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Article

The Use of a Tomato Landrace as Rootstock Improves the Response of Commercial Tomato under Water Deficit Conditions

Mateu Fullana-Pericàs , Miquel À. Conesa, Miquel Ribas-Carbó and Jeroni Galmés 

Research Group on Plant Biology under Mediterranean Conditions-INAGEA, Universitat de les Illes Balears, 07122 Balearic Islands, Spain; ma.conesa@uib.es (M.À.C.); mribas@uib.cat (M.R.-C.); jeroni.galmes@uib.es (J.G.)

* Correspondence: mateufullana@gmail.com; Tel.: +34-971-259-556

Received: 16 April 2020; Accepted: 19 May 2020; Published: 22 May 2020



Abstract: Grafting onto drought tolerant rootstocks has been proposed as a useful strategy to overcome future water scarcity periods. The ‘de Ramellet’ tomato is a drought tolerant landrace selected under semiarid Mediterranean summer conditions under rain-fed or low irrigation. In this manuscript, the responses of a commercial hybrid ‘de Ramellet’ genotype grafted onto a traditional ‘de Ramellet’ (RL) and a commercial Maxifort (Mx) tomato rootstocks under commercial greenhouse conditions are studied. Non-grafted (NON) and self-grafted (SELF) plants were used as controls. Two water regimes were established: well-watered (WW, covering plant water demands) and water deficit (WD, reducing 50% irrigation as compared to WW). The results confirm an improvement in agronomic performance of Mx as compared to NON, but also show a similar improving effect of RL. Grafting enhanced plant growth regardless of the rootstock under WW conditions. Similarly, water-use efficiency (assessed as leaf carbon isotope composition) increased in grafted plants under WD treatment as compared to NON. Despite the lack of significant differences, RL tended to promote higher fruit production and fruit number than Mx, irrespective of the water treatment, whereas RL was the single graft combination with higher fruit production than NON under WD. In conclusion, the results uncover the potential of drought-adapted landraces to be used as rootstocks in order to increase plant growth and fruit production under both well-watered and water deficit cultivation conditions.

Keywords: grafting; greenhouse; Mediterranean landrace; water-use efficiency

1. Introduction

Grafting is an ancient technique used for centuries in many crop species. Earlier use was related to clonal purposes [1], and it has recently become a prime tool to mitigate biotic [2–4] and abiotic [5–7] stresses on the scion, and to increase yield and fruit quality [8]. In particular, grafting has been identified as an effective tool to increase water-use efficiency (WUE) in several crops under non-stress and different drought stress levels [9]. Some rootstocks are labelled as drought tolerant, mainly due to the induction of proline accumulation in the scion’s leaves or to a different hormonal signaling between the scion and rootstock, which lessen drought effects and reduce the impact of the stress over scion growth and yield [10–12]. Notorious efforts have been made to breed new rootstocks, with special focus on the interactive effect of scion performance. Particularly in tomato (*Solanum lycopersicum* L.), many resistance and tolerance traits to both biotic and abiotic stresses are provided by wild relative species, and the most common sources for tomato rootstock are interspecific hybrids (*S. lycopersicum* × *S. habrochaites* S. Knapp and D.M. Spooner) [13].

Tomato is the second most produced vegetable in the world and the first in economic trade exchanges [14]. One of the reasons for tomato’s worldwide expansion is its large genotypic variability.

On the one hand, consumers appreciate the available diversity in sweet taste, acidity and firmness, with those parameters being of high relevance for tomato improvement [15–17]. On the other hand, tomato is adapted to a broad diversity of climates and cultivation conditions and practices [18–21]. In particular, Mediterranean landraces constitute locally-selected tomato genotypes adapted to Mediterranean climate cultivation conditions, mostly outdoor growing in summer, and selected for local uses and management practices [22–24]. The ‘de Ramellet’ tomato is a landrace from the Balearic Islands, heterogeneous in many plant and fruit traits, drought adapted as a consequence of selection under Mediterranean summer cultivation conditions, and with extended fruit shelf-life resulting from the long shelf-life (LSL) phenotype [25]. Despite some growers cultivate ‘de Ramellet’ landraces, most of the production corresponds to ‘de Ramellet’-like commercial F₁ hybrids, which maintain several of the ‘de Ramellet’ fruit attributes, bear diverse biotic resistances and, especially, increase three-to six-fold the fruit production per plant as compared to most ‘de Ramellet’ landraces [19].

Several studies of ‘de Ramellet’ tomato have characterized plant traits and fruit attributes [26–28] and analysed the physiological basis for drought adaptation [18,19,29,30]. The results show some underlying mechanisms of its acclimation to water deficit, but also highlight new ways to improve the ‘de Ramellet’ tomato. For instance, grafting ‘de Ramellet’ landraces onto the most used commercial rootstocks for tomato, besides having no incompatibilities, denoted improvement in WUE and fruit production, suggesting grafting as a potential tool to increase ‘de Ramellet’ agronomic performance [31]. Unlike tomato varieties (i.e., scions), little attention has been given to the use of landraces as a source of genotypes for rootstock improvement. Related to their adaptation to abiotic stresses, tomato landraces might be an important resource to breed for rootstocks intended for abiotic stress tolerance.

Considering the above, a ‘de Ramellet’ (RL) landrace genotype has been tested as a rootstock to improve a commercial ‘de Ramellet’-like F₁ hybrid (RC) agronomic traits and its response to water deficit (WD) under greenhouse conditions, as commonly cultivated. For comparison purposes, RC was also grafted onto the commercial ‘Maxifort’ rootstock (Mx), the most used in the region. Non-grafted and self-grafted plants were included as controls. A better performance of plants grafted onto Mx in terms of plant growth and fruit production as compared to non- and self-grafted plants under WW was expected. The hypothesis is that an increased WUE under WD conditions for plants grafted onto RL, would also affect fruit production, fruit quality and shelf-life. The main objectives of the present study were: (1) to evaluate RL suitability, comparing its agronomic performance with Mx graft combination, and (2) to evaluate RL response to WD in terms of plant growth, fruit production and quality.

2. Materials and Methods

2.1. Plant Material

A commercial F₁ hybrid of ‘de Ramellet’ tomato (‘Palamós’, Semillas Fitó, Barcelona) was used as a scion (RC). According to the seed company, RC has been selected to produce under greenhouse conditions, with high fruit production and extended shelf-life. Plants of RC were either non-grafted (NON), self-grafted (SELF) and grafted onto the ‘Maxifort’ rootstock (Mx, *S. lycopersicum* L. × *S. habrochaites*, De Ruiter Seeds, Bergschenhoek, NL) and onto a ‘de Ramellet’ landrace genotype (RL, UIB2-70, UIB seedbank).

Seeds of RC and both rootstocks were germinated in December 2017 in polystyrene trays filled with peat-based substrate in a greenhouse. The graft was performed 30 days after germination, when plants initiated the third true leaf, using the tube-grafting method [32]. After grafting, all plants were immediately placed in a closed plastic tunnel in a greenhouse with relative humidity near to 100% and a temperature of 20–22 °C, preventing direct sunlight. Seven days before plant transplantation, the plastic tunnel was removed, keeping plants inside the greenhouse. In order to obtain plants with a similar size when transplanting to the greenhouse, non-grafted plants were germinated two weeks later than grafted plants. During this process, all plants were watered daily with Hoagland’s solution diluted with distilled water in a 1:1 ratio.

2.2. Growth Conditions

Sixty days after germination, 12 plants of each graft combination were transplanted to 20 L coco pith grow bags (Dutch Plantin, NL) in a polyethylene greenhouse (100 m wide, 22 m long, 4 m height) for commercial tomato production in Ariany (Mallorca, Balearic Islands: latitude 39°39', longitude 3°8', altitude 103 m a.s.l.). Following commercial practices, three plants with the same graft combination and treatment were transplanted into each grow bag, with a plantation density of 3 plants m⁻² and pruning to keep only 2 stems per plant. Plants were watered daily and fertilized by a computer-automated drip fertigation system (Table S1). During the first 30 days after greenhouse transplantation, all plants were irrigated daily to field capacity. Thereafter, two treatments were established: well-watered (WW) and water deficit (WD), with six plants of each graft combination per treatment. The irrigation dose in WW was commonly used for commercial RC production, with a mean during cultivation period of 2 L day⁻¹ plant⁻¹ during the whole of the experiment. Irrigation in WD was reduced to half WW, with a mean of 1.1 L day⁻¹ plant⁻¹. Considering the whole cultivation period, WW treatment received 749.9 L m⁻² and WD treatment received 406.6 L m⁻². Irrigation water had a pH of 6.0 and an electrical conductivity of 2.7 dS m⁻¹.

During the growth period, the monthly average of the daily average, daily maximum (day) and daily minimum (night) temperatures in the greenhouse were (in °C), respectively, 20.4, 35.1 and 11.6 in April, 21.5, 36.6 and 12.7 in May and 24.5, 37.5 and 16.0 in June 2018. The relative humidity during day hours ranged between 40% and 58%. Pest control was managed following the grower's commercial practices.

2.3. Leaf Carbon Isotope Composition

Leaf carbon isotope composition ($\delta^{13}\text{C}$) was measured in one young fully expanded leaf per plant 70 days after treatment application, excluding the leaf rachis. Leaves were dried in oven at 60 °C to constant weight (*ca.* 72 h) and grinded to fine powder for analysis. Samples were combusted in an elemental analyser (Thermo Flash EA 1112 Series, Bremen, Germany), and CO₂ was directly injected into a continuous-flow isotope ratio mass spectrometer (Thermo-Finnigan Delta XP, Bremen, Germany) for isotope analysis. Peach leaf standards (NIST 1547) were run every six samples. The standard deviation of the analysis was below 0.1‰. Results for $\delta^{13}\text{C}$ are presented as δ vs. PDB.

2.4. Pre-Dawn Leaf Water Potential and Scion Fresh Weight

Leaf pre-dawn water potential (Ψ_{PD}) was measured 70 days after treatment application, on a young fully expanded leaf per plant using a Scholander pressure chamber (Model 600, PMS instruments, Albany, USA).

All plants were cut 1 cm above the graft union (above the root collar in non-grafted plants) 120 days after treatment application. The scion fresh biomass was calculated by weighing the scion immediately after cutting. The scion stem area was calculated by taking a perpendicular picture of the below part of the cut scion and using ImageJ software (NIH, USA).

2.5. Fruit Production, Fruit Quality and Shelf-Life

Fruit production (g plant⁻¹) and total number of fruits (fruits plant⁻¹) were measured as the sum of three different productive periods: 60, 90 and 120 days after treatment application. Fruit size (g fruit⁻¹) and quality parameters were determined from eight healthy fruits of the first harvest of each plant. Quality parameters were determined from the obtained juice after homogenization of the fruits using an electric mixer (LM310E10, Moulinex, Alençon, France). A digital refractometer and electrical conductimeter (PAL-BXACID F5, Atago, Tokyo, Japan) with a 0.2 °Brix and with a 0.10% citric acid precision was used to evaluate total soluble solids (TSS, results expressed as °Brix) and acidity (results expressed as % of citric acid).

To score fruit shelf-life after harvest, 25 fruits per plant were stored in a ventilated shed. Fruits were manually inspected once a week, and all fruits with external evidence of fungal or bacterial infection, cracking or extreme desiccation were removed.

2.6. Statistical Analysis

Differences among graft combinations and between treatments were revealed using a one-way analysis of variance (p -value < 0.05 after Duncan post hoc test). Regression analyses (R^2) were also performed to explain the relationship between parameters. All statistical analyses were performed using *R software* (ver. 3.5.0; R core Team, Vienna, Austria).

3. Results

3.1. Analysis of the Variability of $\delta^{13}\text{C}$ and Growth Parameters under WW and WD Conditions

The studied graft combinations showed non-significant differences in leaf carbon isotope composition ($\delta^{13}\text{C}$) under well-watered conditions (WW) (Figure 1A). All graft combinations increased (i.e., less negative) their $\delta^{13}\text{C}$ values under water deficit conditions (WD) as compared to WW, showing increased WUE under stress conditions (Figure 1A). Under WD, non-grafted plants (NON) had lower $\delta^{13}\text{C}$ than any other combination, denoting lower WUE (Figure 1A).

No differences among graft combinations were observed for predawn water potential measurements (Ψ_{PD}) under WW conditions (Figure 1B). All graft combinations significantly decreased their Ψ_{PD} under WD, with the lowest values corresponding to self-grafted plants (SELF) and the highest to plants grafted onto 'Maxifort' rootstock (Mx).

Under WW, NON had the lowest scion fresh weight (FW) and lower area of the stem above graft union (stem area). Accordingly, SELF plants had higher scion FW and stem area than NON plants (Figure 1C,D). Under WD, plants grafted onto both Mx and 'de Ramellet' landrace (RL) had higher scion FW than NON and SELF, and RL had the highest stem area. With the exception of stem area in NON, all graft combinations significantly reduced scion FW and stem area under WD (Figure 1C,D).

Scion FW and Ψ_{PD} were positively correlated when considering both treatments ($R^2 = 0.83$; p -value < 0.001 , Figure 2A). Within treatments, a significant relationship was found only under WD ($R^2 = 0.82$; p -value < 0.05). In turn, there was a negative correlation between scion FW and $\delta^{13}\text{C}$ ($R^2 = 0.82$; p -value < 0.05 , Figure 2B), due to a large treatment effect on both parameters. Correlation within treatments occurred only under WW ($R^2 = 0.92$; p -value < 0.05) and was a positive correlation (Figure 2B).

3.2. Variation in Fruit Production and Its Correlation with $\delta^{13}\text{C}$ as a Result of Water Deficit, Grafting and the Rootstock Genotype

Non-significant differences in fruit production, fruit number and fruit size were observed among graft combinations under WW (Table 1). Under WD, NON plants had the highest fruit size but the lowest fruit number. NON had also lower fruit production than RL, with SELF and Mx showing intermediate and non-significantly different values to NON and RL. All graft combinations reduced fruit production, fruit number and fruit size under WD as compared to WW.

When considering all graft combinations and treatments, fruit production correlated positively with scion FW ($R^2 = 0.86$; p -value < 0.001) and negatively with $\delta^{13}\text{C}$ ($R^2 = 0.89$; p -value < 0.001) (Figure 3). However, and similar to Figure 2B, these correlations were related to a major treatment effect. Despite non-significant correlations being identified under WD, the relationship between fruit production and scion FW followed a trend similar to the observed when considering both treatments, having Mx and RL higher scion FW and fruit production than NON and SELF. Similarly, there was a non-significant correlation between fruit production and $\delta^{13}\text{C}$, although in this case the main difference was between NON, having the lowest $\delta^{13}\text{C}$ and fruit production, and the remaining graft combinations.

Nevertheless, the trend for WD was positive, thus opposite to the relationship when considering both treatments (Figure 3B).

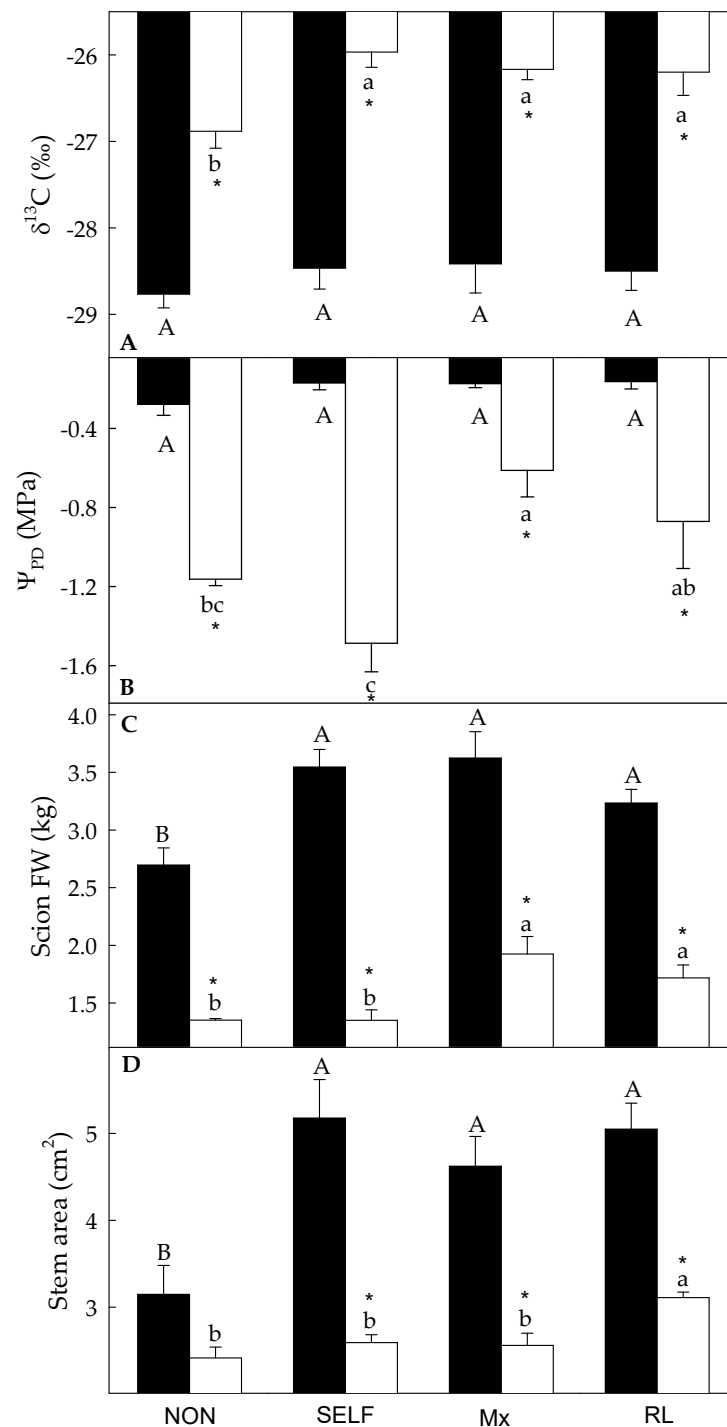


Figure 1. Variation among graft combinations in (A) leaf carbon isotope composition ($\delta^{13}C$), (B) predawn water potential (Ψ_{PD}), (C) scion fresh weight (scion FW) and (D) stem area (cm²). Data are means \pm S.E. ($n = 4-6$). NON refers to non-grafted RC genotype, SELF to self-grafted (RC/RC), Mx to plants grafted onto ‘Maxifort’ rootstock and ‘RL’ to plants grafted onto ‘de Ramellet’ landrace genotype. Filled bars refer to well-watered (WW) and unfilled bars to water deficit (WD) plants. Asterisks in WD bars denote differences between treatments for the same graft combination, capital letters denote significant differences among WW and lowercase letters among WD graft combinations by one-way ANOVA after Duncan post hoc test (p -value < 0.05).

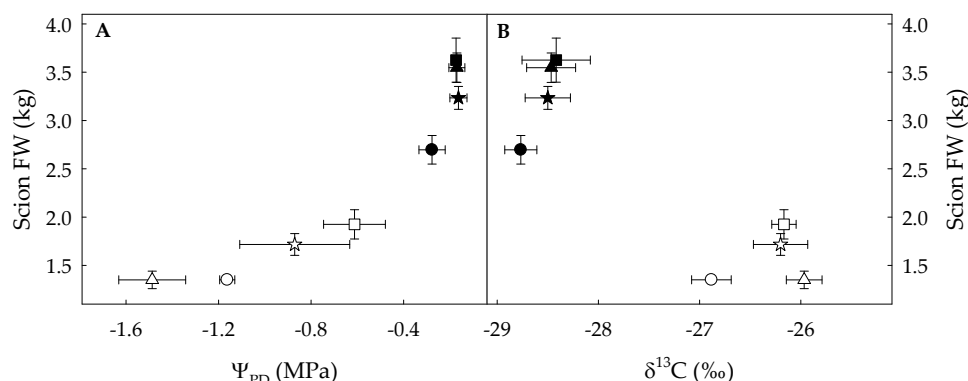


Figure 2. Relationship between scion fresh weight (scion FW) and (A) predawn water potential (Ψ_{PD}), and (B) leaf carbon isotope composition ($\delta^{13}C$). Data are means \pm S.E. ($n = 4-6$). Dots refer to non-grafted RC genotype, triangles to self-grafted (RC/RC), squares to plants grafted onto ‘Maxifort’ and stars to plants grafted onto ‘de Ramellet’ landrace. Filled symbols refer to well-watered (WW) and unfilled to water deficit (WD) plants.

Table 1. Variation in fruit production ($g\ plant^{-1}$), fruit number ($fruit\ plant^{-1}$) and fruit size ($g\ fruit^{-1}$) under well-watered (WW) and water deficit (WD) conditions. Values are means \pm S.E. ($n = 4-6$). NON refer to non-grafted RC genotype, SELF to self-grafted (RC/RC), Mx to plants grafted onto ‘Maxifort’ and RL to plants grafted onto ‘de Ramellet’ landrace rootstocks. Asterisks in WD denote differences between treatments for the same graft combination, and letters denote differences among graft combinations under the same treatment by one-way ANOVA after Duncan post hoc test (* p -value < 0.05).

Treatment	Graft Combination	Fruit Production	Fruit Number	Fruit Size
		g plant ⁻¹	fruit plant ⁻¹	g fruit ⁻¹
WW				
	NON	5758.8 ± 468.8 a	88.8 ± 6.5 a	94.31 ± 11.02 a
	SELF	6352.5 ± 380.8 a	91.7 ± 6.5 a	89.31 ± 1.92 a
	Mx	5391.0 ± 512.4 a	81.7 ± 8.2 a	77.59 ± 9.30 a
	RL	6195.0 ± 498.5 a	93.7 ± 4.3 a	87.04 ± 5.31 a
WD				
	NON	1327.0 ± 133.9 b*	20.2 ± 3.1 b*	67.69 ± 2.08 a*
	SELF	1507.0 ± 117.4 ab*	32.8 ± 4.3 a*	56.80 ± 1.34 b*
	Mx	1628.3 ± 180.5 ab*	38.3 ± 4.0 a*	58.14 ± 1.29 b*
	TR	1920.0 ± 120.7 a*	41.5 ± 5.2 a*	58.39 ± 2.28 b*

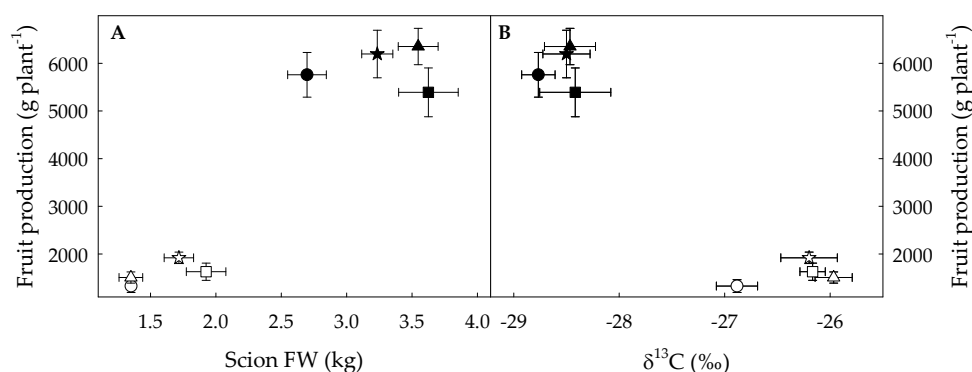


Figure 3. Relationship between fruit production ($g\ plant^{-1}$) and (A) scion fresh weight (scion FW), and (B) leaf carbon isotope composition ($\delta^{13}C$). Data are means \pm S.E. ($n = 4-6$). Dots refer to non-grafted RC genotype, triangles to self-grafted (RC/RC), squares to plants grafted onto ‘Maxifort’ and stars to plants grafted onto ‘de Ramellet’ landrace. Filled symbols refer to well-watered (WW) and unfilled to water deficit (WD) plants.

3.3. Modification of the Scion Fruit Quality and Shelf-Life Related to Water Deficit, Grafting and the Rootstock Genotype

Under WW, NON had the lowest total soluble solids (TSS) and the highest fruit hardness, while no differences among graft combinations were observed for acidity (Table 2). Conversely, under WD differences among graft combinations were found only in acidity, having Mx and RL higher values than NON and SELF. Significant differences between NON and SELF were observed for TSS/acidity ratio under WW, having Mx and RL intermediate values (Table 2). Under WD, Mx and RL had lower TSS/acidity values than NON, but only RL had significantly lower values than both NON and SELF.

Table 2. Variation in fruit total soluble solids (TSS), acidity (% citric acid), hardness (°shore), total soluble solids to acidity ratio and shelf-life (days) under well-watered (WW) and water deficit (WD) conditions. Values are means \pm S.E. ($n = 4-6$). NON refers to non-grafted RC genotype, SELF to self-grafted (RC/RC), Mx to plants grafted onto ‘Maxifort’ and RL to plants grafted onto ‘de Ramellet’ landrace rootstocks. Asterisks in WD denote differences between treatments for the same graft combination and letters among graft combinations under the same treatment by one-way ANOVA after Duncan post hoc test (* p -value < 0.05).

Treatment	Graft Combination	TSS °Brix	Acidity % Citric Acid	TSS/Acidity	Hardness °Shore	Shelf-Life Days
WW						
	NON	4.13 \pm 0.31 b	1.14 \pm 0.07 a	3.87 \pm 0.16 b	57.97 \pm 1.68 a	132.9 \pm 2.9 c
	SELF	5.15 \pm 0.10 a	1.10 \pm 0.05 a	4.81 \pm 0.24 a	50.33 \pm 1.33 b	143.6 \pm 1.8 ab
	Mx	4.97 \pm 0.22 a	1.12 \pm 0.05 a	4.44 \pm 0.09 ab	51.45 \pm 0.60 b	138.6 \pm 1.1 b
	RL	5.23 \pm 0.26 a	1.22 \pm 0.10 a	4.45 \pm 0.31 ab	51.20 \pm 2.73 b	147.2 \pm 0.8 a
WD						
	NON	8.43 \pm 0.28 a*	1.52 \pm 0.10 b*	5.39 \pm 0.44 a*	57.47 \pm 3.14 a	148.6 \pm 2.8 b*
	SELF	8.35 \pm 0.25 a*	1.60 \pm 0.15 b*	5.33 \pm 0.42 ab	58.73 \pm 2.10 a*	170.5 \pm 2.0 a*
	Mx	8.54 \pm 0.35 a*	1.95 \pm 0.09 a*	4.41 \pm 0.17 bc	51.74 \pm 2.52 a	163.9 \pm 5.6 a*
	RL	8.10 \pm 0.35 a*	1.92 \pm 0.13 a*	4.27 \pm 0.19 c	54.92 \pm 2.98 a	164.5 \pm 4.9 a*

A larger variability was found for fruit shelf-life, with NON having the lowest values under both WW and WD treatments. Under WW, RL had higher shelf-life than Mx, with no differences between these grafting combinations under WD. Shelf-life positively correlated with $\delta^{13}\text{C}$ when considering all graft combinations and both treatments ($R^2 = 0.84$; p -value < 0.001) and considering only WD ($R^2 = 0.99$; p -value < 0.001), (Figure 4).

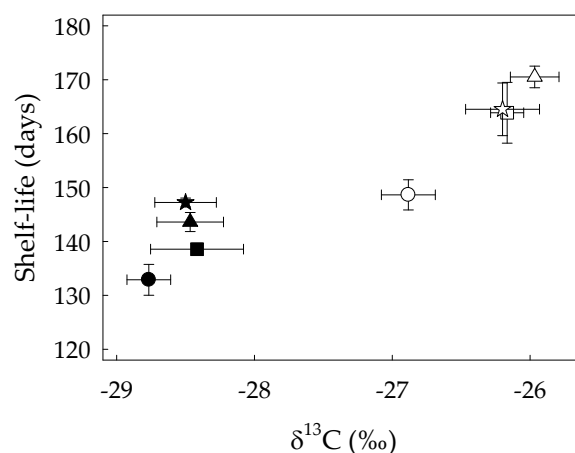


Figure 4. Relationship between fruit shelf life (days) and leaf carbon isotope composition ($\delta^{13}\text{C}$). Data are means \pm S.E. ($n = 4-6$). Dots refer to non-grafted RC genotype, triangles to self-grafted (RC/RC), squares to plants grafted onto ‘Maxifort’ and stars to plants grafted onto ‘de Ramellet’ landrace. Filled symbols refer to well-watered (WW) and unfilled to water deficit (WD) plants.

All graft combinations increased their TSS, acidity and shelf-life under WD as compared to WW. Treatment differences for the TSS/acidity ratio and fruit hardness were restricted to the higher value under WD of NON and SELF, respectively (Table 2).

4. Discussion

4.1. Grafting Maximized Plant Growth

Under WW conditions, the lowest values of NON in scion FW and stem area denote that grafting, regardless of the used rootstock, induced a higher plant growth and vigour (Figure 1C,D). Also, RL showed a similar growth performance to Mx. On the other hand, under WD, Mx and RL had higher Ψ_{PD} than NON and SELF, which correlated with their higher scion FW (Figure 2A). These results suggest that the grafting of the commercial hybrid onto Mx and RL increased its hydraulic conductivity and in turn ameliorated its performance under stress conditions, in agreement with previous observations based on grafting onto compatible rootstocks [33–36].

In this study, $\delta^{13}C$ was used as an integrative WUE indicator [37–39]. Despite there being several studies relating changes in WUE and plant growth derived from grafting (reviewed in [40]), to the best of our knowledge, there is no literature concerning changes in $\delta^{13}C$ in grafted vegetables. All graft combinations increased WUE under WD conditions (i.e., less negative $\delta^{13}C$ values, Figure 1A). Contrary to WW, there were significant differences within WD, which were restricted to the lower WUE of NON as compared to any other combination (Figure 1A). Therefore, contrary to the hypothesis of grafting onto RL providing higher WUE under WD, the results point to the grafting effect per se, irrespective of the rootstock genotype. Hence, and despite the lack of significant correlation, grafting onto Mx and RL under WD significantly increased plant growth with no changes in WUE as compared to SELF and increasing WUE as compared to NON (Figure 1A,C and Figure 2B).

4.2. Grafting onto RL Increased Fruit Production in Both Treatments

There are contrasting results regarding the effect of grafting over scion FW and its relationship with fruit production in tomato. While [41] described a negative relationship between scion FW and fruit production, [42] found no correlation. On the other hand, references [43,44] related the increase in fruit production with higher plant biomass. In this study, the positive relationship between scion FW and fruit production when considering all data was derived from a clear treatment effect ($R^2 = 0.86$; p -value < 0.001). However, under WD, the non-significant trend between both parameters suggests that grafting onto Mx and RL generated more vigorous plants with an enhanced plant growth and fruit production (Figure 3).

As expected, our data showed that plants with increased WUE had lower fruit production (Figure 3B) [45,46]. However, within treatments, no relationship was found, indicating that grafting was an efficient tool to obtain plants with increased fruit production but with no major changes in WUE (Figure 3B). It is worth indicating the correspondence of higher WUE with lower fruit size and higher fruit number under WD (Figure 1A, Table 1). Thus, under water limiting conditions, grafted plants promoted the production of smaller fruits in a higher number as compared to NON. The reduction in fruit size and fruit number per plant under water stress [19,47], and particularly in ‘de Ramellet’ [26], has been commonly described. In grafted plants, the results show a larger reduction in fruit number than in fruit size, which corresponds with a higher WUE (Table 1, Figure 1A).

4.3. Grafting Had an Effect on Fruit Quality and Shelf-Life

There was a clear increase in TSS, acidity and fruit shelf-life under WD as compared to WW, irrespective of the graft combination (Table 2). For TSS and acidity, this is a well-known pattern related to a concentration effect in fruits formed under water scarcity conditions [48,49], and to a large extent agrees with the smaller fruit size under WD (Table 2).

Besides this clear treatment effect, the lower TSS in NON as compared to any graft combination under WW indicates that grafting improved fruit quality under non-limiting water conditions (Table 2). This relation between grafting and fruit quality is well known in several vegetables [50,51], and particularly in tomato under non-stress conditions [52–54]. On the other hand, under WD, both Mx and RL maintained similar TSS/acidity ratio values compared to those observed under WW, denoting their ability to maintain a balanced fruit taste [55,56].

We observed a significant increase in fruit shelf-life under WD as compared to WW (Table 2). This is in accordance with previous studies in ‘de Ramellet’ tomato, where shelf-life was significantly affected by water availability [28]. It has been reported that environmental stresses, such as drought, can alter fruit cuticle composition, coverage and dynamics [57,58]. However, it is still not clear if the extended shelf-life of Mediterranean LSL landraces is related to an increased fruit cuticle deposition or to pleiotropic drought responses [59]. In this experiment, we observed how, when considering both treatments, those graft combinations with higher WUE also had the highest fruit shelf-life (Figure 4). Under WD, the lower shelf-life in NON can be related to the larger fruit size in this graft combination, due to the negative correlation described in ‘de Ramellet’ landraces between both parameters [26].

5. Conclusions

The results in this study demonstrate a notorious graft effect over scion performance, not always related to the rootstock genotype. As compared to a commercial elite rootstock, a genotype of the Balearic ‘de Ramellet’ landrace showed similar and even improved performance under both well-watered and water deficit conditions. Moreover, under water deficit conditions, the ‘de Ramellet’ landrace appeared as the most suitable rootstock in terms of maximizing fruit production, fruit number and fruit shelf-life, while maintaining a balanced ratio of soluble solids and acidity (i.e., attributable to taste). We note that our results refer to a single scion and that its validation should be performed considering different scions and even rootstocks. However, our results demonstrate the interest of landraces over commercial rootstocks when used to graft related, commercial scions. In sum, this study highlights the suitability of Mediterranean landraces as key genetic resources to be used as, or to breed for, novel rootstocks devoted to improving tomato cultivation under the predicted climate change scenario.

Supplementary Materials: The following are available online at <http://www.mdpi.com/2073-4395/10/5/748/s1>, Table S1: Nutrient application through fertigation. Adapted from [60].

Author Contributions: Data curation, M.F.-P.; Formal analysis, M.F.-P.; Funding acquisition, M.À.C., M.R.-C. and J.G.; Writing—original draft, M.F.-P.; Writing—review & editing, M.À.C., M.R.-C. and J.G. All authors have read and agreed to the published version of the manuscript.

Funding: This research was supported with a pre-doctoral fellowship (FPI/1929/2016) granted by the Government of the Balearic Islands to M. Fullana-Pericàs and by the European Union’s Horizon 2020 research and innovation program under the Grant Agreement No. 727929 (TOMRES) awarded to J. Galmés.

Acknowledgments: We thank to Sergi Boleda, Toni Ribot and Maria Marquès from Agroilla SAT for their technical support and plant agronomic management. Also, Gerardo Costea, Cyril Douthe and Martí Seguí are acknowledged for their help in sampling and posterior processing.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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