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Global warming allows two grape crops a year, with about two months apart in ripening dates and with very different grape composition - The forcing vine regrowth to obtain two crops a year

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Summary

With the aim of delaying the ripening of grapes by around two months, a technique has been proposed based on forcing vine regrowth (Gu *et al.* 2012, Martínez de Toda *et al.* 2019). It is a bold method to fight against climate warming that could be only developed in really warm viticultural regions. It consists in shortening the growing shoots to several nodes with the aim of forcing vine regrowth; in order to force budbreak, shoot regrowth, and cropping, the source of inhibition needs to be eliminated and to this end, lateral shoots, leaves, and primary clusters, if they exist, are removed.

But the main drawback of the forcing vine regrowth technique is loss of yield. In order to avoid this loss of yield and not to eliminate the primary clusters already formed in the main shoots, it is possible to force the development of buds of the fifth and sixth nodes, but maintaining the clusters of the main shoots. In this way, the yield of the forced buds would be added to the normal or primary yield of the shoots. The experiences carried out with 'Grenache', 'Tempranillo' and 'Maturana Tinta' varieties in La Rioja (Spain) are presented.

Key words: forcing regrowth; trimming; delayed ripening; anthocyanins; thermal decoupling.

Introduction

One of the best ways to mitigate the effects of climate change may be establishing measurements to delay phenological timing. Among the various viticultural techniques to delay ripening, the canopy management techniques are especially interesting because they can be performed on already installed vineyards without need to establish new vineyards, like relocation of the vineyards to cooler areas or the use of new plant material better adapted to future conditions. It is worth mentioning that various canopy management techniques have been proposed in Rioja, for delaying grape ripening, such as late winter pruning, shoot trimming and minimal pruning among others (Martínez de Toda 2019). Each of these techniques allows delaying the ripening of the grape between 15 and 20 d. Any of these techniques can delay ripening and practically counteract the predicted advance due to climate warming. In recent years, different trials involving forcing of new buds on vine have been conducted with the aim of delaying grape ripening by up to two months, as a strategy for grapevine adaptation to climate change (Martínez de Toda 2020, Martínez de Toda *et al*. 2019).

The main problem with bud forcing techniques is loss of production. A second drawback is the manual work needed to remove axillary shoots, leaves and clusters from the main shoots to favour the development of newly formed latent buds. Furthermore, in terms of its practical application, the elimination of grapes already developed on the main primary shoots is not well-accepted by growers.

In previous studies on severe trimming of shoots to delay ripening (Martínez de Toda *et al*. 2014, Zheng *et al*. 2017) we verified that, in addition to the development of axillary shoots, the development of some latent buds was frequent, specifically those of the node or two higher nodes, of which the already developed axillary shoots had also been trimmed; thus, there was not so much inhibition of the newly formed latent bud. In these studies, clusters of the forced buds were not taken into account and were left on the vine, as is done with clusters produced by axillary shoots (known, in Spanish, as "racima").

The technique in the present study was carried out over two years and consisted of performing severe trimming at the end of flowering, leaving six nodes on primary shoots, as well as the leaves, axillary shoots and existing clusters; that is, maintaining the yield of the main shoots. The next step involved forcing the development of one or two latent buds located on the 6^{th} and 5^{th} nodes, thereby obtaining a double crop: the usual crop of that year and the crop which was prepared in the latent bud for the following year. At this time, there is still no endodormancy in the latent buds and, if we eliminate the inhibition by correlation of the axillary shoots (as the temperature is favorable), these buds will rapidly sprout and develop.

Recently, Poni *et al.* (2020) addressed this issue through a one-year experiment using one cultivar grown in pots. The present article aims to show how obtaining a double harvest from vines is possible by describing two years of field experiments on 'Grenache', 'Tempranillo' and 'Maturana Tinta' varieties in La Rioja (Spain). When trimming on a horizontal plane, the axillary shoots of the nodes in position six and five are also trimmed, thus breaking inhibition due

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to the developed laterals. It is possible to perform a second trimming at the same level ten days later to cut the highest developed secondary shoots (laterals) or to remove them by hand. Our hypothesis is that in this way we can achieve a first crop corresponding to the main clusters, with a ripening delayed about 10/15 d with respect to the control by having reduced the foliar area by trimming, which is in agreement with studies on shoot trimming (Martínez de Toda *et al*. 2014, Zheng *et al*. 2017). In addition, we can get a second crop from the forced latent buds whose ripening will be delayed by up to a month and a half with respect to the control.

Material and Methods

The study was conducted, in the years 2019 and 2020, in two vineyards within Rioja appellation, North of Spain. One was an experimental vineyard, in the University of la Rioja, located in Logroño (42°27′N, 2°25′W, 370 m.a.s.l.) with the varieties of *Vitis vinifera* 'Tempranillo' (clone CL-306 grafted onto 110-R rootstock) and 'Maturana Tinta' (grafted onto 110-R rootstock) which was planted in 2010. Vine rows were north-south oriented with a planting pattern of 1.2 m (within row) × 2.4 m (between rows). Vines were trained to vertical shoot positioning with two arms and pruned to six spurs (12 buds) per vine. The vineyard received a drip irrigation during one and a half months with an average amount of 4.5 $L \cdot vine^{-1} \cdot day^{-1}$ from mid-July when strong water stress was observed.

In each variety, three adjacent rows were selected to form a completely randomized block design, with each row as a block. Within each row, groups of 3 adjacent vines were randomly assigned to the different treatments so there were 9 vines for each treatment. Different plants were used each year. For each of the rows, four different treatments were randomly applied: (F1) Trimming the developed primary shoots at the end of flowering and according to a horizontal plane, above the node number six and performing a second trimming at the same height about ten days later, (F2) Trimming at the end of flowering, above the node number six and removing by hand the two upper axillary shoots, (F3) Trimming at the end of flowering, above the sixth node and removing by hand of all the axillary shoots and (C) Control, without any trimming.

Another vineyard was a commercial one of *Vitis vinifera* 'Grenache' and 'Maturana Tinta' (both grafted onto 110-R rootstock) which is situated in Badarán (42°22′N, 2°49′W, 615 m.a.s.l.; the vineyard was planted in 2000. Vine rows were north-south oriented with the plantation distance being 1.20 m between vines and 2.70 m between rows. The vines of 'Grenache' were trained by traditional gobelet without trellis system and pruned to six spurs (12 buds) per vine. The vines of 'Maturana Tinta' were trained to vertical shoot positioning with two arms and pruned to six spurs (12 buds) per vine as well. There were no irrigation facilities. The treatments were the same as those described for the Logroño vineyard. Both vineyards were managed in accordance with standard viticulture practices of Rioja appellation. Original climate data were provided by the nearest meteorological stations located in Logroño, for the Logroño vineyard and in Villar de Torre for the Badarán vineyard.

The Anthesis dates were determined when 50 % of the flowers were open, Veraison dates were recorded when 50 % of the berries began to show color. The harvest dates were determined for the primary crop at around 22-23 °Brix, which corresponds to the optimum level of ripening for Rioja wine, and for the forced crop at around 20 °Brix (this level of ripening was considered sufficient because at the end of the cycle the ripening slows down, the berries can begin to dehydrate or rot and, in addition, they can be eaten by the birds as they are the only grapes left in the vineyards). The number of forced shoots per primary shoots was determined by direct counting on the nine vines of each treatment. The Smart method (Smart and Robinson 1991) was used to estimate LA per primary shoot at harvest in 15 shoots per treatment; LA per vine was obtained by multiplying LA per shoot and the number of primary shoots per vine. The characteristics of the grape were determined at harvest. For each replicate, primary cluster number per vine was recorded to assess cluster number per primary shoot and cluster weight was measured on 10 random clusters at harvest. Average primary berry weight was determined on 100 randomly sampled berries from all the 3 vines of each replicate. The same methodology was used for the characteristics of forced clusters.

In 2020, the chemical composition of the grape from both the primary crop and the forced crop was studied in the vineyards of 'Grenache' and 'Maturana Tinta' from Badarán and in the vineyard of 'Tempranillo' from Logroño. The grape sample from the forced crop was taken from the group of forced treatments since there are no significant differences for the yield components between these treatments. The grape sample of the primary crop was taken from the primary crop of the set of forced treatments since there are no significant differences between them or with the primary crop of the control. 200 berries were taken per replicate. These berry samples were used to determine Total soluble solids (TSS), titratable acidity (TA), pH, tartaric acid and malic acid based on the OIV standard methods (OIV 2014) and total anthocyanins according to Iland method (Iland *et al*. 2004).

Statistical package SPSS 16.0 (SPSS Inc., Chicago, US) for Windows was used for the statistical analysis. Data were analyzed year by year. One-way analysis of variance (Anova) was performed and in the case of the existence of significant differences, the mean separation was carried out with $p < 0.05$ using Tukey test.

Results

During the year 2019, growing degree days (GDD) calculated according to Winkler Index (1 April-31 October) were 1350 in Badarán and 1712 in Logroño and total rainfall over the same time period was 298 mm and 275 mm respectively. In 2020, GDD were 1354 in Badarán and 1861 in Logroño and total rainfall over the same period was 340 mm in Badarán and 247 mm in Logroño.

Effects of forcing treatments on phenology: Tabs 1 and 2 show the dates of the phenological stages for the different treatments and varieties and for the years 2019 and 2020, respectively. Regarding the control, the anthesis of the forced grape was delayed between 41 and 53 d, the veraison between 33 and 54 days and the harvest between 35 and 57 d, depending on the variety, the treatment and the year. The delay of the primary grape of the forced treatments compared to the control was between 4 and 9 d in the veraison and between 13 and 15 d in the date of harvest. The latest harvest dates for the forced grape took place in 2020, on November 20 for 'Grenache' in Badarán and on November 4 for 'Tempranillo' and 'Maturana Tinta' in Logroño.

Table 1

Effects of forcing treatments, in the 'Garnacha', 'Tempranillo' and 'Maturana Tinta' varieties, on the phenology of the primary and forced crops, in 2019

Year/Variety/Treatment	Anthesis		Veraison		Harvest	
	Primary	Forced	Primary	Forced	Primary	Forced
2019 Garnacha						
Unforced control	10 Jun	-	21 Aug	-	10 Oct	-
F1	10 Jun	1 Aug	30 Aug	30 Sep	23 Oct	15 Nov
F2	10 Jun	1 Aug	30 Aug	30 Sep	23 Oct	15 Nov
F3	10 Jun	1 Aug	30 Aug	30 Sep	23 Oct	15 Nov
2019 Tempranillo						
Unforced control	4 Jun	-	1 Aug	-	8 Sep	-
F1	4 Jun	15 Jul	5 Aug	4 Sep	22 Sep	15 Oct
F2	4 Jun	15 Jul	5 Aug	4 Sep	22 Sep	15 Oct
F3	4 Jun	15 Jul	5 Aug	4 Sep	22 Sep	15 Oct
2019 Maturana Tinta						
Unforced control	6 Jun	-	2 Aug	-	8 Sep	-
F1	6 Jun	19 Jul	6 Aug	5 Sep	23 Sep	17 Oct
F2	6 Jun	19 Jul	6 Aug	5 Sep	23 Sep	17 Oct
F3	6 Jun	19 Jul	6 Aug	5 Sep	23 Sep	17 Oct

Table 2

Effects of forcing treatments, in the 'Garnacha', 'Tempranillo' and 'Maturana Tinta' varieties, on the phenology of the primary and forced crops, in 2020

Year/Variety/Treatment	Anthesis		Veraison		Harvest	
	Primary	Forced	Primary	Forced	Primary	Forced
2020 Garnacha						
Unforced control	8 Jun	-	24 Aug	-	8 Oct	-
F1	8 Jun	30 Jul	1 Sep	8 Oct	16 Oct	20 Nov
F2	8 Jun	30 Jul	1 Sep	8 Oct	16 Oct	20 Nov
F3	8 Jun	30 Jul	1 Sep	8 Oct	16 Oct	20 Nov
2020 Tempranillo						
Unforced control	27 May	-	24 Jul	-	7 Sep	-
F1	27 May	20 Jul	28 Jul	18 Sep	14 Sep	4 Nov
F2	27 May	20 Jul	28 Jul	18 Sep	14 Sep	4 Nov
F3	27 May	20 Jul	28 Jul	18 Sep	14 Sep	4 Nov
2020 Maturana Tinta						
Unforced control	31 May	-	29 Jul	-	7 Sep	-
F1	31 May	24 Jul	4 Aug	18 Sep	14 Sep	4 Nov
F2	31 May	24 Jul	4 Aug	18 Sep	14 Sep	4 Nov
F3	31 May	24 Jul	4 Aug	18 Sep	14 Sep	4 Nov

Effects of forcing treatments on yield components: Tabs 3 and 4 show the results of yield components for the different treatments and varieties and for the years 2019 and 2020, respectively. The number of forced shoots per main shoot varied between 0.92 and 1.66, depending on variety and year and without significant differences between treatments. The number of forced clusters per vine varied between 10.7 and 22.0 and that of primary clusters between 15.5 and 20.1 for different years and varieties and without significant differences between treatments. The cluster weight was around 180 g for the primary clusters and between 60 and 80 g for the forced clusters. The yield per vine was about 3.2 kg for the primary crop and 1.2 kg for the forced crop. Finally, the LA/Y ratio varied between

Table 3

Effects of forcing treatments on yield components in 2019. Different letters within a column show significant differences between values, according to Tukey test (*P* = 0.05)

Year/Variety/Treatment	Forced shoots per primary shoot (n°)	Clusters per vine (n°)		Cluster weight (g)		Yield per vine (kg)		Leaf area/yield ($m^2 \cdot kg^{-1}$)
		Primary	Forced	Primary	Forced	Primary	Forced	
2019 Garnacha								
Unforced control	-	19.3	-	201.5	-	3.89	-	1.43 a
F1	1.2	18.5	19.3	174.0	61.6	3.22	1.19	0.90 b
F2	1.3	19.8	20.2	192.9	60.0	3.82	1.20	0.85 b
F3	1.3	20.1	19.7	185.0	51.8	3.72	1.02	0.95 b
2019 Tempranillo								
Unforced control	-	16.5	-	201.8	-	3.33	-	1.86 a
F1	1.1	17.2	19.4	181.4	66.0	3.12	1.28	1.13 b
F2	1.0	18.0	17.7	178.1	75.1	3.20	1.33	1.20 b
F3	1.1	16.8	18.5	189.3	60.5	3.18	1.12	1.07 b
2019 Maturana Tinta								
Unforced control	-	17,3	-	199.4	-	3.45	-	1.51 a
F1	1.1	15.8	18.7	204.4	50.8	3.23	0.95	0.92 b
F2	1.2	16.5	19.2	178.2	54.7	2.94	1.05	0.96 b
F3	1.1	17.1	19.1	177.2	48.2	3.03	0.92	0.94 b

Table 4

Effects of forcing treatments on yield components in 2020. Different letters within a column show significant differences between values, according to Tukey test (*P* = 0.05)

Year/Variety/Treatment	Forced shoots per primary shoot (n°)	Clusters per vine (n°)		Cluster weight (g)		Yield per vine (kg)		Leaf area/yield ($m^2 \cdot kg^{-1}$)
		Primary	Forced	Primary	Forced	Primary	Forced	
2020 Garnacha								
Unforced control	-	16.3	-	192.4	-	3.13	-	1.62 a
F1	1.58	17.0	19.2	185.0	61.6	3.14	1.19	1.11 b
F2	1.60	17.8	19.8	178.9	60.0	3.18	1.20	1.09 b
F3	1.66	15.5	22.0	183.3	51.8	2.84	1.02	1.21 b
2020 Tempranillo								
Unforced control	-	17.5	-	177.6	-	3.10	-	1.86 a
F1	0.92	17.1	12.4	181.2	95.6	3.10	1.18	1.20 b
F2	1.22	16.0	17.0	174.1	108.2	2.78	1.84	1.19 b
F3	1.15	16.9	16.5	185.3	103.5	3.13	1.71	0.96 b
2020 Maturana Tinta								
Unforced control	-	17,1	-	193.2	-	3.30	-	1.93 a
F1	1.16	16.8	10.7	184.4	73.8	3.10	0.79	1.83 a
F2	1.62	18.1	14.2	176.1	90.7	3.19	1.28	1.64 b
F3	1,22	17.3	13.1	179.3	90.2	3.10	1.18	1.57 b

1.40 and 1.90 $m^2 \cdot kg^{-1}$ for the unforced control and between 0.90 and 1.60 $m^2 \cdot kg^{-1}$ for the forced treatments.

Effects of forcing treatments on grape composition: Tab. 5 shows the results of the composition of the primary crop and the forced crop in 2020. Compared to the primary crop, the forced crop presented a reduction of 40 % in berry weight, a reduction of 10 % in °Brix, a reduction of two tenths in pH, an increase of between 3 and 6 $g \cdot L^{-1}$ in total acidity, between 3.5 and 5 $g \cdot L^{-1}$ in malic acid, between 6 and 8 $g \cdot L^{-1}$ in tartaric acid and an increase between 100 and 120 % in the anthocyanin content. Finally, the forced crop per vine was between 1.08 and 1.51 kg, which accounted for around 30 % of the primary crop per vine.

Discussion

This is a first contribution to the literature demonstrating the possibility of obtaining a double crop in temperate viticulture regions under field conditions and for three different grapevine varieties. In addition, it is the canopy management technique that achieves the longest delay of the ripening period.

Phenology: Delays of about 13-15 d for the main clusters and of about 35-57 days for clusters of the forced shoots were observed for grape ripening, when comparing forced treatments to the control (Tabs 1 and 2). The delay of the main clusters of the forced treatments coincides with that obtained in previous works on severe trimming of shoots

Table 5

Grape composition parameters determined at harvest on primary and forced crop. Year 2020. TSS = total soluble solids; TA = titratable acidity. Different letters within a column show significant differences between values, according to Tukey test ($P = 0.05$). *The experience on the 'Grenache' and 'Maturana Tinta' varieties is located in Badarán, at 620 m a.s.l. and the experience on the 'Tempranillo' variety is located in Logroño, at 370 m a.s.l.

Variety/Site/Type of crop*	Harvest date	Berry fresh weight (g)	TSS (°Brix)	pH	TA ($g \cdot L^{-1}$)	Malic acid ($g \cdot L^{-1}$)	Tartaric acid ($g \cdot L^{-1}$)	Antho-cyanins ($mg \cdot g^{-1}$)	Yield per vine (kg)
Grenache. Badarán									
Primary crop	16 Oct	1.75a	22.9a	3.30a	6.0b	1.32b	6.03b	1.23b	3.05a
Forced crop	20 Nov	1.02b	20.1b	3.15b	12.5a	5.80a	13.64a	2.62a	1.13b
Tempranillo. Logroño									
Primary crop	14 Sep	1.70a	22.0a	3.80a	4.0b	3.51b	4.55b	1.43b	3.00a
Forced crop	4 Nov	1.08b	19.7b	3.63b	7.6a	9.12a	10.21a	2.74a	1.51b
Maturana Tinta. Badarán									
Primary crop	18 Oct	1.35a	22.5a	3.78a	6.3b	2.53b	2.73b	2.95b	2.73a
Forced crop	20 Nov	0.75b	20.1b	3.57b	10.2a	6.08a	11.51a	6.54a	1.08b

to delay ripening (Martínez de Toda *et al*. 2014, Zheng *et al.* 2017) and it is justified by the reduction of leaf surface produced by trimming compared to the control.

The three treatments of forcing induced vine regrowth and shifted the forced fruit ripening to a cooler period of the growing season. The delays between 35 and 57 d in ripening of the forced clusters compared to the control allow this forced grape to ripen in much lower thermal conditions, which is considered interesting in hot regions and with current global warming (Martínez de Toda *et al*. 2019, Martínez de Toda 2020).

Regarding the later harvest dates, it seems that it would be difficult to go beyond November 4 in Logroño and November 20 in Badarán because, from those dates, ripening is very slow, leaves lose chlorophyll and the risks of berry dehydration or rotting increase (Figure).

Yield components: The three forcing treatments led to breaking of compound buds effectively and induced the regrowth of between 0.92 and 1.66 forced fruitful shoots per main shoot and without significant differences between them. As we expected, the buds were in the predormancy phase at this time. As pointed out by Poni *et al*. (2020), this technique will obviously provide better results when shoot vigour is high enough; in the case of shoots of low vigor, the development and the leaf area of new forced shoots will be insufficient. The number of forced clusters per vine was of the same order as the number of primary clusters, but their weight was around 30 % of the weight of the primary ones.

It is possible to obtain a second crop from the forced buds, which can be added to the first crop from the main primary shoots. The second crop represents about 30 % of the primary crop, which is about 1.2 $kg \cdot vine^{-1}$ in our study conditions. This second crop can be harvested or, if it is not worth harvesting, it can be left on the vine, as is done with the clusters produced by the axillary shoots. The second harvest can be done mechanically.

The results on the leaf area/yield ratio in the forcing treatments, that were between 0.90 and 1.60 $m^2 \cdot kg^{-1}$, seem more than enough to maintain the reserves status after a severe canopy trimming, fast plant regrowth, and very late-season ripening. According to Zheng *et al*. (2017), values as high as these in the leaf area/yield ratio indicate that vines possessed sufficient leaf area to mature their berries properly and to accumulate reserves for the next year. Although longer-term studies are needed, the resulting leaf area/yield ratio of this double cropping indicate that it was sufficient for the grapes from the two crops to properly ripen, and it can be assumed that carbohydrate reserves are normally refilled for the next year. On the other hand, Poni *et al*. (2020) studied the effects of this technique on the fertility of basal buds and found that forcing did not reduce their fertility.

Figure: Aspect of the second crop on November 20, 2020 of the varieties 'Grenache' (left) and 'Maturana Tinta' (right) in the Badarán vineyard.

Grape composition: The forced clusters of the second crop produced smaller berries with lower pH, higher acidity, higher tartaric and malic acids and much higher anthocyanins compared to primary clusters of the first crop. The grape composition of the second crop showed that shifting fruit ripening and exposing berries to a cooler condition during fruit ripening can enhance total fruit anthocyanins in red winegrapes in the warmer regions. This second crop is a promising way to restore the anthocyanin to sugar ratio decoupled by climate warming. The quality of red winegrapes is largely determined by their anthocyanins concentration (Winkle-Shirley 2002). It is well-known that temperatures of 15-25 °C increase the accumulation of anthocyanins, while temperatures of 25 °C or higher reduce the level of these compounds (Spayd *et al*. 2002, Yamane *et al*. 2006, Mori *et al*. 2007, Cohen *et al*. 2008, Tarara *et al*. 2008). Moderate temperatures also result in good fruit size, TSS contents, TA and pH, assuming the growing season is warm and long enough to ripen the fruit. The cultivar best suited to a particular region usually ripens its fruit during the cooler portion of the season (Jackson and Lombard 1993).

After forcing, the longer period of forced fruit ripening under cooler weather resulted in smaller berries with lower pH, higher TA, and higher contents of anthocyanins, as previously reported in other regions (Gu *et al*. 2012, Fang *et al*. 2005). Forced clusters always kept more acidity and lower pH, even for the same level of TSS, being the possible reason that low temperatures repressed the respiratory malate degradation (Keller 2015). The best explanation for the improvement of anthocyanins concentration might be that forced treatments created a cooler ripening condition by delaying and prolonging the ripening phase.

Conclusions

By appropriately applying the forcing regrowth technique to 'Grenache', 'Tempranillo' and 'Maturana Tinta' varieties it is possible to obtain a second crop from the forced buds, which can be added to the first crop from the main primary shoots. The second crop represents about 30 % of the primary crop, which is about 1.2 kg·vine^{-1} in our study conditions. Relative to the unforced control, the primary crop matures about 13-15 d later and the secondary crop about 35-57 d later and allow this forced grape to ripen in much lower thermal conditions, which is considered interesting in hot regions and with current global warming.

The second crop produced smaller berries with lower pH, higher acidity, higher tartaric and malic acids and much higher anthocyanins compared to primary crop.

Although longer-term studies are needed, the resulting leaf area/yield ratio of this double cropping indicate that it was sufficient for the grapes from the two crops to properly ripen, and it can be assumed that carbohydrate reserves are normally refilled for the next year.

This is a first contribution to the literature demonstrating the possibility of obtaining a double crop in temperate viticulture regions under field conditions and for three different grapevine varieties.

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