New *Cucumis* Rootstocks for Melon: ‘UPV-FA’ and ‘UPV-FMy’

Andrés Cáceres and Gorka Perpiña

Instituto de Conservación y Mejora de la Agrodiversidad Valenciana (COMAV), Universitat Politècnica de València (UPV), Camino de Vera 14, 46022 Valencia, Spain

María Ferriol

Instituto Agroforestal Mediterráneo (IAM-Universitat Politècnica de València)

Belén Picó and Carmina Gisbert¹

Instituto de Conservación y Mejora de la Agrodiversidad Valenciana (COMAV), Universitat Politècnica de València (UPV), Camino de Vera 14, 46022 Valencia, Spain

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Grafting plants onto resistant rootstocks is a cultural practice spread worldwide to cope with biotic and abiotic stresses, such as fungal diseases, nematodes, drought, salinity, and extreme temperatures. For Cucurbitaceae crops, the most common rootstocks are interspecific hybrids between *Cucurbita maxima* Duchesne and *Cucurbita moschata* Duchesne (Davis et al., 2008). Besides their tolerance to biotic and abiotic stresses, hybrid *Cucurbita* rootstocks are preferred because they show good emergence performance and develop long and thick hypocotyls that facilitate grafting. These hybrids have however some important shortcomings. Their excess of vigor can cause a delay in the flowering and ripening processes in grafted plants (Soteriou et al., 2016), they are not resistant to nematodes (Cohen et al., 2014; Özarslandan et al., 2011), and often they have negative impacts on fruit quality (Guan et al., 2015; Rouphael et al., 2010; Soteriou et al., 2014). These effects on quality are dependent on the rootstock–scion interactions. In melon (*Cucumis melo* L.), for example, an increase of fruit size and seed cavity (Verzera et al., 2014) or modifications of flesh firmness (Colla et al., 2006; Zhao et al., 2011) as a result of grafting are common. Flesh color variations (Colla et al., 2006), vitrescence (Jang et al., 2014), and changes in pH and soluble solids content (Colla et al., 2006; Verzera et al., 2014) have also been reported.

In part because of these quality problems, grafting is less common in melon than in watermelon [*Citrullus lanatus* (Thunb.) Mansf.] and cucumber (*Cucumis sativus* L.). However, in recent years, the withdrawal of methyl bromide (a broad spectrum pesticide highly efficient against soilborne pathogens), and the increment of global temperature, have been favoring the spread of nematodes and fungi highly damaging for melons, such as *Fusarium* spp., *Monosporascus* spp., *Macrophomina phaseolina* (Tassi) Goidanich and *Podosphaera xanthii* (Castagne) Braun & Shishkoff. The global warming has also a negative impact on soil salinization and drought. Consequently, the use of grafted melon plants has gained increased attention. The use of rootstocks belonging to the same species/genus as the scions could minimize the quality problems observed when using *Cucurbita* hybrids as rootstocks. Even though some promising melon accessions have been selected and used to develop *Fusarium oxysporum* Schlechtend. Fr. f. sp. *melonis* (Leach & Currence) Snyder & Hans spp. and *Monosporascus cannonballus* Pollack & Uecker resistant rootstocks (Concurso et al., 2012; Fredes et al., 2016; Verzera et al., 2014), the assessment of a new germplasm that may provide a wider range of resistances without decreasing the fruit quality is a new challenge for melon grafting.

Apart from intraspecific variation, intrageneric variation can also be exploited in melon grafting. The genus *Cucumis* includes a large number of African, Asian, and Australian wild species (Den Nijs and Visser, 1985; Renner et al., 2007; Sebastian et al., 2010; Singh and Yadava, 1984). Strong reproductive barriers prevent the use of these resources for melon breeding (Chen and Adelberg, 2000), but the genus is potentially a good source of new rootstocks. Resistance to nematodes and to soilborne and aerial fungi has been reported in some *Cucumis* species. To date, two species have been assayed as rootstocks: *Cucumis*

metuliferus Naudin (Gisbert et al., 2017; Guan et al., 2014; Kokalis-Burelle and Rosskopf, 2011; Nisini et al., 2002; Sigüenza et al., 2005) and *Cucumis pustulatus* Naudin ex Hook.f. (Liu et al., 2015). Despite their effectiveness in the management of soil pathogens, lower soluble solids content and softer flesh have been observed in fruits from plants grafted onto *C. metuliferus* (Guan et al., 2014; Nisini et al., 2002). Other *Cucumis* species useful as sources of resistance to nematodes, *Fusarium* spp., or both are *C. ficifolius* A.Rich., *C. zeyheri* Sond., *C. africanus* L.f., *C. anguria* L., and *C. myriocarpus* Naudin (Den Nijs and Custers, 1990; Nisini et al., 2002). One of the main difficulties when using these wild species is the reduced size and vigor of the seedlings. Differences in hypocotyl diameters between the rootstock and the scion at the grafting union, either at the time of grafting or later during the development of the grafted plants (Pofu and Mashela, 2011; Pofu et al., 2013), can result in physiological collapse of melon plants under field conditions. Vigor of wild rootstocks can be increased by using interspecific hybrids, which have the additional advantage of combining resistances or other suitable traits from both parental lines. Although hybridization between different *Cucumis* species is extremely difficult, some successful crosses are possible (Kho et al., 1980; Matsumoto et al., 2012; Walters and Wehner, 2002), especially between some wild related African species, which are phylogenetically relatively close (Den Nijs and Visser, 1985; Sebastian et al., 2010).

The research groups of “Cucurbits” and “Grafting Breeding” at COMAV-UPV (Centro de Conservación y Mejora de la Agrodiversidad Valenciana-Universitat Politècnica de València) are working together in the development and characterization of new experimental rootstocks for cucurbit crops (Fredes et al., 2017; Gisbert et al., 2016). Germplasm characterization and crossability studies have been performed within the *Cucumis* genus to generate vigorous rootstocks suitable for melon. Two new interspecific *Cucumis* hybrids with good characteristics to be used as melon rootstocks have been developed: ‘UPV-FA’ (*C. ficifolius* × *C. anguria*) and ‘UPV-FMy’ (*C. ficifolius* × *C. myriocarpus*). Both hybrids have good compatibility with cultivars of the two main melon market classes (muskmelon and Piel de Sapo), are resistant to some of the main fungi that are pathogenic to melon, and do not negatively modify melon fruit quality.

Origin

The two new interspecific hybrids ‘UPV-FA’ and ‘UPV-FMy’ were obtained by crossing three wild African species: *Cucumis ficifolius* (F) (accession BGV012786) as female parent and the two other wild species as male parents, *Cucumis anguria* var. *longipes* (A) (accession BGV12795) and *Cucumis myriocarpus* (My) (accession BGV008535). The three accessions were held at the COMAV’s Genebank. Hybridizations were

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¹Corresponding author. E-mail: cgisbert@btc.upv.es.

conducted in a greenhouse at the UPV, under controlled conditions during the spring–summer season of 2015. Direct and reciprocal crosses were performed in all cross combinations, but fruit set was only obtained using *C. ficifolius* as female parent. Results are in accordance with previous studies, reporting that these three species are in the same compatibility group (Singh and Yadava, 1984), and with the occurrence of some form of unilateral incongruity between *C. ficifolius* and other African species such as *C. anguria*, *C. myriocarpus*, *C. zeyheri*, *C. dipsaceus* Ehrenb. ex Spach., and *C. figarei* A.Rich. (Den Nijs and Visser, 1985). The fruit set percentage was around 70% in both hybrids, quite similar to the value of 80% found in the self-pollinations of the parentals. Also, the average number ($\pm$ SE) of viable seeds per fruit found in the hybrid fruits (227.3 ± 9.9 and 132.7 ± 17.1 for ‘UPV-FMy’ and ‘UPV-FA’, respectively) was similar or even higher than the number found in fruits derived from selfings (164.3 ± 32.8 , 64.3 ± 14.5 , and 129.3 ± 5.2 for F, My, and A, respectively). The germination capacity of the hybrid seeds was tested under different experimental conditions, reaching 100% in treatments with cold stratification (Cáceres et al., 2016a). The hybrid seeds germinated earlier in comparison with their respective parentals (Cáceres et al., 2016a). Hypocotyl diameters were measured in the germinated seedlings at 21 d after sowing. The diameters of ‘UPV-FMy’ (0.28 ± 0.0062 cm) and ‘UPV-FA’ (0.25 ± 0.0075 cm) were higher than those of the wild parents (0.22 ± 0.0068 , 0.24 ± 0.0033 , 0.24 ± 0.0061 cm for F, My, and A, respectively). Seedlings were transplanted to the greenhouse, and the hybrid nature was confirmed using discriminant taxonomic traits between the parentals, such as the presence of *aculei* in stems and petioles, the ratio between the hyaline and opaque parts of *aculei* of ovaries, and the shape of ovaries and fruits (Kirkbride, 1993). Intermediate phenotypes were observed for these characters, which support their hybrid nature (Fig. 1; Cáceres et al., 2016b).

The good cross compatibility of these two interspecific crosses, along with the higher germination rates and wider hypocotyls found in the hybrids compared with their parents, confirms the advantage of using interspecific hybrids instead of single wild *Cucumis* genotypes for grafting purposes.

Responses to Biotic and Abiotic Stress

Wild *Cucumis* species have been reported to possess resistance to several fungal diseases (Matsumoto et al., 2011; Thomas and More, 1990). Among these diseases, fusarium wilt, caused by *F. oxysporum* f. sp. *melonis*, is one of the most severe for melons worldwide. Both hybrids and their respective parents were confirmed as resistant to fusarium wilt by artificial inoculation of *F. oxysporum* f. sp. *melonis* race 1.2 that was performed in a growth chamber following the protocol described by Perche-pied and Pitrat (2004). At 20 d after

Fig. 1. Discriminant morphological characters among *Cucumis ficifolius* (F), *C. anguria* (A), *C. myriocarpus* (My), and their hybrids ‘UPV-FMy’ and ‘UPV-FA’. From top to bottom: leaves, stems, aculei from ovaries with an inferior opaque part and a superior hyaline part, and fruits. The morphology was evaluated on greenhouse growing plants.

Fig. 2. Response of the two hybrids, ‘UPV-FA’ (*C. ficifolius* × *C. anguria*) and ‘UPV-FMy’ (*C. ficifolius* × *C. myriocarpus*), compared with a melon susceptible control against *Fusarium oxysporum* f. sp. *melonis*: plants of cantaloupe (A), ‘UPV-FA’ (B), and ‘UPV-FMy’ (C); against *Monosporascus cannonballus*: roots extracted from naturally infested soil of cv. Piñonet Piel de Sapo (D), ‘UPV-FA’ (E), and ‘UPV-FMy’ (F); against powdery mildew: plants cultivated in an open field of cv. Piñonet Piel de Sapo (G), ‘UPV-FA’ (H), and ‘UPV-FMy’ (I).

Table 1. Plant fresh and dry weights and root parameters of ‘UPV-FA’ (*C. ficifolius* × *C. anguria*), ‘UPV-My’ (*C. ficifolius* × *C. myriocarpus*), and *C. metuliferus* after 45 d of culture on BM medium with sorbitol (0, 0.05, 0.1, and 0.2 M).

Rootstock ^z	Sorbitol (M)	Plant fresh wt (g) ^z	Plant dry wt (g) ^z	Root ^y length (mm) ^z	Tip ^y number ^z	Root diam ^y (mm) ^z
‘UPV-FA’	0	1.05 a ^x	0.069 a	68.43 ab	169.86 ab	0.36 b
	0.05	0.94 ab (−10.3%) ^w	0.061 ab (−11.9%)	91.10 a (+33.1%)	220.28 a (+29.7%)	0.36 b (−0.08%)
	0.1	0.50 d (−52.2%)	0.04 c (−41.8%)	58.32 bc (−14.8%)	168.43 ab (−0.8%)	0.37 ab (+3.1%)
	0.2	0.04 f (−96.0%)	0.008 e (−88.3%)	—	—	—
‘UPV-FMy’	0	0.89 abc	0.071 a	58.91 bc	131.86 bc	0.34 b
	0.05	0.74 c (−17.2%)	0.055 b (−22.2%)	73.11 ab (+24.1%)	195.07 ab (+47.9%)	0.36 ab (+8.0%)
	0.1	0.30 e (−64.2%)	0.027 d (−62.1%)	34.62 d (−41.2%)	78.26 cd (−40.7%)	0.33 b (−2.5%)
	0.2	0.04 f (−95.1%)	0.006 e (−92.2%)	—	—	—
<i>C. metuliferus</i>	0	0.80 bc	0.059 ab	41.34 cd	97.92 cd	0.41 a
	0.05	0.29 e (−63.9%)	0.023 d (−60.6%)	19.20 de (−53.6%)	41.75 de (−57.4%)	0.38 ab (−9.0%)
	0.1	0.06 f (−92.9%)	0.007 e (−88.8%)	3.35 e (−91.9%)	11.0 e (−88.8%)	0.32 b (−21.6%)
	0.2	0.02 f (−97.7%)	0.003 e (−95.0%)	—	—	—

^zN = 15 plants for each treatment (rootstock and sorbitol concentration).

^yRoot parameters were measured with the program WinRhizo’s.

^xDifferent letters in the same column indicate significant differences according to Duncan’s multiple range test ($P \leq 0.05$).

^wThe percentage of reduction or increase in relation to values obtained on media with 0 M sorbitol is shown in brackets (negative symbol was added to indicate reduction compared with the control and positive symbol to indicate increase).

inoculation, plants of ‘UPV-FA’ and ‘UPV-FMy’ showed no symptoms of infection, whereas wilting of leaves and browning of the stem were observed in 50% of melon muskmelon plants (*C. melo* var. *cantalupensis* Naudin), used as susceptible control. All muskmelon plants finally died (Fig. 2A–C), whereas ‘UPV-FA’ and ‘UPV-FMy’ plants continued to grow, remaining symptomless at the end of the assay (40 d). These results are in agreement with those of previous reports that describe resistance to several races of *F. oxysporum* in *C. ficifolius*, *C. myriocarpus*, and *C. anguria* (Liu et al., 2015; Matsumoto et al., 2011; Nisini et al., 2002).

Other soilborne pathogens with increasing economic importance for melon cultivation are nematodes (mainly *Meloidogyne* spp.) and the fungus *Monosporascus cannonballus*, responsible for the melon vine decline disease (Pivonia et al., 2010). Nematode resistance has been described in some *C. anguria* accessions (Den Nijs and Custers, 1990), and nematicide activity was also reported in *C. myriocarpus* fruit extracts (Mashela et al., 2008). Nematode resistance in ‘UPV-FMy’ and ‘UPV-FA’ is under evaluation. Both hybrids were included in a screening assay for evaluating their response to *M. cannonballus* in a naturally infested field. In comparison with the Piel de Sapo Piñonet cultivar, used as susceptible control, both hybrids showed different levels of tolerance, having moderate to mild root damage and no wilted plants. Roots of each genotype extracted from the infested field are shown in Fig. 2D–F. ‘UPV-FMy’ was moderately resistant (with a root damage score of 3 ± 0.50 , in a scale of 0 = no symptoms to 5 = roots severely affected by the fungus), whereas ‘UPV-FA’ was highly resistant (root score 1 ± 0). Roots of both hybrids had also a more vigorous and branched root structure than the Piñonet cultivar. In this field assay, the response to powdery mildew was also observed in both, rootstocks and scion plants. The Piñonet cultivar was highly susceptible (symptom score of 4 ± 0.23), whereas ‘UPV-FMy’ and ‘UPV-FA’ were highly (0.2 ± 0.31) and moderately (1.02 ± 0.31) resistant (Fig. 2E–G).

Table 2. Characteristics of muskmelon fruits harvested from nongrafted plants (NG) and plants grafted onto the experimental hybrids ‘UPV-FMy’ (*C. ficifolius* × *C. myriocarpus*) and ‘UPV-FA’ (*C. ficifolius* × *C. anguria*).

	NG	Grafted onto ‘UPV-FMy’	Grafted onto ‘UPV-FA’
Number of fruit/plant ^z	3.60 a ^y	3.80 a	3.85 a
Fruit weight (g)	727.08 a	688.64 a	659.90 a
Fruit length FL (cm)	10.56 a	10.29 a	10.39 a
Fruit width FW (cm)	11.28 a	11.23 a	10.97 a
Fruit shape (FL/FW)	0.94 b	0.92 a	0.95 b
Cavity width (cm)	5.14 a	4.99 a	4.96 a
Rind firmness (kg·cm ^{−2})	12.30 a	12.76 a	12.72 a
Flesh firmness (kg·cm ^{−2})	2.77 a	2.77 a	2.78 a
Total soluble solids (°Brix)	12.33 a	13.32 b	12.34 a
pH	6.14 a	6.29 a	6.21 a
Hunter L	53.95 a	53.83 a	53.38 a
Hunter a	11.36 a	12.16 b	11.24 a
Hunter b	22.10 a	22.92 a	22.15 a

^zThe total number of fruit collected in each combination was 50 for ‘UPV-FA’, 38 for ‘UPV-FMy’, and 36 for cv. Charentais. All were analyzed for quality.

^yDifferent letters in the same row indicate significant differences according to the Duncan’s range test ($P \leq 0.05$).

The two new putative rootstocks were also evaluated against osmotic stress using clones from plants maintained in vitro. These clones were grown on basal medium (4.4 mg·L^{−1} Murashige and Skoog salts, including vitamins, 2% sucrose, and 0.75% plant agar), containing sorbitol at four different concentrations: 0, 0.05, 0.1, and 0.2 M. The addition of compounds such as sorbitol to culture medium reduces the water potential, so it is harder for plants to uptake water, simulating water-deficient conditions in soil (Verslues et al., 2006). The Piel de Sapo Piñonet cultivar showed great growth inhibition in a previous assay in medium with sorbitol after 45 d of culture (the fresh weight of plants was reduced 49% and 92% in media with sorbitol at 0.05 and 0.1 M, respectively). *Cucumis metuliferus*, which is another wild species used as putative rootstock for melon (Gisbert et al., 2017; Guan et al., 2014; Kokalis-Burelle and Rosskopf, 2011; Nisini et al., 2002; Sigüenza et al., 2005), was also included in the assay conducted to evaluate ‘UPV-FMy’ and ‘UPV-FA’. Differences in vine growth and rooting inhibition were observed after 30 and 45 d (Table 1). After these periods, plant fresh and dry weights were noted. Root characteristics (length, number of tips, and root diameter) were

measured using the WinRhizo’s software. At the lowest sorbitol concentration (0.05 M), vine growth and root development were inhibited in *C. metuliferus* after 30 d of culture, whereas both hybrids ‘UPV-FMy’ and ‘UPV-FA’ only showed a mild vine growth inhibition. This behavior was maintained after 45 d of culture, even at the intermediate sorbitol concentration (0.1 M) (Table 1). Rooting was not observed in any genotype in culture medium with 0.2 M sorbitol. This result was expected as no growth was also observed in other works using this very high concentration (Claeys et al., 2014). Of the two hybrids, ‘UPV-FA’ was more tolerant than ‘UPV-FMy’ (Table 1), with sorbitol causing less root length and branching reduction. A good root development is an important trait for putative rootstocks.

Performance as Rootstocks

The performance of ‘UPV-FA’ and ‘UPV-FMy’ as rootstocks was evaluated with two different melon scions. A first evaluation was performed in a greenhouse under hydroponic conditions, using a muskmelon Charentais as scion. Plants were grafted using the cleft procedure (Lee et al., 2010), and high rates of success were obtained (>90%). The responses of muskmelon plants grafted onto

‘UPV-FA’ and ‘UPV-FMy’ were compared with cantaloupe nongrafted (NG) plants. Similar vine growth was observed in grafted and NG plants. Grafting onto ‘UPV-FA’ and ‘UPV-FMy’ did not delay female flowering or fruit ripening and did not alter the number

of flowers and fruit set. On average, the first female flower opened from 35.3 to 37.3 d after transplanting (DAT), and fruits needed from 40.0 to 41.3 d after pollination to reach full maturity. To evaluate the impact of grafting on fruit quality, fruits were characterized for the following traits: weight (grams), length and width (centimeters), shape (length/width), cavity width (centimeters), rind and flesh firmness ($\text{kg}\cdot\text{cm}^{-2}$) (measured using a digital Penetrometer (8 mm) FHT-803; Melrose, MA), total soluble solids (quantified through a digital Refractometer Atago; Tokyo, Japan), pH (measured using pH-indicator paper pH 1–14 Merck, Darmstadt, Germany), and flesh color (measured with a colorimeter, Minolta CR-400; NJ, using the color parameters Hunter L, a, and b). No significant differences were found in any of these traits between fruits from plants grafted onto ‘UPV-FA’ and fruits from NG plants (Table 2). The fruits from plants grafted onto ‘UPV-FMy’ only differed from those of NG plants in the fruit shape, being slightly more flattened, in the sugars content ($^{\circ}\text{Brix}$ 13.3 vs. 12.3), and in the flesh color (significantly higher value of the parameter *a* that measures color from red to green) (Table 2; Fig. 3). Therefore, quality parameters were not modified or only slightly positively modified by these rootstocks, which did not cause negative impact on commercial traits.

A second evaluation of the experimental hybrids ‘UPV-FA’ and ‘UPV-FMy’ was performed under field conditions using the commercial melon ‘Finura’ (Rijk Zwaan) (*C. melo* var. *inodorus* H.Jacq. market class

‘Piel de Sapo’) as scion. In this assay, both experimental rootstocks were also compared with a commercial rootstock of melon (64-376RZ, Rijk Zwaan) and one *C. maxima* $\times$ *C. moschata* rootstock (the commercial hybrid Cobalt, Rijk Zwaan). In addition, NG and self-grafted (SG) plants of ‘Finura’ were used as controls. All grafted plants were produced by a commercial nursery “Viveros la Sala” (San Pedro del Pinatar, Spain) and were transplanted to an experimental field located in Picassent (Valencia, Spain). Plant vigor was evaluated during the growing period (at 10, 30, and 60 DAT) in a scale of 0 (very low), 1 (low), 2 (intermediate), 3 (high), and 4 (very high), and the appearance of the first female flowers was recorded. Both commercial rootstocks, ‘Cobalt’ and ‘64-376RZ’, conferred high early vigor, similar to the SG melons (average scores, $\pm$ SE, at 10 DAT from 3.25 ± 0.32 to 3.75 ± 0.14), which was associated to an earlier appearance of the first female flower, whereas the two interspecific hybrids resulted in less vigorous plants, similar to the NG melons (scores from 2.63 ± 0.24 to 2.75 ± 0.14). However, no significant differences in plant vigor were found among rootstocks at 30 and 60 DAT (scores ranging from 3.25 ± 0.25 to 4 ± 0 in plants grafted onto the different rootstocks). In fact, at 60 DAT, when most fruits were considered to have reached the commercial ripening stage, the average number of fruits and marketable yield per plant were similar in all the combinations (3.04 fruit/plant and 6.74 kg/plant in average).

Fig. 3. Fruit of muskmelons cv. Vedrantaïs (Charentais type) from ungrafted plants (A) and plants grafted onto ‘UPV-FMy’ (B) and ‘UPV-FA’ (C).

Table 3. Marketable yield and quality traits of melon fruits cv. Finura (Piel de Sapo) harvested from nongrafted plants (NG), self-grafted plants (SG), and plants grafted onto the experimental *Cucurbita* (*C. maxima* $\times$ *C. moschata*) hybrid F1, the commercial *Cucurbita* hybrid ‘Cobalt’, the commercial *Cucumis melo* rootstock ‘64-376RZ’, and two new experimental *Cucumis* F1: ‘UPV-FMy’ (*C. ficifolius* $\times$ *C. myriocarpus*) and ‘UPV-FA’ (*C. ficifolius* $\times$ *C. anguria*).

	NG	SG	Grafted onto <i>Cucurbita</i> F1 ‘Cobalt’	Grafted onto <i>Cucumis</i> ‘64-376RZ’	Grafted onto <i>Cucumis</i> ‘UPV-FMy’	Grafted onto <i>Cucumis</i> ‘UPV-FA’
Marketable fruit yield/plot (kg)	32.33 ^a	27.78 a	26.95 a	26.86 a	24.83 a	22.91 a
Fruit weight (g) ^b	2,502.27 ab	2,578.25 ab	2,960.15 c	2,806.50 bc	2,351.94 a	2,513.56 ab
Fruit length FL (cm)	22.74 a	22.82 ab	23.71 ab	24.14 b	22.45 a	23.39 abc
Fruit width FW (cm)	15.31 ab	15.32 ab	16.28 c	15.71 bc	14.63 a	15.18 ab
Fruit shape (FL/FW)	1.49 ab	1.49 ab	1.46 a	1.54 b	1.53 b	1.54 b
Rind thickness (mm)	5.13 ab	5.44 b	4.62 a	5.42 b	5.46 b	4.68 ab
Flesh thickness (cm)	37.13 ab	38.92 ab	35.61 a	41.17 b	36.58 ab	36.59 ab
Cavity width (cm)	5.76 a	5.77 a	7.22 c	6.03 ab	5.57 a	6.47 b
Rind firmness ($\text{kg}\cdot\text{cm}^{-2}$)	13	13	13	13	13	13
Flesh firmness ($\text{kg}\cdot\text{cm}^{-2}$)	2.15 a	2.41 a	2.24 a	2.60 a	2.48 a	3.26 b
Total soluble solids ($^{\circ}\text{Brix}$)	11.93 ab	12.13 ab	13.59 c	12.56 b	12.41 b	11.23 a
pH	5.75 ab	5.78 ab	5.97 bc	6.09 c	5.50 a	5.59 a
Hunter L	63.65 a	63.30 a	64.99 ab	68.30 b	66.11 ab	66.81 ab
Hunter a	-2.63 a	-2.48 a	-1.86 b	-2.88 a	-2.67 a	-2.57 a
Hunter b	9.42 a	9.23 a	9.26 a	11.56 b	9.75 a	9.24 a

^aDifferent letters in the same row indicate significant differences according to the Duncan’s multiple range test ($P \leq 0.05$).

^bAverage weight for the 16 fruit per treatment (four fruit/plot) used for quality characterization.

Fig. 4. Fruit of Piel de Sapo melons cv. Finura from ungrafted plants (A) and plants grafted onto *C. maxima* $\times$ *C. moschata* hybrid ‘Cobalt’ (B), the *Cucumis melo* ‘64-376RZ’ (C), ‘UPV-FMy’ (D), and ‘UPV-FA’ (E).

Similar to the previous assay with muskmelons, fruit quality traits (including rind and flesh thickness) were measured in 16 representative fruits per combination (4 of each plot). External quality traits, such as fruit shape and rind thickness, were similar in fruits of cv. Finura harvested in plants grafted onto the two interspecific *Cucumis* hybrids ('UPV-FMy' and 'UPV-FA') and onto the commercial melon rootstock '64-376RZ' (Table 3). No differences in fruit size and shape were found among melons developed on these *Cucumis* rootstocks and those developed on NG and SG plants, whereas the *Cucurbita* hybrid 'Cobalt' resulted in significantly larger fruits (average, $\pm$ SE, fruit weight 2960 ± 168.15 g vs. 2502 ± 60.94 g and 2578 ± 100.30 g in NG and SG melons, respectively) with a wider seed cavity (7.22 ± 2.25 cm vs. 5.76 ± 1.71 and 5.77 ± 2.67 cm) (Table 3). These effects are commonly observed when *Cucurbita* hybrids are used for grafting melon or watermelon (Colla et al., 2006; Verzera et al., 2014). The 'UPV-FA' rootstocks also caused a slight increase of fruit seed cavity (6.47 ± 2.35 cm). Figure 4 shows fruits from the different rootstocks in which the higher fruit size and seed cavity can be appreciated.

Regarding flesh properties, we found significantly firmer flesh in fruits from 'UPV-FA' (3.26 ± 0.19 vs. 2.15 ± 0.16 and 2.41 ± 0.26 in NG and SG plants, respectively) and flesh with significantly higher Brix degree in those fruits from the *Cucurbita* rootstocks (13.59 ± 0.28 vs. 11.93 ± 0.45 and 12.13 ± 0.39 °Brix) (Table 3). These two effects do not negatively affect fruit quality. An effect on flesh color was also observed in fruits derived from the commercial *Cucurbita* and melon rootstocks. The former showed a significantly higher value of the *a* parameter (-1.87 ± 0.26), which means less greenish flesh, and the latter caused a significant increase of the *b* parameter value (11.56 ± 0.63), which means a more yellowish flesh. The wild *Cucumis* hybrids did not alter flesh color in comparison with fruits of NG and SG plants (-2.57 ± 0.19 to -2.67 ± 0.12 and 9.24 ± 0.32 to 9.75 ± 0.22 for the *a* and *b* parameter values, respectively, in all combinations).

Use

The results obtained in the characterization of 'UPV-FA' and 'UPV-FMy' indicated that both hybrids can be used as melon rootstocks. The good cross compatibility between the parents facilitates hybrid seed generation, and the high germination rates along with the wider hypocotyls will be essential for grafting management. Their resistance/tolerance to *F. oxysporum* and *M. cannonballus* and their good agronomical performance with two commonly used melon scions make both hybrids comparable with other rootstocks used for grafting melon. In comparison with *Cucurbita* commercial rootstocks, 'UPV-FA' and 'UPV-FMy' have less early vigor and do not anticipate female flowering. However, no differences in vigor and fruit set are found at the end of the growing cycle. These *Cucumis*

hybrids do not cause fruit size increase and only 'UPV-FA' slightly increased cavity thickness, both effects commonly observed with *Cucurbita* hybrids rootstocks. An additional value of these rootstocks is their good tolerance to osmotic stress, especially in 'UPV-FA'. Also, their tolerance to powdery mildew can facilitate their management during rootstock seed production, and as it has been reported in other crops (Guan et al., 2012), it can contribute to improve the scion response to this disease.

Availability

Small trial seed samples of all the breeding lines are available for research purposes (please contact authors).

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