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Use of almond shell and almond hull as substrates for sweet pepper cultivation. Effects on fruit yield and mineral content

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Abstract

The use of almond by products as substrate in greenhouses for growing vegetables has a great economic interest. The objective of this work was to assess the use of two almond by-products (almond shell-AS and almond hull-AH), which had been previously conditioned without composting, as substrates for pepper (cv. Caprino F1) production and to study their effects on the yield, fruit size, and fruit mineral content. Physical, physico-chemical, and chemical characteristics of the almond by-products were determined both initially and during the pepper growing season. Initially, all values of the parameters studied —except sulfur and iron— differed significantly between the two substrates. During cultivation, the 18 substrate parameters and variables tested —except bulk density— exhibited significant variations with time for AS; the same occurred for AH, exceptions being pH, total nitrogen N_t, N-NH_4, bulk density, and manganese. The changes in both substrates for the K, N, and S concentrations were significant. The nutrient levels in AH were higher than for AS. The almond shell and almond hull substrates produced slight decreases in total fruit yield with respect to the control (0.79 and 3.22 for AS and AH, respectively), with a lesser decrease for AS, due to reductions in the number of fruits per plant rather than to reductions in individual fruit weight. The plants grown on the AS and AH substrates showed a decrease in total fruit yield, due to reductions in the number of fruits per plant rather than reductions in individual fruit weight.

Additional key words: *Capsicum annuum;* fertigation; mineral elements; total fruit yield; *Prunus amygdalus.*

Introduction

The profits derived from the sale of hulls to feedlots partially offset the cost of hulling and shelling the almond (*Prunus amygdalus*) crop (Lao & Jiménez, 2004; Urrestarazu *et al*., 2005). Between the outer hull and nutritious kernel lies the shell, primarily composed of cellulose, hemicelluloses, and lignin. Shell strength is a function of the proportions of these chemicals together with the shell morphology, fiber content, and outer shell adherence (Anon, 1997). The almond industry generates large quantities of waste products (Ledbetter, 2008) that need to be recycled or processed for alternative uses. In this regard, there are few studies that have evaluated the use of almond shells as growing media without pre-treatment. For other solid wastes such as grape marc or olive husks, despite their richness in organic matter and mineral nutrients, the presence of phytotoxic polyphenolic compounds makes conditioning treatments necessary before their use for agricultural purposes (Bustamante *et al.*, 2008).

Like other vegetable crops, peppers (*Capsicum annuum*) also can be cultivated on conventional substrates such as perlite, rockwool, sand, and other soilless systems, which have replaced the traditional crop grown in agricultural soil in the greenhouse (Zhai *et al.,* 2009; Díaz-Pérez, 2010). Increasing awareness of the adverse economic and environmental impacts of conventional substrates has stimulated the interest in using organic wastes and agricultural by-products as substrates in soilless culture (Arenas *et al*., 2002; Favaro & Marano, 2003; Urrestarazu *et al*., 2005; Del Amor & Gomez-López, 2009; Lin *et al*., 2009).

Saline water and insufficient levels of essential elements during fruit ripening decrease pepper yield and quality (Chartzoulakis & Klapaki, 2000; Navarro *et*

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Abbreviations used: AH (almond hull); AS (almond shell); C_w (water soluble organic carbon); EC (electric conductivity); IS (ideal substrate); N_t (total nitrogen); OM (organic matter).

al., 2002; García *et al.,* 2011). Nitrogen is required in the largest quantities and phosphorus is found particularly in reproductive organs, being influenced by the plant N content, while the plant potassium requirement is high during flowering and fruit growth (Bar-Tal *et al.*, 2001; Del Amor & Gómez-López, 2009). At low rates of transpiration, insufficient Ca^{2+} uptake by fruits and young leaves means that they may suffer Ca^{2+} deficiency, manifested as "blossom end rot" (Madrid *et al.,* 2004; Rubio *et al.*, 2010). Under magnesium deficiency, pepper shows a decrease in relative growth rate, total dry mass, and the stem and root mass fractions. Micronutrients are involved in numerous biochemical processes and adequate uptake of certain micronutrients is necessary to prevent deficiency-related diseases (Rubio *et al.*, 2002; Zheng *et al.*, 2005).

The chemical and physical properties of the substrate may induce nutritional deficiencies; therefore, intensive testing is needed before using new materials as growing media.

The objectives of this research were to characterize the main physical and chemical properties of almond shell and almond hull-based substrates, to evaluate their effects on bell pepper growth and fruit yield under greenhouse conditions, and to characterize fruit mineral content.

Material and methods

Experimental design

The sweet pepper variety used was Capino F-1, a California-type hybrid which ripens when yellow. The study was carried out in two consecutive years (2009 and 2010), in duplicate each time, in a polycarbonate greenhouse (200 m^2) located in the experimental plot of the University of Murcia (Spain). The data used are the means of these two years. Three substrates were used: perlite (control) and two agricultural by-products, almond shell (AS) and almond hull (AH).

The experiment was performed in three sectors, in duplicate (6 sub-sectors), with two rows of plants per sub-sector and 12 plants per row (48 plants per sector); therefore, 144 greenhouse-grown sweet pepper plants were evaluated.

The seeds were sown in mid-November, the seedlings were transplanted at the beginning of December, and pepper cultivation finished in June. The plants were grown in a greenhouse at a day/night temperature of 20-30/14°C and a relative humidity of 60-70/75%, which were controlled by zenithal ventilation and a cooling system with an adjustable thermostat.

Samples of fruits were harvested every 10 days throughout the fruit growth period (6 times), starting 20 days after fruit set (days 20 to 70 of fruit growth). Two fruits of uniform size per plant were collected, from random locations on four plants, in triplicate for each substrate (24 fruits).

Almond shell and almond hull substrates

Almond shell and almond hull were used: AS is the ligneous material forming the thick endocarp or husk of the almond fruit and AH is the name given to the green, fleshy material forming the exocarp and mexocarp of the fruit. The AH is normally used as an ingredient in animal feedstuffs, whereas AS is used to obtain furfural or is incinerated for energy production.

To obtain the AS and AH substrates, almond fruits were subjected to removal of the hull and breakage and removal of the shell. The AS and AH were crushed separately to a diameter of 0.75-1.25 cm. Commercial perlite, type B-12, in $120 \times 22 \times 17$ cm-bags with a capacity of 40 L, was included as a control in the experiment. The AS and AH were used in bags identical to those of the control, to reproduce the growth conditions and to permit comparisons among the sectors (3 in duplicate, = 6 in total).

Nutrient solution

Based on previous experiments (Madrid *et al*., 2000), the composition of the basic nutrient solution was established by taking into account the concentrations of ions in the irrigation water. The compositions of the irrigation water and initial nutrient solution used are shown in Table 1. In all sectors, the same nutrient solution was applied; it was adjusted periodically according to the analyses of the supply and drainage solutions. At the same time, automatic control of the nutrient solution EC and pH was used. Each sector had an independent drip-irrigation system, composed of a 60-L, automatically-stirred tank containing nutrient solution, electrical valves, filters, polyethylene tubes ($\varnothing = 25$ mm) for nutrient solution distribution, and tubes ($\varnothing = 14$ mm) with self-compensating emitters (2 L h^{-1}) which, in turn, were divided into four emitters supplying 0.5 L

Table 1. Main characteristics of the irrigation water and initial nutrient solution employed for pepper culture (nutrients in mmol L^{-1})

Character	Irrigation water	Nutrient solution
pH	6.38	6.29
EC (dS m^{-1})	0.05	2.51
Cl^-	0.22	2.62
HCO_3^-	0.24	0.99
NO_3^-	0.01	10.80
NH_4+	0.00	0.00
$H_2PO_4^-$	0.00	1.87
K^+	0.01	6.01
Ca^{2+}	0.10	4.44
Mg^{2+}	0.01	2.54
SO_4^{2-}	0.01	7.40
Na^+	0.28	12.09
Fe^{2+}	0.00	0.02
Mn^{2+}	0.00	0.01
Zn^{2+}	0.00	0.01
Cu^{2+}	0.00	0.01
$B(OH)_4^-$	0.03	0.20

plant^{-1}. The fertigation was regulated automatically by demand irrigation, with two height-adjustable electrodes located in the lower part of the tray, which began and stopped the irrigation according to the transpiration rate of the plants.

Growing media and plant analysis

The pH, electric conductivity (EC), organic matter (OM), water-soluble organic carbon (C_w), water-soluble nutrients, and total nutrients were determined in both substrates. The pH, EC, C_w, and soluble minerals were determined in water extracts (1:6 v/v) (ADAS, 1988). The bulk and real densities of the growing media were determined according to the methods of Ansorena (1994). The dry matter content was assessed by drying at 65°C for 24 h and at 105°C for 2 h, and the OM was determined by the loss-on ignition for 24 h at 430°C. The C_w was determined by oxidation with $K_2Cr_2O_7$ in H_2SO_4, according to Tiessen & Moir (1993).

The total nitrogen (N_t) of the AS, AH, and fruits was determined by the semi-micro Kjeldahl method, the NO_3^- by UV-spectrometry (calculated from the difference between the absorbances at 220 and 275 nm, to allow for OM interference) and the NH_4^+ by a steam distillation-extraction of NH_3 and titration with HCl (0.1 N).

The AS, AH, and fruit samples were mineralized in a muffle furnace at 480°C for 8 h and dissolved in HNO_3 (0.6 N). For determination of the various mineral elements, the appropriate aqueous dilutions were made. The P was measured colorimetrically, S by ion chromatography (Metrohm 790), B by the azomethine-H method, total and soluble Ca, Mg, Fe, Mn, Cu, and Zn by atomic absorption spectrophotometry, and K and Na by flame emission spectrophotometry. The results for the soluble elements, in both substrates, were expressed in mg kg^{-1}.

Statistical analysis

The data were analyzed statistically by one-way analysis of variance (ANOVA), with a general linear model, using the SPSS program (version 11.0). Significant differences among the three sector means were calculated by the Tukey multiple range test, at $p < 0.05$. The student test was used to determine the significance of differences between the parameters of the AS and AH substrates.

Results and discussion

Initial properties of the AS and AH substrates

The main physical, physico-chemical, and chemical properties of the AS and AH were analyzed to determine the initial conditions before the experiment commenced (Table 2). The AS and AH were characterized by a similar pH, low EC values (higher for AH), and high bulk density and OM contents, compared with an ideal substrate (IS) for soilless culture. The pH values of both substrates were within the established limits for an IS, while the EC values differed statistically; both were below the optimum range for an IS (Escudero, 1993). The EC of the AS was slightly above the optimal range proposed by Abad *et al.* (1993) and values obtained by Urrestarazu *et al.* (2005) for two different textures of AS. The values of bulk density for the AS (0.43) and AH (0.37) differed significantly; values for perlite type B-12 are around 0.143 g cm^{-3} (Marfa *et al.*, 1993; Favaro & Marano, 2003). The dry matter content of the AH was statistically higher than that of the AS. Regarding the C_w content, the AS and AH showed significant differences, that of AS being lower and closer to the limit set for composts derived from different organic wastes, $C_w < 1\%$, and that of AS being similar to pig slurries (Moral *et al.*, 2008). Based on the

Table 2. Characteristics of the almond shell (AS) and almond hull (AH) used in the experiment (dry weight basis)

Character	AS	AH	Sign.[1]	IS[2]	Character	AS	AH	Sign.[1]
Moisture (%)	12.90	10.00	**		Ca (g kg^{-1})	0.54	3.95	***
Dry matter (%)	87.07	90.01	**		Mg (g kg^{-1})	0.31	1.32	***
Organic matter (%)	94.70	95.40	***	> 94.80[a]	S (g kg^{-1})	0.11	0.09	ns
Ashes (%)	5.30	4.60	**		Na (g kg^{-1})	0.24	0.86	***
pH[3]	6.06	5.24	*	5.5-6.8[b]	Cl (g kg^{-1})	0.08	0.16	**
EC[3] (dS m^{-1})	1.90	2.91	***	3.0-5.0[b]	Fe (mg kg^{-1})	65.10	67.56	ns
Bulk density (g cm^{-3})	0.43	0.37	**	< 0.4[a]	Mn (mg kg^{-1})	6.07	13.60	***
Real density (g cm^{-3})	1.59	1.37	**		Cu (mg kg^{-1})	5.84	17.79	***
C_w[4] (g kg^{-1})	6.95	112.44	***	< 10[c]	Zn (mg kg^{-1})	6.62	10.88	***
N_t[5] (g kg^{-1})	2.24	6.92	***		B (mg kg^{-1})	21.77	25.40	*
NH_4^+ (g kg^{-1})	0.65	1.15	**		Total fats (g kg^{-1})	1.57	5.07	***
NO_3^- (g kg^{-1})	1.30	2.23	**		Glucose (g kg^{-1})	1.93	215.7	***
P (g kg^{-1})	0.18	0.69	***		Fructose (g kg^{-1})	6.40	97.10	***
K (g kg^{-1})	4.97	32.30	***		Sucrose (g kg^{-1})	0.00	12.73	***

[1] *, **, ***, ns are $p \leq 0.05$, $p \leq 0.01$, $p \leq 0.001$, and not significant or $p > 0.05$, respectively. [2] IS: ideal substrate following [a]Abad *et al.* (1993), [b]Escudero (1993), or [c]Hue & Liu (1995). [3] Water extract 1:6 v/v. [4] C_w: water-soluble organic carbon. [5] N_t: total nitrogen.

IS concept (Abad *et al.*, 1993; Escudero, 1993; Hue & Liu, 1995), the AS had more-adequate values of pH, OM, and C_w than did the AH.

Except for S, the levels of mineral elements were higher in the AH. The macronutrient content of the AS was similar to that found in olive mill wastewater by Paredes *et al*. (1999) and lower than that found in solid waste (Paredes *et al.,* 1999; García *et al*., 2005). The N_t content of the AH was higher than that of the AS, and the AH was especially rich in K. The levels of total fats and sugars were higher in the AH, limiting its direct use (without previous composting) since the OM degradation would be greater as a consequence of higher microbiological activity (Paredes *et al*., 1999).

Evolution of the AS and AH substrates during pepper cultivation

The evolution of the pH, EC, N-NH_4^+, N-NO_3^-, and C_w of the water extracts (1:6 v/v), the bulk density, and the total mineral concentrations of the AS and AH during pepper cultivation was determined (Table 3); the sampling of the substrates started 77 days after transplanting, once fruit set had occurred.

The pH values of the AS and AH declined during pepper development, from 7.5 to 7.0 for AS and from 8.8 to 8.5 for AH. This may have been due to the production of organic acids from easily-degradable available carbon, in accordance with Montemurro *et al.* (2009), rather than ammonia production during ammonification and mineralization of organic nitrogen. The pH decreased by 0.5 units – similar to the classic evolution of compost under aerobic conditions (Montemurro *et al*., 2009). The AH reached strongly-alkaline values of pH, which could affect the availability of nutrients to plants due to alteration of the growing medium reaction.

The salinity values of the AS and AH, expressed as EC (1:6 v/v), were below the optimum range for an IS and varied greatly. The AS had a very-low salt content that increased during the development of the pepper plants and was slightly above both the optimal values proposed by Abad *et al.* (1993) and those obtained by Urrestarazu *et al.* (2005) for two different textures of AS. By contrast, the EC of the AH lessened during pepper development, probably due to precipitation of mineral salts, volatilization of ammonia, or the absence of an increase in ion concentrations as a consequence of adequate crop utilization of the nutrient solution and (most likely) a washing effect of the fertigation (Cuesta *et al.*, 2012).

The Cw values of the AS were lower than for AH and closer to the limit set for composts from different organic wastes, 1% Cw (Hue & Liu, 1995). It is worth pointing out that the Cw did not decline significantly until day 192 of pepper cultivation; the highest levels of biodegradation occurred in the AH (initial and final values of 1.18 and 0.39 g L^{-1}, respectively) before sampling day 77, in agreement with Montemurro *et al.* (2009). The concentration of water-soluble organic

Table 3. Evolution of the pH, EC, N-NH_4^+, N-NO_3, and C_w in water extracts (1:6 v/v), the bulk density and the total mineral concentrations in the almond shell (AS) and almond hull (AH) substrates during pepper culture (dry matter basis)

Character	AS				AH			
	Days after transplanting			Sign.[1]	Days after trasplanting			Sign.[1]
	77	133	192		77	133	192	
pH[2]	7.48^b	7.11^a	7.03^a	**	8.87	8.74	8.50	ns
EC (dS m^{-1})[2]	0.18^a	0.20^a	0.29^b	***	1.64^b	0.97^a	0.90^a	***
N-NH_4 (mg L^{-1})[2]	4.75^b	3.94^a	3.89^a	**	7.40	8.15	8.13	ns
N-NO_3 (mg L^{-1})[2]	202.56^b	243.54^c	171.78^a	***	377.54^c	267.80^a	324.92^b	***
C_w (g L^{-1})[2]	0.41^a	0.51^b	0.39^a	***	1.18^b	1.07^b	0.39^a	***
Bulk density (g L^{-1})	0.43	0.44	0.45	ns	0.46	0.47	0.49	ns
N_t (g kg^{-1})	2.48^a	3.92^b	5.26^c	***	17.66	18.86	18.47	ns
P (g kg^{-1})	0.27^b	0.22^a	0.50^c	***	2.15^b	3.08^c	1.21^a	***
K (g kg^{-1})	5.81^b	6.17^b	4.65^a	***	34.51^c	29.46^b	13.51^a	***
Ca (g kg^{-1})	0.49^a	0.65^b	0.92^c	***	15.48^a	26.15^b	25.16^b	***
Mg (g kg^{-1})	0.53^a	0.48^a	0.59^b	***	4.82^a	7.62^c	6.36^b	***
S (g kg^{-1})	0.04^a	0.05^b	0.11^c	***	1.34^a	7.29^b	7.96^c	***
Na (g kg^{-1})	0.17^a	1.19^c	0.88^b	***	2.05^b	2.19^b	1.23^a	***
Fe (mg kg^{-1})	49.51^b	53.02^b	39.95^a	***	237.61^a	337.01^b	389.60^c	***
Mn (mg kg^{-1})	10.95^c	7.69^a	9.65^b	***	42.82	43.50	40.05	ns
Cu (mg kg^{-1})	10.50^a	11.35^a	15.22^b	***	54.97^a	95.94^b	129.80^c	***
Zn (mg kg^{-1})	8.78^b	7.35^a	11.06^c	***	26.99^a	31.88^b	34.43^b	**
B (mg kg^{-1})	14.15^b	12.04^a	11.29^a	**	74.26^a	96.52^b	95.18^b	***

[1] *, **, ***, ns are $p \leq 0.05$, $p \leq 0.01$, $p \leq 0.001$, and not significant or $p > 0.05$, respectively. [2] Water extract 1:6 v/v. Different letters in each line indicate a significant difference ($p < 0.05$) according to the Tukey multiple range test.

compounds was significantly higher in the AH and the higher bulk density of this substrate is indicative of an increased microbial population responsible for a relatively-greater biological degradation of the AH during the cultivation period. This is the major disadvantage of using AH as a growing medium for soilless cultivation, as indicated by Favaro & Marano (2003).

The available nitrogen (NO_3^- and NH_4^+) reflects the differing natures of the materials. Since N was present only as NO_3^- in the nutrient solutions (Table 2), the presence of NH_4^+ in the water extract (Table 3) probably indicates that the balance of NH_4^+ was broken by supplying nitrate, resulting in denitrification and decomposition of OM that produced NH_4^+ and resulted in a new equilibrium (Ao *et al.,* 2008). The N_t content of the AS changed during the pepper culture, probably due to a reduction in weight (concentration effect) resulting from CO_2 production (Sánchez-Monedero *et al.,* 2001). For the AH, one reason for its greater increase in N_t throughout the biodegradation process is probably the composition of the original material, in accordance with Montemurro *et al.* (2009).

The total P in the AS and AH was low and increased slightly in AS during pepper development, indicating that the nutrient solutions had no significant interaction with the organic substrates and that only a minor proportion was consumed by microorganisms (Ao *et al.,* 2008). The K^+ and Na^+ decreased during cultivation; however, Ca^{2+} and Mg^{2+} increased, in accordance with the study of Ao *et al.* (2008) showing that univalent ions have, to some extent, a competitive relationship with bivalent ions in some substrate nutrient solutions.

During pepper culture, the concentrations of the oligoelements were maintained in the AS and increased slightly in the AH. In all cases, higher values were found in substrate AH (3-times higher for Zn and 9-times for Fe).

Effect of the substrates on the concentrations of macro and micro nutrients in pepper fruit

Table 4 shows the evolution of macro and micronutrients in pepper fruits as influenced by the substrate. The N, P, K, Mg, and S concentrations exhibited significant changes, decreasing during development. This may well have been a dilution phenomenon, with the

Table 4. Evolution of the concentrations of macro & micro nutrients (mg/100 g dw) in pepper fruits during the growth cycle, as influenced by the substrate

	N	P	K	Ca	Mg	S	Na	Fe	Mn	Cu	Zn	B
Days after fruit set												
20	2,093[d]	412[c]	2,997[e]	79.9	177[d]	164[a]	82.2[d]	3.68	1.99	1.27	3.09[c]	2.23[b]
30	2,052[c]	405[c]	2,828[c]	79.8	168[c]	192[c]	76.4[bc]	3.62	1.83	1.15	2.68[b]	1.87[ab]
40	1,943[b]	371[a]	2,998[e]	77.7	159[b]	184[b]	78.3[cd]	3.59	2.05	1.13	2.80[b]	1.74[ab]
50	1,932[a]	383[b]	2,956[d]	76.8	158[b]	197[c]	82.6[d]	3.34	1.75	1.06	2.59[ab]	1.59[a]
60	1,940[ab]	372[a]	2,745[a]	77.9	149[a]	167[a]	69.1[a]	3.40	1.55	1.07	2.38[a]	1.53[a]
70	2,101[d]	370[a]	2,803[b]	77.7	150[a]	162[a]	71.2[ab]	3.34	1.51	0.98	2.36[a]	1.50[a]
Substrate												
Perlite	2,240[b]	400	2,978[c]	77.4[a]	165	195[b]	80.9[b]	3.39	1.52[a]	1.24	2.67	1.84
AS	1,929[a]	380	2,742[a]	79.2[ab]	155	164[a]	70.5[a]	3.67	1.79[ab]	1.08	2.76	1.72
AH	1,908[a]	380	2,912[b]	79.5[b]	169	195[b]	72.7[a]	3.47	2.15[b]	1.06	2.73	1.71
*Analysis of variance (*F *values)*												
Days	***	***	***	ns	***	***	***	ns	ns	ns	***	**
Substrate	**	ns	***	*	ns	**	**	ns	*	ns	ns	ns
Days × Substrate	*	ns	***	ns	ns	*	*	ns	ns	ns	ns	ns

*, **, and *** denote significant differences among means at $p < 0.05$, $p < 0.01$, and $p < 0.001$, respectively. ns: not significant. Values followed by the same letter within a column are not significantly different at the 0.05 level of probability, according to the Tukey multiple range test. AS= almond shell; AH = almond bull.

increase at day 70, particularly of nitrogen, resulting from an increase in sink strength during ripening. The substrate influenced significantly the K, N, S, and Na concentrations; K was influenced significantly by time also. The values for Ca did not differ significantly during fruit development for any of the substrates studied, as found also by Flores *et al.* (2009). At harvest, K was most-abundant macronutrient in all samples, mirroring the results of Flores *et al.* (2004), followed by N, P, S, Mg, Ca, and Na. Similar values were obtained for the three substrates, except for Ca —which differed slightly.

Differences were detected in pepper fruit N, the highest values occurring at the beginning and end of the growing season, in accordance with Flores *et al*. (2009). As regards the fruit content of K, the most abundant of the mineral elements analyzed, in accordance with the findings of Bernardo *et al*. (2008) in different pepper cvs., high values were found at the start and end of fruit development with significant differences between the AS and AH (higher K) substrates. Under these conditions of K sufficiency, the fact that increasing its availability did not raise the fruit K content can be attributed to its high mobility, which means that plant organs preferentially supplied with phloem sap (such as fleshy fruits) are replete in this nutrient regardless of K supply. Our findings suggest that a production system involving an AS or AH substrate does not contribute to increasing the K concentration of pepper fruits, as shown previously for cv. Quito (Flores *et al.,* 2009). Despite the fact that the levels of soluble macronutrients were higher for substrate AH than for AS, the fruit macronutrient concentrations on AH were the same as or lower than those on perlite or AS, influenced by the fertigation and differing substrate pH.

The Zn and B concentrations decreased during ripening, exhibiting significant differences. The substrate influenced significantly the fruit Mn content. These data are similar to those obtained by Bernardo *et al.* (2008) in green and red pepper. The accumulation of micronutrients in pepper fruits decreased in the order: Fe > Zn > Mn ≥ B > Cu. Simonne *et al.* (1997) reported a different order of micronutrient accumulation in yellow bell pepper (B > Fe > Mn ≥ Zn > Cu) and lower contents than in our assay. Comparing the micronutrient levels measured in this pepper variety with those of peppers harvested when green or red (Rubio *et al.,* 2002), in all cases the most-abundant micronutrient was Fe, but the concentration of each element determined was higher in the variety studied here. The fruit concentrations of Fe, Cu, Zn, and B were not influenced by the type of substrate, a result similar to that found by Demir *et al.* (2010) for tomato grown in soil amended with poultry manure. Based on the physical and physicochemical characters of the fruits (data not shown), full maturity—optimum harvest time— was reached 65 days after fruit set.

The AS has a high content of lignin, which degrades very slowly, whilst the AH cellulose will degrade faster; hence, it can be considered that our substrates, particularly AH, underwent a form of composting during plant growth. This process may have been the reason why the AH gave the lowest yield (phytotoxicity).

Effect of the substrates on total fruit yield

Table 5 shows the total fruit number, fruit fresh weight and dry matter percentage, and dimensions of the Capino F-1 peppers according to the substrate used. The total fruit yield and total fruit number were affected by the substrate. The plants grown on perlite produced a significantly-greater total yield and higher fruit number than those grown on AS or AH; the total yield for plants grown on AS or AH was lower by 17.7% or 38.3%, respectively (Flores *et al.,* 2009). Urrestarazu *et al.* (2005) also reported that tomato (*Solanum lycopersicon*) and melon (*Cucumis melo*) plants cultivated on AS had reduced total yields with respect to the control substrate (rockwool), but the differences were not statistically significant since, despite a decrease in fruit number, there was no significant change in individual fruit weight. The increased yields of pepper that we observed for perlite could have resulted from greater availability of plant nutrients in this substrate; however, this is unlikely because all the plants were watered with the nutrient solution periodically, according to the analyses of the supply and drainage solutions. Besides, there was a significant increase of the EC in the AS growing medium and a decrease in the AH, coinciding with a decrease in the pepper yield. The yields for AS and AH were decreased significantly with respect to the control, which could have been due to poor aeration, high pH and salinity, and plant phytotoxicity in these growing media.

All the other parameters of morphological and chemical fruit quality determined (average weight, dry matter content, and fruit width, length, and thickness) were unaffected by the substrates. The fruit weights were slightly higher than those reported by Chartzoulakis & Klapaki (2000) for cultivation in sand-perlite (1:3, v/v).

As conclusions, the almond shell and almond hull substrates were characterized by similar pH, low EC and bulk density, and high organic matter contents compared with "ideal" substrates used elsewhere in soilless culture. Relative to an ideal substrate, the AS had pH and C_w values that were more adequate than those of the AH. During the development of the pepper crop, the substrates showed significant changes in all the parameters considered, except in the case of pH, N-NH_4, N_t, bulk density, and Mn concentration for AH, and of bulk density for AS. The AS seems to be an acceptable growing media for soilless culture and represents a viable alternative to soil for pepper cultivation. During crop development, composting of the AH substrate probably occurred, which influenced the number of fruits but not their weight or size. With respect to the control (perlite), the plants grown on the AS and AH substrates showed a decrease in total fruit yield —which was less marked for AS— due to reductions in the number of fruits per plant rather than reductions in individual fruit weight (fruit weight was higher for AS).

Table 5. Total fruit yield of Capino F-1 pepper, according to the substrate used

Substrate	Total fruit yield (kg m^{-2})	Total fruit number	Average fruit weight (g)	Fruit dry matter (%)	Width (mm)	Length (mm)	Thickness (mm)
Perlite	8.40^{c}	119^{c}	161.01	8.50	79.58	69.49	6.33
AS	7.61^{b}	98^{b}	176.94	8.30	75.85	69.83	6.36
AH	5.18^{a}	80^{a}	147.74	8.76	75.54	86.70	5.51
Sig.	***	***	ns	ns	ns	ns	ns

*** denotes significant differences among means at $p < 0.001$, respectively. ns: not significant. Values followed by the same letter within a column are not significantly different at the 0.05 level of probability, according to the Tukey multiple range test.

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