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# The P16 rootstock inhibits the growth but enhances the fruit quality of 'Jonagored' apples when grown under warm summer conditions

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## Abstract

The production of high quality fruit is the main aim of fruit growers. In areas where summers are warm, high apple quality is often difficult to attain, particularly with respect to red cultivars; colour is one of the main features affecting fruit quality. In vigorous red apple cultivars, the use of very dwarfing rootstocks might help overcome the lack of colouring in the fruit. In experiments performed in 2003 and 2004, specimens of apple cv. Jonagored grafted onto P16 rootstocks were compared to others grafted onto M9 rootstocks; fruit thinning was performed to various extents so that trees carried different crop loads. Under the warm summer conditions of the Ebro Valley, Spain, the P16 rootstock showed very strong dwarfing properties. 'Jonagored' trees grafted onto these rootstocks had shorter shoot lengths and a smaller leaf area than those grafted onto M9 rootstocks. The fruits of 'Jonagored' apple trees are usually large, but in 2004, when the crop loads of the P16-grafted trees were far greater than those of the M9-grafted trees, the fruits of the former were smaller than those produced by the latter, although still commercially suitable. The rootstocks were found to affect several fruit quality variables. The soluble solids content of the fruits of the P16-grafted trees was greater than that of the M9-grafted trees, and negatively correlated with the crop load. In 2003, when summer temperatures were higher, fruits developed a less intense red colour than in 2004, although those from the P16-grafted trees were redder in both years. This difference in fruit colour was caused by the higher anthocyanin and lower chlorophyll concentrations of the skins.

**Additional key words**: dwarfism, fruit colour, *Malus* × *domestica*, skin pigments, vegetative growth.

## Resumen

### El patrón P16 inhibe el crecimiento y mejora la calidad del fruto en manzanos 'Jonagored' cultivados en climas de veranos cálidos

La producción de fruta de gran calidad, particularmente los cultivares de manzanas rojas, es especialmente difícil en áreas de clima cálido. En variedades rojas vigorosas la utilización de patrones muy enanizantes puede ayudar a resolver el problema. En las condiciones de cultivo del Valle del Ebro, con veranos muy calurosos, se han comparado manzanos 'Jonagored' injertados sobre patrones P16 y M9, durante los años 2003 y 2004, a los que se aplicaron diferentes niveles de aclareo para conseguir distintas carga de cosecha, y discernir el efecto del patrón sobre la calidad del fruto. El P16 se ha comportado como muy enanizante, dando lugar a brotes mucho más cortos y hojas más pequeñas que el M9. El cultivar 'Jonagored' produce frutos de gran tamaño. Sin embargo, en 2004, los árboles sobre P16 produjeron frutos de menor peso medio, aunque comercialmente apropiados, porque la carga de cosecha resultó mayor que los injertados sobre M9. Se encontraron diferencias en parámetros de calidad del fruto: los frutos de árboles sobre P16 tuvieron un mayor contenido en sólidos solubles que los del M9, parámetro que se relacionó negativamente con la carga de cosecha. En 2003, año especialmente caluroso, el color rojo del fruto se desarrolló mucho menos que en 2004, aunque en ambos años las manzanas de árboles sobre P16 resultaron más coloreadas que las de M9. La diferencia en coloración fue debida a mayores concentraciones de antocianinas y menores de clorofilas en la piel de los frutos producidos sobre el P16.

**Palabras clave adicionales**: color del fruto, crecimiento vegetativo, *Malus* × *domestica,* patrones enanizantes, pigmentos de la piel.

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## Introduction

The production of high quality fruit is a major concern for the apple (*Malus* × *domestica* Borkh) growing industry. Skin colour is an important variable affecting fruit quality, particularly in red apples. The red colour of the fruit is mainly due to the synthesis of anthocyanins, which is activated by differences between daytime and night-time air temperatures and by the type or quantity of light intercepted by the fruit (Saure, 1990). For the apple industry in regions with warm summers, the development of fruit colour is one of the major obstacles to the production of high quality fruit.

The 'Jonagored' apple cultivar is more deeply coloured than the 'Jonagold' cultivar. The production of 'Jonagored' apples might therefore be of interest to apple growers. In the Ebro Valley, Spain, however, preliminary trials showed the fruit of the 'Jonagored' cultivar to develop poor colouring. It was also found to grow vigorously, even when grafted onto M9 rootstocks, to suffer a considerable pre-harvest drop, and to show low flesh firmness (Iglesias Castellarnau *et al*., 2000).

Robinson (1997) reports light penetration in the canopy of trees grafted onto dwarfing rootstocks to be greater, and that fruit of higher quality is produced when it is exposed to this extra light. Awad *et al*. (2001) report the concentration of anthocyanins to be higher in the fruit from the inner part of the canopy than in that from the periphery. Thus, very dwarfing rootstocks might reduce vegetative growth and consequently reduce the canopy density, which should enhance fruit colour and other quality variables. However, little information is available on the performance of very dwarfing rootstocks under very warm growing conditions. P16, a very dwarfing apple rootstock (Czynczyk and Olszewska, 1990), is a result of the Polish rootstock breeding programme aimed at increasing winter hardiness (Wertheim, 1998). Little interest in this rootstock has been awakened in countries with warm climatic conditions, where indeed it has not been tested. The aim of this work was to test the behaviour of this rootstock in terms of vegetative growth and fruit quality. Experiments were performed in the mid Ebro Valley (Spain), in which 'Jonagored' scions were grafted onto P16 rootstocks, and the fruit produced compared to that of trees grafted onto M9 rootstocks.

## Material and Methods

To evaluate the performance of the cv. Jonagored grafted onto different rootstocks, an orchard was planted in 1994 at the Estación Experimental de Aula Dei (Zaragoza, Spain). The trees were planted at a density of 5 × 4 m, trained as central leaders, and managed in accordance with the usual practices of the area, including flood irrigation. In 2003, an experiment was performed with the trees grafted onto M9 and P16 rootstocks. Twelve trees grafted onto each type were selected. Each tree was assigned to one of three fruit-thinning treatments. In two of the treatments the trees were hand-thinned 39 days after full bloom (DAFB) to produce crop loads of 0.2 or 1.5 fruit $cm^{-2}$; in the third treatment the trees were left unthinned. In that year, the trees grafted onto the M9 and P16 rootstocks had an average trunk cross-sectional area (TCSA) of 92.2 ± 14.1 $cm^2$ and 28.5 ± 10.1 $cm^2$ respectively.

In Spain, the summer of 2003 was the warmest of the last 16 years (Table 1), and mean maximum and minimum temperatures between June and August were respectively 3.1ºC and 1.9ºC higher than usual. Expecting temperatures closer to usual, the trial was repeated in 2004. In this year, the average TCSA of the trees grafted onto M9 and P16 rootstocks was 123.0 ± 13.4 $cm^2$ and 39.8 ± 15.2 $cm^2$ respectively. Again, the trees were

**Table 1.** Mean maximum and minimum temperatures (°C) of June, July and August for the 1987-2002 period, and for 2003 and 2004 at the Estación Experimental de Aula Dei (Zaragoza, Spain)

| Month | Maximum temperatures | | | Minimum temperatures | | |
|---|---|---|---|---|---|---|
| | 1987-2002 | 2003 | 2004 | 1987-2002 | 2003 | 2004 |
| June | 29.0 | 33.8 | 32.1 | 13.8 | 17.4 | 15.2 |
| July | 32.4 | 33.9 | 31.9 | 16.3 | 17.6 | 16.1 |
| August | 32.2 | 35.3 | 32.3 | 16.8 | 17.5 | 16.4 |

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Abbreviations used: DAFB (days after full bloom), SE (standard error), SED (standard error of the difference), SPAD (soil plant analysis development), SSC (soluble solids content), TCSA (trunk-cross-sectional area).

either hand-thinned to produce crop loads of 0.2 or 1.5 fruit cm$^{-2}$, or left unthinned. This year, full bloom occurred on 28 April, and thinning treatments were undertaken at 42 DAFB.

To quantify vegetative growth, in 2003 10 shoots per tree were tagged at the beginning of the growing season and measured periodically. In winter, 15 shoots per tree were collected and the length of the internodes measured. To determine the TCSA, trunk girths were measured each winter.

Photosynthesis was quantified on 1 August 2003 and 30 July 2004 by measuring this in 10 leaves per tree that were well exposed to sunlight using a LCi portable photosynthesis system (ADC, Hoddesdon, UK). Chlorophyll concentration in the leaves was measured on 10 leaves per tree, randomly selected, with a SPAD 50 (Minolta Crop., Ramsey, NJ., USA).

To determine the leaf area (using the DELTA-T Area Measurement System; DELTA-T Devices, UK), fresh and dry weight, and the specific leaf weight, random samples of 10 leaves per tree were collected from the middle section of shoots around the tree canopy. In the 2003 growing season, leaves were collected on 28 May, 30 June, 29 July and 12 September. In 2004, they were collected on 5 July, 11 August and 30 September. In 2003 10 leaves per tree were collected to measure the stomatal density by scanning electron microscopy (performed at the Servei de Microscopía Electrónica, University of Lleida, Spain).

Apples were harvested on 28 August 2003 and 25 August 2004. In both years the yields and number of fruits per tree were recorded, and these data were used to calculate the mean fruit weight, the crop load at harvest, and tree productivity.

Each year at harvest, a random sample of 15 fruits per tree was collected to evaluate fruit quality. Determinations were based on fruit length and diameter (L/D ratio), the soluble solids content (SSC) (measured using a PR-101 digital refractometer, Atago Co., Japan), the titratable acidity, flesh firmness (measured using an Effegi fruit tester fitted with an 11.1 mm tip), and surface colour [based on L*, a* and b* values (Mcguire, 1992)] measured using a CR-200 chromameter (Minolta Co., Japan) at three positions on both the blushed and shaded sides of each fruit.

Samples of fruit skin from the blushed and shaded sides of each apple were cut into 1 cm$^2$ discs for the determination of anthocyanins, and into 2 cm$^2$ discs for the determination of chlorophylls a and b and total carotenoids. Spectrophotometric analyses were performed using a Beckmann DU-64 instrument (Beckmann Coulter Inc., USA) following the procedures of Val *et al*. (1994) (for chlorophylls and carotenoids) and Kondo and Inoue (1997) (for anthocyanins). Briefly, chlorophylls and carotenoids were extracted in cold acetone to which a few mg of sodium ascorbate were added, centrifuged for 15 min, and the absorbance read at 645 and 662 nm. Anthocyanins were extracted in acidified methanol, shaken for 2 h and the absorbance read at 530 and 620 nm.

The experiments had a 2 × 3 completely randomised factorial design, with four replications per rootstock and thinning treatment. Single trees were regarded as the experimental unit. The means for the data recorded for different organs per experimental unit were used in statistical analyses. Data were analysed by ANOVA. Regression analysis of different data against crop load levels was performed when the effect of thinning was significant. In addition, patterns of behaviour throughout the growing season were analysed by regression against the date of measurement. When the results were significant, regression lines were compared using the procedure of Snedecor and Cochran (1980).

## Results

### Fruit yields

In 2003 the apple trees bloomed poorly, and the range of crop loads produced by thinning was small. In addition, from the beginning of August a heavy pre-harvest fruit-drop occurred in all trees; the crop load at harvest (28 August) varied between 0.1 and 1.4 fruits cm$^{-2}$ TCSA. The interaction between rootstock type and crop load had no significant effect on any studied variable.

The yield and number of fruits harvested per tree increased significantly with decreasing levels of fruit thinning, and were greater in the M9-grafted trees (Table 2). However, no differences were seen between the rootstocks in terms of productivity or crop load. This resulted in there being no differences in terms of mean fruit weight.

In 2004 the pre-harvest fruit drop was smaller than in 2003; consequently the trees carried a larger crop (Table 2). At harvest, crop loads varied between 0.2 and 3.8 fruit cm$^{-2}$. The interaction between rootstock and fruit-thinning level had no significant effect on any of the variables recorded. Increased yields were

**Table 2.** Yield, number of fruit harvested, tree productivity, crop load and mean fruit weight of 'Jonagored' apple trees grafted onto M9 and P16 rootstocks subjected to different fruit-thinning levels (2003 and 2004)

| | Yield (kg tree$^{-1}$) | | No. fruit/tree | | Productivity (g cm$^{-2}$) | | Crop load (no. fruits cm$^{-2}$) | | Mean fruit weight (g) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2003 | 2004 | 2003 | 2004 | 2003 | 2004 | 2003 | 2004 | 2003 | 2004 |
| *Rootstock* | | | | | | | | | | |
| M9 | 9.1 | 15.3 | 38.5 | 66.4 | 100.1 | 122.9 | 0.64 | 0.53 | 236.5 | 242.2 |
| P16 | 1.6 | 11.4 | 7.1 | 57.4 | 65.1 | 284.9 | 0.52 | 1.41 | 233.5 | 221.7 |
| Significance[1] | *** | ns | *** | ns | ns | ** | ns | ** | ns | * |
| *Thinning level* | | | | | | | | | | |
| No thinning | 10.1 a | 21.3 a | 44.3 a | 106.4 a | 157.3 a | 301.9 a | 1.14 a | 1.60 a | 219.3 | 203.6 a |
| Medium | 5.1 b | 14.7 a | 20.5 b | 63.9 b | 75.5 b | 246.5 a | 0.51 b | 1.07 a | 245.3 | 230.5 b |
| Heavy | 0.9 c | 4.0 b | 3.6 c | 15.5 c | 14.9 b | 63.3 b | 0.09 c | 0.24 b | 240.4 | 261.7 c |
| Significance | *** | ** | *** | *** | *** | ** | *** | *** | ns | *** |

[1] *,**,***, ns: significant at $P \leq 0.05$, $P \leq 0.01$, $P \leq 0.001$ and non-significant respectively. Within each column and factor, values followed by same letter do not differ significantly ($P > 0.05$).

seen on trees grafted onto both types of rootstock, but with no significant differences between them. However, in the P16-grafted trees, tree productivity was far greater and crop loads smaller. This resulted in significantly smaller fruit, as shown by the mean fruit weight. In this year, all the variables recorded were significantly affected by the degree of fruit-thinning in agreement with the patterns expected.

## Fruit quality

In 2003 the interaction between rootstock type and fruit-thinning level had no significant effect on any of the fruit quality variables recorded at harvest. Moreover, no effects of the thinning treatments were detected, a consequence of the small range of variation in crop load. Only the SSC and water content of the fruits were significantly affected by the rootstock type (Table 3).

In 2004, and for all the fruit quality traits evaluated, the interaction between rootstock and fruit-thinning level had no significant effect. Among all the fruit-quality variables recorded, only the SSC was significantly (negatively) correlated with crop load (with respect to both the blushed and shaded sides of the fruit) (Fig. 1). For both sides of the fruit, the regression lines for the M9 and P16 rootstocks differed significantly, the slopes being steeper for the M9- than for the P16-

**Table 3.** Flesh firmness, soluble solids content in the blushed and shaded sides of fruit, and other fruit quality variables of 'Jonagored' apples harvested from trees grafted on M9 and P16 rootstocks, measured in 2003 and 2004

| Rootstock | Flesh firmness | | Soluble solids | | Fruit weight | | Water content (%) | L/D ratio[1] | Acidity (g malic acid L$^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|
| | Blushed (N) | Shaded (N) | Blushed (%) | Shaded (%) | Fresh (g) | Dry (g) | | | |
| *2003* | | | | | | | | | |
| M9 | 73.5 | 72.3 | 14.7 | 14.3 | 243.9 | 40.3 | 83.45 | 0.85 | 6.67 |
| P16 | 83.3 | 84.9 | 17.0 | 17.1 | 233.0 | 45.4 | 80.47 | 0.87 | 6.63 |
| Significance[2] | ns | ns | *** | *** | ns | ns | *** | ns | ns |
| *2004* | | | | | | | | | |
| M9 | 79.6 | 83.7 | — | — | 245.6 | 42.8 | 82.6 | 0.86 | 7.80 |
| P16 | 82.6 | 79.9 | — | — | 235.1 | 42.0 | 82.3 | 0.87 | 7.58 |
| Significance[2] | ns | ns | | | ns | ns | ns | * | ns |

[1] Length and diameter ratio. [2] ns, *, ***: non-significant and significant at $P \leq 0.05$ and $P \leq 0.001$ respecively

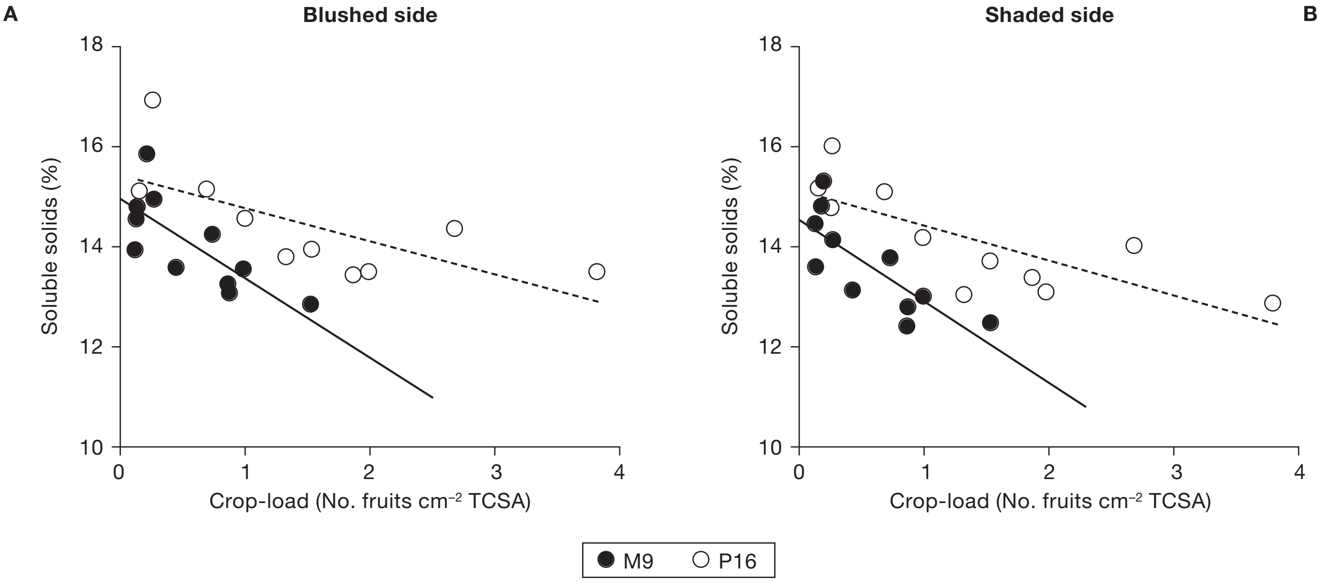

**Figure 1.** Soluble solids concentrations (SSC) in the blushed (A) and shaded (B) sides of fruit harvested in 2004 as a function of crop load in 'Jonagored' apple trees grafted onto M9 or P16 rootstocks. TCSA: trunk-cross-sectional area. Blushed side: M9: SSC = 14.97 – 1.60 × crop load ($r^2 = 60.60$; $P \leq 0.01$); P16: SSC = 15.39 – 0.65 × crop load ($r^2 = 49.26$; $P \leq 0.05$). Shaded side: M9: SSC = 14.52 – 1.63 × crop load ($r^2 = 61.98$; $P \leq 0.01$); P16: SSC = 15.12 – 0.71 × crop load ($r^2 = 59.26$; $P \leq 0.01$).

grafted trees. No significant differences were seen between the rootstocks in terms of most of the fruit quality variables measured (Table 3); however, the fruit from trees grafted onto P16 rootstocks were more elongated (greater L/D ratio).

In 2003, differences were recorded in apple skin chromaticity (Table 4). On the blushed side of the apple, a* values were higher in the fruit from trees grown on P16-grafted trees, and L* values were higher in the fruit from trees grafted onto M9 rootstocks. On the shaded side of the apple, a* and b* values were significantly higher in the fruit from P16-grafted trees. No differences were seen in lightness (L*).

In 2004, no correlation was seen between fruit chromaticity and crop load. However, the a* values were significantly higher and b* values significantly lower on the blushed and shaded sides of the fruit from trees grafted onto the P16 rootstocks (Table 4). Luminescence was significantly greater on both sides of the fruit from the M9-grafted trees.

In 2003, the concentrations of chlorophylls a and b on the shaded side of the fruit from trees grafted onto

**Table 4.** Chromaticity values for the blushed and shaded sides of 'Jonagored' apples harvested in 2003 and 2004 from trees grafted onto M9 and P16 rootstocks

| Rootstock | Lightness | | a* | | b* | |
|---|---|---|---|---|---|---|
| | Blushed | Shaded | Blushed | Shaded | Blushed | Shaded |
| *2003* | | | | | | |
| M9 | 66.1 | 68.7 | –5.2 | –17.0 | 36.8 | 40.8 |
| P16 | 60.8 | 69.3 | 6.7 | –13.5 | 34.9 | 43.0 |
| Signif. | ** | ns | ** | ** | ns | *** |
| *2004* | | | | | | |
| M9 | 58.6 | 68.5 a | 5.1 | –17.7 | 33.0 | 43.1 |
| P16 | 55.5 | 67.0 b | 12.2 | –12.7 | 29.4 | 40.7 |
| Signif. | * | ** | ** | ** | ** | ** |

*,**,***, ns: significant at $P \leq 0.05$, $P \leq 0.01$, $P \leq 0.001$ and non-significant respectively.

**Table 5.** Skin pigment concentrations of the blushed and shaded sides of 'Jonagored' apples harvested in 2003 and 2004 from trees grafted onto M9 and P16 rootstocks

| Rootstock | Chlorophyll a ($\mu$g cm$^{-2}$) | | Chlorophyll b ($\mu$g cm$^{-2}$) | | Total chlorophyll ($\mu$g cm$^{-2}$) | | Carotenoids ($\mu$mol cm$^{-2}$) | | Anthocyanins ($\mu$mol cm$^{-2}$) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Blushed | Shaded | Blushed | Shaded | Blushed | Shaded | Blushed | Shaded | Blushed | Shaded |
| *2003* | | | | | | | | | | |
| M9 | 1.92 | 2.37 | 0.70 | 0.81 | 2.62 | 3.19 | 0.37 | 0.48 | 6.17 | 3.61 |
| P16 | 1.57 | 1.99 | 0.57 | 0.68 | 2.14 | 2.68 | 0.55 | 0.66 | 8.33 | 4.59 |
| Significance | ns[1] | ** | ns | * | ns | ** | ** | *** | ns | ns |
| *2004* | | | | | | | | | | |
| M9 | 1.70 | 1.94 | 0.73 | 0.77 | 2.43 | 2.71 | 0.54 | 0.53 | 11.54 | 3.63 |
| P16 | 1.51 | 1.77 | 0.58 | 0.54 | 2.09 | 2.31 | 0.53 | 0.58 | 19.07 | 5.05 |
| Significance | ns | ns | ** | ns | * | ns | ns | ns | *** | ** |

[1] *,**,***, ns: significant at $P \leq 0.05$, $P \leq 0.01$, $P \leq 0.001$ and non-significant respectively.

M9 rootstocks were significantly higher than those seen in P16-grafted trees (Table 5). The concentration of total carotenoids on both sides of the fruit was higher in apples from the P16-grafted trees. The anthocyanin concentration in the skin was higher on the blushed side than on the shaded side, but neither rootstock type nor crop load significantly affected this.

In 2004, no significant differences were seen in apple skin chlorophyll a concentration on either side of the fruit (Table 5), although the chlorophyll b concentration was significantly higher on the blushed side of fruit from the M9-grafted trees (Table 5). A similar trend was apparent on the shaded side of the fruit. Consequently, on the blushed side the concentration of total chlorophyll was significantly higher in the skin of fruit from the M9-grafted trees. The total carotenoid concentration of the apple skins did not differ significantly with respect to rootstock type. In 2004 the concentrations of anthocyanin was significantly higher on both sides of fruit from the P16-grafted trees (Table 5).

## Vegetative growth and other physiological processes

In 2003, neither crop load, rootstock type, nor their interaction had any effect on tree growth as measured by the relative increase in TCSA. Shoot and leaf growth did not differ with respect to crop load; however, the increase in shoot length was greater in the M9-grafted trees (Fig. 2), and the shoot growth period lasted longer than usual (until as late as 8 September, 147 DAFB). Nevertheless, the mean shoot length and mean internode length of a larger sample of winter shoots did not differ significantly with respect to rootstock type (Table 6). Visual observations showed, however, that the number of shoots growing on trees grafted onto M9 rootstocks was greater in P16-grafted trees.

Regression analysis of the shoot growth data in 2004 showed the crop load borne by the trees to have no significant effect on TCSA. However, this variable increased more in trees grafted onto the M9 rootstocks (Table 6). In this year, shoot growth ended by mid-June, and the length of shoots was generally much shorter than in the previous year (Fig. 2). The shoots of trees grafted onto M9 rootstocks were significantly longer than those of the P16-grafted trees, a consequence of the formers' significantly longer internodes (Table 6). Trees grafted onto M9 rootstocks had more shoots than the P16-grafted trees (data not shown).

In 2003, no changes were seen in leaf area due to the interaction between rootstock type and fruit-thinning level, but on average the leaves of the M9-grafted trees were significantly larger (Table 6). The specific leaf weight of the P16-grafted trees was greater for the M9-grafted trees, and increased in a quadratic pattern (Fig. 3) over the growing season.

On all dates of 2004 on which data were collected, the leaf area was greater in trees grafted onto M9 rootstocks (Table 6). The two rootstocks differed significantly in this respect on 5 July and 30 September. However, neither the fresh nor dry weights of the leaves differed significantly according to rootstock, although the specific leaf weight, which increased throughout the summer (Fig. 3), was significantly higher at the end of the season in the P16-grafted trees.

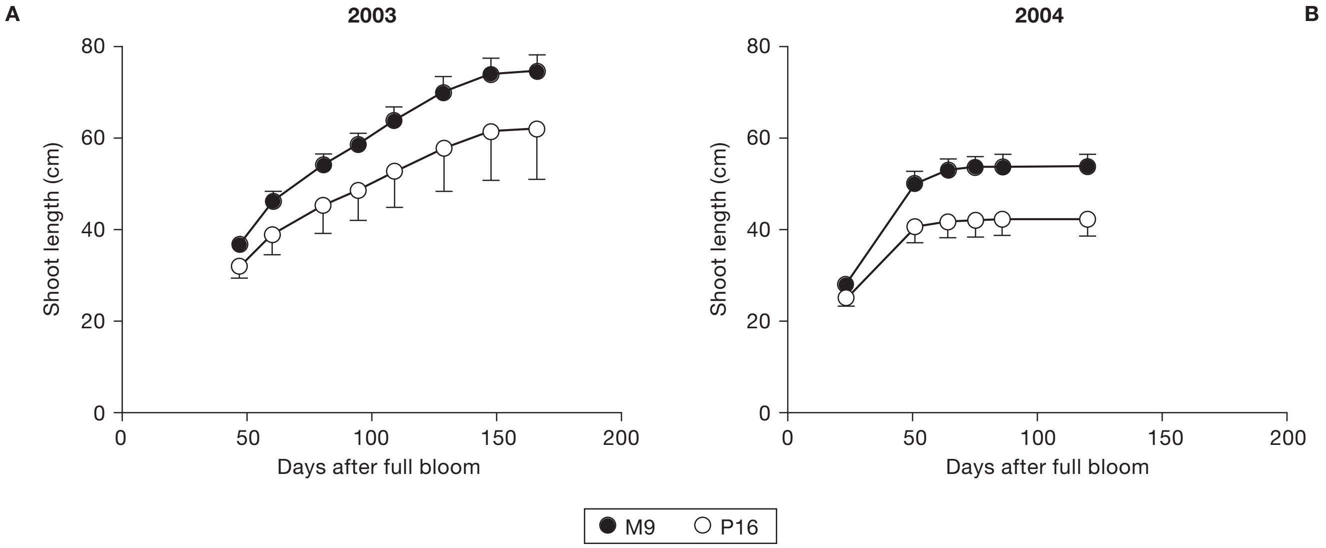

**Figure 2.** Growth in shoot length in 'Jonagored' apple trees grafted onto M9 or P16 rootstocks in 2003 and 2004. Mean ± SE.

No differences were seen in the photosynthetic nor transpiration rates nor stomatal conductance of the leaves from the M9- and P16-grafted trees (Table 7). However, the stomatal density was significantly higher in the leaves of the P16-grafted trees. No differences were seen in the chlorophyll concentration (measured using SPAD) of the leaves from the two types of tree. In 2004, photosynthetic rates were higher and transpiration rates lower than in 2003, but again no differences were seen with respect to rootstock type (Table 7).

In neither year did the interaction between rootstock type and fruit-thinning level have a significant effect on any variable measured.

## Discussion

Increasingly, apple growers are aware of the need to produce high quality fruit, and skin colour, particularly in red apple cultivars, is one of the most important variables valued by consumers. The production of high quality fruit in red apple cultivars is often difficult, particularly in areas where summers are warm. To obtain better results, new cultivars such as 'Jonagored' have been introduced.

When grown under the warm climatic conditions of the Ebro Valley, Spain, the 'Jonagored' cultivar grows vigorously, even when grafted onto M9 rootstocks; however, the fruits are poorly coloured.

Rootstocks affect the fruiting capacity of apple trees and the quality of the fruit produced (Jackson, 2003). In addition, the crop load influences certain variables of fruit quality. To determine to what extent any changes in fruit quality are caused by the rootstock or the crop load borne by the trees, the present experiments included different fruit-thinning levels. In 2003 and 2004, however, poor flower initiation resulted in small crop loads relative to other cultivars (Mata *et al*., 2006) after the fruit-thinning treatments.

**Table 6.** Relative increase in trunk-cross-sectional area (TCSA), length of shoot internodes, and leaf area in 2003 and 2004 of 'Jonagored' trees grafted onto M9 and P16 rootstocks

| Rootstock | Increase in TCSA (%) | | Internode length (mm) | | Leaf area (cm$^2$) | |
|---|---|---|---|---|---|---|
| | 2003 | 2004 | 2003 | 2004 | 2003 | 2004 |
| M9 | 23.4 | 27.6 | 19.6 | 22.2 | 32.9 | 39.9 |
| P16 | 22.1 | 19.9 | 17.9 | 20.4 | 31.1 | 37.3 |
| Significance[1] | ns | * | ns | ** | ns | *** |

[1] *,**,***, ns: significant at $P \leq 0.05$, $P \leq 0.01$, $P \leq 0.001$ and non-significant respectively.

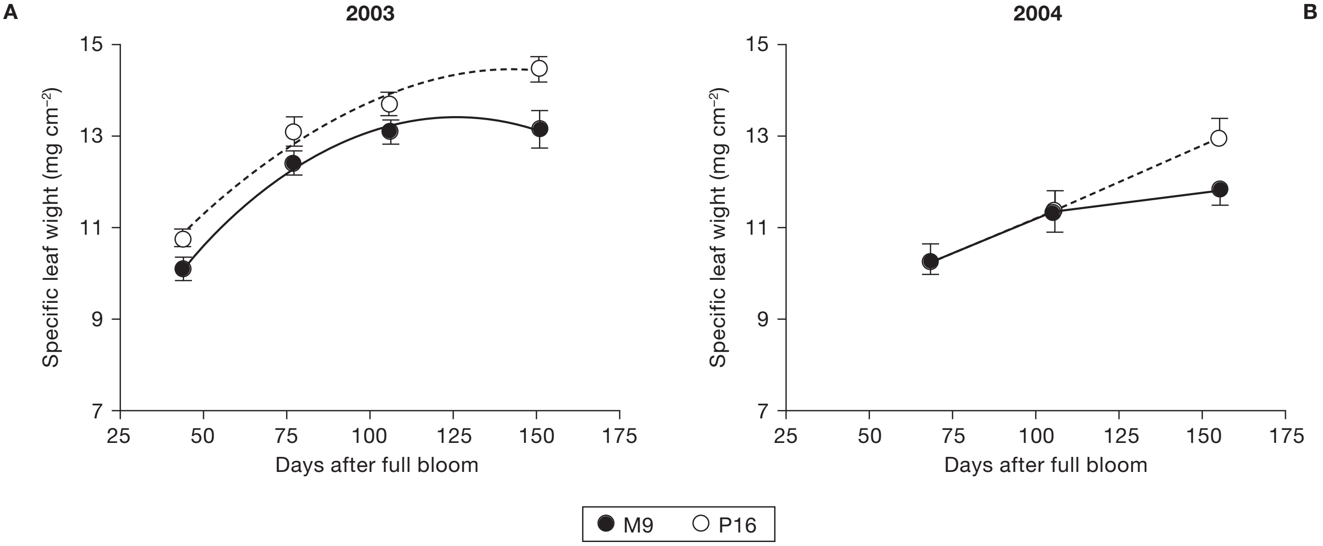

**Figure 3.** Specific leaf weight over the growing seasons of 2003 and 2004 in 'Jonagored' apple trees grafted onto M9 and P16 rootstocks (mean ± SE). 2003: M9: $= 5.620 + 0.124 \times \text{DAFB} - 0.0005 \times \text{DAFB}^2$ ($r^2 = 67.02$; $P \leq 0.001$); P16: $= 6.978 + 0.104 \times \text{DAFB} - 0.0004 \times \text{DAFB}^2$ ($r^2 = 76.58$; $P \leq 0.001$).

In the UK, 'Cox's Orange Pippin' trees grafted onto P16 rootstocks are slightly smaller than those grafted onto M9 rootstocks (Webster and Hollands, 1999). Under the conditions of the Ebro Valley, P16 has been shown to behave as a very dwarfing rootstock; the same has been reported in other locations (Wertheim, 1998). In the present study, the TCSA of the P16-grafted trees was about 70% less than that of the M9-grafted trees. In both years of the study the shoot growth and leaf area were smaller in the former than in the latter trees; however, in 2003, which was a very warm year, the shoot elongation period was longer and the shoots grew longer than in 2004 (when temperatures were closer to normal). Nevertheless, the average leaf area was smaller in 2003 than in 2004.

Cropping levels can affect vegetative growth (Jackson, 2003; Wünsche and Ferguson, 2005) such that the shoot growth of lightly bearing trees is far greater than that of heavily cropped trees. In the present experiment, cropping levels had little effect on vegetative growth, probably because the crop loads were light even in trees left unthinned. In addition, the net photosynthesis was similar in the heavily and lightly cropped trees, presumably because of the light crop loads; increases have been reported in heavily fruiting trees compared to non-bearing trees (Wünsche *et al.*, 2005). In 2003 a higher stomatal density was evident in the leaves of

**Table 7.** Photosynthetic rate (Pn), stomatal conductance ($g_s$), transpiration rate (Tr), stomatal density (Sd) and SPAD (soil plant analysis development) values for the leaves of 'Jonagored' apple trees grafted onto M9 and P16 rootstocks

| **Rootstock** | **Pn (µmol m$^{-2}$ s$^{-1}$)** | **$g_s$ (mmol m$^{-2}$ s$^{-1}$)** | **Tr (mmol m$^{-2}$ s$^{-1}$)** | **Sd (No. stomata mm$^{-2}$)** | **SPAD** |
|---|---|---|---|---|---|
| *2003* | | | | | |
| M9 | 13.05 | 0.27 | 6.87 | 142.4 | 57.1 |
| P16 | 11.34 | 0.26 | 6.78 | 160.2 | 56.5 |
| Significance[1] | ns | ns | ns | * | ns |
| *2004* | | | | | |
| M9 | 15.71 | 0.36 | 5.20 | — | 54.1 |
| P16 | 16.10 | 0.38 | 5.16 | — | 54.1 |
| Significance[1] | ns | ns | ns | — | ns |

[1] ns, *: non-significant and significant at $P \leq 0.05$ respectively.

the P16-grafted trees, which suggests greater gas exchange took place.

In the present work, fruit yields were generally higher on the M9-grafted trees; however, when differences in tree size were taken into account the productivities of the two types of tree were either similar or that of the P16-grafted trees higher. As noted in other studies (Elfving and Schechter, 1993; Mata *et al.*, 2006), the mean fruit weight decreased with increasing crop load irrespective of rootstock type. In 2003, however, the rootstock type had an effect on the water content of the fruit. Presumably, in the very hot summer of 2003, the higher water demand and the relatively small root system of the P16-grafted trees resulted in the lower water content.

Generally, the crop load affects fruit quality (Jackson, 2003; Wünsche and Ferguson, 2005). In the present experiment, the cropping levels induced did not differ appreciably, and the rootstock type only affected the SSC. As reported in other studies (Wünsche and Ferguson, 2005; Mata *et al.*, 2006), the SSC increased in the lightly cropped trees, and was higher in fruit from the P16-grafted trees. This effect was obvious in both years but was most pronounced in 2003, when summer temperatures were the highest.

In 2003, when summer temperatures —and particularly night-time temperatures— were very high, the fruits were brighter and less red (a* values) than in 2004. The development of the red colour of the apple skin is associated with differences between day and night-time air temperatures (Blankenship, 1987). In 2003, the less intense red colour might have been influenced by lower concentrations of anthocyanins in the apple skin. In addition, the fruit from P16-grafted trees were redder than those of the M9-grafted trees, which paralleled differences in the concentrations of anthocyanins and brightness (lightness values).

P16-grafted 'Jonagored' trees are far smaller than their M9-grafted counterparts; the shoots grow less and the leaves are smaller, which results in less dense canopies (Schechter *et al.*, 1991). Dwarfing rootstocks allow for greater light penetration (Robinson, 1997) and consequently to higher quality fruit, particularly in terms of SSC and skin colouring, because the fruit is more exposed to the sun than when rootstocks that promote more vigorous growth are used. Hunter and Proctor (1986) reported a correlation between light interception and fruit colour. In summary, the use of a very dwarfing rootstock such as P16 should be considered when growing vigorous red apple cultivars in regions with warm summers, where good fruit colouring is difficult to attain.

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## References

AWAD M.A., DE JAGER A., VAN DER PLAS L.H.W., VAN DER KROL A.R., 2001. Flavonoid and chlorogenic acid changes of 'Elstar' and 'Jonagold' apples during development and ripening. Scientia Hort 90, 69-83. doi:10.1016/S0304-4238(00)00255-7.

BLANKENSHIP S.M., 1987. Night temperature effects on rate of apple fruit maturation and fruit quality. Scientia Hort 33, 205-212. doi:10.1016/0304-4238(87)90068-9.

CZYNCZYK A., OLSZEWSKA B., 1990. Growth and yielding of 3 apple cultivars on rootstocks of Polish and foreign breeds. Fruit Sci Rep 17, 65-75.

ELFVING D.C., SCHECHTER I., 1993. Fruit count, fruit weight and yield relationships in 'Delicious' apple trees on nine rootstocks. HortScience 28, 793-792.

HUNTER D.M., PROCTOR J.T.A., 1986. The correlation of light interception with yield and fruit color of McIntosh apple strains. Fruit Var J 40, 79-83.

IGLESIAS CASTELLARNAU I., CARBÓ PERICAY J., BONANY ROCAS J., DALMAU BARBAROJA R., GUANTER FEIXAS G., MONTSERRAT SANGÁ R., MORENO TORRES A., PAGÉS GRAU J.M., 2000. Manzano, las variedades de más interés. Institut de Recerca i Tecnología Agroalimentàries, Barcelona. [In Spanish].

JACKSON J.E., 2003. Biology of apples and pears. Cambridge University Press, Cambridge, UK.

KONDO S., INOUE K., 1997. Abscisic acid (ABA) and 1-aminocyclopropane-1-carboxilic acid (ACC) content during growth of 'Satohnishiki' cherry fruit, and the effect of ABA and ethephon application on fruit quality. J Hort Sci 72, 221-227.

MATA A.P., VAL J., BLANCO A., 2006. Prohexadione-calcium effects on the quality of 'Royal Gala' apple fruits. J Hort Sci Biotech 81, 965-970.

McGUIRE R., 1992. Reporting of objective colour measurements. HortScience 27, 1254-1255.

ROBINSON T.L., 1997. Interaction of tree form and rootstock on light interception, yield and efficiency of 'Empire', 'Delicious' and Jonagold' apple trees trained to different systems. Acta Hort 451, 427-436.

SAURE M.C., 1990. External control of anthocyanin formation in apple. Scientia Hort 42, 181-218. doi:10.1016/0304-4238(90)90082-P.

SCHECHTER I., ELFVING D.C., PROCTOR J.T.A., 1991. Canopy development, photosynthesis, and vegetative growth as affected by apple rootstocks. Fruit Var J 45, 229-237.

SNEDECOR G.W., COCHRAN W.G., 1980. Métodos estadísticos. Compañía Editorial Continental SA, Mexico. pp. 528-532. [In Spanish].

VAL J., MONGE E., BAKER N.R., 1994. An improved HPLC method for rapid determination of the xanthophyll cycle pigments. J Chromatogr Sci 32, 286-289.

WEBSTER A.D., HOLLANDS M.S., 1999. Apple rootstock studies: Comparison of Polish, Russian, USA and UK selections as rootstocks for the apple cultivar Cox's Orange Pippin (*Malus domestica* Borkh.). J Hort Sci Biotech 74, 367-374.

WERTHEIM S.J., 1998. Rootstock guide. Apple, pear, cherry, European plum. Publication no. 25, Fruit Research Station, Wilhelminadorp, The Netherlands.

WÜNSCHE J.N., FERGUSON I.B., 2005. Crop load interactions in apple. Hort Rev 31, 231-290.

WÜNSCHE J.N., GREER D.H., LAING W.A., PALMER J.W., 2005. Physiological and biochemical leaf and tree responses to crop load in apple. Tree Phys 25, 1253-1263.