Influence of Different Substrates and Nutrient Solutions on the Yields and the Incidence of Abiotic Disorders of Broccoli

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Abstract
The incidence of different physiological disorders in broccoli in the Mediterranean areas is more frequent during the autumn and spring, the most important period for Spanish exportation of the fresh product. These disorders include brown bud, bud deformation, bracting and hollow stem, which adversely affect the quality of the product. They are related with cultivar sensitiveness but also with nutritional disorders and/or with different stressing factors. In the present experiment we wanted to deep focus on the better understanding the factors affecting the appearance of these disorders. Two nutrient solutions which varied in the potassium/nitrogen ratio, two growing media (perlite and coconut coir dust) and the foliar spray with calcium chloride, were tested in plants of the cultivar ‘Marathon’ grown in a greenhouse in containers in two irrigation regimes. With the low irrigation regime the low K/N ratio increased marketable yields and inflorescence weight but also increased the incidence of the disorders, mainly bud bracting and bud deformation. The type of substrate did not affect yield, but when plants grown in perlite, broccoli buds were more affected by the brown bud disorder. The foliar sprays with calcium sprays differently affect the incidence of the disorders, depending on the type of the disorder. With the high irrigation regime, the low K/N ratio also increased marketable yields and bud weight only in sprayed plants but no differences in the incidence of the disorders were found between nutrient solutions. Marketable yield and, only in sprayed plants, bud weight, were higher with coconut coir dust, and the incidence of brown bud was higher with perlite. Calcium sprays applications increased marketable yield, but also affect the disorders depending of the type. In general, marketable yield was higher with the high irrigation regime and the incidence of the abiotic disorders varied depending of the type: in low irrigation regimes was higher for bud deformation and bracting, but lower for brown bud and hollow stem.

INTRODUCTION
Broccoli (Brassica oleracea L. var italica Plenk) is appreciated for its high contents in vitamin A and indolymethyl-glucosinolate, a derivate of glucobrassicin, which has anti-carcinogenic proprieties. For this reason, its consumption has been increasing in Europe and USA during the last years and one of the objectives of the breeding programmes in this crop is to improve the content in glucosinolate compounds (Van Poppel et al., 1999; Brown et al., 2002).

Broccoli cultivation in Spain starts at mid 70’s for export, mainly to English markets. Nowadays exports exceed 100000 t. The crop is concentrated in the Murcia region but also in Andalusia, Valencia and Navarre, and during autumn, winter and spring.

Particularly during early to middle autumn and middle to end of spring is frequent the incidence of several abiotic disorders that markedly reduce the value of the crop (Maroto et al., 1994).

Some of these disorders, such as brown bud, bracting and inflorescence deformation, seem to be related with high temperatures (Heather et al., 1992; Maroto, 1997). In some cultivars, such as ‘Skiff’, has been proved an exponential effect of the
high temperatures during the week previous to harvest on the brown bud disorder appearance (Lopez-Galarza et al., 1993). It has also proved a cultivar susceptibility over the brown bud disorder (Maroto et al., 1994).

In the case of hollow stem and brown bud disorders, the incidence seems to have a nutritional basis, related with nitrogen and calcium nutrition respectively (Maroto, 1997). Flint (1985) pointed out that the calcium translocation affects the brown bud incidence and Maroto et al. (1993) found a positive effect of calcium sprays in its prevention. In addition, Pascual et al. (1996) observed different ratios $K^+/Ca^{2+} + Mg^{2+}$ between healthy and affected buds.

In addition, Jeni et al. (2001) suggested that the incidence of the brown bud disorder could be related, among different factors, with both solar radiation and great variations in water availability in the soil. They also found lower contents of calcium and higher in potassium and magnesium in affected buds.

The objective of the present study was to find relations among nutrient solution, irrigation ratios and the calcium foliar sprays on the appearance of abiotic disorders in broccoli.

**MATERIALS AND METHODS**

Plants of the broccoli ‘Marathon’, sown on the 31st January 2000 in polystyrene trays filled with coconut coir dust (coir dust), were transplanted on the 8th March 2000 in 8 L containers with an open hydroponic system. Plants were placed in a heated glasshouse provided with cooling system. Two regimes were assayed: V1 (45% of V2) and V2 (ETc increased to obtain approximately a waste percentage of 20%). ETc was calculated from the USA Class A pan evaporation and a crop consumptive use coefficient (Kc) whose values for broccoli are cited by Doorenbos and Pruitt (1977). Two nutrient solutions (S1 and S2; E.C. 2.0 and 2.4 dS m⁻¹ respectively; pH adjusted to 6.5) were assayed, containing the following concentration of macronutrients (mM): S1 (NO₃⁻, 12; H₂PO₄⁻, 1.20; SO₄²⁻, 2.45; Cl⁻, 1.61; K⁺, 6.79; Ca²⁺, 4.05; Mg²⁺, 2.01; Na⁺, 0.8) and S2 (NO₃⁻, 18.65; H₂PO₄⁻, 1.20; SO₄²⁻, 2.45; Cl⁻, 1.61; K⁺, 5.0; Ca²⁺, 8.27; Mg²⁺, 2.01; Na⁺, 0.8).

In each irrigation regime the factors studied were: two nutrient solutions, with two K/N ratios, S1 (2.51) and S2 (1.19); two substrates, perlite (Agroperl™) and coconut coir dust (CocoPeat™); and foliar sprays with calcium chloride at a concentration of 2 g L⁻¹, weekly applied from 10th May 2000, in addition to the control. The experiment was in a randomized orthogonal design of 3 replications of 8 plants for each combination.

Harvest of principal buds was staggered between 26th June and 26th July. Marketable yields, the number of marketable buds and the average bud weight were determined. The disorders studied were: brown bud (B), bud deformation (f), bud bracting (b). Buds were separated in 4 groups (0: healthy buds; 1: light disorder; 2: intense disorder; 3: serious disorder). Marketable yields were calculated for brown bud incidence (buds of 0 and 1 degrees). The disorders incidence were calculated as average disorder index (ADI) = $\sum D_i n_i$, being $d$ the degree $i$ ($i = 0, 1, 2, 3$) of the disorder $D$ (B, f, b) and $n_i$ the number of plants affected by the degree $i$. In addition, the hollow stem (HS) percentage was determined. Data were analyzed by ANOVA. Means were separated by the least significant difference (LSD). The standard deviation in tables was calculated as the square root of the quotient between the absolute value of the residual sum of squares (using the units indicated on the top of the table) and the degrees of freedom of the error.

**RESULTS**

The marketable yields and average bud weight in plants irrigated with V1 were higher with the nutrient solution S2 ($P \leq 0.01$). Almost all inflorescences were marketable, as can be deduced from the quotient between yields and bud weight (Table 1). The brown bud incidence (ABI) was not affected by the nutrient solution and was lower in plants grown on coir dust ($P \leq 0.01$). Calcium sprays lowered brown bud incidence only in coir dust ($P \leq 0.05$; Table 2). Deformation and bracting were overall higher in plants irrigated with the nutrient solution S2 (Table 2). The incidence of bud deformation and bracting
was not affected by the substrate. Deformation was lower in control than in calcium sprayed plants but only in plants irrigated with the nutrient solution S1. No incidence of hollow stem was found in this experiment in V1 regime.

Under V2 irrigation regime, marketable yields were higher in plants fertigated with the S2 nutrient solution (P ≤ 0.05), but differences were only significant in plants sprayed with calcium since the interaction between both factors was significant (P ≤ 0.01). The nutrient solution did not influence the average bud weight (Table 1). Marketable yields were also higher in plants grown in coir dust than in those grown in perlite since the interactions between nutrient solutions or foliar sprays were not significant. In addition, the average bud weight was affected by the substrate. Buds grown in coir dust were higher than those grown in perlite but differences were only significant in calcium sprayed plants. Differences in foliar treatments varied upon substrates (P ≤ 0.01; Table 1).

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The incidence of the brown bud disorder in V2 regime was higher, on average, in the plants grown in perlite (p ≤ 0.01; Table 2). Calcium foliar sprays significantly reduced the incidence of brown bud in all plants except in the plants grown in perlite and fertigated with S1 (Table 2). Deformation bud incidence was similar in all treatments except for the combination S2-perlite-Control in which there were not appreciated any incidence, just in the plants more affected by the brown bud disorder (Table 2). This fact causes the appearance of significant interactions between nutrient solution and substrate or foliar treatments (Table 2). The nutrient solution or substrate did not affect bracting. Calcium foliar sprays increased the incidence, but only in the plants grown in perlite and fertigated with the nutrient solution S2 (P ≤ 0.01; Table 2). No differences in hollow stem were found in any of the factors studied, neither interactions among them.

Although the irrigation regime factor was not included in the ANOVA to avoid greater order interactions, overall, in plants under the irrigation regime V2, the percentage of marketable plants was lower than in plants irrigated under V1 (Table 1), since were more affected by the brown bud disorder. In addition, yields and average bud weights were also lower in the V1 regime. The incidence of deformation and bracting diminished under V2 regime, but hollow stem increased with this regime.

DISCUSSION
The achievement of higher productive parameters with the higher volumes of irrigation is generally known, whenever the lower volumes be sufficiently restrictive.

It also stands to reason that the abiotic disorders related with high temperatures, such as bracting or deformation, have more incidence with low irrigation regimes (Heather et al., 1992). The brown bud disorder is related to calcium nutrition (Maroto et al., 1994; Jeni et al., 2001). Calcium partitioning is affected by translocation and growth rates, and both factors influenced by the temperature and water availability. In our experiment, the incidence of hollow stem was higher with the higher irrigation regime (V2) which suggests that it is related to high growth ratios, in accordance to the statements of Flint (1985) and Maroto (1997).

The results obtained with the nutrient solutions seem related to the ratio K/N since yields in both irrigation regimes increase with low ratios. The incidence of abiotic disorders were higher with lower K/N ratios when plants were irrigated with the low regime, while under high irrigation regime the incidence of disorders were, overall, lower with lower K/N ratios. In the case of the hollow stem, the higher incidence induced by the lowest K/N ratio can be related with a higher growth promote by this nutrient solution, which agrees with the stated by Flint (1985).

Among substrates, the incidence of brown bud was higher in plants grown in perlite. Perlite is an inert substrate while coconut coir dust is organic and has high levels of potassium (Abad et al., 2002). This could affect the incidence of the disorder. However, this does not agree with the results obtained by Pascual et al. (1996) or by Jeni et al. (2001). With the low irrigation regimes, the incidence of disorders was lower in coir dust, suggesting that these disorders could be also related with irrigation deficit since coir dust has higher water-holding capacity than perlite (Noguera et al., 2003).
Foliar calcium sprays reduced the incidence of brown buds, particularly when plants were fertigated with the low K/N ratios. This confirm that this disorder is related with calcium deficiency as commented by different authors (Flint, 1985; Maroto et al., 1993; Jeni et al., 2001) and suggest that the incidence of the disorders affected by calcium nutrition are particularly important with high growth rates (Saure, 1998), which should be confirmed in broccoli in further experiments.

As in other experiments we found, in some aspects, great cultivar susceptibility, the results obtained in the present study should be also confirmed for other cultivars.

**Literature Cited**


Table 1. The effect of nutrient solution, substrate and calcium foliar sprays with low (V1=0.45*V2) and high (V2) irrigation dosages on the marketable yield (g/replication of 8 plants) and average bud weight (g).

<table>
<thead>
<tr>
<th>Substrate</th>
<th>Foliar spray</th>
<th>V1</th>
<th></th>
<th>V2</th>
<th></th>
</tr>
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<tr>
<td></td>
<td></td>
<td>Marketable yield</td>
<td>Average bud weight</td>
<td>Marketable yield</td>
<td>Average bud weight</td>
</tr>
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<td>128.7</td>
<td>1063.0</td>
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<td></td>
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<td>1956.6</td>
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<td>Control</td>
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<td>2031.2</td>
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</table>

LSD (p≤0.05; n=3) 248.58 29.70 262.26 40.05
LSD (p≤0.05; n=6) 175.77 21.00 185.44 28.32

Analysis of variance
Parameter (degrees of freedom) Percentage of the total sum of squares
<table>
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<tr>
<th></th>
<th>Solution (n=1)</th>
<th>Substrate (n=1)</th>
<th>Foliar spray (n=1)</th>
<th>Solution x substrate (n=1)</th>
<th>Solution x foliar spray (n=1)</th>
<th>Substrate x foliar spray (n=1)</th>
<th>Solution x substrate x foliar spray (n=1)</th>
<th>Residual (n=16)</th>
<th>Standard deviation</th>
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<td>12.5**</td>
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<td>6.9*</td>
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<td>18.9**</td>
<td>4.3</td>
<td>20.8</td>
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<td>2.3NS</td>
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<td>4.5NS</td>
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<td>6.9**</td>
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<td>2.3NS</td>
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<td>4.3</td>
<td>20.8</td>
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<tr>
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<td>4.5NS</td>
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</tbody>
</table>

NS, * ** indicates non significant, significant at P≤0.01 and P≤0.05.
Table 2. The effect of nutrient solution, substrate and calcium foliar sprays with low (V1=0.45*V2) and high (V2) irrigation dosages on the incidence of average brown bud index (ABI), average deformation index (Afi), average bracting index (AbI) and hollow stem percentage (HS) disorders.

<table>
<thead>
<tr>
<th>Substrate</th>
<th>Foliar spray</th>
<th>ABI</th>
<th>Afi</th>
<th>AbI</th>
<th>HS</th>
<th>ABI</th>
<th>Afi</th>
<th>AbI</th>
<th>HS</th>
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<td>10.0</td>
<td>5.0</td>
<td>0.0</td>
<td>8.0</td>
<td>6.3</td>
<td>1.3</td>
<td>1.0</td>
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<tr>
<td>Control</td>
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<td>3.0</td>
<td>6.7</td>
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<tr>
<td>Coir dust</td>
<td>Ca</td>
<td>0.0</td>
<td>7.7</td>
<td>6.0</td>
<td>0.0</td>
<td>0.7</td>
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<tr>
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<td>1.7</td>
<td>4.7</td>
<td>5.3</td>
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<td>5.0</td>
<td>8.7</td>
<td>3.7</td>
<td>0.0</td>
</tr>
<tr>
<td>Solution 2</td>
<td>Perlite Ca</td>
<td>4.0</td>
<td>10.0</td>
<td>11.7</td>
<td>0.0</td>
<td>3.0</td>
<td>7.3</td>
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<tr>
<td>Control</td>
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<tr>
<td>Control</td>
<td></td>
<td>1.7</td>
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<td>3.0</td>
<td>7.0</td>
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LSD (p≤0.05; n=3) 1.39 3.41 5.26 - 2.16 4.22 3.40 0.73
LSD (p≤0.05; n=6) 1.00 2.42 3.72 - 1.53 2.98 2.41 0.52

Analysis of variance

<table>
<thead>
<tr>
<th>Parameter (degrees of freedom)</th>
<th>Percentage of the total sum of squares</th>
</tr>
</thead>
<tbody>
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<td>Solution (n=1)</td>
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</tr>
<tr>
<td>Substrate (n=1)</td>
<td>71.1** 6.5NS 5.5NS - 46.0** 6.5NS 3.8NS 5.5NS</td>
</tr>
<tr>
<td>Foliar spray (n=1)</td>
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<tr>
<td>Solution x substrate (n=1)</td>
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<tr>
<td>Solution x foliar spray (n=1)</td>
<td>1.3NS 12.4* 2.7NS - 4.8** 27.0** 10.6* 2.7NS</td>
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<td>Substrate x foliar spray (n=1)</td>
<td>4.2* 0.4NS 0.1NS - 1.8* 5.3NS 6.7NS 0.2NS</td>
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<td>2.5NS 1.5NS 11.7NS - 16.6** 5.3NS 24.2** 14.0NS</td>
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<tr>
<td>Residual (n=16)</td>
<td>12.9 35.1 56.9 - 6.5 35.2 24.9 69.50</td>
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<td>Standard deviation</td>
<td>0.80 1.97 3.04 - 1.25 2.43 1.96 1.27</td>
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NS, *, ** indicates non significant, significant at P≤0.01 and P≤0.05.