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A Water Stress–Tolerant Pepper Rootstock Improves the Behavior of Pepper Plants under Deficit Irrigation through Root Biomass Distribution and Physiological Adaptation

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Abstract: The use of rootstocks tolerant to water stress in pepper crops is a complementary technique for saving irrigation water without affecting yields by means of particular rootstock physiological traits, which changes the scion's perception stress. The present study aimed to analyze the morphological and physiological adaptation of the 'Cuerno' pepper cultivar grafted onto tolerant rootstock NIBER® subjected to capacitance sensor-based deficit irrigation. The stomatal conductance, relative water content and leaf water potential parameters were used to confirm the degree of crop stress. Leaf dry weight and root volume were higher in the grafted plants under the control irrigation and stress treatment conditions. Total fresh root biomass and root volume percentage of grafted plants under water stress were 24% and 33% higher, respectively, than the ungrafted plants. The grafted plants subjected to both water stress and control conditions had a higher marketable production than the ungrafted plants. The higher yields obtained using tolerant rootstocks were explained by the reduced blossom-end rot incidence.

Keywords: *Capsicum annuum*; grafting; production; root density; blossom-end rot

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1. Introduction

Water scarcity for agricultural production remains a challenge, one aggravated by the continuous increase in today's agricultural demands and climate change considerations. If we consider the fact that agriculture represents almost 70% of all water extractions, and up to 95% in some developing countries [1], it is necessary to contemplate farming production alternatives to drastically reduce water use in agriculture without negatively affecting yields or product quality.

In order to minimize irrigation water use and to increase its efficiency, some woody crops have been successfully grown in recent decades by implementing the deficit irrigation (DI) technique [2]. However, herbaceous crops' sensitivity to water stress is much greater, and the success of this technique depends on species to a great extent. One of the reasons explaining this phenomenon is the poor root depth growth capacity of some horticultural crops under DI conditions, owing partly to greater root biomass accumulation with effective water/nutrient uptake on the surface soil horizon [3]. With peppers, most of the studied cases that have applied the controlled DI technique do not report the production levels obtained under normal irrigation conditions. However, differences in yield have been observed depending on the time when the DI is applied, the stress severity and the duration [4–6].

Water stress imposed in some critical pepper growth stages, mainly flowering and fruit set, can have long-term effects that may make completely recovered yield impossible [7].

In addition, water stress could also lead to higher incidence of blossom-end rot (BER) in pepper crops.

Grafts on water stress–tolerant rootstocks can confer drought tolerance up to a certain point and has been proven in cucumber [8], eggplant [8], tomato [9] and watermelon [10]. In peppers, different studies confirm the existence of rootstocks capable of developing physiological mechanisms that confer water stress tolerance [11,12]. In a study that used the water stress–tolerant hybrid rootstock NIBER® and irrigated at 50% of crop evapotranspiration (ETc) [13], this hybrid increased plants' water use efficiency, accounted for by the grafted plants' higher dry biomass and commercial yields compared with ungrafted plants. All this may be attributed to greater root development. Nonetheless, these studies did not investigate the effect of the root system's exploring capacity on the greater adaptation of the water stress–tolerant rootstock. To do so, and under more controlled conditions than those indicated in the previous work [13], the present study centers on determining up to what point a water stress–tolerant rootstock is able to maintain its production capacity under stress conditions caused by DI and to analyze, in turn, the capacity of root exploration, volume and weight to relate it to the differences in the yields or fruit quality that might be found.

2. Materials and Methods

2.1. Growth Conditions

The experiment was carried out from February to June 2022 in the Venlo-type greenhouses belonging to the Universitat Politècnica de València, Spain. Growth took place in 25-L cylindrical containers using washed silica sand of distinct granulometry, with a 10% thickness index and a 2.28 uniformity coefficient [1].

Containers were drip-irrigated using three 4 L/h Netafim® (Netafim Ltd., Tel Aviv, Israel) anti-drain drippers per container with a nutritional solution containing (in mmol/L): 14.0 NO_3^-; 1.5 $H_2PO_4^-$; 2.4 SO_4^{2-}; 0.5 HCO_3^-; 1.6 Cl^-; 1.2 NH_4^+; 6.0 K^+; 5.0 Ca^{2+}; 2.5 Mg^{2+}; 0.2 Na^+; (in µmol L^{-1}): 15 Fe^{3+}; 6 Zn^{2+}; 12 Mn^{2+}; 30 B^{3+}; 0.8 Cu^{2+} and 0.5 Mo^{6+}. The electrical conductivity (EC) and pH of this nutritional solution were respectively 2.2 dS m^{-1} and 6.5. The values of the temperature, relative humidity and accumulated solar radiation are shown in Figure S1.

2.2. Plant Material

The traditional 'Cuerno' pepper cultivar was used and grafted onto rootstock F1 NIBER® (Universitat Politècnica de València and Instituto Valenciano de Investigaciones Agrarias, Valencia, Spain) (GRA) or ungrafted (UGR). Seeding took place on 2 December 2021, on 104-cell polystyrene trays on a peat-based substrate (70% white peat; 30% black peat). Grafting was done on 24 December using the tube method [14]. Transplanting was performed on 1 February 2022. The experiment finished on 11 June 2022.

2.3. Irrigation Management and Control

Volumetric soil water content (VSWC; m^3 m^{-3}) was continuously monitored by TEROS 10 capacitance sensors connected to a ZL6 data logger using the ZENTRA Cloud (METER Group AG, München, Germany). Two sensors per container were placed at 15-cm and 25-cm soil depths, equidistant between two adjacent emitters. The sensor located at the 25-cm soil depth was used to monitor the water drained below the root zone. VSWC was measured and stored every 15 min, and its variation was employed to determine in situ field capacity (FC) (defined as the amount of water held in soil after excess water has drained away and the rate at which the downward water movement materially decreases [2], which coincided with VSWC when its change came close to zero over time [3]). Irrigation was managed based on the VSWC, expressed as the percentage of FC to reduce sensor calibration importance. Irrigation management consisted of maintaining VSWC at 90% and 50% of FC in the control (CON) and deficit irrigation (DI) treatments, respectively, by varying the number of daily irrigations based on accumulated solar radiation, and by also ensuring 20% drainage to avoid salinity problems. VSWC was measured (in triplicate) in each of the four combinations.

The water stress treatment began on 5 April 2022, when the flowers of third nodes were at anthesis, and continued until the end of the experiment. Before the stress treatment commenced, all the fruits set were eliminated, and all the plants were irrigated in the same way as under the CON conditions.

2.4. Physiological Parameters

Stomatal conductance, relative water content and the leaf water potential were measured to confirm the plant water stress level. Stomatal conductance (gs, mol H_2O m^{-2} s^{-1}) was determined as reported in [13] in fully extended leaves (3rd and 4th leaves from the apex) 31, 45 and 59 days after DI treatment (DAT) started between 12:00 h and 14:00 h. For this purpose, the "LI-COR 600" porometer (LI-COR, Nebraska, St, Lincoln, NE, USA) was used. Relative water content (RWC) was measured 28, 42 and 56 DAT in leaves and was determined by weighing leaves before and after a 24-h rehydration process for which distilled water was employed to respectively obtain fresh weight (FW) and turgent weight (TW). To obtain dry weight (DW), leaves were dried at 65 °C for 72 h before being weighed. RWC was determined as RWC (%) = (FW − DW)/(TW − DW) × 100 [5]. The predawn water potential (05:00 h to 06:00 h) and the midday water potential (13:00 h to 14:00 h) ($\Psi_{predawn}$ and Ψ_{leaf}, respectively) were determined, following the methodology applied in [13] using a Schölander-type pressure chamber (model 3000; Soil Moisture Equipment Corp., Santa Bárbara, CA, USA). Determinations were made on fully extended leaves of an identical physiological status as that employed for the previous measurements and after 36, 50 and 63 DAT.

2.5. Production Parameters

Marketable and non-marketable yields, and both fruit weight and number, were determined. Non-marketable yield consisted of fruit affected by BER. Harvesting was spread out between early May and early June.

2.6. Biomass Parameters

The aerial and root biomass parameters were measured at the end of the experiment (67 DAT).

Fresh leaves and stems were weighed before being exposed to dry heat (for 72 h at 70 °C) in a laboratory oven. Then, dry weight (DW) was recorded.

Root biomass and root volume were measured by dividing the substrate into three vertical layers (corresponding to the 0–10, 10–20 and 20–30 cm depths), obtaining the roots from each layer and carefully washing them with distilled water. Root volume (mL) was obtained through the displaced water volume. Finally, the fresh weight (FW) and the DW of roots were obtained in the same way as used for the aerial part.

2.7. Experimental Design and Statistical Analysis

The experiment consisted of a two-factor randomized block design, where factors were water stress (WS) with two levels CON and DI, and grafting (G) with two levels UGR and GRA, formed by four repetitions (n = 16) of five plants. For all the parameters, measurements were taken in all the plants to obtain the mean of the five measurements per repetition. The results obtained for the different parameters were evaluated by an analysis of variance (ANOVA) using the Statgraphics Centurion XVII software (Statgraphics Technologies Inc., Virginia, USA). Means were compared by Fisher's least significant difference (LSD) test at $p \leq 0.05$.

3. Results

3.1. Irrigation Managment

With the irrigation strategies applied, the average 100% volumetric water content of the substrate was maintained in CON, which was 60% in the DI strategy, compared to FC (Figure 1). The quantity of water used to irrigate the CON plants was 57% higher than that administered to the DI plants (CON: 256.2 L/plant; DI: 145.8 L/plant).

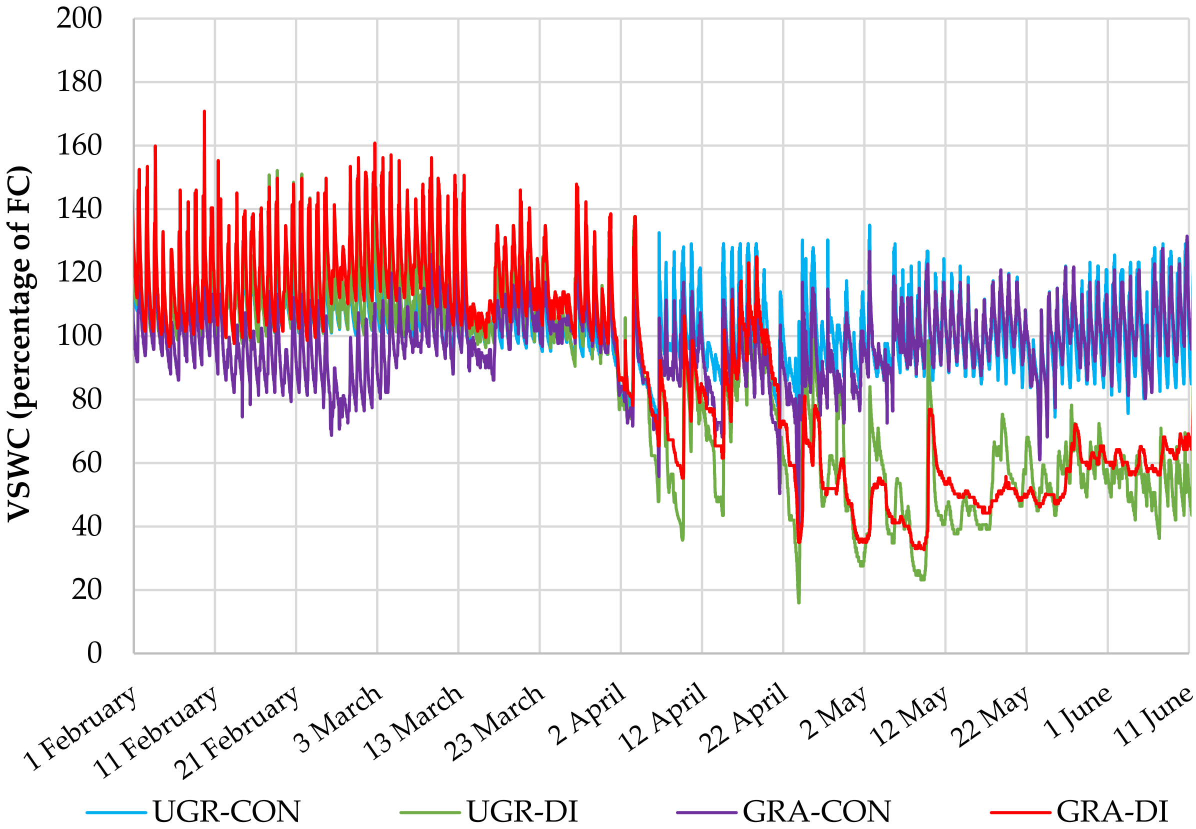

Figure 1. Volumetric soil water content (VSWC) expressed as a percentage of field capacity (FC) for the substrate corresponding to the grafting factor, grafted (GRA) and ungrafted (UGR), and for both water stress levels: control (CON) and deficit irrigation (DI).

3.2. Physiological Parameters

No significant interactions between the two factors (G × WS) were detected (data not shown) for both gs and RWC parameters. No significant differences for the grafting factor were noted. However, for the water stress effect, the stomatal conductance parameter and RWC (except for 28 DAT) were higher in the plants under the CON conditions than those under the DI conditions, as shown in Figure 2.

For both $\Psi_{predawn}$ and Ψ_{leaf} (Table 1), the results indicated significant differences in WS at all the sampling times (except for $\Psi_{predawn}$ at 36 DAT). The plants under the DI conditions had more negative values than those under the CON conditions. Moreover, significant differences appeared among the grafting factor for $\Psi_{predawn}$ at sampling times of 36 and 50 DAT, and for Ψ_{leaf} on 36 DAT, when more negative water potential values were obtained in the UGR plants (Table 1). No significant interactions appeared between factors.

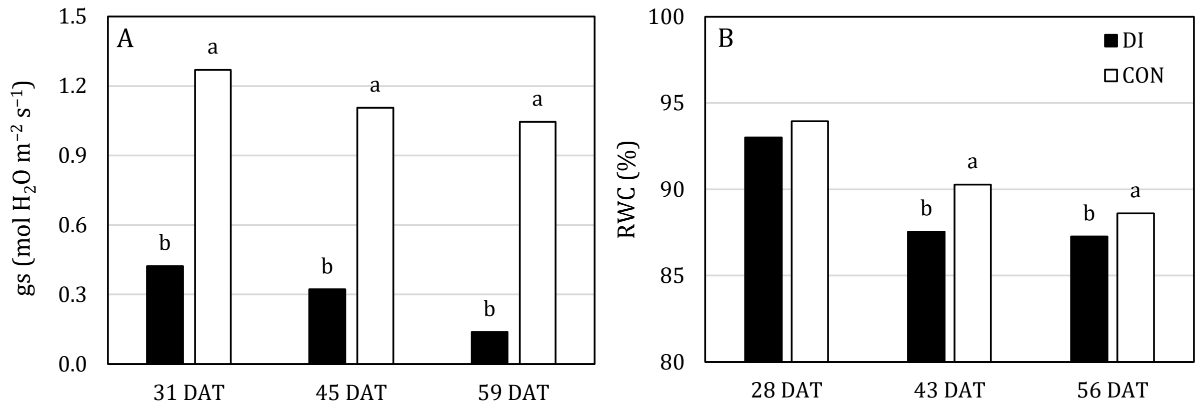

Figure 2. Stomatal conductance (gs) (**A**) and relative water content (RWC) (**B**) for both water stress levels: control (CON) and deficit irrigation (DI). Measurements were taken on 31, 45, and 59 DAT for gs and 28, 43 and 56 DAT for RWC. Different letters indicate significant differences at $p \leq 0.05$ (Fisher's LSD test). Data are the mean of grafted and ungrafted plants (four replicates each).

Table 1. Effect of grafting and water stress on the predawn leaf water potential ($\Psi_{predawn}$) and the midday leaf water potential (Ψ_{leaf}). Measurements were taken on 36, 50, and 63 days after treatment (DAT).

	Leaf Water Potential (MPa)											
	36 DAT				**50 DAT**				**63 DAT**			
	$\Psi_{predawn}$		Ψ_{leaf}		$\Psi_{predawn}$		Ψ_{leaf}		$\Psi_{predawn}$		Ψ_{leaf}	
Grafting (G)												
UGR	−0.426	a	−1.618	a	−0.398	a	−1.410		−0.531		−1.139	
GRA	−0.348	b	−1.463	b	−0.333	b	−1.317		−0.493		−1.205	
Water stress (WS)												
DI	−0.405		−1.639	a	−0.406	a	−1.444	a	−0.696	a	−1.276	a
CON	−0.369		−1.441	b	−0.324	b	−1.283	b	−0.328	b	−1.068	b
G × WS												
UGR-DI	−0.453		−1.698		−0.438		−1.479		−0.710		−1.233	
UGR-CON	−0.400		−1.538		−0.358		−1.342		−0.353		−1.045	
GRA-DI	−0.358		−1.580		−0.375		−1.408		−0.683		−1.320	
GRA-CON	−0.338		−1.345		−0.290		−1.225		−0.303		−1.090	
ANOVA (df)	% Sum of squares											
G (1)	46.50	**	24.34	**	18.99	*	10.69	n.s	0.89	n.s.	5.95	n.s
WS (1)	9.85	n.s	39.52	**	30.59	*	31.29	*	80.96	**	59.12	**
G × WS (1)	1.98	n.s	1.42	n.s	0.03	n.s	0.64	n.s	0.08	n.s	0.61	n.s
Residuals (12)	41.66		34.71		50.39		57.39		18.07		34.31	
Std. Dev. (+)	0.043		0.107		0.061		0.125		0.101		0.092	

The mean values followed by the different lowercase letters in each column indicate significant differences at $p \leq 0.05$ using the LSD test. ** and * denote significance at $p \leq 0.01$ and $p \leq 0.05$, respectively. n.s. denotes no significant difference. (+) Standard deviation, calculated as the square root of the residual mean square. df denotes degrees of freedom.

3.3. Production Parameters

For marketable yield (Table 2), significant differences appeared in WS ($p < 0.01$), and the worst results were obtained for the plants under the DI conditions, with a lower fruit number, lighter weight per plant and lighter weight per fruit (Table 2).

Table 2. Effect of grafting and water stress on marketable yield (fruit/plant, kg/plant, and g/fruit) and blossom end rot (BER) (fruit/plant and %).

	Marketable Yield						BER			
	(Fruit/Plant)		**(kg/Plant)**		**(g/Fruit)**		**(Fruit/Plant)**		**(%)**	
Grafting (G)										
UGR	21.00	b	1.550	b	71.87		21.50	a	54.59	a
GRA	29.00	a	2.152	a	72.83		13.00	b	34.81	b
Water stress (WS)										
DI	11.25	b	0.779	b	69.26	b	19.75		62.09	a
CON	38.75	a	2.923	a	75.44	a	14.75		27.31	b
G × WS										
UGR-DI	8.25		0.555		68.28		25.25		74.93	
UGR-CON	33.75		2.544		75.47		17.75		34.25	
GRA-DI	14.25		1.003		70.24		14.25		49.26	
GRA-CON	43.75		3.301		75.41		11.75		20.36	
ANOVA (df)	% Sum of squares									
G (1)	7.10	**	6.65	**	1.14	n.s	29.64	*	17.96	**
WS (1)	83.89	**	84.18	**	47.75	**	10.26	n.s	55.57	**
G × WS (1)	0.44	n.s	0.44	n.s	1.29	n.s	2.56	n.s	1.59	n.s
Residuals (12)	8.57		8.73		49.83		57.54		24.88	
Std. Dev. (+)	5.07		0.398		3.65		6.84		13.44	

The mean values followed by the different lowercase letters in each column indicate significant differences at $p \leq 0.05$ using the LSD test. ** and * denote significance at $p \leq 0.01$ and $p \leq 0.05$, respectively. n.s. denotes no significant difference. (+) Standard deviation, calculated as the square root of the residual mean square. df denotes degrees of freedom.

For both fruit number and weight per plant, differences were found in grafting factor ($p < 0.01$), with higher GRA values on average for the two WS levels (Table 2).

For the percentage of fruit with BER, significant differences were obtained for both WS levels ($p < 0.01$), and the percentage was higher for DI. On average, for both WS levels, the GRA plants had a lower BER percentage and a lower fruit number with BER than the UGR plants (Table 2).

3.4. Biomass Parameters

For both fresh and dry biomasses of stems and leaves, significant differences in WS were found, and DI had a lower biomass. For the aerial part, it was only for the dry biomass in leaves where significant differences were observed in G, and the DW for the GRA plants was heavier than UGR ones (Table 3).

The GRA plants had higher fresh root biomass, DW biomass, and root volume quantities than the ungrafted plants, on average, for WS ($p < 0.01$). On average, for G, significant differences in WS appeared, with higher (fresh and dry) biomass results, and also for root volume in the plants under the CON conditions (Table 3). For fresh and dry biomasses, significant differences were observed in the interaction, and the GRA-CON plants obtained the highest result. Regarding fresh root biomass, under DI conditions, the plants grafted onto NIBER® developed a higher fresh biomass than the ungrafted ones, and similar GRA-DI values to UGR-CON were obtained for fresh and dry biomass (Table 3).

Table 3. Effect of grafting and water stress on the fresh weight (FW) and dry weight (DW) of leaves, stems and roots, and root volume.

	Leaves				Stems				Roots					
	FW (g)		DW (g)		FW (g)		DW (g)		FW (g)		DW (g)		Volume (mL)	
Grafting (G)														
UGR	766.5		112.3	b	859.9		173.9		305.0	b	33.26	b	394.5	b
GRA	715.9		119.7	a	786.8		181.6		393.2	a	40.58	a	517.8	a
Water stress (WS)														
DI	588.5	b	91.5	b	663.8	b	146.8	b	296.2	b	32.15	b	389.3	b
CON	893.9	a	140.4	a	983.0	a	208.7	a	402.0	a	41.69	a	523.1	a
G × WS														
UGR-DI	660.9		88.4		658.9		147.3		264.4	c	30.96	b	334.0	
UGR-CON	872.2		136.2		1061		200.6		345.6	b	35.56	b	455.0	
GRA-DI	516.2		94.7		668.7		146.4		328.0	b	33.34	b	444.5	
GRA-CON	915.6		144.6		905.0		216.9		458.4	a	47.83	a	591.1	
ANOVA (df)	% Sum of squares													
G (1)	1.22	n.s	2.17	**	1.56	n.s	1.33	n.s	36.72	**	25.56	**	37.69	**
WS (1)	44.48	**	95.82	**	29.69	*	85.83	**	52.92	**	43.41	**	44.37	**
G × WS (1)	4.22	n.s	0.04	n.s	2.00	n.s	1.68	n.s	2.85	*	11.64	*	0.41	n.s.
Residuals (12)	50.07		1.96		66.75		11.16		7.51		19.39		17.53	
Std. Dev. (+)	187.06		4.04		276.35		12.89		23.02		3.68		48.56	

The mean values followed by the different lowercase letters in each column indicate significant differences at $p \leq 0.05$ using the LSD test. ** and * denote significance at $p \leq 0.01$ and $p \leq 0.05$, respectively. n.s. denotes no significant difference. (+) Standard deviation, calculated as the square root of the residual mean square. df denotes degrees of freedom.

Table 4 displays the spatial distribution of the dry biomass for roots per WS level and employed plant combination. Significantly greater root accumulation took place in the first 10 cm for all the studied combinations. It is worth noting that in these first 10 cm, the plants grafted onto NIBER® under the DI conditions had a higher biomass and bigger volume than the ungrafted plants under normal conditions.

Table 4. Distribution of dry biomass and root volume for grafting (GRA and UGR) and water stress factors (CON and DI).

	DW (g)						Volume (mL)					
	0–10 cm		10–20 cm		20–30 cm		0–10 cm		10–20 cm		20–30 cm	
Grafting (G)												
UGR	21.81	b	5.565		5.892	a	226.1	b	69.19		99.23	a
GRA	31.70	a	4.820		4.067	b	373.8	a	72.31		71.71	b
Water stress (WS)												
DI	23.41	b	4.615	b	4.123	b	265.4	b	57.68	b	66.18	b
CON	30.09	a	5.769	a	5.835	a	334.5	a	83.83	a	104.76	a
G × WS												
UGR-DI	21.22	b	5.132		4.609		211.2		55.85		66.95	b
UGR-CON	22.39	b	5.997		7.175		240.9		82.53		131.50	a
GRA-DI	25.61	b	4.099		3.637		319.6		59.50		65.40	b
GRA-CON	37.79	a	5.541		4.496		428.0		85.13		78.03	b

Table 4. *Cont.*

	DW (g)						Volume (mL)					
	0–10 cm		10–20 cm		20–30 cm		0–10 cm		10–20 cm		20–30 cm	
ANOVA (df)	% Sum of squares											
G (1)	44.12	**	11.80	n.s.	33.10	**	62.64	**	0.74	n.s.	20.11	**
WS (1)	20.10	**	28.28	*	29.14	**	13.68	*	52.09	**	39.56	**
G × WS (1)	13.67	*	1.77	n.s	7.24	n.s	4.44	n.s	0.02	n.s.	17.91	**
Residuals (12)	22.11		58.15		30.52		19.24		47.14		22.42	
Std. Dev. (+)	4.04		0.955		1.012		47.3		14.36		16.77	

The mean values followed by the different lowercase letters in each column indicate significant differences at $p \leq 0.05$ using the LSD test. ** and * denote significance at $p \leq 0.01$ and $p \leq 0.05$, respectively. n.s. denotes no significant difference. (+) Standard deviation, calculated as the square root of the residual mean square. df denotes degrees of freedom.

4. Discussion

The plants grown under the DI conditions certainly faced a stress situation, as demonstrated, on one hand, by the follow-up of the substrate's volumetric water content to adjust it to target levels, where the water stress applied in this experiment was maintained for a long enough period of time for plants to display the consequences of such stress. On the other hand, this was demonstrated by the measured physiological parameters, the stomatal conductance, the leaf water potential and the RWC, which are well known to be affected by drought stress [15,16]. The differences in RWC in leaves were the first evidence toward this conclusion, because higher RWC was observed in the leaves of the properly irrigated plants than in those under the DI condition. RWC in leaves is a measurement of plants' water status in relation to their water content. It partly estimates the degree of water stress [17]. In addition, the results of this experiment also showed that the plants that faced stress obtained lower stomatal conductance values for all the taken measurements. Leaf water potential, both at predawn and midday, were also clearly lower in the plants subjected to the deficit irrigation treatment.

The agronomic results obtained in this experiment demonstrated that grafting the traditional cv. Cuerno onto the tolerant NIBER® rootstock increased yield under both the CON and DI conditions. Under the DI conditions, however, the NIBER® rootstock was not equal to the ungrafted plants under the CON conditions because the generated stress was likely important and grossly reduced yield, which was more marked than that observed in previous experiments using the same rootstock conducted in soil conditions [13].

It can be stated that the degree of water stress to which the crop was submitted in order to maintain the 60% volumetric content in FC terms led to soil moisture that was too low for DI irrigation under these conditions because, when comparing the obtained yield between the two treatments, the CON plants obtained a 73% higher yield than the DI plants. Notwithstanding this, the loss in yield was less than that obtained when grafting the cv. Cuerno onto the NIBER® rootstock, whose marketable fruit production grew for both the CON and DI situations compared to the ungrafted plant yield.

Indeed, grafted plants subjected to water stress are capable of generating a 1.8-fold higher marketable mean yield compared to the production of ungrafted plants in the same situation. In CON situations, the grafted plants increased production by 23% compared to the ungrafted plants.

The differential behavior in yield between the two plant combinations could be associated with a robust root system in plants using NIBER® as rootstock. In fact, the whole biomass and root volume were higher in the plants grafted onto NIBER® than in the ungrafted ones under both optimal and stress irrigation conditions. These results are a consequence of the higher percentages of NIBER roots in the 0–10 cm layer, which normally sees a higher accumulation of pepper roots in high-frequency irrigation, as has been observed by [18] in drip-irrigated pepper and tomato crops; in our experiment, this accounted for 72%, on average, DW for both DI and CON conditions. Nevertheless, the total fresh biomass for roots in the grafted plants under stress conditions was 23% higher than in the ungrafted ones, and this percentage was higher (26%) for the root volume.

The higher root biomass and volume could be explained by the direct effect of a greater photosynthesis capacity in rootstocks tolerant to abiotic stresses. This has been frequently reported elsewhere as associated with a strong root system, which contributes to a higher water and nutrient uptake [11,12,14,19,20].

In any case, the better marketable yields noted when NIBER® was used as rootstock can be explained by lower BER incidence and, therefore, a greater marketable fruit number, and not by heavier mean fruit weight, as this parameter barely presented any variation between grafted and ungrafted plants. The lower BER incidence would have given way to better marketable fruit yields, which were similar in this case. From our experiment, the results showed that the BER percentage in the grafted plants was 36% lower than in the ungrafted plants.

This disorder has been related by some authors with high oxidative processes caused by the production of reactive oxygen species (ROS) [21]. Nevertheless, other authors related this disorder to scarce Ca translocation to organs and tissues with low or null transpiration, which results in this element being scarcely available locally [22].

In previous experiments, we found a better antioxidant capacity of NIBER®, which could explain the present and past observations of its BER tolerance [23]. On the other hand, some authors have stated that the rootstock can enable more water and ions to be transported to aerial parts, as observed by Roufhael et al. [24] in grafted mini-watermelon crops and Lee et al. [8] in different horticultural crops. Kyriacou et al. [25] suggested that lower BER incidence in pepper, observed in distal fruit zones, can be attributed to the improvement made by the rootstock in nutrient uptake/transport terms, Ca in this case, to apical fruit cells toward greater cell wall integrity. In our case, the obtained predawn water potential values would agree with the milder BER effects when using the NIBER® rootstock, because less-negative potentials denote higher water content in the grafted plants under both the DI and CON conditions. This demonstrates that the nighttime root pressure in the plants grafted onto NIBER® is higher and thus facilitates non-transpiring organs and fruit to acquire Ca [26,27]. This fact could be justified by the higher root volume found in the grafted plants, which would permit higher water uptake and intake through root pressure for the same soil water potentials [28].

5. Conclusions

To conclude, the DI in which water stress-tolerant rootstocks like NIBER® are employed can be considered helpful for lowering water use by cushioning effects on yield. However, more studies should be conducted to better adjust the irrigation reduction to values better tolerated by pepper plants. Even under extreme conditions like those herein applied, crop yield increased under both the regular irrigation and water stress conditions because of reduced BER incidence, and this could be due to the consequence of obtaining higher root mass and volume in the shallower root layer.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/horticulturae9030362/s1, Figure S1: Temperature (°C), relative humidity (%) and accumulated solar radiation (Wh/m^2) values.

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