

## Research Paper

# Valorizing Ibericus traditional melons for organic farming: Crop limitations, use of grafting, and impact on agronomic performance and fruit quality

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## ABSTRACT

Melon (*Cucumis melo* L.) is a major crop in Spain, where traditional cultivars of the Ibericus group, selected by local farmers over centuries, are still grown for local markets and self-consumption. These landraces are valuable for organic and sustainable farming, but their productivity is limited by biotic and abiotic stresses. Understanding the limiting factors is essential to guide cultural or genetic strategies that help mitigate their impact. This study evaluated the agronomic performance and fruit quality of 17 Ibericus cultivars, cultivated as non-grafted and grafted onto commercial *Cucurbita* and experimental *Cucumis* rootstocks. Trials were conducted over two years in three contrasting organic fields: (i) a non-stressed location without prior melon cultivation, (ii) a pathogen and virus-prone location with a long melon-growing history, and (iii) a site with saline conditions. Viral (WMV, CMV, CABYV, ToLCNDV), powdery mildew, and soilborne pathogens (*Macrophomina phaseolina*, *Neocosmospora* spp., *Fusarium* spp.) severely affected yield. While salinity had minimal impact on yield, it increased SSC in Piel de Sapo, Amarillo, and Rochet cultivars. Under extreme salinity and low rainfall, pathogen dynamics changed, affecting plant development. Grafting reduced plant mortality and increased yield across cultivars, though rootstocks varied in their pathogen resistance profiles. *Cucumis* rootstocks, especially F1Pat81, maintained fruit quality better than *Cucurbita*. Varieties 03PS ('Piel de Sapo'), 22AM-GO ('Amarillo'), and 32BL ('Blanco') demonstrated favourable performance under saline conditions, particularly when grafted onto F1Pat81 or *Cucurbita* rootstocks, and are recommended for organic farming. Overall, traditional Ibericus melons demonstrate strong potential for organic systems; however, breeding for improved pathogen resistance and rootstock optimization remains essential to promote their cultivation.

## 1. Introduction

Melon (*Cucumis melo* L.) is an essential crop of the *Cucurbitaceae* family. Melon fruits are highly appreciated and mainly consumed as a dessert, although also as a vegetable in some regions (Esteras et al., 2020). Spain is the first producer of melon in the European Union, with 660 thousand tons, followed by Italy and France. In Spain, this crop is mainly grown in the Mediterranean Eastern coastal area known as the

“Spanish Levant”, characterized by both greenhouse and open field production, as well as in the Central Spain region of Castilla-La Mancha, where melon is grown in open field (MAPA, 2024).

The presence of domesticated *C. melo* plants in the Mediterranean basin is ancient, with the earliest seed record dated to the Late Bronze Age. However, these seeds are closer to those of modern non-sweet melons, such as those belonging to the horticultural groups Chate, Flexuosus, and Ameri, than to those of modern sweet melons (Sabato

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et al., 2019). Sweet melons should have been introduced to Spain in the Middle Ages, during the Islamic conquest of the Iberian Peninsula, when sweet casaba-type melons were introduced from Central Asia to Europe (Paris et al., 2012, 2009). Local farmers cultivated, conserved, and exchanged their seeds, carrying the best varieties to the most popular markets (Escribano and Lázaro, 2009). Through centuries of selection by the local farmers and consumers, these melons adapted to the diverse agro-climatic conditions of the Iberian Peninsula. Ancient Spanish cultivars, i.e., traditional cultivars, have been maintained for centuries by farmers until genetic erosion began in the 20th century due to varietal replacement (Lázaro et al., 2017). This genetic erosion, caused by the replacement of traditional cultivars with modern uniform varieties, has reduced the pool of traits present in local diverse melon populations. This diversity was managed through farmers' cultivation and selection practices, with local exchange and gene flow among landraces encouraging genetic variation, and continued cultivation leading to local adaptation to specific biotic and abiotic stresses (Khouri et al., 2022).

A recent grouping of melons (Pitrat, 2016) classifies the Spanish sweet melons into the Ibericus group groups such as Piel de Sapo, Rochet, Amarillo, Blanco, or Tendral. One of the main worldwide market types is Piel de Sapo, characterized by an elliptical or acorn fruit shape, more or less wrinkled surface, no vein tracts, thick rind, crispy light-green or light-orange juicy flesh, high sugar content, low aroma, late maturity, and long shelf life (Pitrat, 2016). Piel de Sapo is quite different from the other main worldwide-known commercial groups: Inodorus (including Honeydew and Earls) and Cantalupensis (including Cantaloupes and Charentais). Apart from the Piel de Sapo subgroup that is widely cultivated for global markets (Esteras et al., 2013), traditional cultivars from this and the other Ibericus subgroups are still mainly grown in Spain for self-consumption and local markets. In contrast to modern uniform cultivars bred for global markets, these landraces preserve a wide range of agronomic and sensory characteristics. Their diversity in fruit quality and adaptation to local environments makes them especially relevant for organic and sustainable farming, where crop diversity and resilience are central to production success. For many years, Spanish commercial breeders focused on selecting cultivars from the Piel de Sapo and Amarillo subgroups, different in rind color but sharing many plant and fruit characteristics (Escribano and Lázaro, 2012). A study of traditional Spanish melon cultivars found a wide variability in a very small area with vast historical importance in melon farming (Region of Comunidad de Madrid, in Central Spain), which means that by exploring traditional production areas, the probability of discovering useful ancestral genetic resources is high (Escribano and Lázaro, 2009). Traditional cultivars and their preservation offer an excellent opportunity for breeders, as the success of new varieties largely relies on enhanced sensorial quality (Lester, 2006). Some studies have analyzed the flesh and rind volatile organic compound composition of commercial and traditional Spanish cultivars and found differences between them (Esteras et al., 2020, 2018). Escribano and Lázaro (2012) found that traditional melon cultivars are equally or more appreciated than commercial varieties. However, these traditional cultivars are no longer available in the market. It is in the great trait diversity where traditional cultivars could be of interest, as they are usually capable of capturing the attention of consumers who seek unique, nutritious local varieties (Dwivedi et al., 2019). More than 1,000 Spanish accessions are conserved in several plant germplasm collections (Lázaro et al., 2017). Local traditional landraces from the Comunitat Valenciana (Eastern Spain) can be found in gene banks such as the Universitat Politècnica de València GenBank and the Spanish National Inventory (<https://bancocrf.inia.es/es>). One way to make these traditional cultivars more attractive could be to produce them under organic farming conditions, as organic foods are widely perceived to be tastier and healthier than conventionally produced products, and also environmentally respectful, since the production process is less damaging to the environment (De Magistris and Gracia, 2008). Appearance, freshness, nutritive value, and taste are key factors determining consumer preferences for organic foods, and

consumers often prefer them due to their health benefits and lower environmental impact, with demand for organic fresh fruit and vegetables increasing in recent years (Rahman et al., 2021). Traditional cultivars could become strategic resources for modern organic agriculture. Their preservation and reintroduction into production systems could not only safeguard important genetic resources but also provide opportunities to meet consumer demands for flavourful, sustainable product.

Annunziata and Vecchio (2016) define organic farming as a production system that maintains the health of soils and ecosystems, relying on ecological processes, biodiversity, and cycles adapted to local conditions rather than on the use of inputs with adverse effects. Spain has Europe's second-largest organic farming surface area, with >2.67 million hectares, just after France with 2.89 million hectares (Eurostats, 2023). In the case of organic production, Spain is the fourth in terms of fresh vegetables (including melons) dedicated area, after France, Italy, and Poland (Eurostats, 2023). Organic farming faces a series of difficulties, the main one being a yield gap compared to conventional farming systems, with organic crops producing on average 80 % of conventional crops (de la Cruz et al., 2023; De Ponti et al., 2012; Ponisio et al., 2015). This gap is important for vegetables and melons, where significantly lower yields have been observed, with conventional yield ratio of 0.85 (de la Cruz et al. (2023).

To reduce this yield gap, it is essential to understand the environment and the abiotic and biotic factors that affect cultivation in organic farming. The main problem many traditional cultivars face is the lack of resistance to important pests and diseases (Dwivedi et al., 2019), which cause yield reduction or less stable production. The threat is especially significant under a climate change scenario in which the pressure of biotic and abiotic stressors is expected to increase, challenging global food security (Rouphael et al., 2018). Using varieties adapted to local pests and pathogens could help increase crop production's stability. In the case of soilborne pathogens, the main control strategy is the use of resistant rootstocks onto which the desired scions are grafted. Grafting is a way to secure yield stability and quality in vegetable crops, so it is mainly employed for producing high-value *Solanaceae* and *Cucurbitaceae* crops (Kyriacou et al., 2020). Grafting on melon primarily focuses on facing pathogens such as *Fusarium* wilt, *Monosporascus* wilt, and *Meloidogyne* nematodes (Pico et al. 2017; Kyriacou et al. 2018). The influence of the rootstock not only extends to resistance to stresses but also affects nutrient uptake and plant vigour, so that careful scion-rootstock pairings can optimize plant performance and support organic production (Arya et al., 2024). However, the combination of scion-rootstock can also influence the quality parameters of the fruit depending on the compatibility (Németh et al., 2020). In melon, the most popular rootstocks are those belonging to the *Cucurbita* genus, as they protect against many soilborne pathogens and abiotic stresses. Still, these rootstocks can negatively affect fruit quality parameters such as fruit size, soluble solids, and volatile organic compound (VOC) contents (Pico et al. 2017; Guo et al. 2024; di Santo and Barrios-Masias 2024; Cáceres et al. 2024). The use of rootstocks belonging to the same genus could contribute to minimizing compatibility problems, thereby leading to enhanced fruit quality and fruit yields, increasing profits for farmers and improving nutritional values for consumers (Cáceres et al., 2017; Camalle et al., 2023). However, the resistant rootstocks of the *Cucumis* genus are not sufficiently studied in terms of the advantages they could bring in fruit yield and quality (Pico et al. 2017; Cáceres et al. 2024). Therefore, identifying the best rootstock-scion combinations, adapted to local biotic and abiotic stresses, will help revitalize traditional melon cultivars cultivation and improve marketability for producers.

Therefore, the objective of this study is to characterize a large collection of traditional Spanish Ibericus sweet melon and evaluate their performance under organic farming conditions, focusing on yield, fruit quality, and resistance to pathogens across multiple environments and growing seasons. In addition, the study aims to identify the main biotic and abiotic limiting factors and assess the effects of grafting onto both

experimental *Cucumis* and commercial *Cucurbita* rootstocks on overall plant performance and fruit quality.

## 2. Materials and methods

### 2.1. Study locations

Three different fields were used in this study, each representing different agronomic conditions. The first field was located near the area of Moncada, in the province of Valencia (39°33'26.8" N, 0°25'06.5" W), with no previous melon cultivation history, having been used for cultivating citrus fruits for the last 20 years. The second field was located in the area of the city of Valencia known as "La Punta" (39°26'41.3" N, 0°21'14.9" W), with a previous history of melon cultivation and reports of viral and soilborne diseases. The third field was located in the area known as "Parque Natural Agrario de Carrizales" (38°08'32.8" N, 0°42'44.7" W) in the province of Alicante, an area famous for melon cultivation under soil and water saline conditions (Fig. 1).

Daily climatic data (rainfall and mean temperature) from each field were obtained from public databases ("Agencia Estatal de Meteorología" ([www.aemet.es](http://www.aemet.es)) and "Sistema de Información Agroclimática para el Regadío" (<http://riegos.ivia.es/red-siar>)), selecting the nearest station to each field. Soil and water conductivity were measured for the 3 locations. Water conductivity was measured with an electrical conductivity meter (CM35, CRISON, Barcelona, Spain). Soil conductivity was determined following Primo and Carrasco (1980). A total of 10 soil samples per field were collected and homogenized. They were then dried at room temperature, sieved (2 mm), and the conductivity was measured (dS/m). These fields were also employed in a previous study by the group involving snake melon (Flores-León et al., 2021).

### 2.2. Plant cycle

The assays were all performed under organic conditions following the agricultural practices previously described in Flores-León et al. (2021). In Carrizales, the water supplied is characterized by its high electrical conductivity, resulting in a salt stress condition. In La Punta, the repetitive melon cultivation in the field has led to an infestation of soilborne pathogens. Finally, in Moncada, the lack of previous cucurbits cultivation provided unstressed conditions. Assays were performed during two consecutive years, Year 1 and Year 2. Supplementary Table 1 describes cultivars and rootstocks used in each assay. The selected traditional cultivars were provided by the Universitat Politècnica de València Germplasm Bank and were selected to represent all subgroups of the Ibericus melon Group. These cultivars have been previously studied by the group (Flores-León et al., 2022)

In year 1, in all fields, 17 non-grafted cultivars (NG) were cultivated (5 Piel de Sapo, 4 Amarillo, 4 Blanco, 3 Rochet, and 1 Tendral). Additionally, in the fields of La Punta and Carrizales, 8 selected cultivars among the 17 NG (2 Piel de Sapo, 2 Amarillo, 2 Blanco, and 2 Rochet) representing most of the Spanish types, were cultivated grafted onto two rootstocks: the experimental melon hybrid F1Pat81 (obtained by crossing a *Cucumis melo* accession of the *agrestis* subspecies, resistant to *Monosporascus cannonballus* (Roig et al., 2012), and another *C. melo*

accession of the *melo* subspecies, Ibericus Piel de Sapo type, and proved to be useful for grafting Piel de Sapo melons previously (Cáceres et al. 2024), and the commercial *Cucurbita maxima* Duch. x *moschata* Duch. ex Poir. F1 hybrid Cobalt (resistant to *Fusarium oxysporum*, Rijz Zwaan). A randomized complete block design with four plants per treatment and block was used (four blocks).

In year 2, a total of 8 cultivars, also selected among the 17 grown NG in year 1 (2 Piel de Sapo, 1 Amarillo, 2 Blanco, 2 Rochet, and 1 Tendral) were cultivated. Five of them had also been assayed grafted in year 1 (1 Piel de Sapo, 1 Amarillo, 1 Blanco, and 2 Rochet). These eight cultivars were grown in the fields of La Punta and Carrizales along with two commercial hybrids used as controls Cristiano (Semillas Fito Semillas Fitó S.A.U) and Finura (Rijk Zwaan Ibérica S.A.R.L.). In both fields, plants of the 10 cultivars were grown NG and grafted onto 5 different rootstocks: the previously described F1Pat81 and Cobalt, as well as another commercial *Cucurbita maxima* Duch. x *moschata* Duch. ex Poir. F1 Hybrid Shintoza (resistant to *Fusarium oxysporum*, Interseminas S.A.), and 2 experimental wild *Cucumis* interspecific rootstocks Fian (*C. ficifolius* A. Rich x *C. anguria* L.) and Fimy (*C. ficifolius* x *C. myriocarpus* E. Mey. ex Naud) with resistance to different soilborne diseases (Cáceres et al., 2017), and that were proved to be useful for grafting Piel de Sapo melons previously (Cáceres et al. 2024). A randomized complete block design with 3 plants per treatment and block was used (3 blocks).

### 2.3. Pest and pathogen detection

Pests affecting the crops during the crop cycle were monitored with biweekly field visits. Additionally, plants showing viral symptoms were sampled, and the incidence of Watermelon mosaic virus (WMV), Moroccan watermelon mosaic virus (MWMV), Zucchini yellow mosaic virus (ZYMV), Cucumber mosaic virus (CMV), Cucurbit yellow stunting disorder virus (CYSDV), Cucurbit chlorotic yellows virus (CCYV), Cucumber green mottle mosaic virus (CGMMV), and Tomato leaf curl New Delhi virus (ToLCNDV) was studied in both years. Moreover, Cucurbit aphid-borne yellows virus (CABYV) was included in the second-year analysis. The presence of ToLCNDV, the only DNA virus studied, was determined by tissue printing as described by Sáez et al. (2021). Total RNA was extracted from young leaves using Extrazol reagent (Blirt) for the rest of the viruses. The extracted RNA was retrotranscribed using random primers with the RevertAid RT Reverse Transcription Kit (ThermoFisher). The obtained cDNA was directly used for the PCR amplification of the CP-regions of WMV, MWMV, ZYMV, CMV, CYSDV, CCYV, CGMMV, and CABYV following the methods described by López-Martín et al. (2024).

Airborne fungal attack was recorded. Additionally, plants showing symptoms of soilborne pathogens were analyzed to identify the causal agents, using the methods employed by Flores-León et al. (2021). Fragments of necrotic stem base and upper root tissue were surface-disinfected (1 min in 1.5 % NaClO solution, followed by several washing steps with sterile bi-distilled water). These plant fragments were placed in a Potato Dextrose Agar (PDA) (CULTIMED, Barcelona, Spain) medium amended with streptomycin sulphate (0.5 g/l). Plates were incubated in dark conditions (25 °C, 3–5 days). The emerging



Fig. 1. Traditional melon fields located in Moncada, near Valencia (A), in the Agrarian Natural Park of Carrizales, in Alicante (B), and in La Punta, the periurban area of Valencia (C). All locations are in the Comunitat Valenciana (Eastern Spain).



colonies were transferred to individual PDA plates to obtain pure cultures. The isolates were then identified morphologically by comparing their somatic and/or sexual/asexual reproductive structures. Molecular characterization was also made by PCR amplification of the ribosomal ITS fragment for most of the isolates, as well as TEF-1 $\alpha$  and RPB2 gene fragments for the case of certain *Fusarium* species, using ITS1/ITS4 (White et al., 1990), EF1/EF2 (O'Donnell et al., 1998) and rRPB2-7cF/rRPB2-11aR (Reeb et al., 2004) primers, respectively. Sequences obtained allowed the identification of isolates by their comparison with sequences deposited in public databases like GenBank (using BLASTn tool) or Fusarium ID Database (<http://www.westerdijkinstitute.nl/fusarium/>), as well as by performing phylogenetic reconstructions employing Bayesian inference methods from multilocus alignments of combined genomic regions for some of the mentioned *Fusarium* taxa and related public sequences.

## 2.4. Fruit characterization

All melon fruits of marketable size were weighed during harvest to calculate the yield per plant. Fruit characterization parameters were measured as described by Flores-León et al. (2022). Two fruits from each plant were characterized for fruit weight (FW in g, measured with digital scale), fruit length, diameter and cavity (FL, FD and FC, respectively, in cm, measured with a ruler), Rind Thickness (in mm, with a Vernier caliper), rind and flesh firmness (RF and FF respectively, measured with a penetrometer in kg/cm<sup>2</sup>), fruit pH (universal pH indicator paper), soluble solids content (SSC, °Brix, measured in juice drops using a hand-held Pocket refractometer (PAL- $\alpha$ , Atago CO., LTD, Tokyo, Japan)). Finally, both the fruit flesh and rind colours were measured in Hunter L, a, and b coordinates (CR-400 colorimeter, Konica Minolta, Inc., Tokyo, Japan).

## 2.5. Statistical analysis

Fruit characterization traits and agronomic data were considered as dependent variables. Location, scion and rootstock, as well as their interactions, were treated as independent factors, and analysed by performing MANOVA to assess their impact. ANOVA tests, followed by Tukey and Dunnett's test, were used to analyse the performance. Stat-Graphics Centurion version 17.2.04 and IBM SPSS Statistics 25 for Windows were used for this purpose. RStudio (build 2021.09.1 + 372) was employed with R (version 4.1.2) for the use of packages ggplot2 (version 3.5.1), and tidyr (version 1.3.0) (Wickham, 2016; Wickham and Wickham, 2017).

## 3. Results

### 3.1. Assays characteristics

#### 3.1.1. Climate conditions

The rainfall in year 1 was much more abundant than usual in Valencia. In fact, La Punta and Moncada fields received nearly four and twice as much rain, respectively, as the field of Carrizales in Alicante (Suppl. Table 2). This excess of rain was mainly concentrated in June, with July being the driest month. The second year was more regular, and similar rain amounts were measured in Valencia and Alicante, although the distribution was different, as precipitation in Carrizales was concentrated at the end of the crop cycle in August.

Regarding mean temperatures, those at the beginning of the growing cycle (April and May) were approximately 1 °C higher in Carrizales and La Punta compared to Moncada, in the first year. Also, temperatures approximately 1 °C higher were registered in Carrizales compared to La Punta through most of the growing cycle in the second year (Suppl. Table 2).

#### 3.1.2. Salinity levels

Carrizales field was selected to represent salt stress. In both years, values for both water conductivity (4.5 and 6 dS/m) and soil conductivity (3.17 dS/m and 1.66 dS/m), were significantly higher than those of La Punta and Moncada (both locations with  $\approx$ 2 dS/m of water conductivity and low soil salinity, 0.3–0.7 dS/m, respectively) (Suppl. Table 2).

### 3.2. Pests and viruses

The main pest detected both years was aphids, vectors of different viruses, present in La Punta and Moncada, but not in Carrizales.

Regarding viral infections, the first year a severe attack of WMV affected the melon crop in La Punta. All the *Ibericus* types were affected, with infection percentages ranging from 10 to 50 % of the plants. Rochet 04RC, Amarillo 23AM-EN, and Piel de Sapo 08PS presented the highest infection percentages, whereas Amarillo 16AM presented the lowest (Fig. 2A). No effect of the rootstock was found as the infection percentage of NG plants (40 %) was similar to that of grafted plants (30 % F1Pat81 and 36 % Cobalt grafted plants, respectively) (Fig. 2B). Infection with CMV, although less severe, was detected in Moncada (Amarillo types and, again, the Rochet 04RC were the most susceptible types, with infection rates from 10 to 20 %). Carrizales was free of viral infections. The other studied viruses (ZYMV, MWMV, CYSDV, CGMMV, and ToLCNDV) were not detected in the prospected areas.

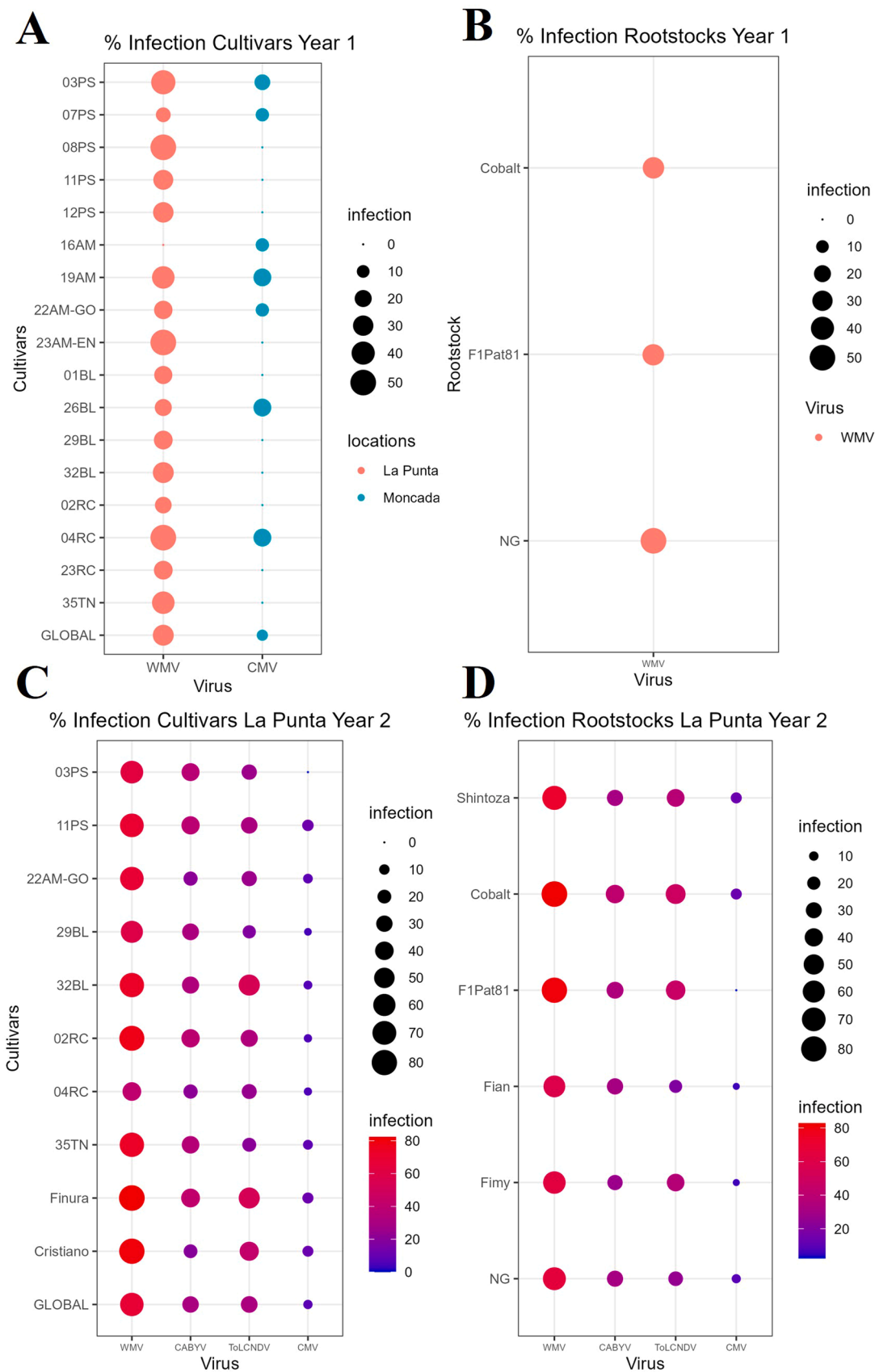
In the second year (Fig. 2C), WMV was also the most prevalent virus in La Punta, affecting 67 % of the plants, but this time, another aphid-borne virus, CABYV, and the whitefly-transmitted ToLCNDV were also detected, although at lower rates (30 %). CMV was also present in approximately 8 % of the plants. The four viruses affected most of the cultivars. The commercial cultivars Cristiano and Finura, commercial hybrids of melons, tended to reach higher infection levels than traditional landraces (WMV:  $\approx$ 80 % vs 60–70; ToLCNDV:  $\approx$ 80 % vs 20–50 %). Overall, grafting did not affect the infection of viruses, with both grafted and NG presenting similar infection rates. ZYMV, MWMV, CYSDV, CCYV, and CGMMV were not detected in this second year (Fig. 2D).

### 3.3. Air and soilborne fungal pathogens

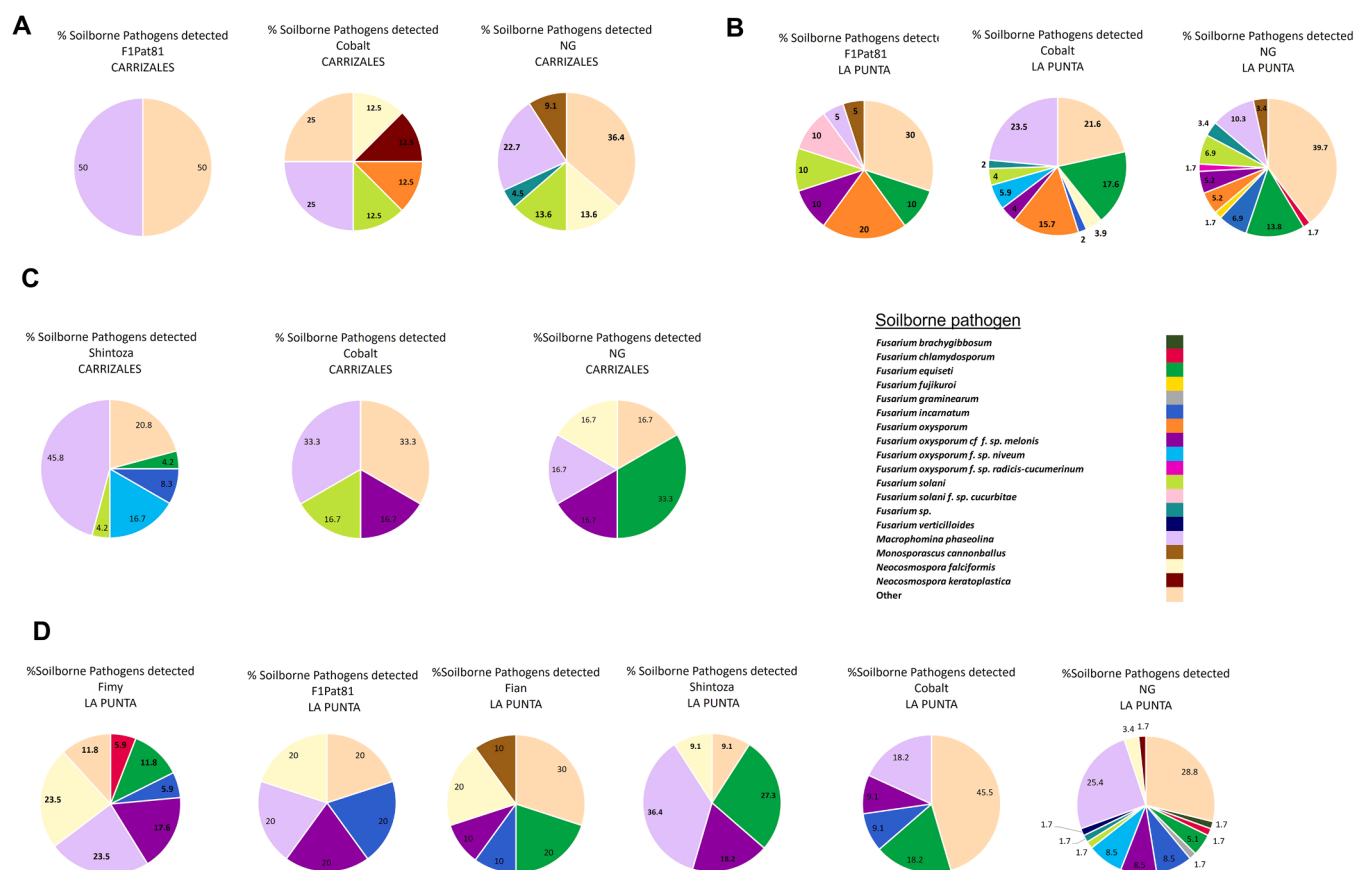
The main airborne fungal disease affecting sweet melons was Powdery Mildew (PM), caused by *Podosphaera xanthii* (Castagne) U. Braun & Shishkoff. In the first year in Moncada, around 40 % of plants showed PM symptoms compared to 16 % in La Punta, where the PM attack was more severe in the second year, reaching 45 % of plants affected. The plants in Carrizales remained free of this fungus. Amarillo and Rochet landraces were more sensitive to this pathogen than Piel de Sapo landraces (50 % vs 30 %).

No plants with symptoms of soilborne fungal pathogens were detected in Moncada. However, in the first year in La Punta and Carrizales, a number of plants died due to soil-borne pathogens' infections. Mortality was much more severe in La Punta than in Carrizales (Average 28 % vs 11 %). In both fields, NG plants were more severely affected (43.8 % and 17.1 %) than plants grafted onto Cobalt (40 % and 7 %) and F1Pat81 (15 % and 14 %). In Carrizales (Fig. 3A), *Macrophomina phaseolina* (Tassi) Goid was the more prevalent pathogen detected in the affected roots (accounting approx. from 20 to 50 % of the pathogens found in roots), followed by two species of *Neocosmospora*, *N. falciformis* (Carrión) Summerb. & Schroers and *N. keratoplastica* Geiser, O'Donnell, Short & Zhang, and several species of *Fusarium*, *F. solani* (Mart.) Sacc. and *F. oxysporum* Schltdl. *Fusarium* spp. and *M. phaseolina* are quite common pathogens causing melon diseases in Spain and worldwide (Vicente González et al., 2020). It is important to note that fungi from the *Neocosmospora* genus, *N. falciformis* and *keratoplastica* have been only recently reported affecting melon plants (González et al. 2020b, c). NG plants showed in general a higher diversity of soil-borne pathogens than





**Fig. 2.** Percentage (%) of infection of different viruses detected in sweet melon cultivars in each field and assay. Each year is also accompanied by the (%) of grafted and NG plants infected. The size of the circle indicates de % of plants infected. For Year 1 graphs (A-B) the different colors indicate the prospection location of the detected viruses. In the Year 2 graphs (C-D), the colors emphasize the differences in the percentage of infection.



**Fig. 3.** Percentage of soilborne pathogens detected in Year 1 (A, B) and Year 2 assay (C, D) in Carrizales (A, C) and La Punta (B, D) on *Cucurbita* (Cobalt and Shintoza), *Cucumis* (F1Pat81, Fian and Fimy) and non-grafted (NG) plants.

grafted plants, consistently with their higher mortality. For example, *Monosporascus cannonballus*, a typical melon soilborne pathogen causing melon vine decline, was isolated from the NG plants (9.1 %) but was not detected in Cobalt and F1Pat81 grafted plants. Consistently, these rootstocks have been reported to be tolerant to this fungus (Roig et al. 2012).

In La Punta, we detected a much higher diversity of soilborne pathogens (Fig. 3B), consistently with the longest history of melon cultivation. Although *M. phaseolina* accounted for 5 to 24 % of the isolated pathogens, *Fusarium* species were much more frequent, mainly *Fusarium oxysporum* (f. sp. *melonis* and *niveum*) and *F. solani*, but also *F. equiseti* and *F. incarnatum*, a species complex reported as the causal agent of postharvest rot in melon (Wonglom and Sunpapao, 2020). Diverse *Neocosmospora* spp. were present, but less frequently, as was *M. cannonballus*. Again, pathogen diversity was higher in NG plants.

In the second year, we tested three additional rootstocks in both fields. Mortality was higher in La Punta than in Carrizales (16.3 % vs 8.7 %). In Carrizales (Fig. 3C), only non-grafted and *Cucurbita* grafted plants were affected by soilborne pathogens, with 3.7 %, 23.7 % and 17.6 % (non-grafted, Shintoza and Cobalt, respectively). The main pathogen affecting *Cucurbita* rootstocks was again *M. phaseolina* (33.3 to 45.8 %), but this time with a higher percentage of mixed infection with *F. oxysporum* f. sp. *melonis/niveum* and *F. solani*, and a lower percentage with *Neocosmospora* species. NG melons this year were less affected by *M. phaseolina* and more by *N. falciformis*, *F. oxysporum* f. sp. *melonis*, and *Fusarium equiseti* (Corda) Sacc., *F. solani* and *M. cannonballus* were not detected this year in nongrafted melons.

This second year in La Punta (Fig. 3D, Supplementary Figure 1.), non-grafted plants also displayed higher levels of mortality (28 %) than grafted plants in both *Cucurbita* (Shintoza: 14.3 %; Cobalt: 18 %), and *Cucumis* (F1Pat81: 6 %, Fian: 9.8 % Fimy: 18 % rootstocks). Regarding

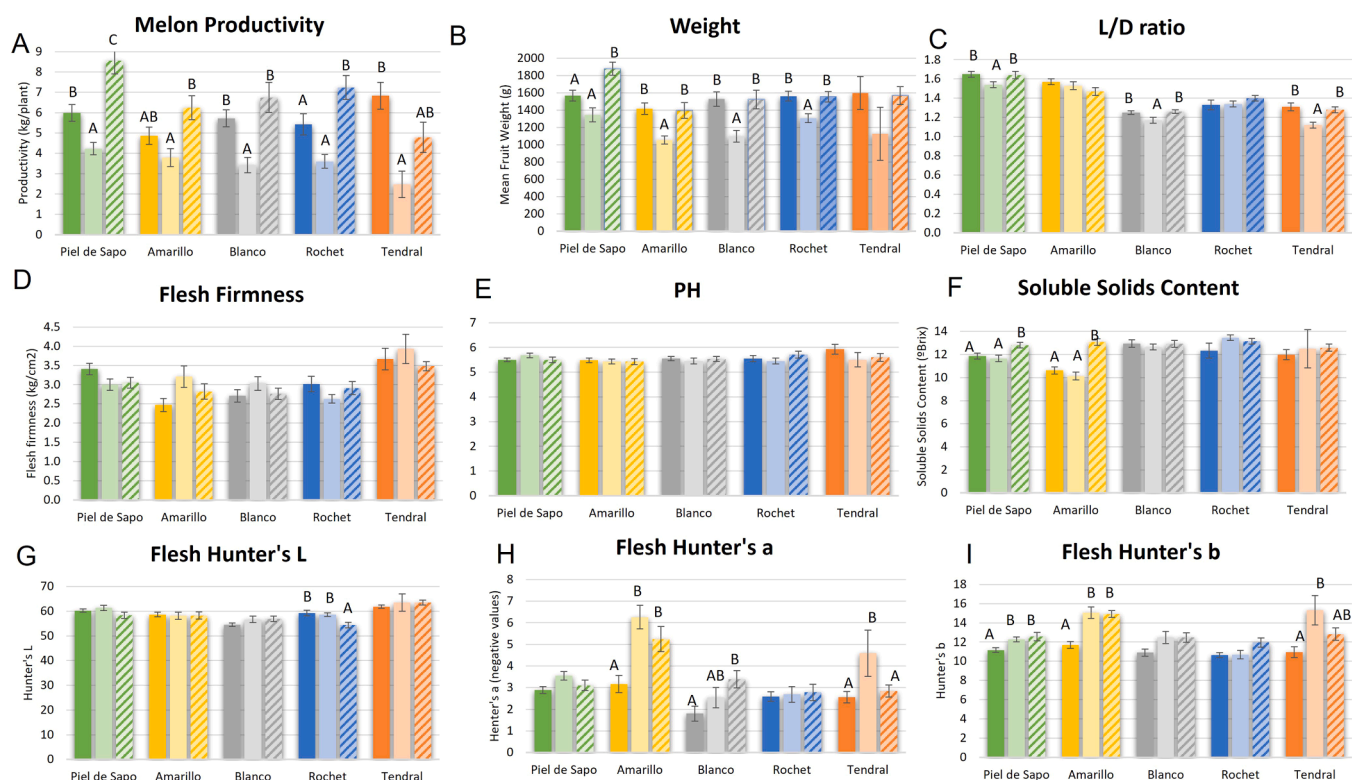
soilborne pathogens, the main one was again *M. phaseolina* (18.2 to 36.4 %), but also with higher infection percentage of *F. oxysporum* f. sp. *melonis* and *Neocosmospora* species. It is relevant the lack of *F. solani*, frequent in Carrizales and La Punta in Year 1. Again, it is important to note the higher diversity of pathogens detected affecting non-grafted plants.

### 3.4. Yield and fruit quality of traditional Ibericus varieties in different stressful conditions

#### 3.4.1. Non grafted melons

A large set of traditional Ibericus landraces of different market types were cultivated under organic farming conditions in three fields displaying different environmental and stressful profiles. Fig. 4 compares the agronomical and quality traits of non-grafted cultivars grouped per market type (Piel de Sapo, Amarillo, Blanco, Rochet and Tendral) in the three fields grown year 1.

Most Ibericus types had a moderate marketable yield under the organic farming conditions of Moncada and Carrizales fields (Fig. 4). As stated earlier, the epidemiological conditions were different in these two fields. Moncada experienced a mild infection of CMV and a moderate PM attack, which did not cause plant mortality. Soil-borne pathogens were not present in this field. In contrast, Carrizales was virus-free, but had a moderately diverse soilborne pathogen profile (*Macrophomina* and *Neocosmospora*, and some diversity of *Fusarium* species), leading to moderate plant mortality (Figs. 2 and 3). The Carrizales field also had high saline conditions compared to Moncada. These different agroecological conditions affected plant mortality (17 % NG died in Carrizales), but did not have a significant effect on production per plant (varying from 4.8 to 10 kg, and from 5 to 8 kg, in Carrizales and Moncada, respectively) or fruit weight (from 1.4 to 1.8 kg and 1.5 to 1.6 kg,



**Fig. 4.** Productivity and fruit characteristics of traditional non-grafted sweet melon cultivars from each of the 5 subgroups (Piel de Sapo, Amarillo, Blanco, Rochet and Tendral) for Moncada (full color), La Punta (light color) and Carrizales (strips) common between fields. Bars with the same letters indicate no significant differences between each site Tukey's test ( $P \leq 0.05$ ). If no letters are present, no significant differences were observed between the samples.

respectively). Supplementary Figure 2 includes the details of the different cultivars. Some specific cultivars, such as 03 PS, 07PS, and 08PS (>8 kg/plant) or 32BL, and 02RC (nearly or over 10 kg/plant), even had higher production per plant and fruit weight in Carrizales compared to Moncada, so they can be recommended for cultivation in these agroecological conditions. Quality traits such as fruit shape, firmness, and acidity were similar in both fields (Fig. 4). However, interestingly, the soluble solid content was significantly higher in the fruits of plants grown in saline soil. This effect was more pronounced in Piel de Sapo and Amarillo market types (12.5–14.8 in Carrizales vs 11–13.5 in Moncada).

In the assay of the year 1, the pathological conditions of La Punta had a much greater effect on mortality and production. Moderate viral attacks of the potyvirus WMV, more damaging than CMV, a mild PM attack, and the diverse profile of soilborne pathogens (Figs. 2 and 3), that caused a mortality of around 44 % of the non-grafted plants, significantly affected the production. In fact, production in La Punta dropped to 2.5–4 kg/plant (Fig. 4). This loss of production occurred in most cultivars (Supplementary Figure 2). Fruits were also smaller (reduction in weight  $\approx$ 300 g–500 g). Fruit firmness, sweetness, and acidity were not affected compared to Moncada.

In the second year, we repeated the experiment with some selected varieties, some of which were selected among those that behaved well, grafted and NG in the first year: 03PS, 22AM-GO, 32BL, 02RC, and 04RC. We added some of the cultivars assayed NG in the first year, which were highly appreciated by consumers in organoleptic tests, 11PS, 29BL, and 35TN, along with two different commercial varieties, Finura and Cristiano. Fig. 5 and Supplementary Figure 3 compare the behavior of non-grafted cultivars of the different market classes in the two fields grown in year 2. This year, no significant differences were found in the production per plant between the two fields in most cultivars (Supplementary figure 3), and the response of the commercial varieties was similar to that of the traditional cultivars, with low production per plant

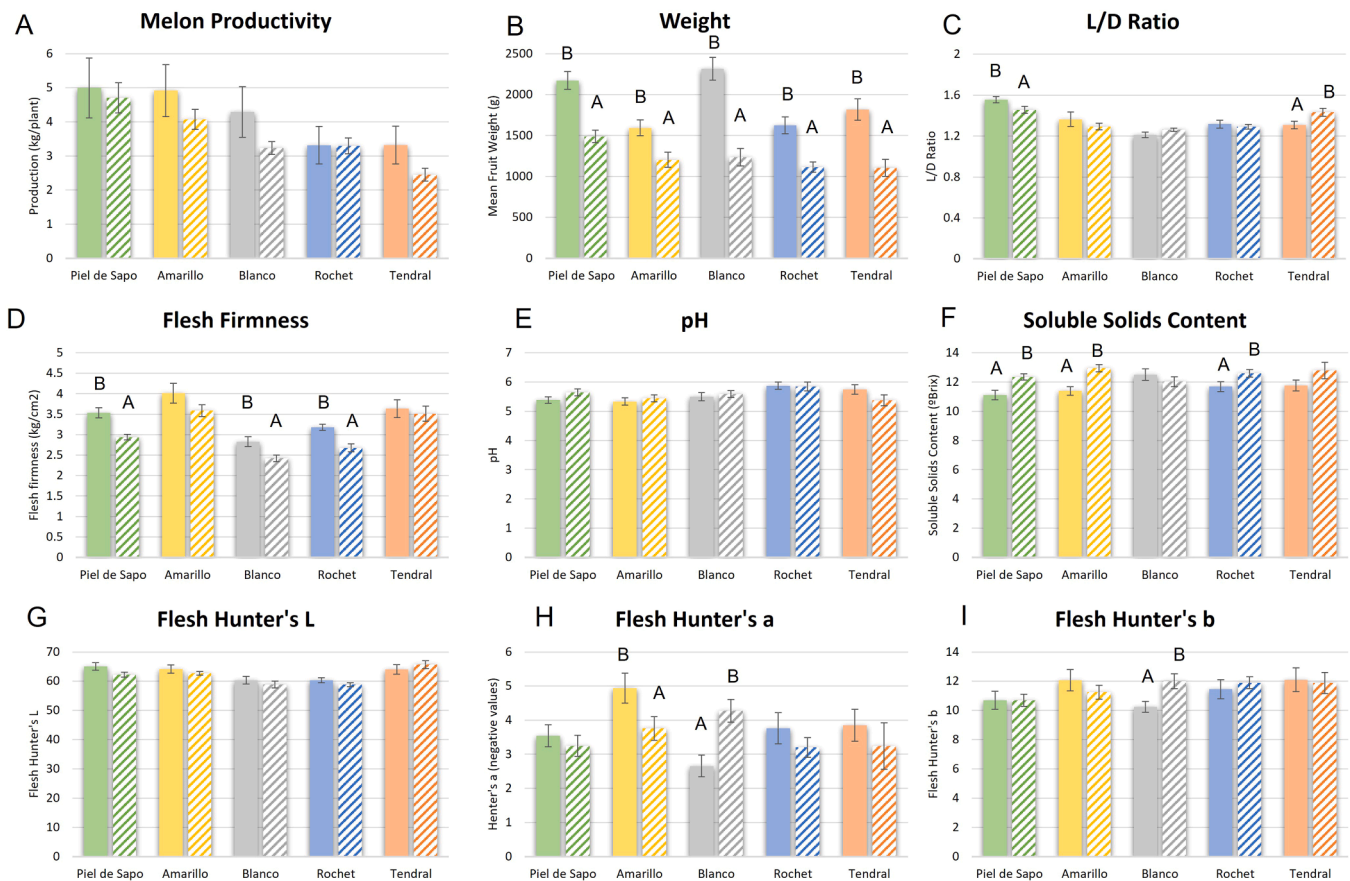
in the field of Carrizales.

The water for irrigation had a higher conductivity in the second year (4.5 vs 6 dS/m in years 1 and 2, respectively). This likely contributed to changing the fungal profile, richer in *Fusarium* species. Additionally, the lack of rain during the growing cycle and the concentration of precipitation in August and at the end of the cycle also affected the vegetative development of the plants and altered melon production in this field. Even so, the more severe viral and soilborne fungal attack caused a higher mortality in NG plants in La Punta, leading to a reduced total production in this field (16–40 kg vs 17–50 kg in La Punta and Carrizales, respectively). Quality traits such as fruit shape, firmness, and acidity were similar in both fields. However, interestingly, as it occurred the first year, melons grown in saline soil have more soluble solids, mainly Piel de Sapo, Amarillo and Rochet market classes (12.5–13 °Brix in Carrizales vs 10.5–11 °Brix in La Punta). The most productive cultivars and with the best quality in La Punta and Carrizales could be recommended for organic farming in this types of agroclimatic conditions (Supplementary figure 3). For example, 03PS, 32BL, and 22AM-GO were quite productive, even in these unfavourable conditions (>4 kg/plant), whereas most of the others, such as 35TN, 04RC, and 29BL, showed reduced productions (<3 kg/plant).

### 3.4.2. Grafted melons

As stated before, grafted melons in Carrizales had lower mortality rates (7 % and 14 % in F1Pat 81 and Cobalt, respectively) than NG (17.1 %). Grafted plants also produced significantly more than those NG (Fig. 6). This was consistently observed for most traditional cultivars. The yield of 03PS grafted onto F1Pat81 and Cobalt was 12 and 10.4 kg/plant, respectively, while the yield of 12PS grafted onto F1Pat81 and Cobalt was 10.4 and 11.5 kg/plant, respectively. In comparison, non-grafted (NG) 03PS and 12PS plant yield was 9.0 and 7.7 kg/plant, respectively (Fig. 6). Thus, grafting resulted in an average increase of 24.8 % in 03PS and of 43.8 % in 12PS. Similar or even higher increases





**Fig. 5.** Productivity and fruit characteristics of sweet non-grafted melon cultivars from each of the 5 subgroups (Piel de Sapo, Amarillo, Blanco, Rochet and Tendral) La Punta (light colour) and Carrizales (strips) common between fields in the Year 2. Bars with the same letters indicate no significant differences between each site Tukey's test ( $P \leq 0.05$ ). If no letters are present, no significant differences were observed between the samples.

in production per plant were observed in Amarillo varieties 22AM-GO (118.8 %) and 22AM-EN (95.3 %), in Blanco 01BL (73.2 %), and in Rochets, 02RC (29.7 %) and 04RC (66.9 %). The grafting effect on production was higher in Amarillo and Blanco varieties, which produced less when NG than Piel de Sapo. The Blanco variety 32BL was quite tolerant to the stress in Carrizales, with similar production in NG compared to grafted plants. Therefore, we recommend this variety as one of the least affected by salinity and the moderate soil-borne fungal attack found in this field. Our results proved that grafting can be an efficient management strategy in saline soils, even when soilborne pathogens are present under low to moderate pressures.

La Punta (Fig. 6) conditions were much more severe, and despite grafted plants having similar production per plant to non-grafted (between 2.9 and 5.3 kg/plant), grafting, mainly with the F1Pat81 rootstock, allowed a significant reduction of mortality (from 43.8 % in NG to 15 % in F1Pat81 grafted plants). Not only the high diversity of soilborne pathogens, with a greater diversity of damaging *Fusarium* species, but also the presence of PM and a moderate attack of the aggressive potyvirus WMV can account for this low production, even of grafted plants.

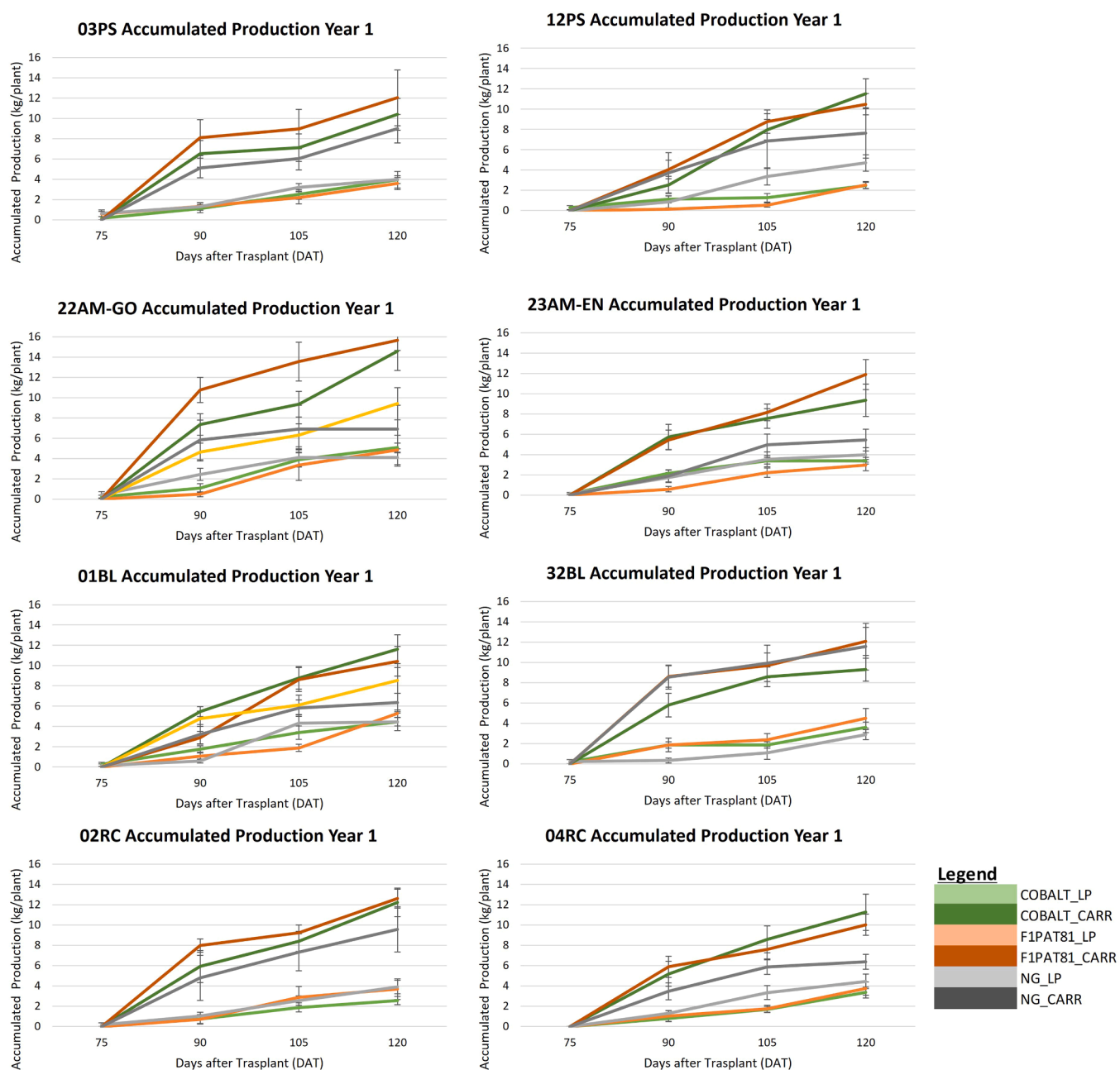
Overall, grafting had little effect on fruit quality in melons, with location having the most significant effect on fruit characteristics (Table 1, Fig. 7, and Supplementary Table 4.A. and 4.B.). The main fruit characteristic affected by grafting was SSC, with some changes in the flesh fruit colour (a-value and b-value). Some specific scion-rootstock combinations resulted in improved fruit characteristics, such as F1Pat81 increasing the weight of Amarillo 23AM-EN in Carrizales or increasing SSC in all Amarillo melons in La Punta compared to NG. Cobalt also improved fruit weight and SSC in some melons (03PS, 04RC, and 01BL), but also increased fruit seed cavity in Amarillo 23AM-EN, a

negative trait for marketable melons.

In the second year, we repeated the grafting experiment with some selected varieties, both grafted and non-grafted, including two different commercial varieties, Finura and Cristiano, as controls.

The climatic conditions of Carrizales were less favourable more saline water for irrigation, lack of rain during the growing cycle, precipitation concentration in August, different fungal profile, thus altering melon production in this location, leading to lower production, as previously stated (Fig. 8.). These conditions affected differentially to grafted plants, with higher mortality in plants grafted onto *Cucurbita* rootstocks. Overall, as previously stated, production per plant was low, ranging between  $\approx 2.5$ –8.5 kg, and the effect of grafting varied between cultivars. Traditional Piel de Sapo and Tendral, displayed a higher production when grafted. For instance, yield in 11PS and 35TN increased between 80–150 % (2.5–2.8 kg/plant vs 5.6–8.4 kg/plant) employing *Cucurbita* rootstocks, while 03PS displayed a 40 % increase with F1Pat81. Similar results were found with 32BL and 22AM-GO and commercial Finura that increased productions grafted both with *Cucurbita* and *Cucumis* rootstocks (*Cucumis* 30–80 % and *Cucurbita* 20–50 %). However, other varieties, 29BL, 02RC and commercial Cristiano displayed similar results both grafted and non-grafted. Therefore, grafting can help to mitigate the effects of this combined effect of salt stress with drought and fungal attack, but with more effect in some specific cultivars.

In La Punta, grafting significantly reduced the mortality (*Cucurbita* rootstocks 14 and 18 %, and *Cucumis* rootstocks 6 to 18 % compared to the 28 % of NG). No overall differences were found due to grafting in production per plant (2.5–4 kg/plant in NG vs 2.5–4.5 kg/plant in grafted plants), although some specific combinations resulted in higher

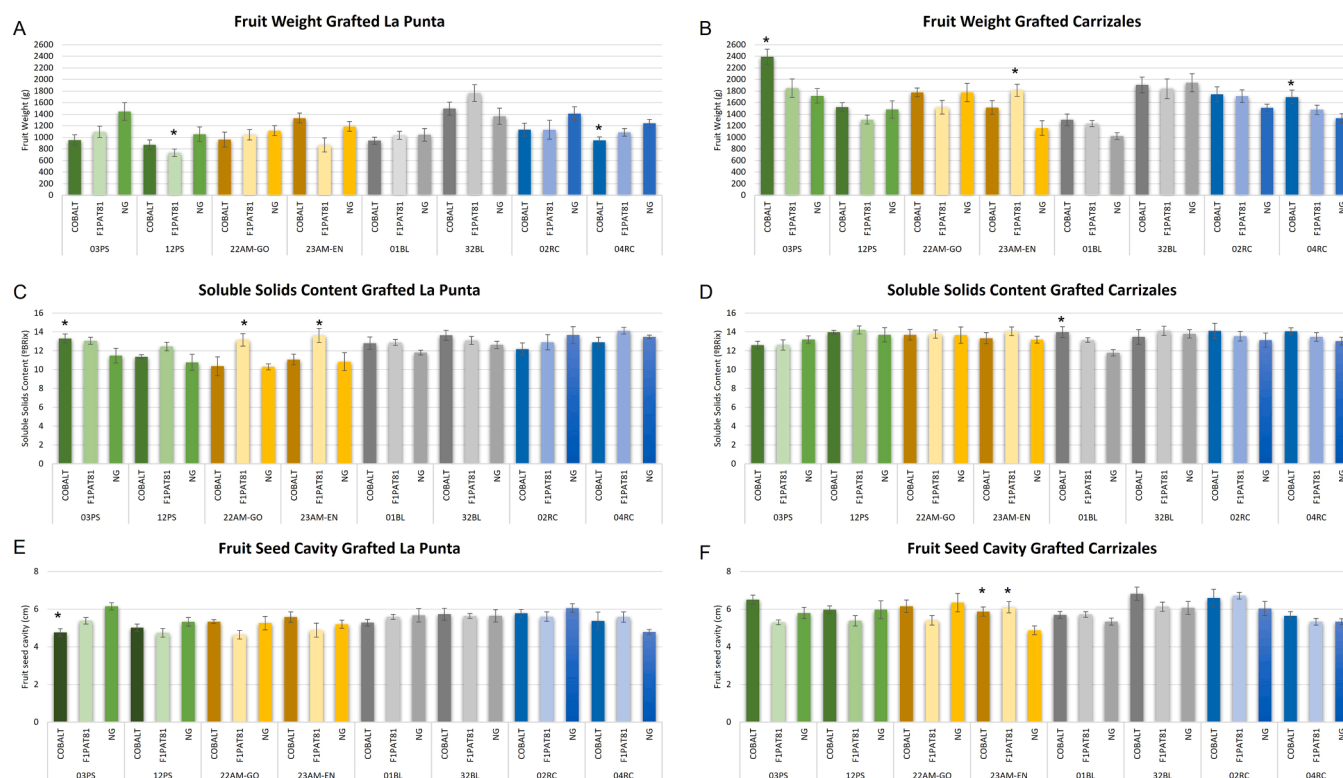


**Fig. 6.** Field accumulated production for grafted melons onto COBALT (green), F1Pat81 (orange) and non-grafted (grey) plant from the field of Carrizales (CARR) (dark) and La Punta (LP) (pale) for the Year 1 assay.

**Table 1**

Effect of the location, scion, rootstock and their interaction on the fruit characteristics (FW: Fruit Weight; FL: Fruit Length; FD: Fruit Diameter; FF: Fruit Firmness; RF: Rind Firmness; ExoTh: Exocarp thickness; RTh: Rind thickness; SSC: Soluble Solids Content; FHL: Flesh Hunter's L; FHa: Flesh Hunter's a; FHB: Flesh Hunter's b; RHL: Rind Hunter's L; RHa: Rind Hunter's a; RHb: Rind Hunter's b; FC: Fruit seed Cavity) of the traditional melon cultivars for the non-grafted plant fruits and grafted rootstocks for La Punta and Carrizales for Year 1. The statistical ANOVA p-value is provided (ns: non-significant, \*Significant at  $P < 0.05$ , \*\*Significant at  $P < 0.01$ , \*\*\*Significant at  $P < 0.001$ ).

|               | FW  | FL  | FD  | FF  | RF | ExoTh | RTh | pH  | SSC | FHL | FHa | FHB | RHL | RHa | RHb | FC  |
|---------------|-----|-----|-----|-----|----|-------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Scion (S)     | *** | *** | *** | *** | —  | ***   | *** | *** | *** | *** | *** | *** | *** | *** | *** | *** |
| Rootstock (R) | ns  | ns  | ns  | ns  | —  | ns    | **  | ns  | *** | ns  | *   | *** | ns  | ns  | ns  | ns  |
| Location (L)  | *** | *** | *** | **  | —  | ns    | *** | ns  | *** | **  | ns  | ns  | ns  | *   | **  | *** |
| SxR           | ns  | ns  | ns  | ns  | —  | **    | *   | **  | ns  | ns  | ns  | ns  | ns  | ns  | ns  | *   |
| SxL           | *** | ns  | ns  | *   | —  | **    | *   | *** | *** | *   | ns  | **  | *   | *** | *   | ns  |
| RxL           | *** | **  | *** | ns  | —  | ns    | ns  | ns  | *   | **  | **  | ns  | ns  | ns  | ns  | *   |



**Fig. 7.** Mean Fruit weight (A, B), Soluble Solids Content (C, D) and Fruit Seed Cavity (E, F) for the different Ibericus cultivars grafted onto Cobalt (Dark colour), F1Pat81 (Light colour) and NG from La Punta (A, C and E) and Carrizales (B, D and F) in year 1. Bars presenting with a (\*) indicates significant differences to the non-grafted control (Dunnett's test  $P \leq 0.05$ ).

yields, such as 03PS grafted on Fim, which increased from 4.3 kg/plant to 7.2 kg/plant. It seemed that these extreme conditions (higher viral and soilborne fungi presence) severely hampered productivity, even with the use of grafting.

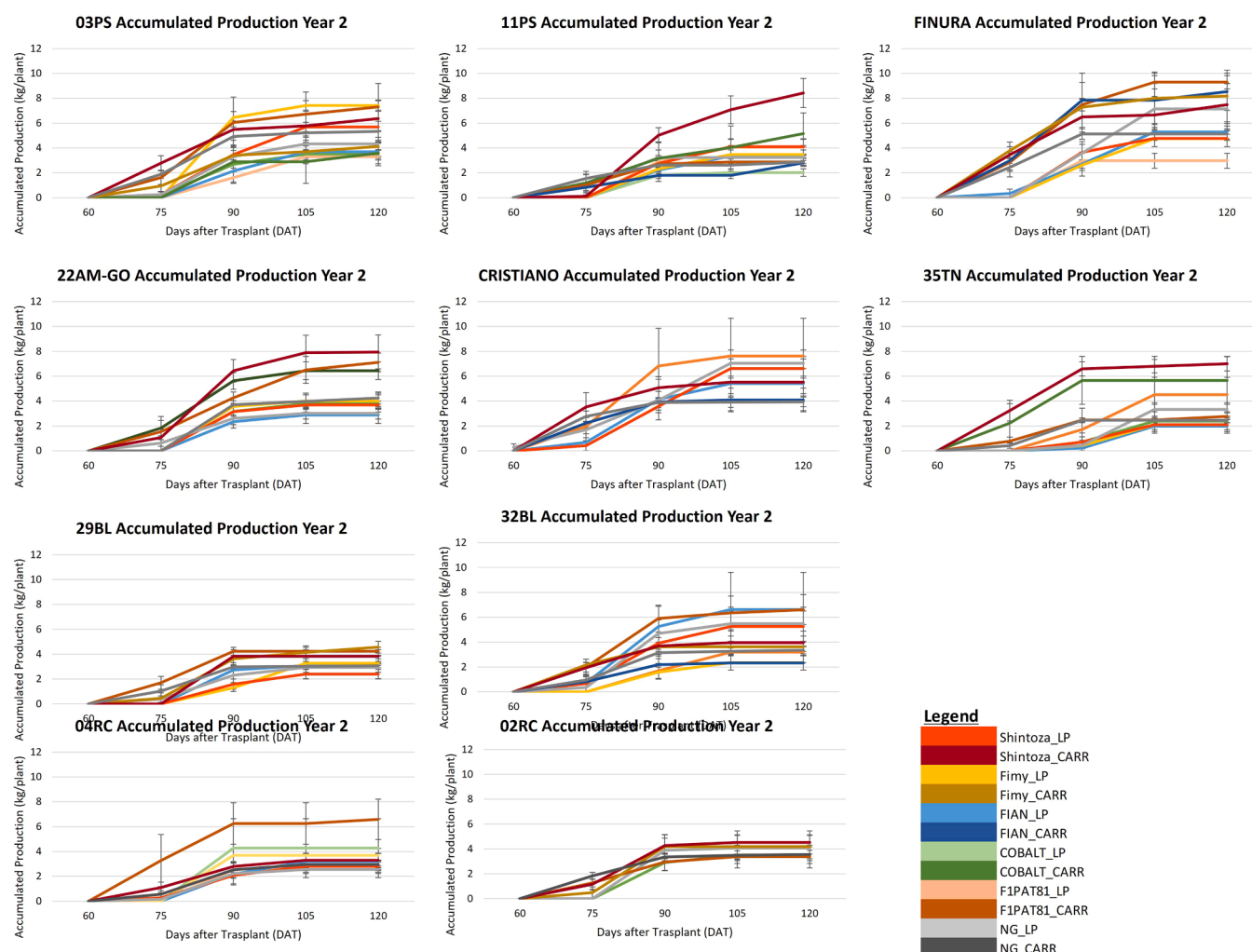
Overall, grafting did have an effect on fruit quality in melons, although the most important factors were location and the scion (Table 2, Supplementary Table 5.A. and 5.B.). *Cucurbita* grafted plants presented higher fruit weight, larger fruit diameter, and higher seed cavity. Differences in fruit flesh colour and rind colour were also observed, but these variations occurred between different rootstocks, not with the NG control. SSC did not seem to be affected by grafting. *Cucumis* grafted plants overall maintained more similar fruit characteristics to the NG control plants.

#### 4. Discussion

Viral pressures mediated by insect vectors represent a key ecological constraint to melon production under organic farming systems. The aphid-transmitted viruses WMV, CMV, and CABYV, as well as ToLCNDV, transmitted by whiteflies, are widely spread in the Mediterranean basin (Velasco et al. 2020; Desbiez et al. 2020; De Moya-Ruiz et al. 2021; Rabadán et al. 2021; López-Martín et al. 2024). Several accessions resistant to these viruses have already been described within the exotic melon germplasm, belonging to the Acidulus, Conomon, Kakhri-Agrestis, and Momordica groups (Kassem et al., 2015; López et al., 2015; Martín-Hernández and Picó, 2020; Pérez-de-Castro et al., 2020; Schoeny et al., 2017). Some of these sources have been successfully used to introgress resistance into the Ibericus melon background (Palomares-Rius et al. 2018; Pérez-de-Castro et al. 2019; Pérez-de-Castro et al. 2020; Pérez-Moro et al. 2024). Therefore, the introduction of resistance into these traditional cultivars is a feasible and important objective to promote traditional melon cultivation under organic farming conditions, as the effect of climate change will likely

lead to more severe and diverse viral infections (Velasco et al. 2020). Other control methods could be used by protecting against the viral vectors, such as anti-insect screens, which have proven to be effective in controlling pests such as *Aphis gossypii* in cucumbers in walk-in tunnels (Antignus et al., 1998) or the use of parasitoids, which display high specificity towards their prey, leading to less impact to the environment (Lopes et al., 2009). But these alternative methods are not as reliable, and the use of resistant cultivars is the best in terms of efficiency, economy, and ecology (Gómez et al., 2009; Messelink et al., 2020).

The main aerial pathogen detected in the present study was Powdery mildew caused by *Podosphaera xanthii*. This pathogen is widespread, easily identifiable, and primarily affects the Cucurbitaceae family (Pérez-García et al., 2009). This fungus did affect our melon cultivation, especially in Moncada and La Punta. Traditional Ibericus landraces have been assayed against different races of PM. For example, Alvarez et al. (2005) reported the response of 127 melon accessions to *P. xanthii* race 1 and race 2, finding some resistant cultivars from the South of Spain, origin of the fungal isolates. However, most of them were not resistant to both races. McCreight (2006) studied the resistance of 22 cultivars to *P. xanthii* and found that "Amarillo", "Moscatel Grande", and "Negro" Spanish cultivars were resistant to race 1 of *P. xanthii*, but susceptible to race 2. No artificial inoculation assays have been carried out with the landraces used in our assay, so it is unknown if they are resistant to specific powdery mildew races. Likely, what we have in the fields is a mixture of PM races. Moreover, it has been proven that temperature plays a key role in powdery mildew resistance since both low ( $<25^{\circ}\text{C}$ ) (Tores et al. 1996; Beraldo-Hoischen et al. 2021; López-Martín et al. 2022) and high temperatures ( $>35^{\circ}\text{C}$ ) (Hosoya et al., 2000; McCreight, 2006) can cause a breakdown of resistance, enabling sporulation. Hence, the high susceptibility observed in our assays could also be explained by the high temperatures registered in Spain during spring and summer, which would help overcome the possible resistance found in any of the studied traditional cultivars. More than 21 races of *P. xanthii* have been



**Fig. 8.** Field accumulated production for grafted melons onto COBALT (green), F1Pat81 (orange), FIAN (blue), FIMY (yellow) and Shintoza (red) and non-grafted (grey) plants from the field of Carrizales (CARR) (dark) and La Punta (LP) (pale) for the year 2 assay.

**Table 2**

Effect of the location, scion, rootstock and their interaction on the fruit characterization (FW: Fruit Weight; FL: Fruit Length; FD: Fruit Diameter; FF: Fruit Firmness; RF: Rind Firmness; ExoTh: Exocarp thickness; RTh: Rind thickness; SSC: Soluble Solids Content; FHL: Flesh Hunter's L; FHa: Flesh Hunter's a; FHB: Flesh Hunter's b; RHL: Rind Hunter's L; RHa: Rind Hunter's a; RHB: Rind Hunter's b; FC: Fruit seed Cavity) of the traditional melon cultivars for the non-grafted plant fruits and grafted rootstocks for La Punta and Carrizales for Year 2. The statistical ANOVA p-value is provided (ns: non-significant, \*Significant at  $P < 0.05$ , \*\*Significant at  $P < 0.01$ , \*\*\*Significant at  $P < 0.001$ ).

|                  | FW  | FL  | FD  | FF  | RF | ExoTh | RTh | pH  | SSC | FHL | FHa | FHB | RHL | RHa | RHB | FC  |
|------------------|-----|-----|-----|-----|----|-------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Scion (S)        | *** | *** | *** | *** | —  | ***   | *** | *** | *** | *** | *** | *** | *** | *** | *** | *** |
| Rootstock (R)    | *** | **  | *** | ns  | —  | **    | ns  | ns  | ns  | ns  | **  | *   | ns  | *** | ns  | *** |
| Localization (L) | *** | *** | *** | *** | —  | ***   | **  | *   | *** | *** | ns  | *** | ns  | *   | ns  | *** |
| S x R            | *** | *** | *** | ns  | —  | **    | *** | ns  | **  | ns  | *** | **  | *** | *** | ns  | ns  |
| S x L            | *   | **  | *   | *** | —  | ***   | *   | **  | *** | ns  | *** | *** | *** | **  | *** | *** |
| R x L            | *   | *** | **  | ns  | —  | Ns    | Ns  | ns  | ns  | ns  | *   | *   | ns  | ns  | ns  | ns  |

identified to date, with resistant cultivars often belonging to exotic groups such as Momordica or Acidulus (Cui et al., 2022). Introgression of resistance to this airborne fungal pathogen into the Ibericus background has been successfully performed employing the resistant Acidulus cultivar “TGR-1551” (Palomares-Rius et al. 2018; López-Martín et al. 2022).

Spain is one of the countries most vulnerable to climate change (CEDEX, 2017). This means that an increase in the difficulty of disease management is expected in the future (Garrett et al., 2006). Soils are complex structures, and stress combinations can affect plant growth in different ways. Salinity is one of the most prominent abiotic stresses. It

can affect not only plant growth, but also the soilborne microorganism diversity and behaviour. We found two different pathogenic profiles in Carrizales and La Punta, with a higher fungal pathogen diversity in the non-saline soil, although the longer history of melon cultivation in this field could also account for this higher pathogen diversity. The lower pathogen diversity can account for the lower mortality of melon plants found in saline soil, in both years. However, for some pathogens, salinity could promote growth and result in more severe plant infections, as has been reported for *F. solani* (Tiwari et al., 2024). Consistently, we found more *F. solani* in saline than in non-saline soil. Other factors, such as the increase in global temperature, could favour the quick spread of certain



fungal pathogens due to the longer warm seasons, such as the thermotolerant *M. cannonballus* and *M. phaseolina* (Basseto et al., 2011; Hunjan and Lore, 2020). Consistently, both pathogens have been more frequently found in Carrizales, characterized by a warmer and drier climate than in La Punta. Resistances to these pathogens have already been found in *C. melo* (Alvarez et al., 2005; Castro et al., 2020; de Sousa Linhares et al., 2020; Roig et al., 2012), although as noted by some authors (Cohen et al., 2022; de Sousa Linhares et al., 2020) factors such as temperature are important in identifying resistant material. Difficulties in the selection process and complex genetics make it difficult to breed cultivars resistant to soilborne pathogens. Grafting is a more feasible method to fight against them. *Cucurbita* spp, but also *Cucumis* rootstocks with resistance to many soilborne pathogens and other soil abiotic stresses have been selected (Cohen et al. 2012; Cáceres et al. 2017, 2024; Flores-León et al. 2021). The emergence of new pathogens, such as *N. falciformis* and *N. keroparasitica*, will be an important factor in the research and development of new rootstocks (V. González et al., 2020a). Our study showed, in fact, higher mortality in different years and assays in NG plants compared to grafted plants, so suggesting that the different types of rootstocks used can help to reduce the mortality of these traditional Ibericus melons under different types of soil stress under organic farming conditions. One important factor to consider when using grafting in melon is that *Cucurbita* and *Cucumis* rootstocks had different pathogen profiles, with *M. cannonballus* only appearing to affect NG and plants grafted onto *Cucumis* rootstocks, and *Fusarium solani* being more frequent in NG and plants grafted onto *Cucurbita* rootstocks. For example, *Monosporascus cannonballus*, a typical melon soilborne pathogen causing melon vine decline, was isolated from the NG plants, but was not detected in Cobalt and F1Pat81 grafted plants. Consistently, these rootstocks have been reported to be tolerant to this fungus (Roig et al. 2012). These two types of rootstocks have also been reported to cause a differential effect on melon fruit quality (Flores-León et al. 2021; Cáceres et al. 2024), so both pathogen epidemiology and fruit quality should be considered when selecting rootstock-scion combinations for melon organic farming.

Melon is generally considered moderately tolerant to salinity; however, considerable variability exists among cultivars. Certain varieties, such as Inodorus “Sancho”, “Kuizilike”, and Chandalak “Huangdanzi”, have demonstrated vigorous growth under saline conditions (Xiong et al. 2018; Da Silva et al. 2021; Yang et al. 2023). Salinity can also influence both fruit quality and productivity, with reported effects including increased soluble solids content (SSC), reduced flesh firmness, smaller fruit size, and, in some cases, a higher number of fruits (Tedeschi et al. 2011; Huang et al. 2012; Da Silva Dias et al. 2018). However, some studies have found no significant impact of salinity on SSC (Araújo et al., 2024). Our findings indicate that salinity enhances SSC, particularly in the “Amarillo” and “Piel de Sapo” cultivars. Similarly, Tedeschi et al. (2011) reported increased SSC in Ibericus “Tendral” melons under high salinity levels compared to controls. Visconti et al. (2019) further demonstrated that the irrigation method using saline water significantly affected SSC in “Piel de Sapo” melons. In a more recent study, Flores-León et al. (2024) observed increased sucrose content and SSC in Ibericus melons grown under saline conditions. Fruit flesh colour also varied among fields, likely related to the ripening stage. Zainal et al. (2019) reported that factors such as flesh colour are related to factors such as temperature, water availability and time. In that sense, Sousa et al. (2019) indicated that salinity had a lower effect on fruit flesh colour than harvest time, as fruit spent more time in the field, with the ripening process advancing, altering the flesh fruit colour. These results generally indicated that Ibericus melons are good options for cultivation under organic farming conditions, even when saline water and soils are employed. However, viral infections and soilborne pathogens in combination with drought and extreme saline conditions can hamper their cultivation, so genetic breeding and adapted cultural practices are required to minimize the effects of viruses and fungi and abiotic stressful conditions.

Viruses and soilborne pathogens affect the cultivation of traditional Ibericus melons under organic farming conditions more than other stresses, such as soil and water salinity. One efficient way of managing soilborne pathogens is grafting. Grafting is a useful tool, but certain rootstock-scion interactions can lead to fruit quality reduction, shorter postharvest time and incompatibility between the rootstock and the scion (Gaion et al., 2018). During the first year, some combinations did show an SSC increase due to grafting, especially F1Pat81. Both flesh and rind colour, as well as flesh firmness in some cases, were also affected by grafting, with both *Cucurbita* and *Cucumis* rootstocks. Grafting also influenced physical factors such as weight, fruit length, diameter, exocarp and rind thickness. These effects of grafting were already known in melon (Trionfetti Nisini et al. 2002; Verzera et al. 2014; Cáceres et al. 2017, 2024). It is important to note that during the second year no effect on SSC was found due to grafting, something that has already been reported in different studies (Crinò et al., 2007; Guan et al., 2014; Verzera et al., 2014). In general, the use of grafting reduced plant mortality, with little effect on the fruit quality compared to NG fruits.

## 5. Conclusion

Traditional Spanish melon cultivars are quite susceptible to biotic stresses, especially viral infections and soilborne pathogens. In this work, we have identified the main viral and fungal agents that affect traditional melon under organic farming conditions. This knowledge will be very useful for implementing appropriate cultural practices and introgressing genetic resistance derived from resistant exotic melons, already known and used in other genetic backgrounds, into these varieties. Results showed that combinations of viruses and soilborne pathogens can more severely hamper sweet melon production than moderate salt stress, which can also improve fruit sweetness. However, a combination of low rainfall periods and high salinity can impact soilborne pathogen profiles and severely compromise melon production. The employment of rootstocks can be useful to mitigate the effects of these combined biotic/abiotic stresses, but alone, they are not a definitive solution in all cases. Overall, *Cucumis* rootstocks had less effect onto scion melon fruits than *Cucurbita* rootstocks, although some effects on fruit quality are dependent on the scion-rootstock combination.

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## CRedit authorship contribution statement

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## Declaration of competing interest

The authors declare no competing interests.

## Supplementary materials

Supplementary material associated with this article can be found, in the online version, at [doi:10.1016/j.scienta.2025.114437](https://doi.org/10.1016/j.scienta.2025.114437).

## Data availability

The original contributions presented in the study are included in the article's Supplementary Material; further inquiries can be directed to the corresponding author/s.

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