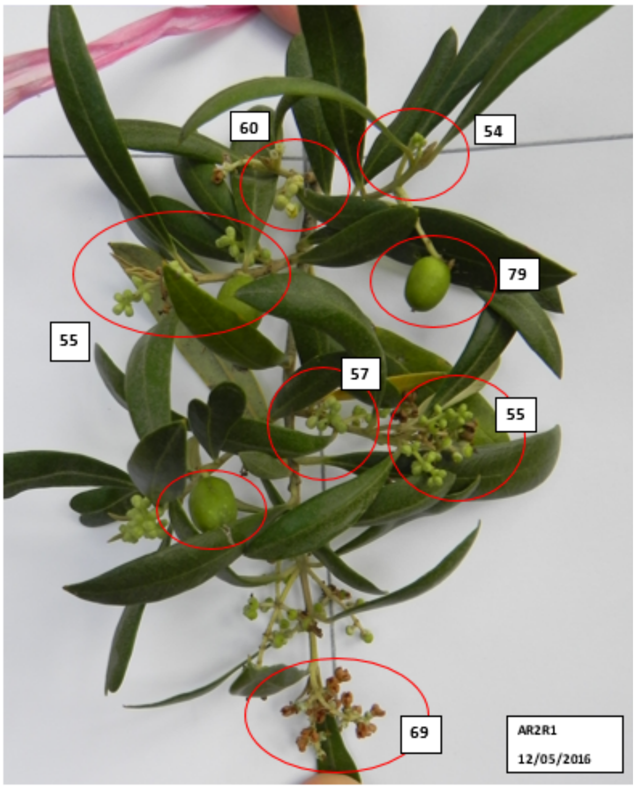

Fig. 9. Flowering branch of 'Arbequina' in May 12, 2016. Six different phenological stages (54, 55, 57, 60, 69 and 79) are observed in a random assortment.

4. Discussion

This study has identified that environmental conditions have a high influence on olive flowering phenology, not only on the date for full flowering as previously reported (Garcia-Mozo et al., 2009), but also on the length of the flowering and full flowering period. The significant year by location interaction indicates that the site-specific environmental conditions of each year and location are determinant for the behavior of the flowering.

The flowering phenology observed in Andalucía is in accordance with previous report in the same locations (Navas-Lopez et al., 2019); with very similar flowering phenology of Úbeda and Baena, located in the typical olive growing area in the South of the Iberian Peninsula. However, Gibraleón, with milder winters, showed earlier full flowering dates and also slightly longer length of flowering period than Úbeda and Baena. We have also calculated the difference between the most delayed and most advanced phenology stage by each cultivar, location and date. Those differences were higher in Gibraleón respect to the other two Andalucía locations.

However, the greatest differences on flowering phenology were found when comparing locations in Andalucía vs. Tenerife. Full flowering date occurs much earlier in Tenerife than in Andalucía. Besides, flowering period is much more prolonged in Tenerife; even, two full flowering periods were found in some years and locations. On the reviewed bibliography no such a long flowering period was previously reported. This is mainly caused by the lack of synchronization on flowering bud burst. In fact, up to 9 different phenology stages were observed in single branches in some Tenerife locations.

As this erratic behavior occurs in both cultivars studied, it could be mainly caused by the differences in the environmental conditions between Andalucía and Tenerife. Tenerife, with Subtropical climate, is characterized by higher minimum temperatures in Autumn and winter and by a lower daily temperature range, and Andalusia, with Mediterranean climate, had lower autumn and winter temperatures, especially in Baena and Úbeda. Therefore, we can hypothesize that the lack of enough winter chilling in Tenerife caused a lack of synchronization on the flower bud burst. This hypothesis agrees with previous studies assigning to low winter temperatures a fundamental role on the occurrence of flowering (Hartmann and Porlingis, 1957; Ramos et al., 2018). Among the years studied, 2016 showed milder winter temperatures. Accordingly, the flowering period was longer that year respect to 2017 and 2018.

Due to the high relevance of flowering stage on the impact of heat and water stress, studies have been attempted to develop models to forecast flowering date in olive (De Melo-Abreu et al., 2004; Garcia-Mozo et al., 2009). On the basis of those studies, the effect of future climate warming in olive growing areas has also been modeled (Lorite et al., 2018). Those previous studies used flowering phenology datasets of Mediterranean climates or different devices to artificially modify the climatic conditions as greenhouses or growth chambers (Gabaldón-Leal et al., 2017). The fact that most of the studies on the chilling requirements on olive has been done in areas where those requirements are rapidly fulfilled has led to the unclear identification of the chill requirements and the temperature range where olive as species is accumulating chilling hours. Some studies indicated that chilling accumulation occurs with temperatures around 7ºC (De Melo-Abreu et al., 2004) up to 12-15ºC (Orlandi et al., 2002; Ramos et al., 2018). The use of phenology data from contrasting climatic conditions, as the Subtropical here reported, has been proposed to improve the forecasting model performance (Gabaldón-Leal et al., 2017). In our study, locations in Tenerife showed minimum winter temperatures rarely lower than those values above mentioned, but flowering was recorded, which underlines the difficulties to established clear thresholds for chilling accumulation.

Flowering phenology was previously evaluated in some non-Mediterranean climates as the case of Argentina locations, some of them with no enough chilling (Aybar et al., 2015); but only flowering date was recorded and the only observed effect of lack of winter chilling was a low flowering intensity. In fact, most of the previous studies have in common that the only significant effect identified of the lack of winter chilling is the absence of flowering. Then, other flowering parameters as the length of the flowering period of olive has been rarely considered. In other fruit crops, some additional effects of warm winter have been described as erratic floral bud-break in pistachio (Elloumi et al., 2013), low rate of effective fructification in apple (Petri and Leite, 2004) and increases in length of bloom period in cherry (Lakatos et al., 2014).

Our study suggests that, when olive is grown on natural climates with apparently not enough chilling temperatures, as the Subtropical, the first effect on flowering phenology is not the lack of flowering but the lack of synchronization of flowering bud burst. This has been common to the two olive cultivars here studied, 'Picual' and 'Arbequina'. Besides, blooming in each bud seem to be independent and it could not be stablished a relationship between the position in the shoot with the time of blooming. This led on the above-mentioned excessive enlargement of the flowering period observed in Tenerife, including two full flowering periods in some cases. A "second flowering" was mentioned in Hawaii (USA) olives trees of cultivar 'Koroneiki' under warm winter conditions (Miyasaka and Hamasaki, 2016). This lack of synchronization on flowering phenology could led on lack of synchronization of fruit ripening, with a negative impact in both final yield and oil quality (Bustan et al., 2014) and, therefore, should be avoided.

Among the climatic factors here considered, the main differences are a higher daily temperature range and a lower winter minimum temperature in Andalucía respect to Tenerife. Rainfall was also higher in Andalucía, but this was compensated by a higher irrigation supply in Tenerife. A slightly longer flowering period and earlier flowering date was observed in 'Picual' trees when grown in 4° C artificially warmed environments with open top chambers respect to typical Mediterranean climate of Córdoba, Southern Spain (Benlloch-González et al., 2018). On the contrary, negative correlation between temperature and the duration of the length of the flowering period was previously observed (Rojo and Pérez-badia, 2015; Vuletin Selak et al., 2013). But those studies only used data from Mediterranean conditions were chilling requirements were sufficiently fulfilled. The accumulation curves of chilling portions (CP) and growing degree days (GDD) was very different in the Tenerife locations respect to Úbeda and Baena, located in typical olive growing areas with a Mediterranean climate. However, it is striking that in Canales Altas, where two flowering periods have been observed in 2016 in both 'Arbequina' and 'Picual', a CP and GDD pattern similar to Gibraleón in Andalucía was observed. In 2016, the CP accumulation in Canales Altas is significant from February 2016, a time when flowering has already started. Similarly, in Los Tomillos 2018, two flowering periods were also found for 'Arbequina'. Interestingly, the 2017-2018 season is the one when a higher CP was accumulated in Los Tomillos. Again, this CP accumulation occurs only when flowering has already started in this location. It is also interesting that no CP has been accumulated in Los Tomillos in any of the three years under study and, however, flowering has been observed. Finally, the earliness of flowering in Tenerife locations respect to Andalucía ones could be due to a higher GDD accumulation in the former ones. In any case, we need to gather much more phenology and climate data to really stablish a correlation between the different temperature regimes and the occurrence of asynchronous flowering.

Considering that different climate change scenarios forecast an increase in winter temperatures in Mediterranean climate where olive is grown, measures to prevent the lack of synchronization of olive flowering should be developed. One possible strategy could be the breeding and selection of new cultivars with low winter chilling requirements, taking advantage of potential genetic variability for winter chilling requirements. In the present study, the lack of flowering bloom synchronization seems to be a bit more intense in 'Arbequina' than in 'Picual'. However, more experiments with a larger set of cultivars planted in areas with high winter temperatures are needed to really look for genetic variability on winter chilling requirements, as previously suggested (Belaj et al., 2020). For the identification of cultural practices to mitigate the lack of chilling temperatures, it has been suggested that water stress may play a role in the flowering of olive similar to that of low winter temperatures (Connor and Fereres, 2005). For that reason, cultural practices related to irrigation withholding has been proposed in other fruit trees to substitute winter chilling (Atkinson et al., 2013) as well as in olive (Castillo-Llanque et al., 2014).

Besides, the development of advanced phenology models adapted to the assessment of the impact of climate change on olive, will require to add the length of the flowering period as a critical factor affected by climatic conditions. As other authors have reported before (Benlloch-González et al., 2018; Fadón and Rodrigo, 2018) flowering is a complex process influenced by many factors, apart from air temperature as, for example, photoperiod (Garcia-Mozo et al., 2009; Lorite et al., 2018). Therefore, inclusion of more factors than air temperature is recommendable in future models.

Equally, more investigation should be done to determine differences found between growth chamber and field experiments to determine chilling requirements on olive. In growth chamber experiments, differences between shoots with chilling and no chilling accumulation was on the percentage of bud burst (Ramos et al., 2018). However, in field experiments as the one here reported and a previous one (Benlloch-González et al., 2018), the effect of lack of chilling was the advancement of phenology and enlargement of the flowering period. In fact, well long ago, it was proposed that winter chilling has an effect of synchronization of bud burst rather than in flower induction (Rallo and Martin, 1991).

5. Conclusions

Based on the results here presented, we propose that future works studying the effect of lack of winter chilling on olive should include the length of flowering period as a parameter to be modeled. Then, to achieve accurate phenological models, the experimentation under warm winters and the consideration of new modelling approaches will be necessary to really determine the effect of winter chilling on different olive cultivars.

Author contributions

MGM, IJL and RR conceived the ideas and designed the experiments. DR, LL, and IJL obtained research funding for preforming the experiments. DR, CMW, IJL found the locations included in the study. MGM, JFN, CMW and JMC gathered the phenology data. IJL, DR and RR gathered the climatic data. LL, JFN and LL performed the statistical analysis. MGM and JMC prepared the first draft of the manuscript. RR performed a preliminary critical revision of the manuscript. All authors revised the initial draft of the manuscript and approved the final version of the manuscript.

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Declaration of Competing interest

None declared

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Appendix A. Supplementary data

Climatic data of in the three Andalucía (Úbeda, Baena and Gibraleón) and Tenerife (Canales Altas, El Viso and Los Tomillos) locations in 2016, 2017 and 2018. Daily mean of air temperature (mean, maximum, average and range) and monthly rainfall are included.