

Vegetative and reproductive growth of ‘Fuji’ and ‘Rosy Glow’ trees grafted on ‘Geneva’ rootstocks as an alternative to ‘M9’

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Abstract: In the Po Valley, the apple ‘M9’ rootstock has always been the one mostly adopted although recently it is undergoing a slow decrease in its utilization. The main causes of this phenomenon are soil fatigue, new pests and diseases, new cultivation systems, and poor adaptability to new environmental conditions due to climate change. An experimental orchard for the comparison of rootstocks produced by the Geneva research program, was set up in 2020 at the F.lli Navarra Agriculture Foundation in Malborghetto di Boara (FE). The purpose of the trial was to evaluate the performance of four different Geneva rootstocks in the Po Valley: ‘CG969’, ‘CG11’, ‘CG210’, ‘CG935’ in comparison with the control ‘M9 T337’. The trial was set up with a randomized block scheme including two varieties suitable for lowland production, ‘Fuji’ and ‘Rosy Glow’. The parameters measured were related to the vegetative-productive growth, canopy light penetration, fruit quality at harvest, and return bloom. In the cv ‘Fuji’, ‘CG935’ rootstock showed the best performance in comparison with ‘M9 T337’ control, while for the cv ‘Rosy Glow’, ‘CG210’ rootstock showed the best responses. However, since rootstock effects may differ from site to site, further studies are needed, over several productive seasons to evaluate them in relation to the environmental conditions and the peculiarity of the growing area.

Keywords: Apple; Solaxe; Physiology; ‘M9’; Geneva.

1. Introduction

Grafting in fruit trees is an ancient technique that allows vegetative propagation (Basile and DeJong, 2018). The main objective of this practice is to maximize plant performance by joining individuals belonging to different species. The advantages of this technique include: i) adaptation of plants to different climatic and soil conditions (e.g. calcareous soils, saline soils); ii) regulation of vegetative development and fruiting; iii) anticipate fruiting; iv) replacement of plant parts; v) prevention of viruses or other diseases (thanks to the employment of resistant rootstocks); vi) nutrition and fruit quality improvements; and vii) reduction of cultivar vigor (Aldini, 1953). Furthermore, rootstock can play an important role in mitigating extreme weather conditions due to climate changes, such as drought (Valverdi and Kalcsits, 2021).

So far, the ‘M9’ rootstock has always been the reference rootstock in apple production. It was obtained from apple trees by mass selection of the ‘Metz Yellow Paradise’ population in East Malling (UK) in 1879. It has attracted interest over time, triggered by the fact that it allows to obtain plants with reduced vigor, about 60-70% less than seedling rootstocks (Sansavini et al., 2014). In addition, it is generally compatible with all cultivated varieties and induces early fruiting and high productivity and fruit quality at harvest (Sansavini et al., 2014). However, nowadays the continuous spread of “fire blight” (*Erwinia amylovora*) is threatening the apple orchard survival since ‘M9’ is highly susceptible to this disease. For this reason, it would be interesting to have resistant rootstock to *E. amylovora*, as well as to woolly aphid (*Eriosoma lanigerum*), collar rot (*Phytophthora* spp.) and apple proliferation (*Candidatus Phytoplasma mali*). Furthermore, soil fatigue, a phenomenon that occurs when the same crop is replant-

ed on the same plot for prolonged periods, is also a very important aspect to evaluate. Indeed, tolerance towards soil fatigue is a highly desirable trait since the permanent orchard structure requires to re-plant in the same lines as the previous plantations, preventing the rows from being moved to a different position (Höller and Guerra, 2020).

Studies comparing the effect of rootstocks on fruit have often been inconsistent because they lack evaluating other factors which contribute to production, such as crop load, tree size, light penetration, and number of seeds. It is difficult to test the effects of one factor such as rootstock without considering other potential sources of variability that could alter the impact of rootstock on fruit size at harvest (Yahya et al., 2004). Indeed, Palmer et al. (1997) reported that crop load had a significant influence on fruit size, documenting that high crop yield leads to smaller fruit rather than to a reduced yield. The number of seeds per fruit also appeared to be an important factor in determining fruit size (Tenne, 1963). However, not all varieties appeared to be influenced by seed number, as shown in ‘Gala’ (Yahya et al., 2004). Vegetative differences induced by rootstock have been examined in several studies (Basile and DeJong, 2018). Autio and Southwick (1986) found that ‘Starkrimson Delicious’ trees on vigorous rootstocks were less productive and efficient, being characterized by the lower yield per canopy area. Evaluations on fruit weight also indicated that plants grafted on ‘M9’ rootstocks (Autio and Southwick, 1993) were better performing than trees on vigorous rootstocks, due to a better balance between vegetative and productive activities. It is important to underline that, beside rootstock, climatic conditions are widely recognized as a major determinant of fruit quality (Hodgson, 1967; Janick and Moore, 1975), followed by canopy management, nutrition, and other agricultural practices, but their individual and combined importance varies considerably depending on the crop (Castle, 1994).

Light exposure (Robinson et al., 1983) has been shown to be very important for fruit quality, even more than the rootstock. Indeed, light affects fruit growth and quality, including color, soluble solids content and fruit fresh weight (Robinson et al., 1983). Rootstocks may affect soluble solids by modifying fruit-to-leaf ratio and carbon relations (Flore, 1996; Lakso, 1994). Similarly, canopy and crop load management may strongly impact fruit quality. Autio (1991) found a strong positive relationship between crop density and ripening date. More specifically, the author reported that a delayed ripening was recorded in high planting density orchards obtained adopting size-controlling rootstocks and that the differences in fruit maturity were mainly due to the rootstock (John et al., 1992). Conversely, Lord et al. (1985) found that fruit firmness was not affected by the rootstock in the cv. ‘Empire’, whereas soluble solids content and starch content were slightly higher in fruit from trees on vigorous rootstocks than on dwarfing rootstocks. On the same variety, Perry and Dilley, (1984) reported that there was no difference between trees on different rootstocks in fruit firmness at harvest and during postharvest storage, and in postharvest starch degradation. Thus, results about the effect of rootstock on fruit quality are contrasting. Drake et al., (1988) highlighted that more vigorous rootstocks were responsible for less fruit coloration. Webster and Hollands (1997) also showed that in ‘Cox’s Orange Pippin’ grown on 24 different clones of ‘M9’ there was not consistent effect on flowering date, return bloom, and fruit set. However, the effects on fruit quality at harvest induced by most of the rootstocks studied were characterized by high variability, both spatial and temporal. Thus, these factors must be evaluated in relation to both the climatic conditions of the growing area where the study is carried out and the tree age.

This study aimed at comparing the performance of different rootstocks alternative to the traditional ‘M9’, in two apple varieties representative of the Po Valley production, ‘Fuji’ and ‘Rosy Glow’, evaluating also the effects on harvested yield and fruit quality.

The rootstocks evaluated were from the Cornell Geneva (USA) series, whose apple rootstock research and selection program has been active since 1970 (Fazio and Robinson, 2024), also thanks to its access to vast germplasm resources (Aldwinkle et al., 1976; Utkhede, 1986). This available genetic diversity allowed the identification of individuals tolerant to soil fatigue syndrome, a complex disease caused by several agents such as *Phytophthora* spp., *Pythium* sp., and *Rhizoctonia solani* (Mazzola 1998; Mazzola and Manici 2012), as evidenced by studies carried out in different locations in the United

States and around the world (Auvil et al, 2011; Fazio et al., 2012; Leinfelder and Merwin, 2006; Rumbergher et al., 2004; Laurent et al., 2010; Yao et al., 2006; Fazio and Robinson, 2024).

2. Materials and Methods

The trial was carried out in an orchard located in Malborghetto di Boara (Ferrara), Emilia-Romagna, Italy, located at the F.lli Navarra Foundation for Agriculture (44°51'32.4 "N 11°39'24.7 "E 44°51'37.2 "N 11°39'24.3 "E). The experimental orchard was set up in a randomized block design with the combination among two apple varieties ('Fuji' and 'Rosy Glow') and five rootstocks ('M9', 'CG969', 'CG11', 'CG210', 'CG935'). The orchard was planted in 2020 with a planting density of 4.3 m × 1.66 m (1400 trees/ha) for 'Rosy Glow' and 4.3 m × 2 m (1162 trees/ha) for 'Fuji' and was covered with grey anti-hail net (25% shading). Trees were trained to a Solaxe system (Lauri and Lespinasse, 2000).

The first part of the study was carried out during the 2022 growing season, when the apple orchard was at its third leaf, which corresponded also to the first year of fruit production. For each variety/rootstock combination, six trees were selected for the study, divided into randomized blocks between rows (a total of 60 trees). On the same trees, return bloom was assessed during spring 2023 (fourth leaf).

Standard cultural practices for pruning, fertilization, and irrigation were carried out during the season. For both varieties, full bloom occurred on 14 April 2022, and 12 April 2023. The four Geneva rootstocks used have the following features:

- 'Geneva 11' ('CG11'), obtained by the crossing 'M26' × 'Robusta 5', has improved resistance to diseases such as bacterial fire blight (*E. amylovora*) and tolerant to *Phytophthora* spp., possesses dwarfing ability, higher production efficiency than 'M9' and, to some extent, can be an excellent alternative to soil disinfection (Höller and Guerra, 2020). It is not resistant to woolly aphid and soil fatigue (Pasqualini et al., 2020).
- 'Geneva 969' ('CG969'), obtained by the crossing 'Ottawa 3' × 'Robusta 5', is similar to 'M7' rootstock in terms of vigor, has higher productivity than M9, and high resistance to fire blight, tolerance to *Phytophthora* spp., woolly aphid, and winter cold resistance (Höller and Guerra, 2020).
- 'Geneva 935' ('CG935'), obtained by the crossing 'Ottawa 3' × 'Robusta 5', is a rootstock with good production efficiency. It tends to be more vigorous than rootstock 'M26' and is highly resistant to bacterial fire blight, *Phytophthora* spp., as well as to winter cold, but not to woolly aphid. It also has tolerance to soil fatigue (Pasqualini et al., 2021).
- 'Geneva 210' ('CG210'), obtained by the crossing 'Ottawa 3' × 'Robusta 5', has a vigor equivalent to rootstock 'M7', is resistant to soil fatigue, fire blight, and woolly aphid, and very tolerant to root rot (*Phytophthora* spp.) and winter cold (Pasqualini et al., 2021).

These rootstocks, with the exception of 'CG210', have in common a poor suckering ability that can cause problems during stump multiplication (Pasqualini et al., 2021).

2.1. Parameters monitored

During the 2022 growing season, the main growth parameters were monitored at regular times intervals during the season for the various cultivar/ rootstock combinations. In addition, canopy light penetration was also assessed. Measurements were carried out from 20 May 2022 until harvest. In spring 2023, the return bloom and fruit set were assessed at the full flowering stage.

2.1.1. Seasonal fruit and shoots growth

Seasonal fruit growth was monitored on six fruit per plant, three on each side of the canopy, for a total of 360 fruit (six trees per treatment). From 36 days after full bloom (DAFB) onwards, fruit diameter was periodically measured using an electronic caliper equipped with a data logger. In detail, measurements were taken at 35, 45, 56, 67, 77, 89, 106, 116, 126, 138, 148, 158, 171, and 181 DAFB. In 'Fuji', harvest was carried out on 03 October 2022 (173 DAFB), so the last measurement in the field was taken on 19 September 2022 (158 DAFB) while for 'Rosy Glow' it was taken on 11 October 2022

(180 DAFB). Fruit diameter (mm) was converted to fresh weight (g) with a specific equation for each variety:

$$\text{'Rosy Glow' fruit fresh weight} = 0.0006 \times \text{Fruit} \quad (\text{eq. 1})$$

$$\text{'Fuji' fruit fresh weight} = 0.0003 \times \text{Fruit} \quad (\text{eq. 2})$$

For both regressions, equations had a coefficient of determination of 0.99 and were obtained using fruit diameters and fresh weights data previously collected from several orchards and vegetative seasons.

In addition, shoot growth measurements were carried out on four shoots per tree, two on each side of the canopy (for a total of 240 measurements), using a measuring tape. Measurements were taken at 35, 45, 56, 67, 77, 89, 106, 116, 126, 138, 148, 158, 171, and 181 DAFB. For both fruit and shoots, absolute and relative growth rates (AGR and RGR, respectively) were calculated using the following equations:

$$\text{Fruit AGR} = \frac{w1 - w0}{\tau1 - \tau0} \quad (\text{eq. 3})$$

$$\text{Fruit RGR} = \frac{w1 - w0}{(\tau1 - \tau0) \times w1} \quad (\text{eq. 4})$$

$$\text{Shoot AGR} = \frac{L1 - L0}{\tau1 - \tau0} \quad (\text{eq. 5})$$

$$\text{Shoot RGR} = \frac{L1 - L0}{(\tau1 - \tau0) \times L1} \quad (\text{eq. 6})$$

Where W1 and W0 represent fruit fresh weight measured at time 1 (T1) and at the previous measuring time (T0), respectively. Similarly for shoots, L1 and L0 represent shoot length measured at T1 and T0, respectively.

2.1.2. Light distribution within the canopy

In order to assess the light distribution within the canopy and its variation during the growing season, the photosynthetic active radiation (PAR) incoming inside the canopy was measured on individual trees (60 trees) using a ceptometer (Accupar LP-80, Decagon) on 05 July 2022 (82 DAFB) and repeated on 07 October 2022 (176 DAFB). Both measurements were carried out around solar noon. Each measurement lasted approximately three hours, with PAR measurements taken both under the net and outside the net at the start and end of the measuring session. Measurements were taken in different positions within the orchard: i) above the canopy, just under the hail net and ii) at two different heights within the canopy, approximately at 1.20 m and at 1.60 m from the ground. These values were then compared to measurements taken in full light. Based on these data, the percentage of light that was not intercepted by the canopy (%LNI) was calculated using the following equation:

$$\% \text{ LNI} = \frac{\text{LNI}}{\text{LUN}} \times 100 \quad (\text{eq. 7})$$

Where LNI is the PAR measured at 1.20 m and 1.60 m, and LUN is the PAR measured under the net.

2.1.3. Fruit quality at harvest

Fruit harvest was carried out on 3 October 2022 (173 DAFB) for 'Fuji' trees, and on 17 October

2022 (188 DAFB) for ‘Rosy Glow’. For each block, 12 fruit were then sampled (a total of 36 fruit for each cultivar/rootstock combination).

The following fruit quality parameters were measured: diameter, fresh weight, color (background and overcolor), firmness, starch content, and soluble solids content. An electronic caliper (Mitutoyo) was used to measure the fruit diameter, whereas an electronic scale was used to measure fruit fresh weight. Fruit skin color was measured with colorimetric cards released by the consortium “MelaPiù” and CTIFL for ‘Fuji’ and ‘Rosy Glow’, respectively. Fruit flesh firmness was measured on the sides of each fruit (after removing the peel) with a hand-held fruit firmness tester (FT327, Inderst) equipped with an 11-mm probe. Starch content at harvest was evaluated only on ‘Rosy Glow’ on 12 fruit per rootstock. The Lugol’s test was used to evaluate the fruit starch, by applying on both side of the fruit (after removing the peel) the Lugol’s solution and interpreting the results using the standard codes provided by CTIFL (“Code amidon Pomme”). Fruit solids content was measured with an analog refractometer (House FFV7070-FT, Labbrox)

2.1.4. Return bloom

On 1 April 2023, the number of flowers in king flower stage (60 BBCH scale) and the number of corymbs were counted on two branches, on both sides of the canopy of each of the 60 selected plants. Return bloom was evaluated on the same branches where fruit and shoot growth surveys were conducted in 2022. In addition, on selected branches, their length and diameter were measured in order to evaluate the branch area assuming the branch as a cylinder and thus calculating the lateral area (BCA) with the following equation:

$$BCA = \pi \times \text{Branch diameter} \times \text{Branch length} \quad (\text{eq.8})$$

Then, the number of flowers and fruit was normalized based on the lateral area of the branch, by dividing the number of flowers or fruits by the calculated BCA.

On 5, 6, and 7 April 2023, late radiation frosts occurred, resulting in damage to flowers on both varieties, with minimum temperatures recorded at the meteorological station in Malborghetto di Boara (Ferrara) of -1.6 °C. A damage of around 10% was quantified. Finally, on 5 May 2023, the number of intact fruit, about 1-3 mm in diameter, was counted to calculate the percentage of fruit set (%FS) using the following equation:

$$\%FS = \frac{\text{No fruit}}{\text{No Flowers}} \times 100 \quad (\text{eq. 9})$$

2.2. Statistical analysis

Data from the two cv. (‘Fuji’ and ‘Rosy Glow’) were analyzed separately. Within each variety, the significance of the effect of the rootstock on each measured parameter was assessed by analysis of variance (ANOVA) using the SNK test as a post hoc test for mean separation ($p < 0.05$). Analyses were performed using SAS (SAS Institute Inc.) statistical software.

3. Results

3.1. Seasonal fruit growth in ‘Fuji’ trees

Seasonal fruit diametrical growth in ‘Fuji’ did not show any difference up to 106 DAFB. From 116 DAFB until harvest, fruit on ‘CG969’ presented significantly lower size of about 2-3 mm compared to trees on ‘M9’, ‘CG11’, and ‘CG935’ (Figure 1a). Similarly, absolute growth rate (AGR) in ‘Fuji’ trees on ‘CG969’ showed the lowest values at 45, 116 and 138 DAFB (Figure 1b). Relative growth rate (RGR) did not show differences throughout the season (data not shown). Looking at the seasonal pattern

of fruit fresh weight (Figure 1c), ‘Fuji’ fruit growth was similar to the diametrical growth, although it was more linear. At harvest trees on ‘CG969’ presented the lowest fruit weight, resulting about 20 g lower compared to other treatments.

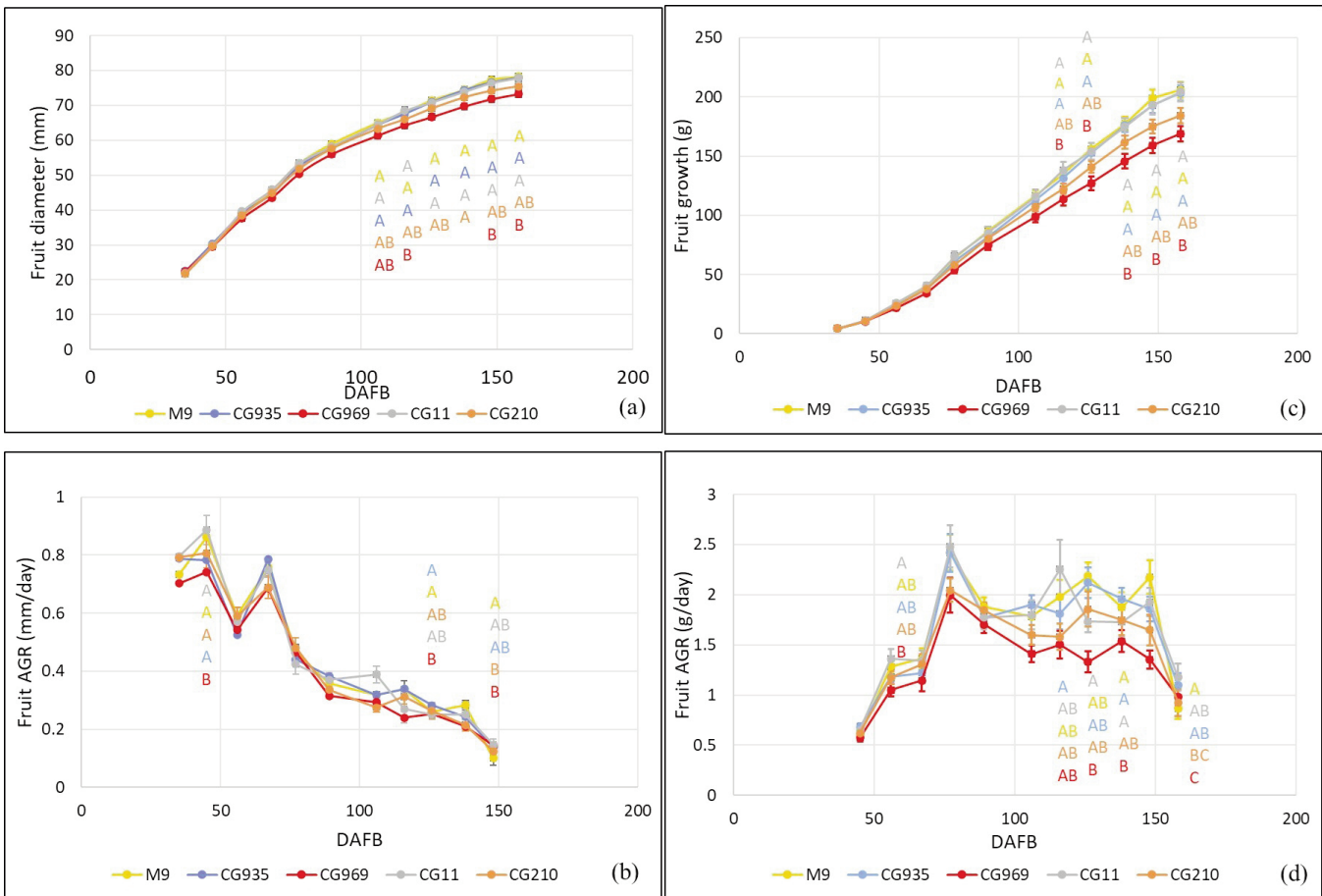


Figure 1. Seasonal fruit growth (a, c) and absolute growth rate (AGR) (b, d) of fruit expressed in diameter (a, b) and fresh weight (c, d) produced on ‘Fuji’ trees grafted on different rootstocks: ‘M9’ (yellow line), ‘CG935’ (blue line), ‘CG969’ (red line), ‘CG11’ (grey line) and ‘CG210’ (orange line). Each point represents the average of 36 fruit collected on six trees. Within each monitoring day, different letters indicate significant differences between rootstocks according to the SNK test ($p < 0.05$).

3.2. Seasonal fruit growth in ‘Rosy Glow’ trees

In ‘Rosy Glow’ trees, seasonal fruit growth (Figure 2a) showed difference among rootstocks from 56 DAFB to harvest (181 DAFB), with trees on ‘CG11’ having the lowest fruit diameters compared to the other rootstocks, along with trees on ‘CG935’ that showed the smallest fruit from 158 to 181 DAFB. In terms of AGR (Figure 2b), at 45 and 56 DAFB trees on ‘CG11’ presented the lowest fruit growth (Figure 2a). This trend changed at 148 DAFB when trees on ‘CG935’ had the lowest fruit AGR compared to the other rootstocks (0.04-0.07 mm/day). At 158 DAFB, trees on ‘CG210’, ‘CG969’, and ‘M9’ showed faster fruit growth, and this trend was also confirmed at 181 DAFB. The seasonal pattern in fruit RGR (Figure 2c) showed lower relative growth in trees on ‘CG11’ at 67 DAFB and in trees on ‘CG935’ at 148 DAFB. Trees on ‘M9’ manifested different behavior unlike the previous parameters with fruit growth significantly lower at 67 DAFB and on average lower at 148 DAFB. No significant difference was found on the other dates.

In ‘Rosy Glow’ trees, seasonal fruit growth in terms of mass showed significant differences between rootstocks (Figure 2d) as for seasonal growth in diameter (Figure 2a), with fruit with lower

weights in trees on ‘CG11’ from 56 to 181 DAFB, and in trees on ‘CG935’ from 158 to 181 DAFB. Trees on ‘CG11’ showed lower AGR at 45, 56, 106, 116, and 148 DAFB (Figure 2e), while trees on ‘CG935’ had fruit with lower growth rates (ca. 0.1-0.4 mm/day) at 116, 148, and 158 DAFB. Trees on ‘CG969’ exhibited intermediate AGR at 48 and 58 DAFB, as occurred for trees on ‘CG210’ at 48 and 158 DAFB. RGR (Figure 2f) exhibited the same difference found in fruit diameter (Figure 2c) with lower values in trees on ‘CG11’ at 67 DAFB (0.01 mm/mm/day) and trees on ‘CG935’ at 148 DAFB (0.03 mm/mm/day).

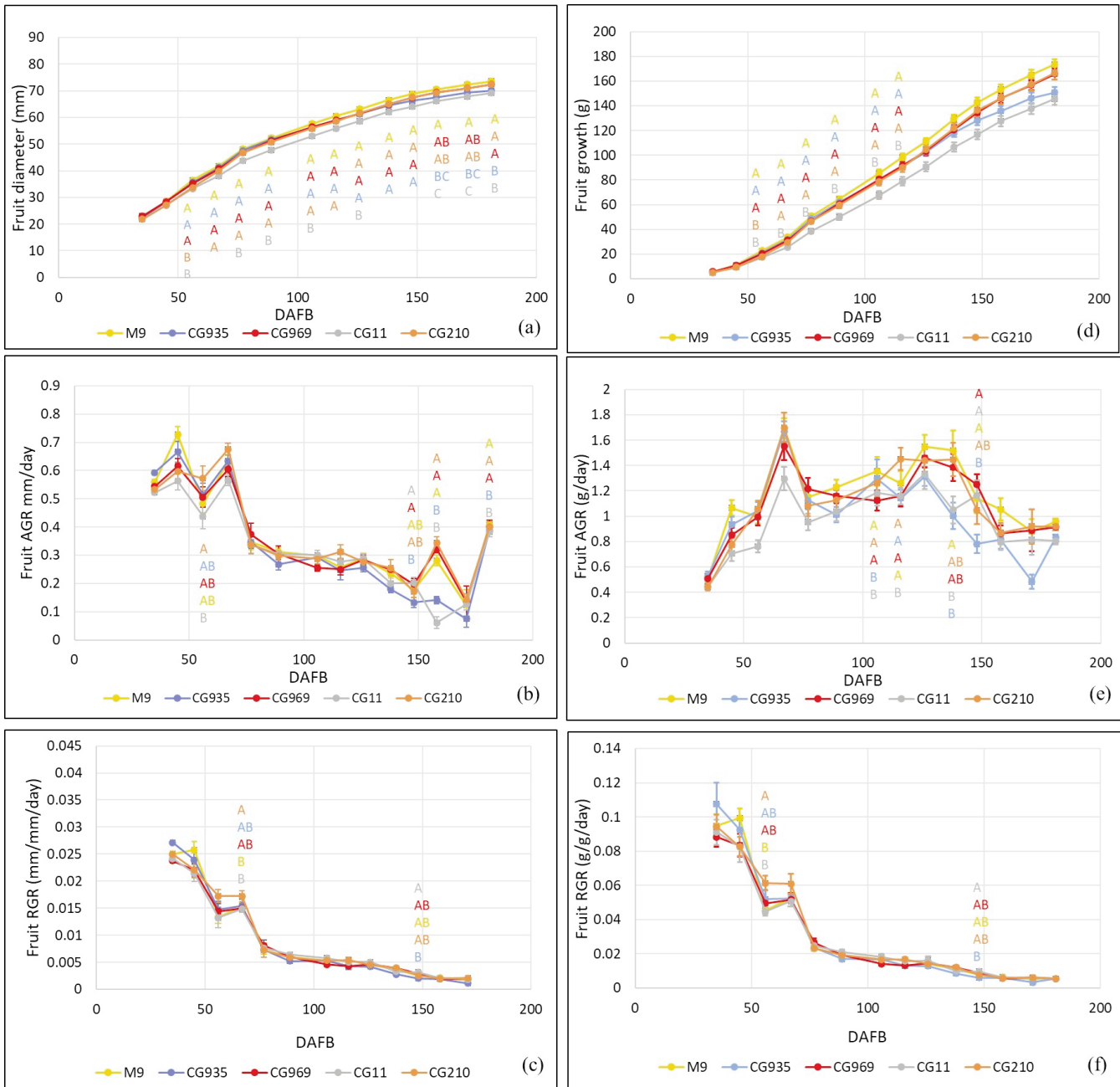


Figure 2. Seasonal fruit growth (a, d) and absolute (b, e) and relative (c, f) growth rate (AGR and RGR, respectively) of fruit expressed in diameter (a, b, c) and weight (d, e, f) on ‘Rosy Glow’ trees grafted on different rootstocks: ‘M9’ (yellow line), ‘CG935’ (blue line), ‘CG969’ (red line), ‘CG11’ (grey line) and ‘CG210’ (orange line). Each point represents the average of 36 fruit collected on six trees. Within each monitoring day, different letters indicate significant differences between rootstocks according to the SNK test ($p < 0.05$).

3.3. Seasonal vegetative shoot growth in ‘Fuji’ and ‘Rosy Glow’ trees

In both cultivars, the seasonal shoot growth, AGR and RGR (Figure 3a, b, and c) did not show differences among rootstocks in ‘Fuji’ trees. Similarly, in ‘Rosy Glow’ trees, seasonal shoot growth did not show differences among rootstocks throughout the season (Figure 3d), whereas shoot AGR at 45 and DAFB (Figure 3e) was lowest in trees on ‘CG935’ and ‘CG11’, while trees on ‘M9’ and ‘CG210’ had an intermediate behavior. At 89 DAFB, trees on ‘CG935’ maintained the lowest shoot growth (0.07 and 0.12 cm/day, respectively), while trees on ‘M9’ and ‘CG210’ showed the same trend as at 45 DAFB. Shoot RGR (Figure 3f) showed statistical differences between rootstocks only at 89 DAFB with trees on ‘M9’, ‘CG969’ and ‘CG935’ having the lowest shoot RGRs.

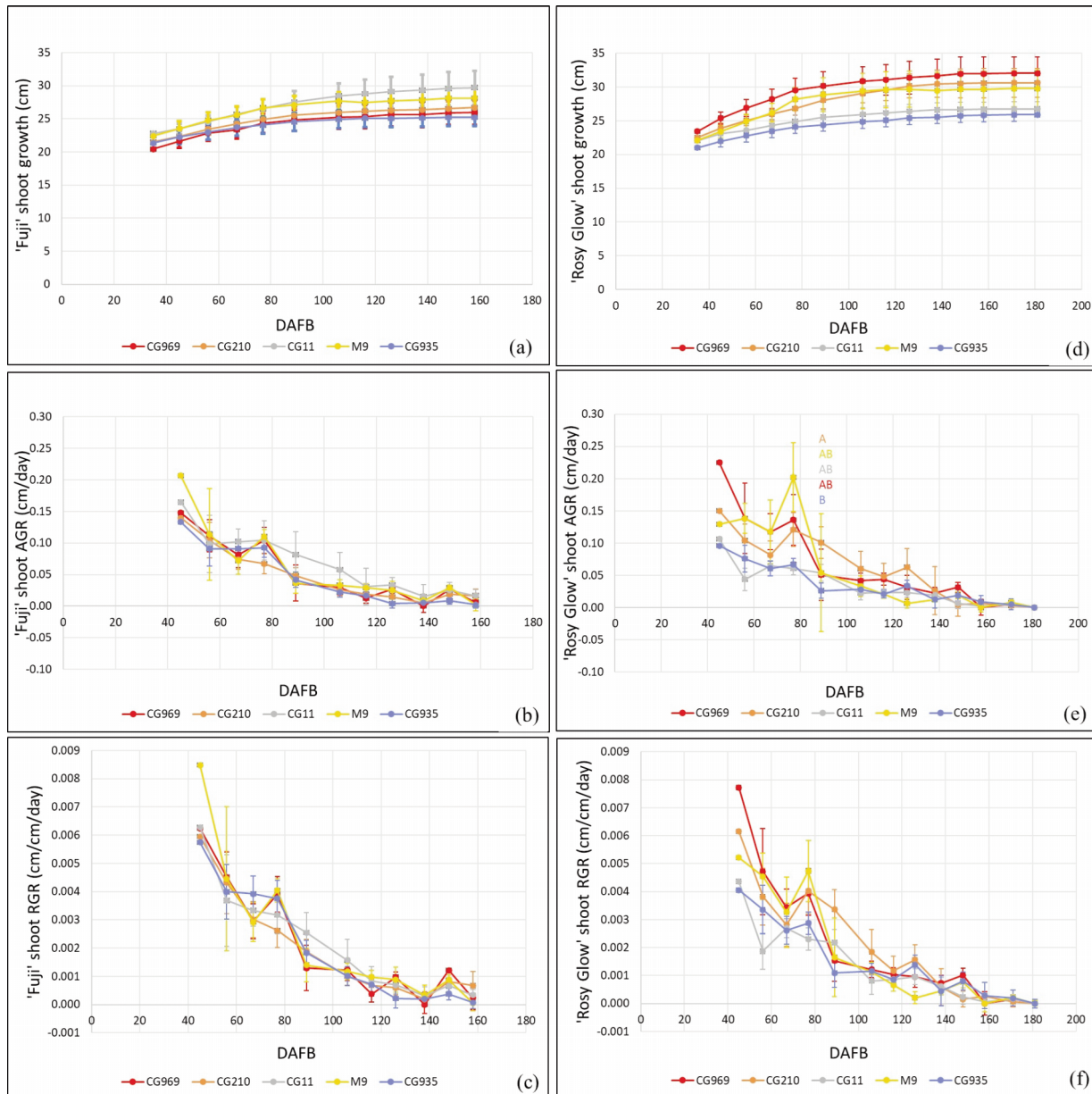


Figure 3. Seasonal shoot growth (a, d) and absolute (b, e) and relative (c, f) shoot growth (AGR and RGR, respectively) rate in ‘Fuji’ (a, b, c) and ‘Rosy Glow’ (d, e, f) trees grafted on different rootstocks: ‘M9’ (yellow line), ‘CG935’ (blue line), ‘CG969’ (red line), ‘CG11’ (grey line) and ‘CG210’ (orange line). Each point represents the average of 36 shoots measured on six trees. Within each monitoring day, different letters indicate significant differences between rootstocks according to the SNK test ($p < 0.05$).

3.4. Intra-canopy light distribution in ‘Fuji’ and ‘Rosy Glow’ trees

In ‘Fuji’ trees, light penetration on 82 and 176 DAFB at 1.20 m above ground level (Figure 4a) did not show any difference among rootstocks, whereas in ‘Rosy Glow’ trees (Figure 4d) the ‘CG11’ and ‘CG935’ rootstocks on 82 DAFB induced a lower light penetration inside the canopy (193.7 and 178.3 $\mu\text{mol}/\text{m}^2/\text{s}$, respectively) suggesting an improved light interception by the upper part of the canopy. At mid-canopy (1.60 m from the ground; Figure 4b) ‘Fuji’ trees on ‘CG969’ and ‘CG210’ had lower light penetration at 82 DAFB (379.7 and 307.2 $\mu\text{mol}/\text{m}^2/\text{s}$, respectively) thus showing a better light interception by the part of the canopy above the measuring point than the other cv/rootstock combinations. Similar results were found also later in the season (on 176 DAFB) in trees on ‘CG969’ and ‘CG210’.

The percentage of light intercepted by the canopy, showed an effect of the rootstock only in ‘Rosy Glow’ tree (Figure 4f) on 82 DAFB with trees on ‘CG11’ and ‘CG935’ having lower percentage of light not intercepted by the canopy (13.7% and 12.6%, respectively).

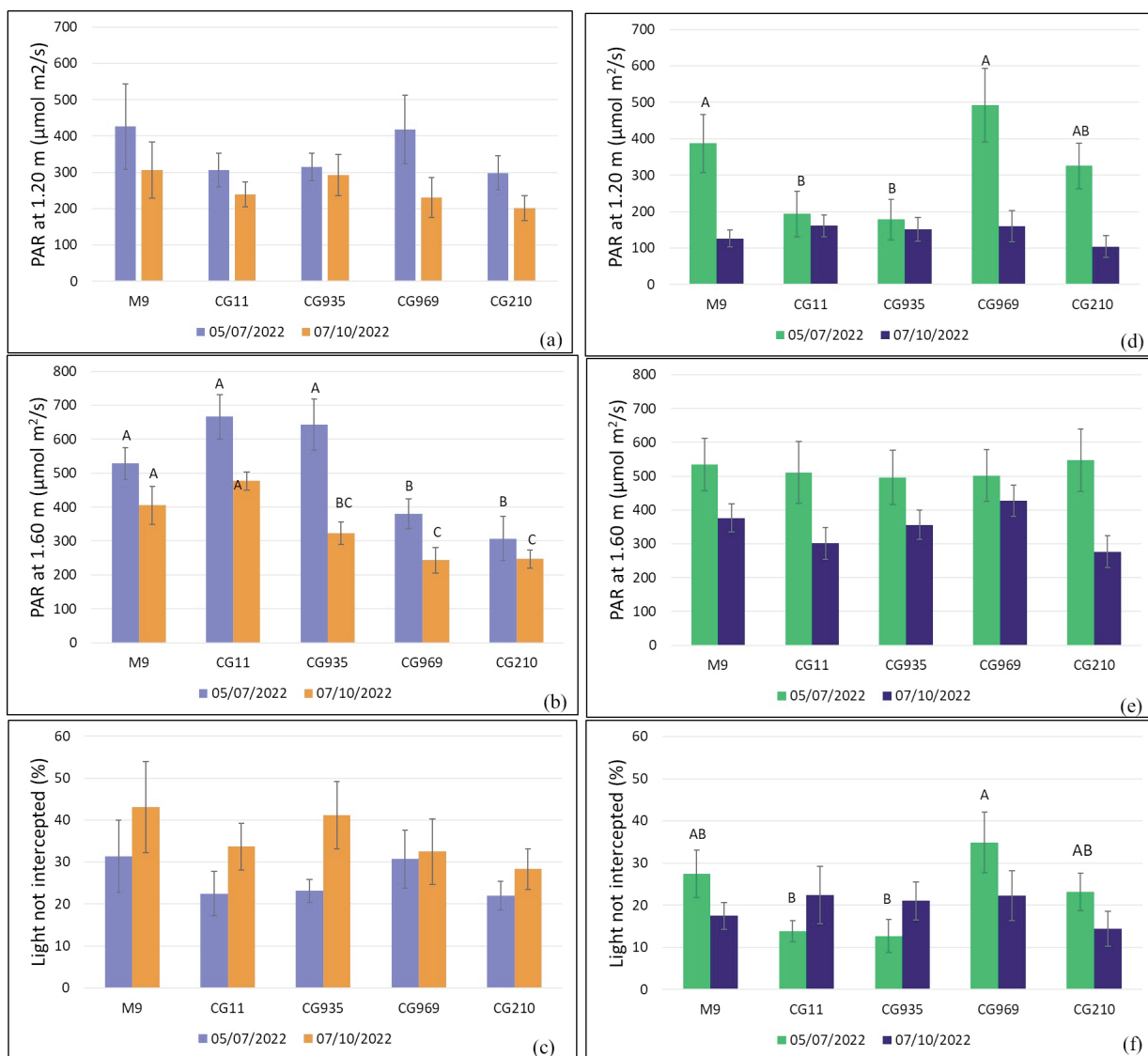


Figure 4. Photosynthetic active radiation (PAR) measured within the crown (1.20 m above ground) (a, d), half-crown (1.60 m above ground) (b, e) and percentage of PAR not intercepted by the whole canopy (c, f) on 82 and 176 DAFB in ‘Fuji’ (a, b, c) and ‘Rosy Glow’ (d, e, f) trees grafted on different rootstocks: ‘M9’, ‘CG11’, ‘CG935’, ‘CG969’, and ‘CG210’. Each column represents the average of six trees per treatment. Lower values indicate plants with better canopy interception. Within each monitoring day, different letters indicate significant differences between rootstocks according to the SNK test ($p < 0.05$).

3.5. Fruit quality at harvest

In ‘Fuji’ trees, significant differences were found between rootstocks for fruit flesh firmness. The highest flesh firmness values were found in fruit from trees grafted on ‘CG969’ (12.2 kg). Conversely, the statistically lowest values were observed in trees on ‘CG935’ (11.2 kg), while trees on ‘M9’, ‘CG11’, and ‘CG210’ (Figure 5b) had intermediate values. Fruit from ‘Rosy Glow’ showed lower diameter when grafted on ‘CG11’ (69.7 mm; Figure 5d) as well as a lower fresh weight (150.5 g; Figure 5d). In ‘Rosy Glow’ trees, fruit firmness (Figure 5e) was lower in trees on ‘CG969’ and ‘M9’, while trees on ‘M9’ and ‘CG210’ showed the lowest soluble solids content (15.2 °Brix; Figure 5e). Similarly to ‘Fuji’ (Figure 5c), ‘Rosy Glow’ trees (Figure 5f) did not show differences in fruit coloration among the rootstocks. Starch content presented similar values regardless of the rootstock considered, with values between 2.5 and 3.2 CTIFL.

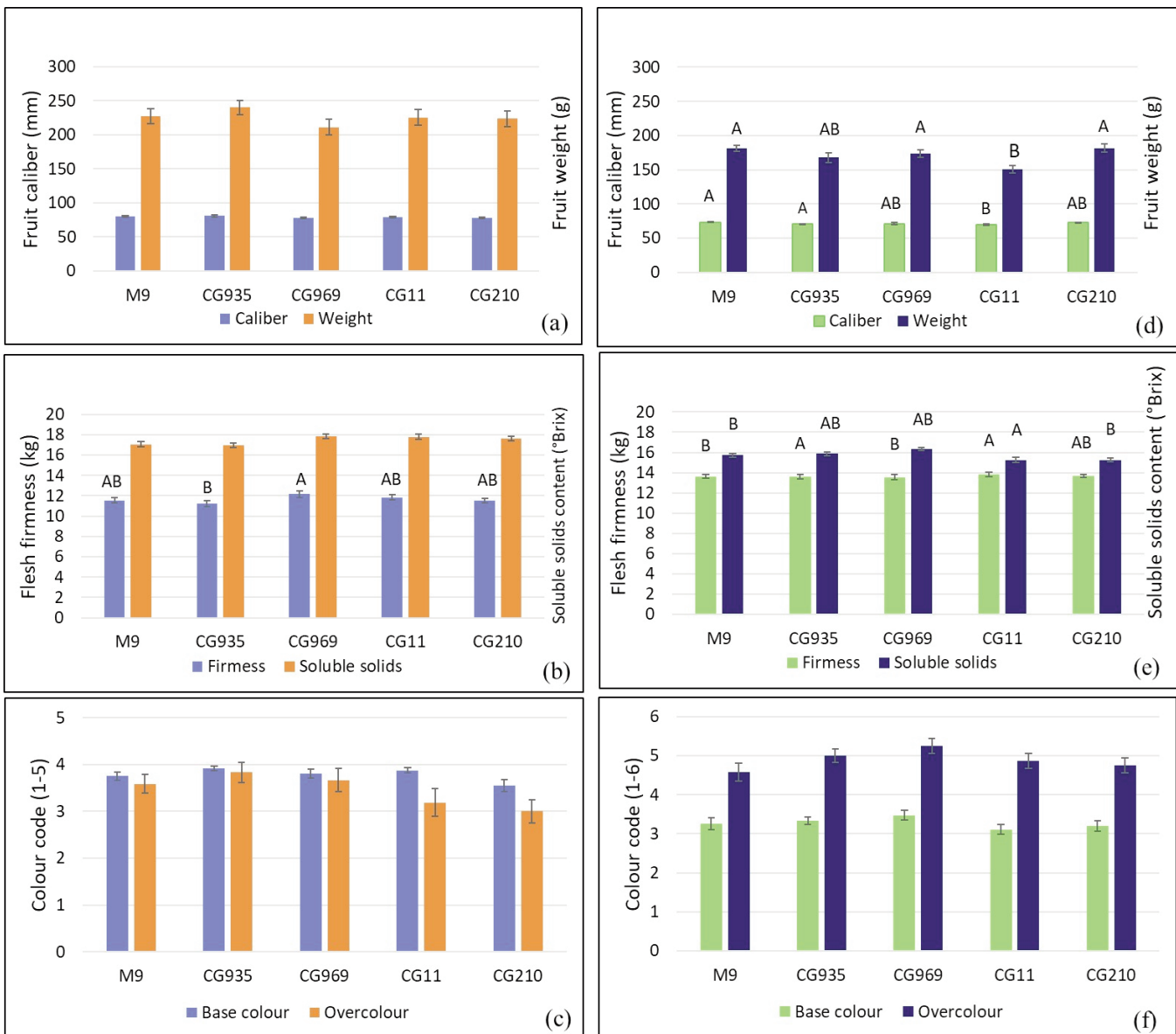


Figure 5. Fruit quality parameters at harvest: fruit diameter and weight (a, d); firmness and soluble solids content (b, e); color and overcolor (c, f) in ‘Fuji’ (a, b, c) and ‘Rosy Glow’ (d, e, f) trees grafted on different rootstocks: ‘M9’, ‘CG935’, ‘CG969’, ‘CG11’, and ‘CG210’. Separately for each parameter, different letters indicate significant differences between rootstocks according to the SNK test ($p < 0.05$).

3.6. Return bloom

In ‘Fuji’, branch length and diameter showed similar values regardless of the rootstock (Figure 6a). In ‘Rosy Glow’ (Figure 6c), branch length and diameter showed lower values in trees on ‘CG11’ than on the other rootstocks. “CG11” showed a mean brunch length of 68.5 cm, while on the other rootstocks the mean value was above 80 cm. Branch diameter was 9.95 mm in “CG11”, while in “M9” and “CG210” this parameter was 13.30 mm and 13.17 mm, respectively. Differences were observed in ‘Fuji’ trees in the number of corymbs and flowers (Figure 6b). The highest values were found in trees on ‘CG935’, while both parameters were significantly lower in trees on ‘CG11’ (ca. 16 corymbs and ca. 67 flowers). In trees on the other rootstocks, the number of fruit was significantly higher. In ‘Rosy Glow’ trees, the number of corymbs, flowers, and fruit were similar independently of the rootstock. Similarly in ‘Rosy Glow’ trees, no difference between rootstocks were found for the number of flowers or fruit per cm² of branch lateral area, with average values ranging between 0.04 and 0.007 flowers/cm². No differences were observed for the fruit set percentage, with average values ranging between 35.5% and 44.6%.

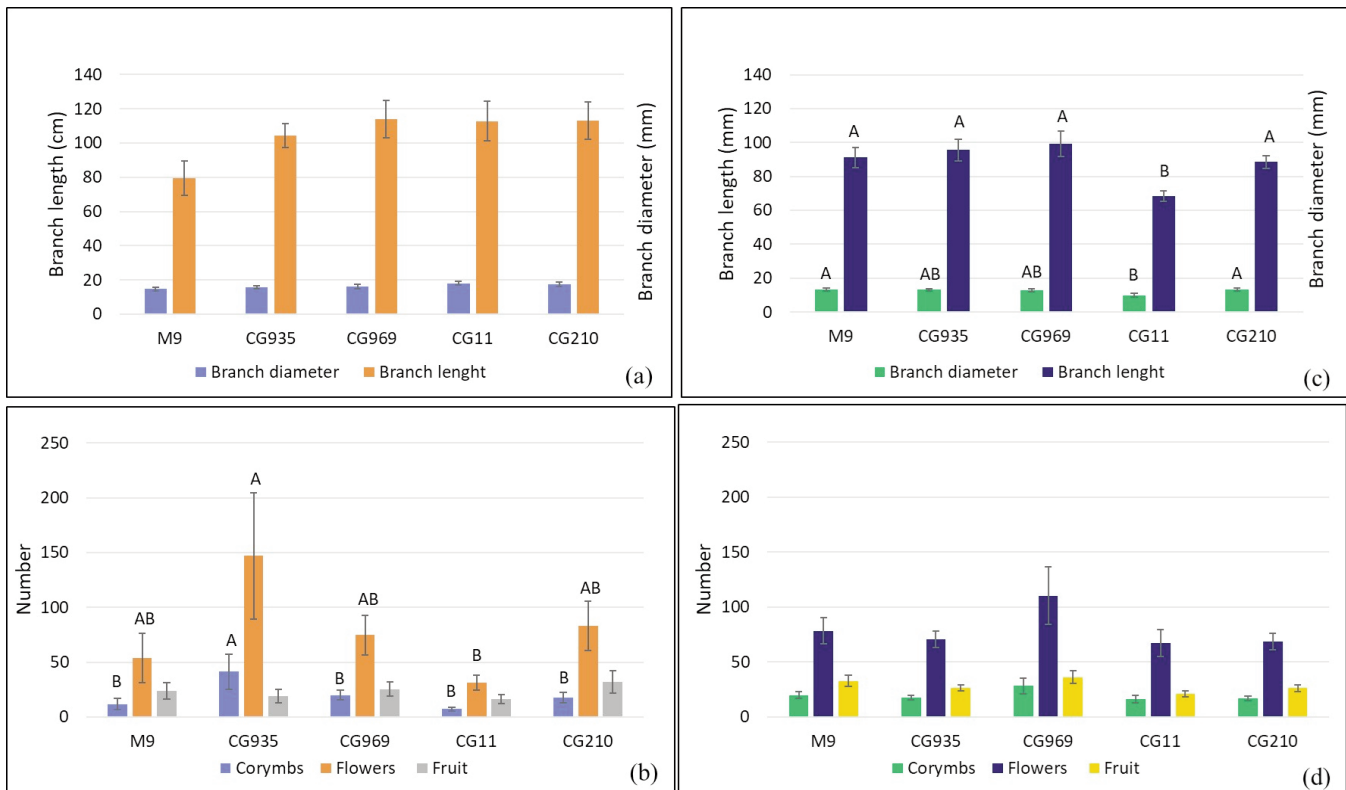


Figure 6. Return bloom in spring 2023. Branch length and diameter (a, c), and number of corymbs, number of flowers, and number of fruit (b, d) in ‘Fuji’ (a, b) and ‘Rosy Glow’ (c, d,) trees grafted on the different rootstocks: ‘M9’, ‘CG935’, ‘CG969’, ‘CG11’, and ‘CG210’. Separately for each parameter, different letters indicate significant differences between rootstocks according to the SNK test (p < 0.05).

4. Discussion

The results of this study showed that the rootstock effect on fruit and shoot growth differed depending on the cultivar considered. Indeed in ‘Fuji’, ‘CG969’ induced a reduced fruit growth, followed by ‘CG210’ (Figures 1a, b), whereas in ‘Rosy Glow’, the lowest fruit growth was induced by ‘CG11’. In the latter cultivar, ‘M9’ induced the highest fruit growth. Palmer et al. (1997) suggested that this could be due to the differences in crop load between cultivars. Another possible explanation could be related to higher vegetative vigor (Autio and Southwick, 1986). However, in the case of our study shoot growth

and the related growth rates (AGR and RGR) showed no statistical differences among the rootstocks throughout the trial (Figure 3a, b, and c). ‘M9’, ‘CG11’, and ‘CG935’ (in order of increasing vigor according to Holler and Guerra, 2020) achieved the greatest fruit growth during the season.

Trees on ‘CG11’ and ‘CG935’ showed lower absolute vegetative growth (Figure 3e). In this case, we could not impute the lower production to higher vegetative vigor. It is noteworthy that ‘CG11’ and ‘CG935’ have a vigor comparable to ‘M9 T337’ although in previous research ‘CG935’ was attested with higher vigor than rootstock ‘M9 T337’ (Holler and Guerra 2020).

Interestingly, fruit AGR (Figures 1b and 2b) showed, in both cultivars, a growth peak at 67 DAFB, which could correspond to the last stages of cell division. In ‘Fuji’ trees, shoot growth manifested a growth acceleration at 77 DAFB (10 days after the last fruit growth peak), ‘CG11’ and ‘CG210’ trees had the highest and lowest AGR, respectively (Figure 3b,3e), while in ‘Rosy Glow’ trees, ‘CG969’ and ‘CG935’ induced the highest and lowest AGR, respectively. In both varieties, trees on ‘M9 T337’ showed intermediate behavior.

Light interception showed different results between the two varieties. In ‘Fuji’, trees grafted on ‘CG969’ and ‘CG210’ rootstocks (Figure 4b) presented the lowest values of PAR measured in the middle of the canopy; this means that they were able to better intercept the light, because probably they had more vegetative growth in the central part of the canopy. Instead, PAR measurements at the ground level showed no differences on both dates evaluated (Figure 4a), indicating that foliar distribution varies within the canopy in each cv/rootstock combination but with no negative effects on light interception. As reported by Palmer (1999), vegetative vigor greatly influences light distribution within the canopy and the carbohydrates repartitioning for fruit growth.

In this study, the plants cv ‘Fuji’ grafted on ‘M9 T337’, ‘CG935’, and ‘CG11’ showed the highest PAR values at ground level, indicating a higher light penetration capacity and a decreased light interception (Figure 4b). This was probably related to the lower vegetative vigor, but better photosynthetic allocation to the fruit in agreement to the highest fruit growth recorded on these rootstocks. In contrast, ‘Rosy Glow’ trees grafted on ‘CG11’ and ‘CG935’ showed lower PAR values measured at the ground level at 82 DAFB (Figure 4d), being thus those able to better intercept the incoming radiation. Undoubtedly, ‘Rosy Glow’ trees on ‘CG11’ and ‘CG935’ have a denser canopy at 1.60 m height, as no differences were observed when measuring PAR in the bottom part of the canopy on both dates. Trees on ‘CG969’ rootstock showed the highest PAR values measured, meaning thus a lower canopy interception. This disagrees with Palmer (1999) who classified this rootstock as vigorous, as also indicated by Holler and Guerra (2020).

Also, in the case of fruit quality, the effect of the rootstock on the measured parameter depended on the cultivar considered. In ‘Fuji’ trees, the rootstock did not affect significant fruit size and fresh weight at harvest (Figure 5a). Lord et al. (1985) showed contrasting results between varieties and rootstocks in relation to fruit firmness, with soluble solids content being slightly higher in fruit from trees on vigorous rootstocks compared to the dwarfing ones. Since ‘CG935’ induced fruit with lower firmness than the other rootstocks (Figure 5b) and according to Holler and Guerra (2020), ‘CG935’ was reported to be a rootstock of medium vigor, followed by ‘CG969’. Drake et al. (1988) showed that vigorous rootstocks were responsible for lower fruit coloring, although in ‘Fuji’ trees this parameter gave no statistical difference between rootstocks (Figure 5c). The cv ‘Rosy Glow’ had larger fruit size when grafted on ‘M9’ (Figure 5d), while fruit fresh weight and size were lower in trees on ‘CG11’ (Figure 15d), despite the greater light interception of the canopy (Figure 4d) and thus distribution of photosynthates.

In cv ‘Rosy Glow’, fruit firmness seemed to be unaffected by the rootstock (Figure 5e), as ‘M9’, of lesser vigor, and ‘CG969’, reported as more vigorous (Holler and Guerra 2020), have the lowest firmness values. Soluble solids were lower in trees on ‘M9’ and ‘CG210’, which were considered slightly more vigorous than ‘M9 T337’ (Figure 5e), as also reported by Lord et al. (1985).

In this study, ‘Fuji’ trees on ‘CG935’ produced the lowest number of corymbs compared to the other rootstocks (Figure 6b). There was no difference in fruit set, in both varieties. Webster and

Hollands (1997) reported no consistent effect of the rootstock on return bloom and fruit set among rootstocks of ‘Fuji’ trees. Conversely in ‘Rosy Glow’, the results of our study are in line with those of Webster and Hollands (1997). While the results of this study provide valuable insights, it is important to note that additional years of observation are necessary to confirm and further validate these findings. Long-term data will help determine whether the observed trends persist over time and under different environmental conditions.

5. Conclusions

The results of this preliminary study suggest that for ‘Fuji’ the ‘CG935’ rootstock performed better in terms of both fruit growth and return bloom than ‘M9 T337’. It should be noted that this rootstock did not induce the best canopy light interception compared to the other rootstock considered. When grafted on ‘CG210’ rootstock, cv ‘Rosy Glow’ showed good seasonal fruit growth, in contrast to the ‘M9 T337’ that induced lower fruit growth.

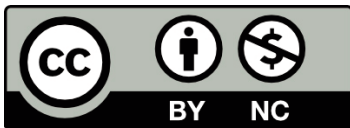
The choice of a training system such as Solaxe in trees grafted on ‘CG210’ could be very important to promote better light interception in the inner part of the canopy as suggested by the results of our study. In general, for both varieties, one or two rootstocks showed interesting characteristics, although it was difficult to identify with certainty the best rootstock for all the parameters analyzed, due to the complexity of the results obtained. The cv ‘Rosy Glow’ had the lowest fruit growth when grafted on ‘CG11’, while ‘Fuji’ had less satisfactory results when grafted on ‘CG969’, because of the lower fruit growth, and when grafted on ‘CG11’ because of the fewer number of flowers and corymbs. Additional years of evaluation are required to have more discriminating and conclusive results.

References

- Aldwinkle, H.S. and Preczevski, J.L. (1976) ‘Reaction of terminal shoots of apple cultivars to invasion by *Erwinia amylovora*’, *Phytopathology*, 66, pp. 1439-1444.
- Al-Hinai, Y.K. and Roper, T.R. (2004) ‘Rootstock effect on growth and quality of Gala apples’, *HortScience*, 39(6), pp. 1231-1233. doi: [10.21273/HORTSCI.39.6.1231](https://doi.org/10.21273/HORTSCI.39.6.1231)
- Autio, W.R. and Southwick, F.W. (1986) ‘The effects of rootstock and root-interstem combination on the growth, productivity, and anchorage of a spur and standard strain Delicious apple tree’, *Fruit Varieties Journal*, 40(4), pp. 128-133.
- Autio, W.R. (1991) ‘Rootstock effect ripening and other qualities of Delicious apples’, *Journal of the American Society for Horticultural Science*, 116(3), 378-382. doi: [10.21273/JASHS.116.3.378](https://doi.org/10.21273/JASHS.116.3.378)
- Autio, W.R. and Southwick, F.W. (1993) ‘Evaluation of spur and standard strains of ‘McIntosh’ on three rootstocks and one dwarfing interstem over ten years’, *Fruit Varieties Journal*, 47(2), pp. 95-102.
- Auvil, T.D., Schmidt, T., Hanrahan, I., Sánchez, F., McFerson, J.R. and Fazio, G. (2011) ‘Evaluation of dwarfing rootstocks in Washington apple replant sites’, *Acta Horticulturae*, 903, pp. 265-271. doi: [10.17660/ActaHortic.2011.903.33](https://doi.org/10.17660/ActaHortic.2011.903.33)
- Basile, B. and DeJong, T.M. (2018) ‘Control of fruit tree vigor induced by dwarfing rootstocks’, *Horticultural Reviews*, 46, pp. 39-97. doi: [10.1002/9781119521082.ch2](https://doi.org/10.1002/9781119521082.ch2)
- Boini, A., Bortolotti, G., Perulli, G.D., Venturi, M., Bonora, A., Manfrini, L. and Corelli-Grappadelli, L. (2022) ‘Late ripening apple production benefits from high shading and water limitation under exclusion netting’, *Horticulturae*, 8(10), pp.884. doi: [10.3390/horticulturae8100884](https://doi.org/10.3390/horticulturae8100884)
- Castle, W.S. (1995) ‘Rootstock as a fruit quality factor in citrus and deciduous tree crops’, *New Zealand Journal of Crop and Horticultural Science*, 23(4), pp.383–394. doi: [10.1080/01140671.1995.9513914](https://doi.org/10.1080/01140671.1995.9513914)
- Drake, S.R., Moffitt, H.R., Fellman, J.K. and Sell, C.R. (1988) ‘Apple quality as influenced by fumigation with methyl bromide’, *Journal of Food Science*, 53(6), pp.1710-1712. doi: [10.1111/j.1365-2621.1988.tb07822.x](https://doi.org/10.1111/j.1365-2621.1988.tb07822.x)

- Fazio, G. and Robinson, T. (2024) 'Guiding principles in the Geneva® apple rootstock breeding program', *Italus Hortus*, 31(1), pp. 27-42. doi: [10.26353/j.itahort/2024.1.2742](https://doi.org/10.26353/j.itahort/2024.1.2742)
- Fazio, G., Chang, L., Grusak, M.A. and Robinson, L.B. (2012) 'Soil pH, soil type and replant disease affect growth and nutrient absorption in apple rootstocks', *New York Fruit Quarterly*, 20, pp. 22-28.
- Flore, J.A. (1996) 'Stone fruit', in Schaffer, B. and Andersen, P.C. (eds.) *Handbook of Environmental Physiology of Fruit Crops. Volume I: Temperate Crops*. Boca Raton: CRC Press.
- Guerra, W. (2020) 'Nuovi portinnesti per il melo dagli Stati Uniti', *Frutticoltura*, 92020.
- Holler, I. and Guerra, W. (2020) 'Portinnesti per il melo: le prospettive', *Frutta e vite – Rivista specializzata del Centro di Consulenza*, 45(1), pp.24-28.
- John, A. and Marini, M.E. (1992) 'Maturity and quality of 'Delicious' apples as influenced by rootstock, apple rootstocks', *Horticultural Reviews*, pp.197–312.
- Lakso, A.N. (1994) 'Apple', in Schaffer, B. and Andersen, P.C. (eds.) *Handbook of Environmental Physiology of Fruit Crops. Volume I: Temperate Crops*. Boca Raton: CRC Press.
- Laurent, S.T., Merwin, A., Fazio, I.A., Thies, G. and Brown, M.G. (2010) 'Rootstock genotype succession influences apple replant disease and root-zone microbial community composition in an orchard soil', *Plant and Soil*, 337(1-2), pp.259-272. doi: [10.1007/s11104-010-0522-z](https://doi.org/10.1007/s11104-010-0522-z)
- Lauri, P.E. and Lespinasse, J.M. (2000) 'The vertical axis and solax systems in France', *Acta Horticulturae*, 513, pp. 287-296. doi: [10.17660/ActaHortic.1998.513.34](https://doi.org/10.17660/ActaHortic.1998.513.34)
- Leinfelder, M.M. and Merwin, I.A. (2006) 'Management strategies for apple replant disease', *New York Fruit Quarterly*, 14(1), pp. 39-42.
- Lord, W., Greene, D. W., Damon, Jr., & Baker, J. H. (1985). 'Effects of Stempiece and Rootstock Combinations on Growth, Leaf Mineral Concentrations, Yield, and Fruit Quality of "Empire" Apple Trees', *Journal of the American Society for Horticultural Science*, 110(3), pp. 422–425. doi: [10.21273/JASHS.110.3.422](https://doi.org/10.21273/JASHS.110.3.422)
- Mazzola, M. (1998) 'Elucidation of the microbial complex having a causal role in the development of apple replant disease in Washington', *Tree Fruit Research Laboratory, The American Phytopathological Society*, 88(9), pp. 930-938. doi: [10.1094/PHYTO.1998.88.9.930](https://doi.org/10.1094/PHYTO.1998.88.9.930)
- Mazzola, M. and Manici, L.M. (2012) 'Apple replant disease: role of microbial ecology in cause and control', *Annual Review of Phytopathology*, 50(1), pp. 45–65. doi: [10.1146/annurev-phyto-081211-173005](https://doi.org/10.1146/annurev-phyto-081211-173005)
- Moore, C.S. (1975) 'Relative importance of rootstock and scion in determining growth and fruiting young apple trees', *Annals of Botany*, 39(1), pp. 113-123.
- Palmer, J.W., Giuliani, R. and Adams, H.M. (1997) 'Effect of crop load on fruiting and leaf photosynthesis of 'Braeburn'/M.26 apple trees', *Tree Physiology*, 17, pp. 741-746. doi: [10.1093/treephys/17.11.741](https://doi.org/10.1093/treephys/17.11.741)
- Palmer, J.W. (1999) 'Light, canopies, fruit and dollars', *Compact Fruit Tree*, 32(4), pp. 119-122.
- Pasqualini, J. (2021) 'Portinnesti del melo: nuove selezioni, caratteristiche e primi risultati Sperimentali', *24esima Giornata tecnica, La frutticoltura delle valli del Noce*. San Michele all'Adige. Trento Italy. 19 February 2021, pp. 1-7.
- Perry, R.L. and Dilley, D.R. (1984) 'The influence of interstem on ripening indices of Empire apples. Compact Fruit Tree, Apple Rootstocks', *Horticultural Reviews*, pp.197-312.
- Robinson, T.L., Seeley, E.J. and Barritt, B.H. (1983) 'Effect of light environment and spur age on 'Delicious' apple fruit size and quality', *Journal of the American Society for Horticultural Science*, 108, pp. 855-861. doi: [10.21273/JASHS.108.5.855](https://doi.org/10.21273/JASHS.108.5.855)
- Rumberger, A., Yao, S., Merwin, I.A., Nelson, E.B. and Thies, J.E. (2004) 'Rootstock genotype and orchard replant position rather than soil fumigation or compost amendment determine tree growth and rhizosphere bacterial community composition in an apple replant soil', *Plant and Soil*, 264(1/2), pp. 247–260. doi: [10.1023/B:PLSO.0000047760.13004.94](https://doi.org/10.1023/B:PLSO.0000047760.13004.94)
- Sansavini, S., Costa, G. and Gucci, R. (2014) *Arboricoltura generale*. Patròn Editore.

- Valverdi, N.A. and Kalcsits, L. (2021) 'Apple rootstock genotype affects scion responses to water limitations under field conditions', *Acta Physiologiae Plantarum*, 43, 97. doi: [10.1007/s11738-021-03266-6](https://doi.org/10.1007/s11738-021-03266-6)
- Warrington, I.J., Stanley, C.J. and Tustin, D.S. (1996) 'Light transmission, yield distribution, and fruit quality in six tree canopy forms of 'Granny Smith' apple', *Journal of Tree Fruit Production*, 1(1), pp. 27-54. doi: [10.1300/J072v01n01_03](https://doi.org/10.1300/J072v01n01_03)
- Webster, A.D. (1995) Rootstock and interstock effects on deciduous fruit tree vigour, precocity, and yield productivity, *New Zealand Journal of Crop and Horticultural Science*, 23(4), pp. 373-382. [10.1080/01140671.1995.9513913](https://doi.org/10.1080/01140671.1995.9513913)
- Yao, S., Merwin, I.A. and Brown, M.G. (2006) 'Root dynamics of apple rootstocks in a replanted orchard', *HortScience*, 41(5), pp. 1149-1155. doi: [10.21273/HORTSCI.41.5.1149](https://doi.org/10.21273/HORTSCI.41.5.1149)



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