Assessment of Drought-Tolerant *Citrullus* Rootstocks for Watermelon Cultivation Under Full and Deficit Irrigation

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Introduction

The context of climate change that we are living in is driving the water scarcity in Mediterranean horticulture, and all over the world. Therefore, management that increases water use efficiency of crops while preserving yield and fruit quality is needed. Deficit irrigation is a key tool to reduce water usage (Fereres and Soriano, 2007). Watermelon (*Citrullus lanatus* L.) is a widely cultivated cucurbit crop, very sensitive to water limitations, especially in the early growth and fruit set stages (Morales et al., 2023).

Grafting is a commonly used strategy in watermelon production across Europe (including Spain) for improving tolerance to abiotic and biotic stresses and stabilizing productivity. The main rootstocks used are the interspecific *Cucurbita* hybrids contributing to plant vigor and a most efficient resource uptake, as well as giving protection against soilborne diseases (Liu et al., 2025, Louws et al., 2010). Negative effects on fruit quality of watermelons grafted onto *Cucurbita* hybrids have been previously reported (Alexopoulos et al., 2007, Soteriou et al., 2015).

Lately, *Citrullus* spp. germplasm is being tested as a promising drought tolerance source in cultivated watermelon, supported by recent analysis that have revealed substantial genetic variation and stress-related gene families associated with drought resilience. (Gkanogiannis et al., 2024). Also, physiological studies showed that the rootstocks derived from *Citrullus colocynthis* maintain the yield of the scion under water stress (Bikdeloo et al., 2021; Sehularo et al., 2025). Previous studies of the group found that *Citrullus*-based grafting generally maintains fruit quality much closer to that of non-grafted plants, compared to grafting onto *Cucurbita*, preserving sugar-acid balance and typical watermelon flavor profiles (Fredes et al., 2016). Others support that grafting can enhance yield production without compromising the soluble solids content (SSC), yet fruit quality outcomes are environmental-dependent, resulting in the need of evaluations under different commercial conditions (Devi et al., 2020; Jordana et al., 2023). Even so, SSC may increase under moderate water reduction stress due to concentration effects without necessarily impacting in the overall quality (Proietti et al., 2008).

In the current work, two watermelon cultivars were evaluated, grafted onto commercial *Cucurbita* and *Citrullus* rootstocks under 100% vs 50% irrigation in two commercial fields near Valencia, focusing on yield and SSC to identify combinations suitable for water-limited scenarios.

Materials and Methods

Experiments were conducted in summer 2024 in two open-field commercial sites in the Valencia horticultural belt (Spain): Museros (39°34'34.8"N 0°21'46.0"W) and Alcàsser (39°23'12.3"N 0°27'35.9"W). Each site included full irrigation according to the usual practices (100%) and deficit (50%) irrigation regimes; the 50% level represented a moderate reduction, commonly used to assess drought responses in cucurbits (Morales et al., 2023; Rouphael et al., 2008). Irrigation scheduling and application followed local commercial management at each site.

Two watermelon scions were used: commercial ‘Style’ and traditional ‘Negra de Altura’ (NA, BGV016458). Five rootstocks were evaluated: the commercial *Cucurbita* control ‘Shintoza’; two *Citrullus* accessions (*C. colocynthis* VIR-1996 (‘13’) and *C. lanatus* var. *citroides* BGV0005167 (‘14’)), plus the hybrids BGV0005167 x VIR-1996 (‘14x13’) and BGV0005167 x *C. mucosospermus* PI 494527 (‘14x18’). For each scion, self-grafted and non-grafted controls were included. At each location, and within each irrigation treatment, the 13 treatments were arranged in a randomized complete block design with two replications. Plots consisted of three plants. Grafting followed the standard cucurbit splice/one-cotyledon protocols to ensure high survival, uniformity and reproducibility of the commercial practices.

Four traits were recorded in each plot: fruit number, mean fruit weight (kg), yield (kg/plant) and soluble solids content (SSC), which was determined in pulp juice using a digital refractometer and expressed as ºBrix.

All statistical analyses were performed using StatGraphics Centurion (StatPoint Technologies Inc., Warrenton, VA, USA).

Multi-factor ANOVAs (Type III sums of squares) were conducted for each of the four traits evaluated (fruit number, mean fruit weight, yield and SSC), including site, irrigation, scion and rootstock as fixed factors, and followed by 95% LSD multiple-range tests and pairwise contrasts to identify significant differences among factor levels and combinations.

Results and Discussion

For all traits evaluated, there was a significant effect of the field site: every variable showed higher values in Museros compared with Alcàsser. Irrigation regime also had a significant effect on all traits: yield, number of fruits per plant and mean fruit weight were consistently higher under full irrigation (100%), whereas SSC increased under deficit irrigation (50%). Differences in plant vigor were also observed across field sites and irrigation regimes, with more vigorous growth under full irrigation in both sites (Figure 1). Regarding the scion, 'Style' produced a higher fruit number and registered higher SSC, while 'Negra de Altura' (NA) resulted in greater yield and mean fruit weight. In contrast, rootstocks did not show a significant effect in the global analysis. These results indicate a clear interaction between rootstock performance and environmental context, which has already been found in previous studies (Jordana et al., 2023, Rouphael et al., 2008,). The site-scion-irrigation interactions were significant for all variables; therefore, rootstock effects were examined separately for each specific combination.

In Museros with NA, all rootstocks performed similarly for yield (Figure 2A1) under each irrigation regime. For the remaining traits, differences were only significant under deficit irrigation. *Citrullus* rootstocks outperformed the commercial control 'Shintoza' for specific factors: rootstocks '13', besides self-grafted NA, increased SSC (Figure 2A2), and '14x13' enhanced fruit number (Figure 2A3). Conversely, 'Shintoza' and '14' produced larger fruits than the hybrids '14x13' and '14x28' (Figure 2A4). Although differences between irrigation levels were present for some rootstocks, these were less frequent than expected, likely because the irrigation supplied at Museros was high enough that 50% treatment did not impose strong water stress.

With 'Style' as the scion in Museros, in both irrigation regimes, 'Shintoza' rootstock consistently achieved high yield and fruit number (Figure 2A1, 2A3), not significantly different from '14x13' and '14x28' at full irrigation, and from '13' at 50% irrigation. All rootstocks produced fruits with similar weights (Figure 2A4). However, under full irrigation, for the self-grafted and when the hybrids '14x13' and '14x28' were used as the rootstock, the SSC was higher than with 'Shintoza' (Figure 2A2). For this Museros-'Style' combination, the non-grafted treatment was excluded because plants failed to survive transplanting in both blocks.

In Alcàsser, with NA under deficit irrigation, rootstocks '14' and '14x28' produced yields similar to 'Shintoza', higher than the self-grafted and non-grafted plants (Figure 2B1). For mean fruit weight (Figure 2B4), 'Shintoza' and '14' produced larger fruits than the self-grafted, while all other rootstocks performed similarly. Rootstock '14x28' exceeded the fruit number of '14x13', '13', and the non-grafted. Under full irrigation, '14' and '14x28' produced more fruits than both 'Shintoza' and '14x13' (Figure 2B3). No significant differences were found for SSC at Alcàsser with this scion (Figure 2B2).

For 'Style' in Alcàsser, no rootstock effects were detected for SSC (Figure 2B2) or mean fruit weight (Figure 2B4). Under deficit irrigation, '14x28' outperformed the self-grafted and non-grafted treatments for yield (Figure 2B1), and 'Shintoza' and '14x28' produced more fruits than the self-grafted and non-grafted treatments (Figure 2B3). Under full irrigation, rootstocks '14' and '14x28' produced higher yields than '13' and the non-grafted treatment (Figure 2B1), and 'Shintoza', '14', and '14x28' produced more fruits than the non-grafted plants (Figure 2B3). Similarly to what has been described for NA in Alcàsser, SSC remained stable with all rootstocks and for both irrigation levels (Figure 2B2). These results support the strong environmental influence on this quality trait, previously reported (Devi et al., 2020).

Moreover, water reduction had a consistent negative impact on watermelon performance in most site-scion combinations. In general, reducing irrigation from 100% to 50% significantly decreased yield and fruit number, except in Museros when cultivating the commercial scion 'Style', whose production remained stable under deficit irrigation. This reduction is consistent with previous studies reporting that watermelon production is highly sensitive to water limitation (Morales et al., 2023). Mean fruit weight was significantly lower in the 50% water deficit only in NA fruits grown in Museros; in all other combinations fruit weight was unaffected by irrigation level. SSC also remained stable, except for the SSC of the 'Style' fruits cultivated in Alcàsser, which increased under 50% irrigation. Similarly to our results, other studies reported that grafting doesn't consistently modify SSC under water stress, maintaining stable soluble solids accumulation across irrigation regimes (Rouphael et al., 2008).

Conclusions

This study demonstrates that watermelon responses to grafting and irrigation depend strongly on the interaction between cultivation conditions, scion and rootstock. Although no overall rootstock effect was detected across traits, notable context-specific differences were found. Differences observed between sites highlighted the importance of local irrigation practices, with higher water availability in Museros mitigating yield losses under 50% irrigation. Effective rootstock selection requires considering specific production environments, as grafting effects are not universal but highly context dependent.

In the work here presented several experimental *Citrullus* rootstocks were identified that in some cases showed a performance comparable to the commercial *Cucurbita* rootstock 'Shintoza', either in full irrigation regime or with water deficit. Future analysis on fruit quality attributes of samples collected during this study will be carried out to determine the effect of grafting onto these experimental *Citrullus* rootstocks on quality parameters and confirm their usefulness as alternative to the classic *Cucurbita* hybrid rootstocks.

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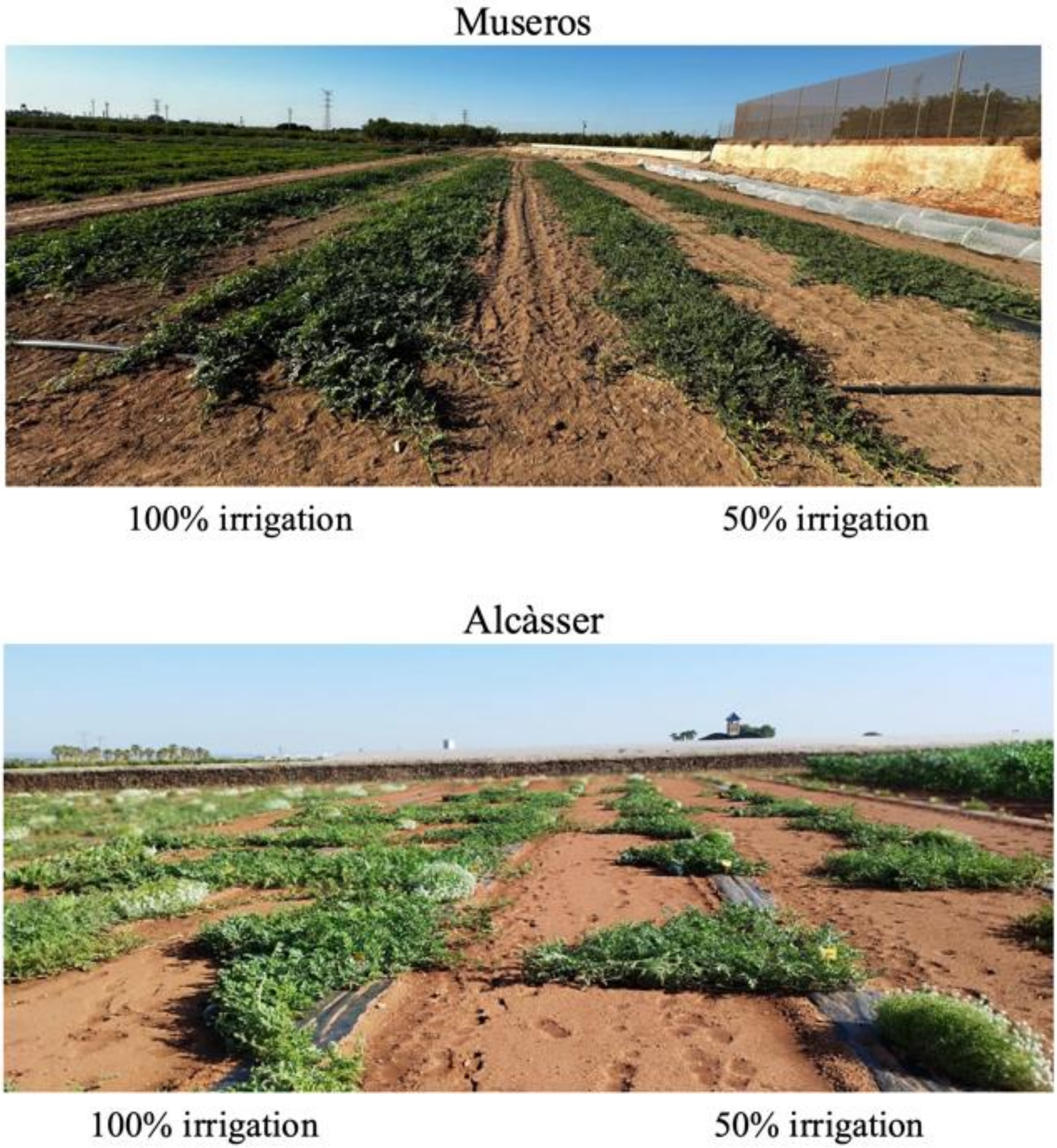

Figure 1. Differences in plant vigor in the two experimental fields, Museros (left) and Alcàsser (right), under full (100%) and deficit (50%) irrigation regimes.

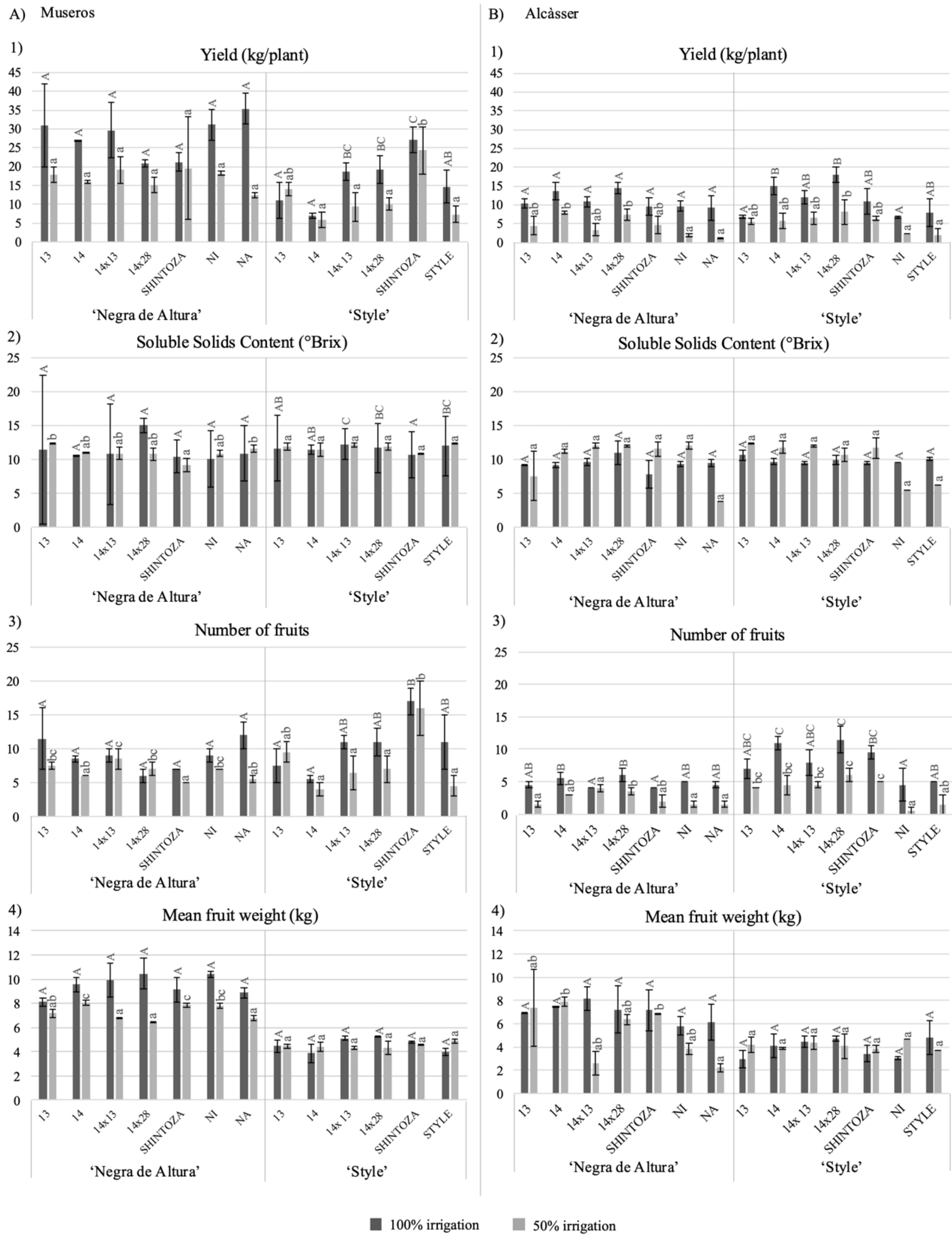

Figure 2. Mean yield (1), SSC (2), number of fruits (3) and mean fruit weight (4) for 'Negra de Altura' and 'Style' grafted onto different rootstocks under full (100%, dark bars) and deficit (50%, light bars) irrigation in A) Museros and B) Alcàsser. Rootstock included '13' (*Citrullus. colocynthis* VIR-1996), '14' (*C. lanatus* var. *citroides* BGV0005167), '14x13' (BGV0005167 x VIR-1996), '14x28' (BGV0005167 x *C. mucosospermus* PI 494527), the commercial control 'Shintoza', the non-grafted control ('NI') and the self-grafted controls ('NA' for 'Negra de Altura' and 'STYLE' for 'Style'). Bars represent means ± SE. Different letters indicate significant differences among rootstocks within each site-scion-irrigation combination (LSD, $p < 0.05$).