HortScience 59(8):1143–1149. 2024. https://doi.org/10.21273/HORTSCI17850-24

Melon Grafting Effects on Plant Performance and Yield in the High Desert

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Keywords. arid climate, common scion, *Cucumis melo*, fruit quality, squash hybrid rootstocks

Abstract. **Farmers in the high desert are challenged by a short growing season and slow crop establishment of warm-season vegetables. Yet an increasing demand for local produce in nearby urban areas presents an opportunity to diversify farms while adapting to climate uncertainty. Vegetable rootstocks can confer advantages under biotic and abiotic stress conditions, but information on which and how melon rootstocks can improve management does not exist for high desert and short-season regions. Commercial, squash-hybrid rootstocks (i.e., *Cucurbita maxima* × *C. moschata*) were grafted with a common scion (*Cucumis melo* cv. Sarah's choice). Nine rootstocks in 2021 and four selected rootstocks in 2022 were evaluated in four field trials (two per year) in northern Nevada at two distinct locations. Melon grafting did not consistently increase crop performance in the high desert, and it was influenced by location and year. Throughout the initial half of the harvesting period, grafted plants tended to produce more melons, irrespective of location or year, offering a potential appeal for melon growers operating in shorter growing seasons. However, a slight reduction in fruit quality (i.e., °Brix) was observed in some grafted plants compared with the ungrafted control. The benefits of grafting melons onto squash hybrids in high desert conditions remain uncertain and may depend on microenvironment and farming practices that affect crop establishment, such as mulching effects on soil temperature.**

Even though melons (*Cucumis melo*) perform well under arid conditions, the high desert of northern Nevada is a challenging environment mainly due to late frosts, cold soils coupled with the onset of hot and dry climate early in the growing season, and the risk of early frosts in late summer. These conditions may restrict the growing season to ~105 d from transplanting to the final harvest. In Reno at the beginning of June, soil temperatures lag behind air temperatures that can support warm-season crops (Bristow et al. 2021), and soil temperatures at a soil depth of 10 cm are often below 20 °C (Western Regional Climate Center 2021). The optimal soil temperature for establishment of cucurbits, such as melon and watermelon, ranges between 24 and 35 °C (Brandenberger et al. 2021; Michael et al. 2010). In northern latitudes, cold soil temperatures early in the season delay root growth, canopy development, and fruit set; may induce blossom end rot; and can delay harvest (Brandenberger et al. 2021). Vegetable grafting can increase yields and improve root chill tolerance (Bristow et al. 2021; Martínez-Ballesta et al. 2010), which could enhance warm-season crop performance in locations with a short growing season.

Received for publication 1 Apr 2024. Accepted for publication 29 May 2024.
Published online 26 Jul 2024.
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Vegetable grafting has been shown to confer early establishment in cucurbits such as watermelon (Pal et al. 2020), cucumber (Aslam et al. 2020), and bitter gourd (Tamilselvi and Pugalendhi 2017). Melons are commonly grafted on squash hybrid rootstocks, a cross between *Cucurbita maxima* and *C. moschata*, to confer resistance to soilborne diseases [US Department of Agriculture, National Institute of Food and Agriculture (USDA-NIFA) 2015], production earliness (Schultheis et al. 2015), and salinity tolerance (Balkaya et al. 2016). Squash hybrid rootstocks may improve melon establishment due to a faster developing root system (Reza Salehi-Mohammadi 2009), resulting in a faster canopy growth, earlier flowering and harvest than ungrafted melons (Guan et al. 2015; Schultheis et al. 2015). A trade-off to grafting melons with some interspecific squash hybrids is the reduction in fruit quality (e.g., total soluble solids and fruit texture) (Zhao and Guan 2018). Little information exists on how grafting may improve melon performance in the high desert and influence yield and fruit quality.

We conducted four field trials in northern Nevada between 2021 and 2022 to evaluate nine commercial cucurbit rootstocks grafted with a common melon scion. The trials were conducted in two locations with distinct environmental conditions (e.g., soils and weather) to identify rootstocks that could consistently provide an advantage over the ungrafted cultivar, and we evaluated 1) total yield, 2) production over time, 3) number of fruits per plant, 4) fruit weight, 5) soil canopy cover, 6) normalized difference vegetation index (NDVI), 7) stomatal conductance (g_s), and 8) fruit °Brix.

Materials and Methods

Plant material. Grafted plants were obtained from Plug Connections (Vista, CA, USA), which performed the grafting using the one cotyledon method (Guan and Zhao 2019). To reduce the vigour of the rootstock, the entire root system was removed during grafting, and the rootstock was stimulated to develop new adventitious roots. Plants were shipped to the University of Nevada, Reno (UNR), at a two-leaf stage on 102-cell trays. Plants were acclimated for 2 weeks in a UNR greenhouse at 26.5 and 24 °C during the day and night, respectively, and an average relative humidity of 40%. During acclimatization plants were fertilized with a 20% Hoagland solution three times per week.

In 2021, nine squash-hybrid rootstocks from the cross between *C. maxima* × *C. moschata* were selected based on commercial availability and produced by different seed companies to potentially include more genetic diversity among them. The rootstocks selected were Carnivor, Bs1, Tz148, Just, Rs841, Aq, Ercole, Cobalt, and Shintosa (for details on the rootstocks, refer to USDA-NIFA 2015; www.vegetablegrafting.org). All rootstocks were grafted with cultivar Sarah's Choice, a Cantaloupe-type melon used in the area, and the ungrafted cultivar was used as a control. In 2022, four rootstocks were selected based on yield and production earliness from the previous year: BS1, Carnivor, Cobalt, and Ercole.

Field characteristics and farm management. Field trials were conducted in two locations: in Reno at the UNR Valley Road Greenhouse complex (39°32′28.11″N, 119°48′15.99″W) on a gravelly loam soil (Web Soil Survey, USDA 2021), and in Fallon on two fields at Lattin Farms (2021: 39°27′55.94″N, 118°49′49.66″W; 2022: 39°27′40.11″N, 118°49′49.90″W), both fields were identified as a dia loam soil type (Web Soil Survey, USDA 2021). Reno is located near the north end of the Sierra Nevada mountains at 1373 m above sea level, and Fallon is located 97 km east of Reno at 1207 m above sea level and in the middle of the high desert. The geographic difference between locations results in distinct weather patterns, with precipitation being more abundant in Reno (108 mm) than Fallon (79 mm) during the winter and spring months. However, air temperatures are similar between locations. According to historical data, in June, the average minimum and average maximum temperatures are 10.3 and 28.8 °C in Fallon and 11.1 and 28.5 °C in Reno (Western Regional Climate Center 2021). Yet it is common that in Fallon crops are planted up to 2 weeks earlier than in Reno (Lattin R, personal communication). In 2021, transplanting was on 27 May in Fallon and 4 Jun in Reno, and in 2022, transplanting was on 1 Jun in Fallon and 9 Jun in Reno.

Drip irrigation and black plastic mulch were used in all trials except for the 2021 trial in Reno, which had no plastic mulch. Irrigation, fertilization, and other agronomic management was led by the farmer in Fallon; in the Reno trials, the management was conducted to reflect the farmer's practices. In Reno, fertigation of 60 $kg \cdot ha^{-1}$ of nitrogen and 15 $kg \cdot ha^{-1}$ of P_2O_5 were applied using urea and monopotassium phosphate as fertilizer in 2021; in 2022, only 100 $kg \cdot ha^{-1}$ of nitrogen were applied based on a soil test (data not shown).

Experimental design. All field trials were set up as a randomized complete block design (RCBD). Each field trial had the rootstock–scion combination (i.e., phenotype) and the ungrafted control replicated six times for a total of 60 plots per field in 2021 (10 phenotypes) and 30 plots per field in 2022 (five phenotypes). In Fallon, each plot had six plants in both years, whereas in Reno, each plot had eight plants in 2021 and six plants in 2022. In Fallon, the field layout was determined by the space (planting beds) provided by the farmer within a melon field. For Fallon in 2021, it was three 137-m-long beds, and in 2022, it was two 128-m long beds. For Reno, the trials had 12 and six 55-m-long beds for 2021 and 2022, respectively. For all trials, plant spacing was 90 cm within row and 200 cm between rows and beds. Buffer plants were used at the start and end of each row and on each side of the trial.

Field measurements. Soil canopy cover and NDVI values were measured weekly on the two central plants of each plot within 14 and 56 d after transplant (DAT), which is when canopies reached maximum growth. Multispectral images were acquired using an agricultural digital camera (Tetracam, Inc., Chatsworth, CA, USA), later processed through PixelWrench2 software, and then imported to Python software for pixel processing (Bristow et al. 2021; Rossum and Drake 2009). Pixels representing melon canopy (NDVI >0.5) were extracted and divided per total pixels to calculate the percent cover, which was then converted into covered surface area using a formula derived from the field of view calculator in PixelWrench2 (Bristow et al. 2021).

Stomatal conductance measurements were taken weekly with a SC-1 Leaf Porometer (METER Group, Inc., Pullman, WA, USA) between 35 and 70 DAT. The instrument was calibrated each day of measurement, and readings were taken between 12 PM and 1 PM from a recently mature leaf on a healthy vine and from the two central plants of each plot.

In 2021, harvests were conducted from 52 to 112 DAT in Fallon, and from 62 to 112 DAT in Reno. In 2022, harvests were conducted from 62 to 111 DAT in Fallon and from 67 to 105 DAT in Reno. In each harvest, all plots had ripe fruit collected, counted, and weighed. The total number of fruits per plant was calculated by dividing the total number of melons by the number of plants per plot. Single fruit weight was determined by dividing the total fresh weight of fruits harvested by the number of fruits per plot. Total yield and production over time were determined by the average melon production per plant per plot and scaled up to one hectare considering the plant spacing layout used in the experiment. Fruit quality (i.e., soluble solids; °Brix) was measured on melons harvested 3 d before, and stored in a refrigeration chamber at 5 °C. Fruit was cut in half, one 2 × 2 cm cube was collected from each half and in proximity to the seed cavity, juice squeezed, and °Brix measured with an analog RSA-BR92T refractometer (Cole-Parmer, Vernon Hills, IL, USA) (Suh et al. 2012).

Analytical approach. A two-way, three-way, and a repeated-measures two-way analysis of variance (ANOVA) for RCBD were used as statistical models. The analysis was performed using R 4.1.2 version (R Core Team 2021) and the following packages: 1) lmerTest (Kuznetsova et al. 2017), 2) ggplot2 (Wickham 2009), 3) rstax (Kassambara 2021), and 4) stats (R Core Team 2021). A three-way ANOVA, incorporating year, location, and phenotype as independent variables, was initially employed for total yield, fruit per plant, fruit weight, and Brix grade. A mixed-effects model, treating block as random and location and year as fixed effects, was used to assess error variance among different blocks, locations, and years, with consideration for interaction effects between phenotypes, locations, and years. Because of significant interactions between location and phenotype, location was excluded. Hence, a two-way ANOVA that considered year and phenotype as independent variables was adopted for each location, including the phenotype by year interaction. This analysis only included the five (four grafted and one ungrafted) consistent phenotypes across years. Finally, an ANOVA with a repeated-measures model was used for assessing differences among grafted and ungrafted plants for production over time, soil canopy cover, and NDVI. For significant ANOVAs, a pairwise comparison *t* test with Bonferroni *P* values adjustment was performed to assess significant differences between each phenotype combination (R Core Team 2021).

Results

Plant performance was highly dependent on location, and most measured variables showed a strong interaction between phenotype and location. Thus, results are presented by location, and year by phenotype interactions are discussed. Our study shows that melon grafting did not provide a consistent advantage for yield in the high desert. For consistency, we only present figures of the phenotypes used in both years, which excluded five of the nine rootstocks used in 2021 (Supplemental Fig. 1).

Soil canopy cover

Fallon. Canopy development among phenotypes differed between 2021 and 2022 (phenotype-by-year interaction $P = 0.04$; Fig. 1A). In 2021, the ungrafted control developed canopy faster than the grafted phenotypes. For instance, at 27 DAT, the ungrafted phenotype had a 35% soil canopy cover compared with an average of 25% for the grafted ones. At 49 DAT, most of the grafted phenotypes were similar to the control and reached >80% of soil canopy cover. In 2022, the ungrafted control had a slower canopy development than the grafted phenotypes, which grew faster during the first 4 weeks after transplanting (e.g., 27 DAT; Fig. 1A). At 49 DAT, Carnivor and Ercole had a higher soil canopy cover compared with the control and the other grafted phenotypes. No differences were observed for NDVI among phenotypes within year, but 2022 had an overall higher NDVI than 2021 (Supplemental Fig. 2).

Reno. Canopy development was similar between 2021 and 2022 (phenotype-by-year interaction $P = 0.28$; Fig. 1B). In 2021, early canopy development (15 DAT) was slower for Cobalt, which lagged behind with a soil canopy cover of 5.8% compared with the other phenotypes that had >7% of soil canopy cover. At 43 DAT, all phenotypes had similar growth rates; however, by 50 DAT, Ercole reached a soil canopy cover of 85% and outperformed all other phenotypes, which averaged 78%. In 2022, soil canopy development was similar at early stages and differences were only noted at 50 DAT, mirroring a pattern seen in Fallon at the same growth stage, where Carnivor and Ercole exhibited a larger canopy and Cobalt had a smaller canopy development. No differences were observed for NDVI among phenotypes within year, but 2022 had an overall higher NDVI than 2021 (Supplemental Fig. 2).

Stomatal conductance

Fallon. Stomatal conductance was 27% higher in 2021 than in 2022 for all phenotypes, and g_s patterns remained similar (year-by-phenotype interaction P value = 0.65; Fig. 2A). In Fallon 2021, g_s was similar across all phenotypes (~800 mmol H_2O m^{-2} s^{-1}) except for Carnivor that tended to be higher (820 $mmol \cdot H_2O \cdot m^{-2} \cdot s^{-1}$) than the ungrafted control (790 $mmol \cdot H_2O \cdot m^{-2} \cdot s^{-1}$) ($P = 0.09$). In 2022, g_s was similar across all phenotypes (~580 $mmol \cdot H_2O \cdot m^{-2} \cdot s^{-1}$).

Reno. Similar to Fallon, stomatal conductance was 28% higher in 2021 than in 2022 for all phenotypes, with g_s patterns remaining similar between years (year-by-phenotype interaction $P = 0.47$; Fig. 2B). In Reno 2021, Carnivor had higher g_s than Bs1, averaging 788 and 688 $mmol \cdot H_2O \cdot m^{-2} \cdot s^{-1}$, respectively. No difference was observed between the grafted phenotypes and the control. In 2022, g_s was similar among phenotypes (~530 $mmol \cdot H_2O \cdot m^{-2} \cdot s^{-1}$).

Total yield and production over time

Fallon. Yields were ~50% lower in 2022 than in 2021 (2021: 36 $t \cdot ha^{-1}$; 2022: 18 $t \cdot ha^{-1}$; Fig. 3A), and yield differences among phenotypes were only observed in 2021. No differences in yield patterns were observed between the 2 years (year-by-phenotype interaction

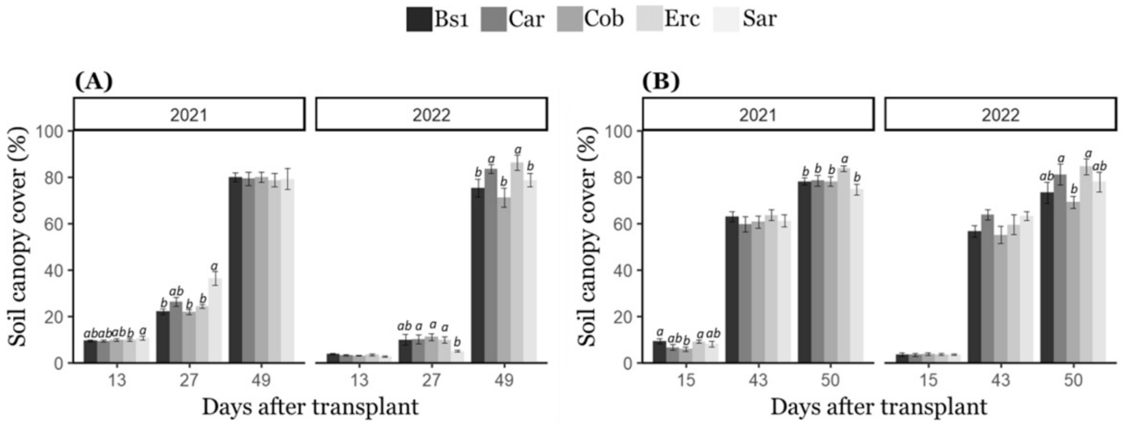

Fig. 1. Soil canopy cover of the melon cultivar Sarah's Choice grafted onto Bs1, Carnivor (Car), Cobalt (Cob), Ercole (Erc), and the ungrafted cultivar as control (Sar) during the 2021 and 2022 field trials in Fallon (**A**) and Reno (**B**). Mean comparisons are within each day after transplant. Means not sharing any letter are significantly different at the 5% level of significance. Error bars represent the standard error of the mean.

P = 0.28). In 2021, the ungrafted control was the best performing phenotype with an average yield of 42 t·ha^{-1}. Most of the grafted phenotypes (i.e., AQ, Carnivor, Cobalt, Ercole, Just, RS-841, and TZ148) had a lower yield than the ungrafted control with an average of 35 t·ha^{-1} (Supplemental Fig. 1). In 2021, only BS1 had a similar yield than the ungrafted phenotype.

The total number of harvests was 12 in 2021, which was four more than in 2022 (Fig. 4A and B). Harvests started 4 d earlier in 2021 than in 2022 (58 and 62 DAT, respectively). In 2021, the ungrafted control had its four highest harvests at 62, 65, 90, and 112 DAT with 6.2, 6.2, 7.5, and 6.9 t·ha^{-1} per harvest, respectively. Most of the grafted phenotypes had production peaks concentrated between 65 and 71 DAT. Carnivor and BS1 had higher yields than most of the other phenotypes at 68 DAT (Carnivor: 9.7 t·ha^{-1}, BS1: 9.4 t·ha^{-1}). Overall, the grafted plants had their highest single yield within the first 2 weeks of the start of harvest, and the ungrafted control had higher yields in the last 2 weeks of harvest. In 2022, there were no differences in any single-day harvest between phenotypes except for Carnivor producing more than the control at 70 DAT (7.2 and 3.9 t·ha^{-1}, respectively).

Reno. As in Fallon, yields were reduced about 50% in 2022 compared with 2021 (2021: 46 t·ha^{-1}; 2022: 21 t·ha^{-1}; Fig. 3B), and yield differences among phenotypes were only observed in 2021. In 2021, and in contrast to yields in Fallon, the ungrafted control had a 25% lower yield than four of the nine grafted phenotypes (i.e., Carnivor, Cobalt, Ercole, RS-841; Supplemental Fig. 1). In 2022, yields were similar among phenotypes, but Cobalt tended to be lower than Carnivor, Ercole, and the ungrafted control (P = 0.07), which correlated with Ercole's lower canopy development.

The total number of harvests in 2021 was 11, which was five more than in 2022 (Fig. 4C and D). Harvest started 5 d earlier in 2021 than in 2022 (62 and 67 DAT, respectively). Different patterns in production over time were observed between the 2 years (year-by-phenotype interaction P = 0.006). In 2021, the grafted plants produced more melons than the control in the first four harvests, with Carnivor producing earlier than any other phenotype. Ercole had the highest harvest peak later in the season at 105 DAT (13.7 t·ha^{-1}). In 2022, no difference in any single-day harvest was observed between grafted phenotypes and the control. Although no statistical differences were observed within a single-day harvest, the control had its production peak at the third harvest (74 DAT) with a yield of 12.8 t·ha^{-1}, whereas the grafted phenotypes produced 3.5 t·ha^{-1}. The grafted phenotypes had their production peak at 78 DAT with an average of 8.7 t·ha^{-1} compared with the 7.5 t·ha^{-1} of the ungrafted control.

Fruit count and weight

Fallon. Fruit weight decreased by 44% in 2022 compared with 2021 (2021: 1.96 kg/fruit 2022: 1.1 kg/fruit), which helps explain the decreases in total yield observed between years. Fruit weight was mostly similar among phenotypes within year, but the fruit weight pattern among phenotypes and years tended to be different (year-by-phenotype interaction P = 0.097) (Fig. 5A). Overall, the ungrafted control had one of the heaviest fruits in both years. In 2021, the ungrafted control produced heavier melons (2.12 kg/fruit) than Carnivor (1.83 kg/fruit), whereas in 2022, the ungrafted control produced heavier melons (1.25 kg/fruit) than Cobalt (1.04 kg/fruit).

The number of fruits per plant were similar among phenotypes in both years, and no interaction was observed between year and

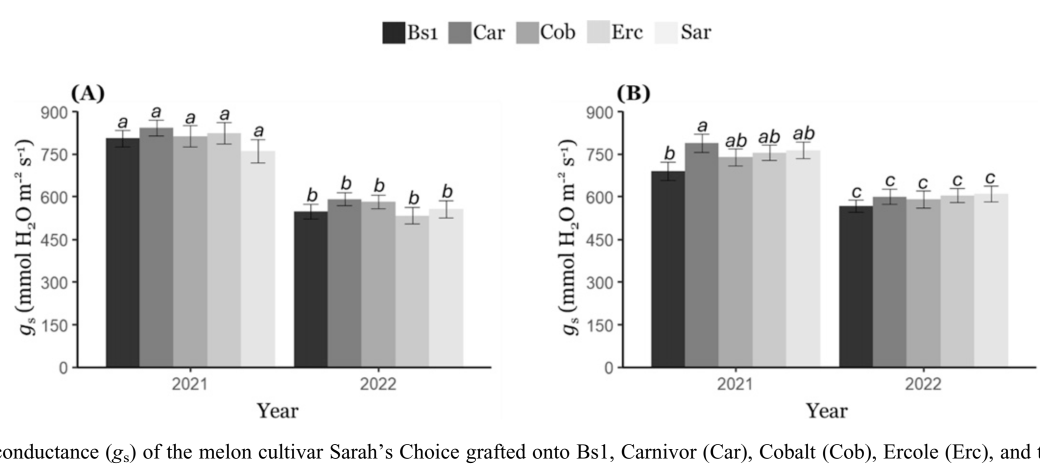

Fig. 2. Stomatal conductance (g_s) of the melon cultivar Sarah's Choice grafted onto Bs1, Carnivor (Car), Cobalt (Cob), Ercole (Erc), and the ungrafted cultivar as control (Sar) during the 2021 and 2022 field trials in Fallon (**A**) and Reno (**B**). Means not sharing any letter are significantly different at the 5% level of significance. Error bars represent the standard error of the mean.

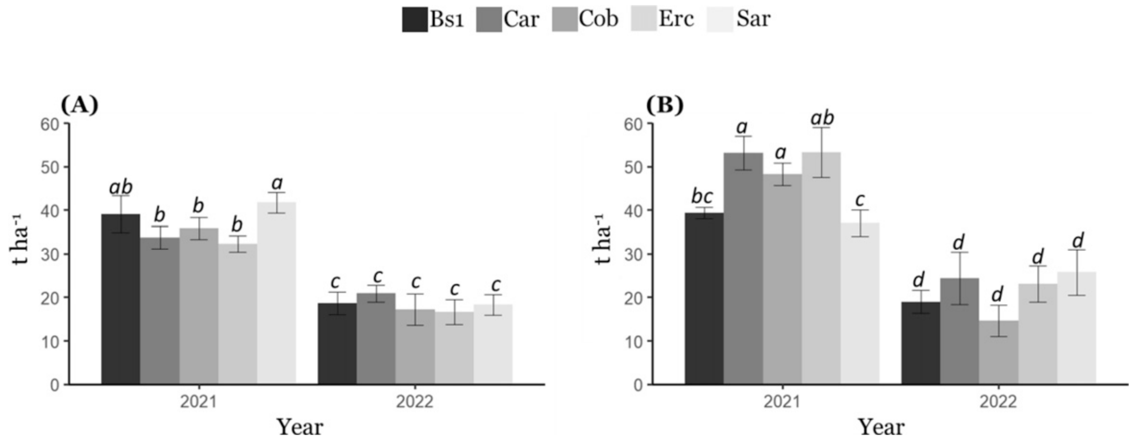

Fig. 3. Total yield of the melon cultivar Sarah's Choice grafted onto Bs1, Carnivor (Car), Cobalt (Cob), Ercole (Erc), and the ungrafted cultivar as control (Sar) during the 2021 and 2022 field trials in Fallon (**A**) and Reno (**B**). Means not sharing any letter are significantly different at the 5% level of significance. Error bars represent the standard error of the mean.

phenotype (P = 0.83) (Fig. 6A). Regardless of the 50% decrease in yield between years, the average number of fruits per plant only tended to be lower in 2022 than in 2021 (P = 0.058) with an average of 3.6 and 3.0 fruits per plant in 2021 and 2022, respectively.

Reno. Fruit weight was similar in both years and across all phenotypes (2021: 1.6 kg; 2022: 1.7 kg) (Fig. 5B), and no interaction was observed between year and phenotype (P = 0.94). Overall, the fruit weight in Reno was between the fruit weights obtained from Fallon in both years, and fruit weight did not correlate with the decreases in total yield observed between years.

On the other hand, the number of fruits per plant dropped 59% in 2022 compared with 2021 (2021: 5.8 fruits per plant; 2022: 2.4 fruits per plant; Fig. 6B). In 2021, Ercole produced 7.4 fruits per plant, which was more fruits per plant than all the other phenotypes, including the ungrafted control (4.6 fruits per plant). Carnivor also produced more fruits per plant (6.3 fruits per plant) than the ungrafted control. In 2022, the number of fruits per plant was similar among phenotypes, and there was a year by phenotype interaction (P = 0.009).

Fruit quality (°Brix)

Fallon. In 2022, the ungrafted phenotype and Carnivor produced melons with higher soluble solids (12.2 and 12.3 °Brix, respectively) than the other phenotypes (Fig. 7A). The phenotype with the lowest soluble solids content was Cobalt with an average of 11.3 °Brix. No measurements were conducted in 2021.

Reno. The fruit soluble solids were higher in 2021 than in 2022 (Fig. 7B). The soluble

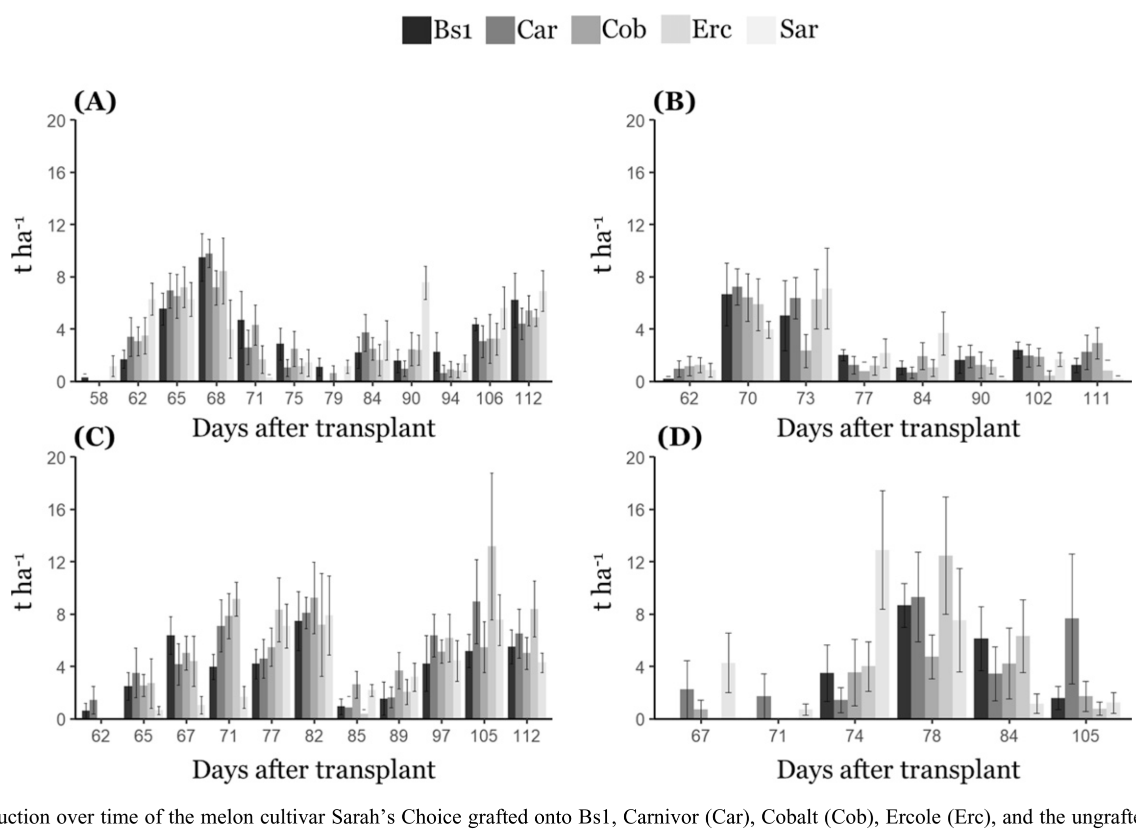

Fig. 4. Production over time of the melon cultivar Sarah's Choice grafted onto Bs1, Carnivor (Car), Cobalt (Cob), Ercole (Erc), and the ungrafted cultivar as control (Sar) during the field trials in Fallon 2021 (**A**) and 2022 (**B**), and in Reno 2021 (**C**) and 2022 (**D**). Means different at the 5% level of significance are reported in Supplemental Table 1. Error bars represent the standard error of the mean.

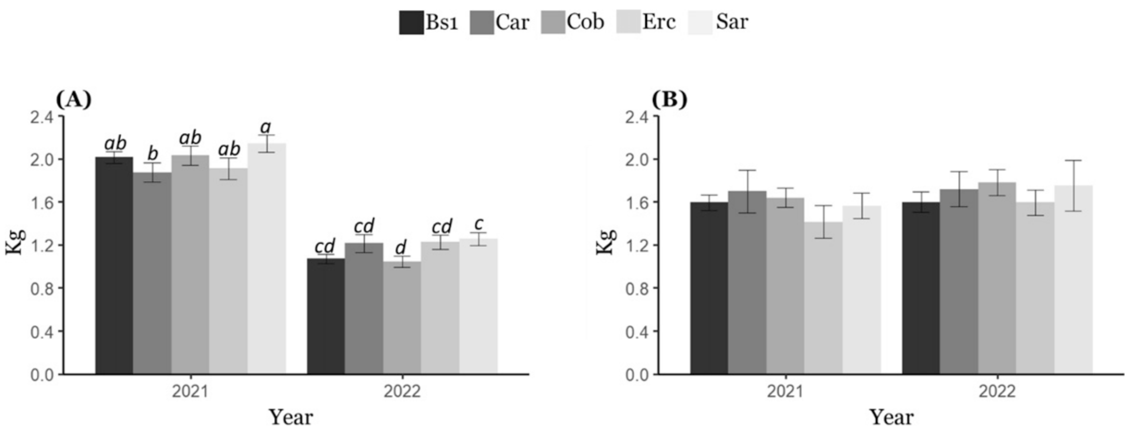

Fig. 5. Fruit weight of the melon cultivar Sarah's Choice grafted onto Bs1, Carnivor (Car), Cobalt (Cob), Ercole (Erc), and the ungrafted cultivar as control (Sar) during the 2021 and 2022 field trials in Fallon (**A**) and Reno (**B**). Means not sharing any letter are significantly different at the 5% level of significance. Error bars represent the standard error of the mean.

solids ranged between 13.5 and 15 °Brix in 2021 and between 11.8 and 13.3 °Brix in 2022. Brix grade patterns were similar in both years (year-by-phenotype interaction $P = 0.41$). The ungrafted phenotype produced sweeter melons than the grafted phenotypes in both years (2021: 15.2 °Brix; 2022: 12.5 °Brix). Bs1 had the lowest soluble solids content for both years with an average of 13.5 °Brix in 2021 and 11.5 °Brix in 2022.

Discussion

This study shows that melon grafting did not consistently improve melon crop performance in the high desert, suggesting that the root systems of the rootstocks may only provide an advantage under specific soil and environmental conditions. For instance, yields differed based on location and year although most of the harvested melons from grafted phenotypes occurred in the first half of the harvesting season (except for Reno 2022). Harvest earliness can be related to a faster developing root system of the squash hybrid rootstocks (Salehi et al. 2009). The reduction in ~50% yield in 2022 compared with 2021, regardless of location, indicated that weather conditions early in the season may have had a bigger impact on melon performance than specific location and management. Fruit quality was better in the ungrafted control, with some rootstocks decreasing sweetness (°Brix) across year and location (e.g., Bs1), which has been reported elsewhere (e.g., Zhao and Guan 2018). Overall, the benefits of melon grafting to overcome abiotic stress (e.g., suboptimal soil temperatures) in the high desert were not consistent, which adds to the few available studies on grafted melons from other regions showing conflicting results.

Improved performance under colder soil temperatures may have been conferred by several rootstocks in the Reno 2021 trial because it was conducted without plastic mulch, which can accelerate soil warming. Previous studies show that plastic mulch can increase soil temperature by up to 5 °C in colder environments (Ibarra et al. 2001; Snyder et al. 2015; Tarara 2000). In Reno 2021, soil temperatures at a 10-cm depth had an average minimum of 21.7 °C in the first 2 weeks after transplanting, and soil temperatures below 24 °C are considered suboptimal for melons and can negatively affect plant establishment (Brandenberger et al. 2021; Korkmaz & Dufault 2001; Orzolek et al. 2010). Grafting melons onto squash hybrids has been demonstrated to offer an advantage in colder soils due to improved acclimation during the initial establishment phase from a more rapidly developing root system that enhances nutrient supply to the shoot (Salehi et al. 2009; Shrestha et al. 2022). Consequently, grafted melons may exhibit faster canopy growth and earlier flowering and harvest compared with ungrafted melons under suboptimal soil temperatures (Guan et al. 2015; Schultheis et al. 2015). It could be speculated that in 2021, the Fallon trial may have had higher soil temperatures than in Reno, which could explain why yield advantages from the grafted phenotypes were only observed in a single trial.

The overall 50% yield reduction observed in both locations in 2022 compared with 2021 may have been caused by wind gusts greater than 60 $km \cdot h^{-1}$ and minimum average air temperatures as low as 6 °C and below 10 °C for 9 d within the first 2 weeks after transplanting. In comparison, during the same period in 2021, minimum air temperatures were ~5 °C higher. Air temperatures below 10 °C can delay plant establishment and negatively affect melon production, impacting

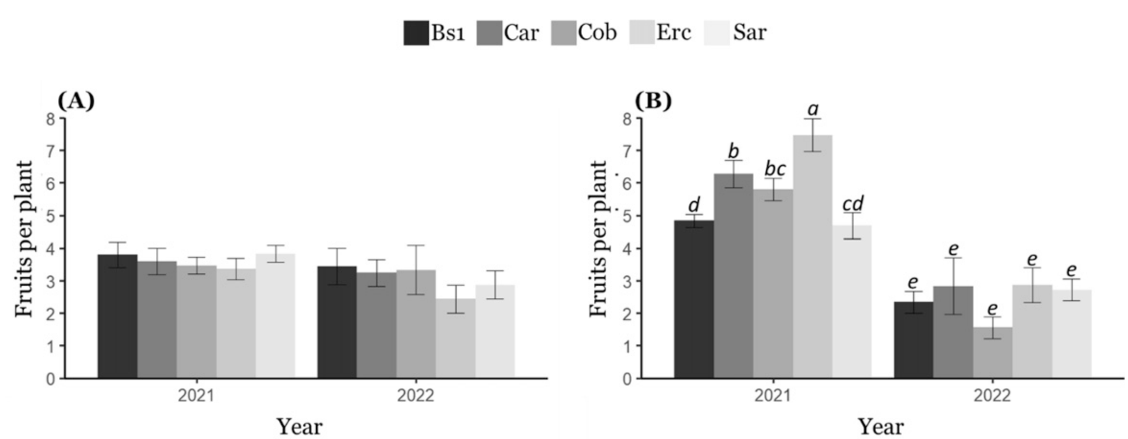

Fig. 6. Number of fruits per plant of the melon cultivar Sarah's Choice grafted onto Bs1, Carnivor (Car), Cobalt (Cob), Ercole (Erc), and the ungrafted cultivar as control (Sar) during the 2021 and 2022 field trials in Fallon (**A**) and Reno (**B**). Means not sharing any letter are significantly different at the 5% level of significance. Error bars represent the standard error of the mean.

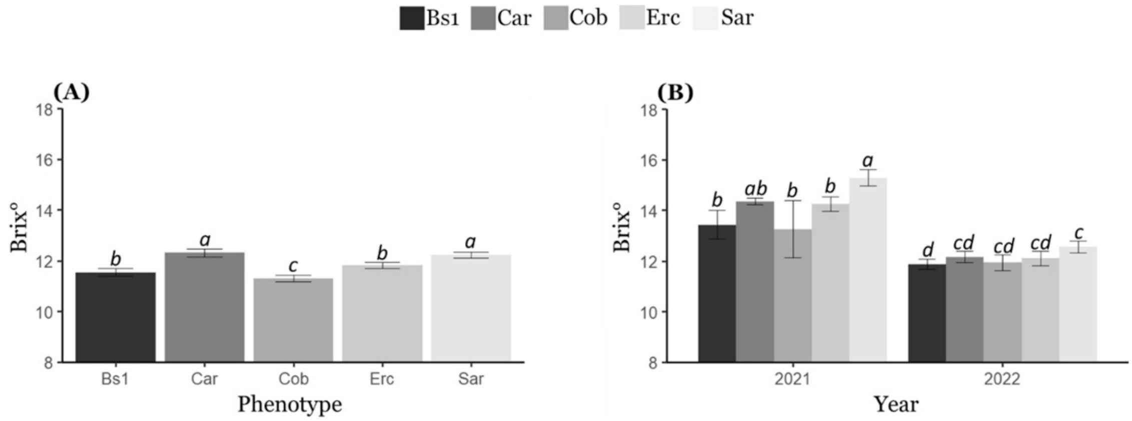

Fig. 7. Fruit soluble solids (°Brix) of the melon cultivar Sarah's Choice grafted onto Bs1, Carnivor (Car), Cobalt (Cob), Ercole (Erc), and the ungrafted cultivar as control (Sar) during the 2021 and 2022 field trials in Fallon (**A**) and Reno (**B**). No °Brix measurements were taken in Fallon in 2021. Means not sharing any letter are significantly different at the 5% level of significance. Error bars represent the standard error of the mean.

both fruit weight and number of fruits per plant (Kormaz and Dufault 2021). In addition, the small root system of transplants is unable to support transpiration demands under high wind conditions, which results in further water stress and delay in crop establishment (Hodges et al. 2006). Photosynthate production is dependent on total leaf area, which affects the carbon assimilation capacity. For both locations in 2022, we observed 50% lower canopy development from transplanting until 35 DAT and a more than 25% decrease in g_s between 35 and 70 DAT compared with 2021. Both these factors may have led to an overall lower carbon assimilation capacity (Barzegar et al. 2013), which could explain the observed reduction in yield. Interestingly, the 2022 reduction in yield was due to lower fruit weight in Fallon and fewer fruits per plant in Reno. Number of fruits per plant is mainly affected by the number of female or bisexual flowers, success in pollination, and fruit set, whereas fruit weight depends mostly in cell division during the early fruit set stage and subsequent cell expansion (Shin et al. 2007). Both fruit weight and number of fruits per plant are dependent on large amounts of photosynthates to provide energy for the metabolic processes involved (Ezura et al. 2023). In fact, there is a trade-off between these yield traits, and a higher number of melons per plant often leads to smaller fruits and vice versa (Long et al. 2004; Zalapa et al. 2008).

The inconsistency in yield performance of grafted plants among sites is not unusual because the yield performance of grafted melons varies depending on the choice of cultivar, the rootstock genotype, and the environment (Sharma et al. 2020). For instance, grafted melons on Carnivor in the humid continental climate of New Hampshire (USA) exhibited an increase in yield attributable to fruit size (Ohletz and Loy 2021). Conversely, in the humid subtropical climate of North Carolina and South Carolina (USA), melons grafted on Carnivor did not show a yield increase (Schultheis et al. 2015). In the arid environment of the Kalyobiya Governorate (Egypt), melons grafted on Cobalt increased yields over the ungrafted plants due to a greater number of fruits per plant (Ezzo et al. 2020), which is a trait mostly influenced by the environment rather than by the genotype (Sharma et al. 2020). Thus, this and other studies report conflicting results about the benefits of melon grafting to yield increases, and instead suggest that grafted melons are highly dependent on the genotype by environment by management interactions (King et al. 2010; Sharma et al. 2020).

Early canopy development was strongly correlated with the melon production over time, which has been determined to affect the harvest period (Ohletz and Loy 2021). Production earliness in grafted melons seems to be a consistent trait independently of the climatic region of cultivation. Experiments conducted in North Carolina and South Carolina (USA), New Hampshire (USA), and in the Kalyobiya Governorate (Egypt) reported that grafted plants produced earlier and a higher percentage of the total harvest during the initial harvests compared with the ungrafted controls (Ezzo et al. 2020; Ohletz and Loy 2021; Schultheis et al. 2015). Yet in this study, canopy performance of the common scion did not show differences in NDVI across phenotypes, locations, and within year (Supplemental Fig. 2). NDVI can be correlated with leaf N content (Padilla et al. 2014), but our NDVI data suggest that there were no differences in N uptake or that leaf N content was close to optimal among phenotypes. On the basis of the composite equation proposed by Padilla et al. (2014), we observed that for all phenotypes, regardless of location and year, standing N content increased from ~2.91% to ~5.3%, and the N nutrition index (NNI) rose from 1.25 to 2.36. This is consistent with previous research showing that melons accumulate nitrogen and chlorophyll during plant establishment (Castellanos et al. 2011; Padilla et al. 2014) and indicates that melon plants had sufficient N for optimal growth (Thompson 2022). However, according to NNI values, N content at the beginning of NDVI measurements were sufficient (14 DAT; NNI = 1.25) but became excessive once the canopy was fully developed (49 DAT; NNI = 2.36). Yet studies in melon and in rice report that NDVI becomes less reliable in predicting nitrogen and chlorophyll content once plant canopy is fully developed and with saturated NDVI values (e.g., >0.75 in rice) (Padilla et al. 2014; Rehman et al. 2019).

Although all phenotypes consistently produced fancy USDA-grade standard melons (i.e., °Brix > 11), fruit quality was higher in the ungrafted control than most of the grafted phenotypes, which is consistent with previous work showing that squash-hybrid rootstocks negatively affected the TSS in melons (Guan et al. 2015; Kyriacou et al. 2018; Zhao and Guan 2018). The reduction in °Brix in both locations between years may have been caused by colder air temperature in 2022 that negatively affected plant canopy development, and reduced stomatal conductance and presumably carbon assimilation, resulting in a shortened fruit set and harvest period (Dufault et al. 2006; Kyriacou et al. 2018). Reductions in carbon assimilation in melons can determine a higher competition for assimilates within the plant and consequently decrease the sweetness of the fruit flesh (Valantin-Morison et al. 2006).

To our knowledge this is the first study in which melons grafted on squash hybrids are tested in the high desert under a short growing season. Our trials did not offer a consistent benefit on yield performance among the grafted phenotypes and the ungrafted control, which aligns with previous research. This suggests that yield traits in grafted melons are dependent on the scion genotype, the environment, and farm management, as has been demonstrated by previous studies. Advantages of these commercial rootstocks may be better perceived under biotic stress conditions. However, farmers operating under a short summer growing season may consider grafting melons to concentrate their melon production in the first half of the harvest period. Nevertheless, given this work and previous studies on yield performance of grafted melons, it appears that more experimentation is required to further assess if specific scion–rootstock melon combinations could increase yields for farmers under specific environments.

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