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Impact of rootstock on fruit physical properties of 'Pink Lady' apple

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A B S T R A C T

During 2018 and 2019, we evaluated the main fruit physical properties [weight (FW), length (L), diameter (D), geometric mean diameter (D_g), length/diameter ratio (L/D ratio), sphericity (φ), surface area (S), fruit volume (V) and solid density (ρ)] of 'Pink Lady' apple grafted on dwarf M.9 T337, semi-dwarf M.26 and semi-vigour MM.106 rootstocks. Results showed that rootstocks significantly changed the properties evaluated with the exception of L/D ratio, φ and ρ. Among rootstocks, M.9T33 7 produced the best properties, whereas lower and statistically similar values were obtained from M.26 and MM.106 rootstocks. All rootstocks promoted D higher than 66 mm, whereas only M.9 T337 induced D ≥70 mm. The rootstocks did not have the capacity to change the fruit shape of the 'Pink Lady' club cultivar.

Keywords: club cultivar, fruit size, fruit weight, fruit shape indexes, *Malus domestica* Borkh., rootstock.

И З В О Д

Током 2018. и 2019. године оцењивали смо главна физичка својства плода [маса (FW), дужина (L), пречник (D), средњи геометријски пречник (D_g), однос дужина/пречник (L/D однос), сферичност (φ), површина (S), запремина (V) и специфична маса (ρ)] сорте 'Pink Lady' калемљене на кржљавој M.9 T337, полукржљавој M.26 и средњебујној MM.106 подлози. Резултати су показали да су подлоге значајно мењале испитиване особине са изузетком L/D односа, φ и ρ. Међу подлогама, M.9 T337 је условила најбоље вредности, док су мање и статистички сличне вредности промовисале подлоге M.26 и MM.106. Све подлоге су изазвале пречник плода већи од 66 mm, док је само M.9 T337 индуковала пречник плода ≥70 mm. Подлоге нису имале способност да промене облик плода клуб сорте 'Pink Lady'.

Кључне речи: клуб сорта, крупноћа плода, тежина плода, индекси облика плода, *Malus domestica* Borkh., подлога.

1. Introduction

Grafting is the most common way of propagating fruit trees and dates back several thousand years or more. This method of vegetative propagation is used for two principal reasons: many fruit trees do not come true from seed since woody species are highly heterozygous (seeds from a 'Golden Delicious' apple will not grow into 'Golden Delicious' trees) and cuttings do not root easily. Grafting can be defined as a natural or deliberate fusion of plant parts by which vascular continuity is established between them (Pina and Errea, 2005) and the resulting genetically composite organism functions as a single plant.

As known, rootstocks are of paramount importance in modern fruit production due to their capability of adapting scion cultivars to diverse environmental conditions and cultural practices. In recent decades, many studies have addressed the influence of rootstocks on scion properties and vice versa. It has been irrefutably proven that this part of the plant has a multiple effect on the grafted scion i.e. cultivar. Namely, rootstock plays a major role in growth pattern, tree vigour, tolerance to biotic and abiotic stresses (drought, winter hardiness, pathogens, diseases, potentially toxic compounds in the soil such as salt or heavy metals), photosynthetic rate, leaf nutrient composition, adaptability to climate and soil conditions, bearing age, productivity and fruit quality (Lochard and Schneider, 1981; Kappel et al., 1997; Al-Hinai and Roper, 2004; Sotiropoulos, 2006; Kheiralipour et al., 2008; Ikinci and Bolat, 2019; Milošević et al., 2018, 2019). A harmonious combination of rootstock and cultivar is a desirable category in fruit growing due to the interaction between them as well as with soil and climatic conditions of the prevailing area (Kosina, 2009).

Successful fruit production requires hardy, disease-resistant cultivars with high fruit quality, mainly a long-term consumption period (Khanizadeh et al., 2000). Modern apple production is based on growing cultivars with adequate consumer acceptability that are grafted on dwarfing rootstocks, and with 3,000–5,000 trees per hectare in orchards. The predominant rootstock worldwide in highly intensive orchards is M.9 with clones, especially M.9 T337, followed by semi-dwarf MM.106 for spur types of apples such as 'Starking', 'Starkrimson' and 'Red Chief Delicious'. In Serbian apple orchards, MM.106 is often used, especially for the 'Idared' cultivar, since the trees

have moderate tree size suitable for semi-dense planting systems. M.26 rootstock (with tree vigour between M.9 and MM.106) is rarely used in European orchards; however, recently, in Serbian irrigated plantations, 'Idared' has often been grafted on this rootstock.

There are hundreds of apple cultivars. Dobrzański et al. (2006) mention more than 7,500 known apples, but only between 20 and 40 are produced and commercially traded around the world (Somogyi et al., 1996; Strohm, 2013). Among them, only 13 covered nearly 72% of the entire European apple acreage in 2007. 'Golden Delicious' with clones (16.3%) had the highest share, followed by 'Jonagold' (9.7%) and 'Gala' (8.6%) mainly in Italy, Spain, France, Germany and Poland (Strohm, 2013). Relatively new cultivars such as 'Pink Lady', a club cultivar bred in the 1970s, are becoming more popular in Europe. The cultivar was selected from a breeding programme at Stoneville Horticultural Research Station near Perth in Western Australia, and imported into New Zealand, where it has been grown on a commercial scale for export (Corrigan et al., 1997). 'Pink Lady' originated from a cross between 'Lady Williams' and 'Golden Delicious' in 1973 by J.E.L. Cripps (Cripps et al., 1993). According to the consumer panel assessment of five late-harvest apples, 'Pink Lady' had the best ratings for consumer acceptability, purchase frequency, purchase price and "nicest" looking apple in comparison with 'Braeburn', 'Fuji', 'Granny Smith' and 'Red Dougherty' (Corrigan et al., 1997).

However, the cultivation of 'Pink Lady' as a club cultivar is limited and strictly controlled. If a potential grower obtains approval from the owner of this cultivar for the cultivation and sale of fruit, a high royalty fee is paid. For these and other reasons, Serbian growers and consumers are not familiar with 'Pink Lady' apple. Therefore, we decided to examine the most important physical characteristics of the fruit of this cultivar grafted on three clonal rootstocks differing in vigour in order to gain better knowledge of its external fruit quality and reaction to these rootstocks.

2. Materials and methods

2.1. Plant material and experimental setup

Apple *cv*. 'Pink Lady' (Fig. 1), also called 'Cripps Pink', grafted on dwarf M.9 T337 rootstock, semi-dwarf M.26 rootstock and medium-vigour MM.106 rootstock was used as a plant material. The orchard was established in 2006, at a 3.0 m × 1.2 m planting distance; the training system was slender spindle.

Figure 1. Fruits of 'Pink Lady' (*Source*: T. Milošević, original)

The orchard was located in Prislonica village (43°57'N, 20°26'E) near the city of Čačak, western Serbia at 320 m a.s.l. and managed following the usual standard procedures under a non-irrigated practice. Fruit thinning was not performed in order to maintain the apparent impact of the rootstock evaluated. Each rootstock/cultivar combination was represented by 5 trees in three replications in a randomised block design.

Soil and weather conditions for this area were explained in our earlier study on apple (Milošević et al., 2019).

2.2. Measurements of fruit physical properties

Fruits were randomly hand picked (15 fruits in three replicates, n = 45) at the end of the second ten-day period of November in 2018 and 2019 from all parts of the canopy. Then, fruits were transported to the laboratory of the Faculty of Agronomy in Čačak and their physical properties were determined. Fruit weight (FW) was measured on a MAULsteel 5000 G digital balance (Jakob Maul GmbH, Bad König, Germany). Fruit linear dimensions – length (L) and diameter (D) (both in mm) – were measured using a Starrett 727 caliper gauge (Athol, MA, USA). L/D ratio, also called fruit elongation index, was calculated.

Other physical properties such as geometric mean diameter (D_g, mm), sphericity (φ), surface area (S, cm^2), volume (V, cm^3) and apparent solid density (ρ, kg m^{-3}) were calculated by using the equations presented in Table 1.

Table 1.
Equations for calculating some physical parameters of the fruit and their creators

Equation	Source	Serial number
$D_g = \sqrt[3]{LW^2}$	Mohsenin (1986)	(1)
$\varphi = D_g / L$	Mohsenin (1986)	(2)
$S = \pi D_g^2$	McCabe et al. (1986)	(4)
$V = \frac{4}{3}\pi\left(\frac{L}{2}\right)\left(\frac{D^2}{2}\right)$	Torabi et al. (2013)	(5)
$\rho = FW / V$	Mohsenin (1986)	(6)

2.3. Data analysis

Data for both 2018 and 2019 were pooled and then they were calculated as mean values. The results were processed statistically by analysis of variance (ANOVA) using the Microsoft Office Excel software (Microsoft Corporation, Redmond, WA, USA). The significance of differences between means was determined by LSD test at $P \leq 0.05$.

3. Results and discussion

Fruit weight differed significantly between M.9 T337 and the other two rootstocks (Table 2). The heaviest fruits were harvested from M.9 T337 whereas M.26 and MM.106 produced the lightest on average, with no significant differences between them. This information is useful for fruit classification by weight and size as well as for optimal packaging calculations and design (Tabatabaeefar and Rajabipour, 2005; Kheiralipour et al., 2008). Fruit length was the highest in 'Pink Lady' on M.9 T337, intermediate on M.26 and the lowest on MM.106. Fruit diameter, as an important parameter for fruit grading and packaging, was higher on M.9 compared to both M.26 and MM.106 rootstocks, which had statistically similar values. Similar tendencies were observed for D_g, also called fruit size index (Table 2). As known, fruit size is an important factor determining consumer acceptability, productivity and price (Al-Hinai and Roper, 2004).

Table 2.
Weight, fruit linear dimensions (length and diameter), size and shape indexes of 'Pink Lady' fruits on three clonal rootstocks

Rootstock	Fruit weight (g)	Fruit length (mm)	Fruit diameter (mm)	Geometric mean diameter (mm)
M.9	159.55 ± 6.00 a	64.70 ± 1.22 a	70.22 ± 0.95 a	68.31 ± 1.01 a
M.26	138.95 ± 5.97 b	61.29 ± 1.18 b	66.15 ± 0.99 b	64.47 ± 1.02 b
MM.106	134.35 ± 3.94 b	60.14 ± 0.74 c	66.01 ± 0.67 b	64.03 ± 0.62 b

The different small letter(s) in columns indicate significant differences among means for each rootstock at $P \leq 0.05$ by LSD test

The potential for fruit size development in apple is determined by crop load and the genetic carrying capacity of each cultivar, as well as by environmental conditions and cultural practices such as rootstock, thinning, fertilization and irrigation. Jones et al. (1997) reported fruit weight of 'Pink Lady' between 124.2 and 187.7 g in southern Tasmania and Henríquez et al. (2010) 273.05 g in Chile. In a study by Talluto et al. (2008) performed in Sicily, the FW of 'Pink Lady' was 146 g under non-irrigated conditions and 196 g under irrigation. These authors also reported that M.9 increased fruit weight whereas MM.106 decreased it. Similar tendencies were found by Marini et al. (2002), who reported that M.9 showed the best effect on the FW of 'Gala' compared to 7 dwarfing rootstocks. We also found a positive effect of M.9 on this trait in our earlier study on apple (Milošević et al., 2019). According to Cripps et al. (1993), 'Pink Lady' fruits are medium to large in size (70 to 75 mm average diameter). In our study, all rootstocks induced a diameter greater than 66 mm, which is the first class of apple fruits in trade; however, only M.9 T337 produced fruits with a diameter ≥70 mm. Cripps et al. (1993) also suggested that dwarfing rootstock should be used for 'Pink Lady'; MM.106 is generally suitable, MM.104 and MM.109 rootstocks have also been used in evaluations, but M.26, which could be suitable, has not been tested. Our data for FW and both fruit linear dimensions were much lower than those obtained by Henríquez et al. (2010) and Özongun et al. (2014) for the same cultivar grafted on MM.106.

Sphericity is an expression of the shape of a solid relative to that of a sphere of the same volume which is indicative of its tendency toward being generally oblong in shape (Omobuwajo et al., 1999). Despite lower values of M.26 and MM.106 for L and D, all rootstocks produced fruit of a statistically similar shape (Table 3). According to Cripps et al. (1993), 'Pink Lady' is oblong-conical in shape, which confirmed our L/D ratio and φ values.

Table 3.
Fruit physical properties of 'Pink Lady' grafted on three clonal rootstocks

Rootstock	L/D ratio (Elongation)	Sphericity	Surface area (cm^2)	Fruit volume (cm^3)	Solid density ($kg\ m^{-3}$)
M.9	0.92 ± 0.01 a	1.06 ± 0.01 a	147.14 ± 4.40 a	168.93 ± 7.67 a	971.80 ± 46.40 a
M.26	0.93 ± 0.01 a	1.05 ± 0.01 a	131.15 ± 4.20 b	142.29 ± 6.92 b	1016.25 ± 61.06 a
MM.106	0.91 ± 0.01 a	1.07 ± 0.01 a	128.98 ± 2.52 b	138.14 ± 4.09 b	994.23 ± 47.81 a

The different small letter(s) in columns indicate significant differences among means for each rootstock at $P \leq 0.05$ by LSD test

Relatively high L/D ratio and φ values of 'Pink Lady' apple on all rootstocks are indicative of the tendency towards a sphere. These values also indicated that Pink Lady' fruit might follow the combination of rolling and sliding action on its flat surfaces. The values of the L/D ratio (which relates the fruit L to D) in our study may suggest that 'Pink Lady' will roll rather than slide on its oblong-conical surfaces. However, the values of the L/D ratio found to be close to the φ values may also mean that the fruit of this cultivar will undergo a combination of rolling and sliding action on its flat surfaces (Khan et al., 2019).

Surface area is important when expressing the transfer of heat, water vapour, gases, pesticides, and foliar nutrients into or out of fruits (Clayton et al., 1995) and would be useful in determining the mass of the cuticular membrane per unit fruit surface area (Peschel et al., 2007). Fruit volumes must be known for accurate modelling of heat and mass transfer during cooling and drying (Wright et al., 1986). As expected, S and V were higher on M.9 T337 than on both M.26 and MM.106 rootstocks, with no significant differences between them (Table 3). Results obtained by Ikinci and Bolat (2019) showed that the clonal rootstocks M.9 and MM.106 induced better fruit size and volume of 'Anna' apple than seedling rootstock.

Solid density (ρ) is the weight per unit volume of the solid material and excludes any interior pores which are filled with air. This trait is important for the drying process in order to achieve desirable properties without an unnecessary expenditure of energy. Statistically, there were no significant differences in solid density for the studied rootstocks (Table 3). Significant differences in this trait have also not been found in other studies (Ortega et al., 2013). Mišić (2004) reported that solid density in apple fruits varied from 0.78 g cm^{-2} in 'Jonathan' to 0.91 g cm^{-2} in 'London Pippin' (syn.: 'London Pepping'), whereas O'Neill et al. (1998) and Kheiralipour et al. (2008) reported a solid density of 837 kg m^{-3} in 'Gala' apple and 837.68 to 827.91 kg m^{-3} in 'Red Spur' and 'Delbard Estivale' apples, respectively. In a study by Ozturk et al. (2010), solid density was 887.82 kg m^{-3} for 'Granny Smith', 948.56 kg m^{-3} for 'Golden Delicious' and 950.87 kg m^{-3} for 'Starking Delicious'. Our data for this trait were higher than those obtained by the above-mentioned authors probably due to genetic factors and fruit ripening stage. Torabi et al. (2013) reported a strong cultivar effect on solid density in apple. Interestingly, although differences among the rootstocks were not significant, the fruits of 'Pink Lady' on M.26 were heavier than the density of water, while the others were close to 1 (if the ρ values are expressed in g cm^{-3}), indicating that the fruits were prematurely harvested and unsuitable for the processing industry, especially drying. This statement primarily refers to the fruits of 'Pink Lady' that do not meet the criteria for fresh consumption.

4. Conclusions

The choice of a suitable rootstock is paramount for obtaining the desired physical properties of apple fruit. The obtained results showed that fruit weight, dimensions, size, surface area and fruit volume were significantly influenced by the choice of rootstock. However, the influence of rootstocks on fruit shape indices and solid density was not significant. The best traits evaluated were achieved when 'Pink Lady' was grafted on dwarfing rootstock i.e. M.9 T337, which indicates its superior positive effect on fruit physical properties. There is no doubt that the impact of rootstock on fruit quality attributes is much more complicated than some variables can measure. Information on engineering properties of *cv*. 'Pink Lady' may be useful in designing much of the equipment used for handling, grading, sizing and packing systems, conveying and postharvest processing; however, further work is required to substantiate the results obtained in this study.

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Competing Interests

The authors declare there are no competing interests.

Author Contributions

Tomo Milošević conceived and designed the experiment, prepared figures and tables, authored or reviewed drafts of the paper, and approved the final draft. Nebojša Milošević performed the experiments, analyzed the data, and approved the final draft.

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