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New Wood Fibre Substrates Characterization and Evaluation in Hydroponic Tomato Culture

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Summary

The FIBRALUR® wood fibre substrate has been successfully evaluated as substrate in tomato and melon culture. This material could replace the current hydroponic substrates like rockwool or perlite. The appearance of wood fibre bags for hydroponics culture deteriorates throughout crop cycles and it is a commercial disadvantage for farmers. In this work four new variants of wood fibre substrates that improve the disadvantage of original material have been evaluated and compared with coconut fibre and perlite. Experiment had been carried out for two tomato crop cycles in a greenhouse placed in Barasoain (Navarra). Seven substrates were used in a random block design. Measures of crop yield and quality as well as evaluation of substrates properties were carried out. Physical-chemical properties were determined at the beginning and at the end of each crop cycle. In the first cycle wood fibre substrates were significantly less productive than coconut fibre and significantly higher than perlite. No yield differences were obtained at the second cycle. With regard to substrates properties, an increase of water retention in wood fibre substrates and an increase of air volume in coconut fibre were observed throughout crop cycles.

Key words. properties – quality – substrate – soilless – yield

Introduction

The FIBRALUR wood fibre substrate has been successfully evaluated as substrate in greenhouse tomato and melon culture (Muro et al. 2005; Domeño et al. 2009). Therefore it can be used as an alternative to other currently substrates like rockwool or perlite, that have problems for recycling, peat that is a non renewable resource or coconut fibre which properties are variable depending on its source and it is need to import to our country. Moreover, this material is a residual of human activities and after its use as substrate could also be recycled as amendment in soils.

The wood fibre substrate presents one disadvantage that can be observed throughout hydroponic crop cycles. The appearance of wood fibre bags deteriorates with time. This is due to a compression of material and a reduction of volume. This is a disadvantage from the standpoint of commercial. Nowadays, new variants of this wood fibre substrate are being developed to improve these disadvantages. These new variants are manufactured by a granulation process and by an adhesive addition.

When a new material is evaluated as substrate, it is necessary to know its properties and to observe its agronomical behaviour. The objective of this work is to determine the evolution of the properties of the new variants of wood fibre substrate during two crop cycle and the response of tomato greenhouse culture. They are also compared with perlite and coconut fibre.

Materials and Methods

In this work an experiment in tomato greenhouse culture was carried out throughout two cycles with different substrates. The experiment was carried out in heated greenhouse placed in Barasoain (Navarra) throughout two consecutive production cycles of tomato, (*Lycopersicon esculentum* Mill), cv. 'Jack'. The first cycle was a summer-autumn cycle from June 2007 to November 2007, and the second was a winter-spring cycle from March 2008 to July 2008. Planting density was 2.14 plants m^{-2} and cultural practices were the same used for entire greenhouse. The nutrient solution applied by fertirrigation is shown in Table 1, pruning was made at a single stem and the pollination was carried out by bumblebee (*Bombus terrestris*).

Treatments

Seven substrates were compared. Five wood fibre substrates, coconut fibre substrate and perlite. The wood fibre substrates were:

- Original wood fibre substrate, FIBRALUR® (Original WF): It is made up by sawmill residues and manufactured by a thermo-mechanical process with hot water.
- Granules 1 (G1): substrate made up by wood fibre granulated
- Granules 2 (G2): substrate made up by adhesive added to wood fibre and then granulated.

Table 1. Nutrient solution used in the tomato greenhouse culture throughout two crop cycles

	Vegetative phase	Fruit development phase
NO_3^- (mmol L^{-1})	14.0	15.0
$H_2PO_4^-$ (mmol L^{-1})	2.5	2.5
SO_4^{2-} (mmol L^{-1})	2.5	3.0
Cl^- (mmol L^{-1})	1.0	1.0
NH_4^+ (mmol L^{-1})	0.5	0.5
K^+ (mmol L^{-1})	6.0	7.0
Ca^{2+} (mmol L^{-1})	5.0	5.5
Mg^{2+} (mmol L^{-1})	2.5	2.5
Na^+ (mmol L^{-1})	0.0	0.0
pH	5.8	5.8
EC (dS m^{-2})	2.5	2.8

- Granules 3 (G3): substrate made up by FDS granulated. FDS is a wood fibre substrate similar to FIBRALUR but manufactured without hot water.
- Granules 4 (G4): substrate made up by adhesive added to FDS and then granulated.

To carry out the granulation process was need to add water to the wood fibre material. At this time the adhesive was or not added to the material. Then, the mixture was spilled in a trommel. The granulated material collected was dried and was put in the bags.

Substrate properties and evolution

The Physical-chemical properties of substrates were determined at the beginning and at the end of each culture cycle.

Bulk density (BD), particle density (PD) and total pore space (TPS) were determined according to De Boodt et al. (1974). The air water relationships were determined according to ISHS methodology (Burés 1997) obtaining the retained air and water volumes with suction pressures of pF 1, 1.7 and 2. Values of air volume (AV), as the amount of air at pF 1, easily available water (EAW), as the amount of free water when the tension increased from pF1 to 1.7, water buffer capacity (WBC), as the amount of free water when the tension increased from pF 1.7 to 2, and less readily available water (LRAW), as the amount of water retained at pF2, were calculated.

The pH, electrical conductivity (EC) and available mineral elements concentration were determined following the "saturation extract" method. pH was measured in saturate extract and EC and available nutrient content were determined in the filtered solution. Total nitrogen was determined by Kjeldahl (Aenor 2002) and Cation exchange capacity (CEC) was measured according to Lax et al. (1986). Nitrogen draw down index (NDI_{75}) was determined using the method of Handreck (1992).

Crop response

Treatments were replicated four times and each plot consisted in 10 tomato plants placed in two substrate bags.

Ripe fruits were harvested twice a week. Fruit were classified into size grades according to European norm 790/2000 and into marketable and unmarketable yield. Each size class was weighted and the number of fruits was determined.

In order to evaluate the possible influence of the substrate on the quality of the fruit, two samples of tomato of each plot were taken and juiced in the middle of the harvest. pH, acidity and soluble solid content (°Brix) were measured in the juice. °Brix was determined by refractometry at 20 °C and acidity by titration with NaOH 0.1 N up to pH 8.2.

Results

Substrates properties and evolution

Initial physical properties are showed in Table 2. BD and PD values were within the optimal range given by Abad et al. (2001). All wood fibre substrates, granulated or not, showed the same PD value because this property is typical of the material and is not affected by compression or particle size (Ansorena 1994). Wood fibre and perlite AV values were also above the optimum (Abad et al. 2001). Wood fibre substrates showed significantly higher AV values than coconut fibre and similar to perlite. But AV was also variable among wood fibre substrates from 49.2 to 63.5 %.

Original WF and G1 showed similar values of EAW, WBC and LRAW and G2 and G4 showed lower values of EAW than G1 and G3. These differences were significant between G3 and G4 and no significant between G1 and G2.

The physical properties evolution throughout crop cycles is showed in Table 2. TPS values did not change significantly throughout crop cycles but AV values changed. It can be emphasized the significant AV reduction in all wood fibre substrates, except G3, and perlite and the significant AV increase in coconut fibre. In consequence an increase of EAW values in wood fibre substrates and perlite and a reduction in coconut fibre were observed. These differences in EAW throughout crop cycles were only significant for coconut fibre and perlite.

The chemical properties are showed in Table 3. The higher EC of coconut fibre, 6.5 dS m^{-1}, and CEC, 0.73 meq g^{-1}, compared with wood fibre substrates were important. The C/N ratio was higher in wood fibre substrates than in coconut fibre and it can be observed that among wood fibre substrates, C/N ratio was lower in substrates with adhesive. Table 3 shows that all NDI_{75} values were lower than 1 and indicates that microorganism are consuming soluble nitrogen in the medium nutritional solution (Arenas et al. 2002). Only for G1 and G3 there were significantly differences in NDI_{75} respect to all other substrates. It was due to their lower nitrogen content and higher C/N ratio. The content of fibrous components of substrates are showed in Table 4. The content of lignin was significantly higher for coconut fibre and significant differences were observed between wood fibre substrates for this component.

Table 5 shows the nutrient concentration in saturated media extract of substrates. The significantly high levels of Cl^-, Na^+ and K^+ in coconut fibre were important according to the high levels obtained by Abad et al. (2002). In

Table 2. Physical properties at the beginning and at the end of each crop cycle (CC) of new variants of wood fibre substrate (G1, G2, G3, and G4), Original wood fibre (WF) substrate, Coconut fibre and Perlite.

		G1	G2	G3	G4	Original WF	Coconut fibre	Perlite	Ideal substrate**
BD ($g\ cm^{-3}$)	Initial	0.09b A*	0.09bc A	0.08cd AB	0.08de A	0.07e A	0.08cd A	0.12a B	< 0.4
	After 1 CC	0.08b A	0.09b A	0.07b B	0.07b A	0.08b A	0.06c B	0.14a A	
	After 2 CC	0.09b A	0.08bc A	0.08bc A	0.08c A	0.08bc A	0.06d B	0.14a A	
PD ($g\ cm^{-3}$)	Initial	1.56c A	1.56c A	1.56c B	1.56c C	1.56c C	1.65b A	2.63a A	1.4 – 2.6
	After 1 CC	1.59c A	1.58c A	1.60c AB	1.59c B	1.60c B	1.66b A	2.60a B	
	After 2 CC	1.63b A	1.63b B	1.60c A	1.63b A	1.61b A	1.65b A	2.59a C	
TPS (vol %)	Initial	94.30a A	94.50a A	94.90a A	95.10a A	95.10a A	95.20a A	95.30a A	> 85
	After 1 CC	94.90b A	94.55b A	95.40b A	95.30b A	95.30b A	96.60a A	94.70b A	
	After 2 CC	94.45c A	95.05ab A	94.95ab A	95.25b A	95.25b A	96.55a A	94.65ab A	
AV (vol %)	Initial	54.70ab A	58.20ab A	49.20b A	63.50a A	58.00ab A	23.80c B	52.40b A	20 – 30
	After 1 CC	42.10a B	43.75a B	44.90a A	45.15a B	40.05a B	36.90ab A	33.35b C	
	After 2 CC	38.45a B	36.30a C	37.65a A	39.45a B	41.60a B	43.65a A	40.70a B	
EAW (vol %)	Initial	13.30bc A	9.20c A	21.30b A	11.50c A	13.80bc A	30.10a A	13.20bc B	20 – 30
	After 1 CC	15.80bc A	14.05c A	18.15b A	18.95b A	22.80a A	24.05a AB	17.95b A	
	After 2 CC	16.50ab A	18.00ab A	20.95a A	19.10ab A	17.55ab A	17.00ab B	10.30b C	
WBC (vol %)	Initial	0.50d A	1.80c A	1.50c B	0.50d B	0.50d A	5.90a A	4.30b A	4 – 10
	After 1 CC	2.65a A	3.00a A	4.20a A	2.80 A	2.55a A	1.95a A	3.70a A	
	After 2 CC	1.10b A	4.95a A	0.5b C	2.50ab A	3.25ab A	0.95b A	2.15ab A	
LRAW (vol %)	Initial	20.60b B	19.80b B	17.80b B	14.40b C	18.30b A	30.60a A	20.80b B	
	After 1 CC	27.65bc AB	28.25bc A	23.50c B	23.75c B	25.10c A	30.10b A	34.40a A	
	After 2 CC	33.15a A	30.95a A	30.70a A	29.50a A	27.75a A	31.30a A	36.05a A	
TAW (vol %)	Initial	13.30c A	11.00c B	22.85b A	12.00c B	14.30bc B	36.00a A	17.50bc B	20 – 40
	After 1 CC	18.45ab A	17.05b AB	22.35ab A	21.75ab A	25.35ab A	26.00a B	21.65ab A	
	After 2 CC	17.60ab A	22.95a A	21.45a A	21.60a A	20.80a A	17.95ab B	12.45b C	

BD: Bulk density; PD: particle density; TPS: total pore space; AV: Air volume; EAW: easy available water; WBC: water buffer capacity; LRAW: less readily available water; TAW: total available water.
G1 (wood fibre granulated); G2 (wood fibre granulated + adhesive); G3 (wood fibre manufactured in dry granulated); G4 (wood fibre manufactured in dry granulated + adhesive)
*Mean values in properties columns followed by the same lowercase letter do not differ significantly ($P \leq 0.05$) and mean values in each substrate group columns followed by the same capital letter do not differ significantly ($P < 0.05$).
**According to De Boodt and Verdonck (1972); Abad et al. (2001, 2004)

wood fibre substrates it can be observed that substrates with adhesive had a higher Cl^- concentration because of the Cl^- content of adhesive.

Crop response

Yield values of two crop cycles are showed in Table 6. Autumn marketable yield was significantly higher in coconut fibre. The wood fibre substrates showed similar yield values and higher than perlite. In spring cycle no significant differences were shown for marketable production. No significant differences were obtained for unmarketable production in neither of the two cycles. The spring yield was clearly higher than autumn yield.

No significant differences were obtained for fruit acidity and pH in neither of the two crop cycles like is showed in Table 6. Differences were showed for °Brix in spring cycle. Values of fruit acidity and °Brix were higher in autumn cycle.

Discussion

Substrates properties and evolution

Initial BD and PD values of wood fibre substrates and coconut fibre were significantly lower than BD and PD values of perlite and this is an advantage because their transportation and management in the placement will be easier. All TPS values were higher than 94 %, all were aerating substrates. The significantly differences observed among wood fibre substrates and coconut fibre for AV, were due to its granulometry because coconut fibre had finer particles than wood fibre substrates. Original WF and G1 showed similar values of EAW, WBC and LRAW, therefore the granulation process would not affect the properties of substrates. These values were similar to the values obtained by Gruda and Schnitzler (2004) for Toresa special weakly compressed. However G2 and G4 showed lower values of EAW than G1 and G3 respective-

Table 3. Initial chemical properties of new variants of wood fibre substrate (G1, G2, G3, and G4), Original wood fibre (WF) substrate, Coconut fibre and Perlite.

	pH	EC ($d Sm^{-1}$)	CEC ($meq g^{-1}$)	TC (% dry wt)	TN (% dry wt)	C/N ratio	NDI_{75}
G1	6.3 a*	0.6 a	0.28	569.6	1.0	565	0.6 b
G2	6.3 a	1.1 a	0.24	574.2	2.5	229	0.7 a
G3	5.8 a	0.7 a	0.26	574.2	0.8	749	0.6 b
G4	5.3 a	0.9 a	0.25	575.4	2.6	222	0.7 a
Original WF	6.0 a	0.3 a	0.22	575.4	1.3	456	0.7 a
Coconut fibre	5.8 a	6.5 b	0.73	492.5	4.5	109	0.8 a
Perlite	6.8 a	0.2 a					

EC: Electrical conductivity; CEC: Cation exchange capacity; TC: Total carbon; TN: Total nitrogen; C/N: carbon nitrogen ratio; NDI_{75}: Nitrogen draw down index
G1 (wood fibre granulated); G2 (wood fibre granulated + adhesive); G3 (wood fibre manufactured in dry granulated); G4 (wood fibre manufactured in dry granulated + adhesive)
*Mean values in columns followed by the same letter do not differ significantly ($P < 0.05$) between substrates.

Table 4. Content of fibre constituents in new variants of wood fibre substrate (G1, G2, G3, and G4), Original wood fibre (WF) substrate and Coconut fibre.

	Cellulose ($g kg^{-1}$ dry wt)	Hemicelluoses ($g kg^{-1}$ dry wt)	Lignin ($g kg^{-1}$ dry wt)
G1	154.6 a*	489.7 a	288.2 bc
G2	153.7 a	482.4 a	311.3 b
G3	162.6 a	477.9 a	266.9 c
G4	176.2 a	480.3 a	281.6 bc
Original WF	179.4 a	488.7 a	300.3 bc
Coconut fibre	78.2 b	348.9 b	434.9 a

G1 (wood fibre granulated); G2 (wood fibre granulated + adhesive); G3 (wood fibre manufactured in dry granulated); G4 (wood fibre manufactured in dry granulated + adhesive)
*Mean values in columns followed by the same letter do not differ significantly ($P < 0.05$) between substrates.

ly, therefore, the addition of adhesive decreases the useful water retention capacity.

The lower C/N ratio observed in substrates with adhesive can be due to the presence of N in the adhesive formulation. Possible process of nitrogen immobilisation could occur because of the high levels of C/N ratio (Abad et al. 2002) and NDI_{75} values validated this. But in spite of nitrogen immobilization was pointed for all substrates, nitrogen deficiency was not observed in trial with plants.

These levels of C/N also pointed a high stability of materials. According to Abad et al. (2002) pointed for coconut fibre and can be observed in Table 4, part of the carbon of used substrates was in form of cellulose and lignin, resistant to microbial degradation. Values of fibrous components of wood fibre substrates were similar to values obtained by Ghoos (1993).

Changes in AV and EAW values in wood fibre substrates throughout crop cycles can be due to the appearance of fine particles and to the compression of material (Gruda and Schnitzler 2004; Jackson and Wright 2009). Although the TPS values remain stable, the pore size decreases and so, the AV values decrease and EAW increase. The stability of TPS and the decrease of air AV throughout time was observed by Jackson and Wright (2009) in wood fibre substrates used for 70 weeks. Moreover similar evolution of AV and EAW were also observed by Lemaire et al. (1989) and Barraud (1990) for others wood fibre substrates. The behaviour of coconut fibre properties was the opposite of the previous one. It can be due to its initial properties. Coconut fibre showed lower initial AV value because showed finer size distribution. These small particles could be easier degraded and disappear or could form aggregates that make increase the pore size and the AV values, moreover these finer particles could be swept by irrigation.

The evolution of coconut fibre properties were different to evolution observed in Domeño et al. (2009). In this other work the AV values decrease throughout six months with tomato culture and consequently the values of water retention increased. These differences can be due to the great variability of coconut properties depending on their source. However, the behaviour of coir was similar to the observed by Lemaire et al. (1989) for this material. In that work Lemaire et al. (1989) observed an increase of AV and

Table 5. Initial nutrient concentration in saturated media extract of new variants of wood fibre substrate (G1, G2, G3, and G4), Original wood fibre (WF) substrate, Coconut fibre and Perlite.

	Nutrient concentration (mg l^{-1} in the saturated media extract)							
	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Cl^{-}	NO_3^{-}	P	SO_4^{2-}
G1	38.6 ab*	7.5 ab	34.6 b	55.7 b	7.6 b	6.8 a	2.3 b	138.3 a
G2	93.6 a	17.2 ab	36.7 b	68.0 b	87.7 b	5.0 a	1.0 b	174.0 a
G3	55.9 ab	11.9 ab	33.1 b	60.2 b	6.1 b	5.1 a	2.7 b	183.9 a
G4	80.7 a	15.5 ab	27.5 b	49.2 b	73.5 b	4.8 a	2.1 b	146.7 a
Original WF	11.3 b	1.5 b	22.8 b	34.9 b	4.6 b	4.4 a	0.6 b	14.6 b
Coconut fibre	69.2 ab	26.7 a	335.0 a	1318.2 a	857.3 a	4.1 a	26.9 a	115.6 a
Perlite	10.1 b	0.9 b	30.8 b	5.9 b	3.8 b	6.7 a	1.0 b	8.6 b

G1 (wood fibre granulated); G2 (wood fibre granulated + adhesive); G3 (wood fibre manufactured in dry granulated); G4 (wood fibre manufactured in dry granulated + adhesive)
*Mean values in columns followed by the same letter do not differ significantly ($P < 0.05$) between substrates.

Table 6. Yield (kg m^{-2} and fruit m^{-2}) and quality (Acidity, pH and °Brix) parameters measured in the two crop cycles of tomato with new variants of wood fibre substrate (G1, G2, G3, and G4), Original wood fibre (WF) substrate, Coconut fibre and Perlite.

	Yield (kg m^{-2})		Fruit (no m^{-2})		Quality		
	Marketable	Unmarketable	Marketable	Unmarketable	Acidity (g L^{-1})	pH	°Brix
Autumn cycle							
G1	11.53 ab*	0.91 a	50 a	8 a	5.20 a	4.17 a	5.07 a
G2	10.50 b	0.77 a	48 a	7 a	4.06 a	4.05 a	4.72 a
G3	10.92 b	0.86 a	50 a	8 a	4.89 a	3.96 a	5.07 a
G4	9.98 b	1.04 a	45 ab	9 a	4.34 a	4.17 a	5.30 a
Original WF	10.44 b	0.89 a	47 a	7 a	4.82 a	4.27 a	4.72 a
Coconut fibre	12.89 a	0.70 a	53 a	7 a	4.82 a	4.30 a	4.77 a
Perlite	7.95 c	1.43 a	40 b	13 a	5.26 a	4.12 a	4.55 a
Spring cycle							
G1	15.28 a	0.23 a	57 a	2 a	3.49 a	4.16 a	3.90 c
G2	14.04 a	0.28 a	54 a	3 a	2.81 a	4.30 a	4.13 bc
G3	14.29 a	0.20 a	56 a	1 a	3.26 a	4.30 a	4.40 ac
G4	14.52 a	0.16 a	56 a	1 a	3.75 a	4.33 a	4.95 a
Original WF	13.10 a	0.21 a	50 a	1 a	3.60 a	4.30 a	4.75 ab
Coconut fibre	13.67 a	0.19 a	53 a	1 a	3.52 a	4.28 a	4.70 ab
Perlite	15.03 a	0.23 a	56 a	2 a	3.64 a	4.29 a	4.10 bc

G1 (wood fibre granulated); G2 (wood fibre granulated + adhesive); G3 (wood fibre manufactured in dry granulated); G4 (wood fibre manufactured in dry granulated + adhesive)
*Mean values in columns followed by the same letter do not differ significantly ($P < 0.05$) between substrates.

a decrease of water availability after six months in spite of its biostability index was very high.

Crop response

Obtained yield values were similar to obtained by ITGA (Instituto Técnico Agrícola de Navarra) for this tomato cultivar in perlite culture (Sanz de Galdeano et al. 2003). The differences among crop cycles could be due to favourable climatic conditions of spring cycle and to the improved properties of substrates. Moreover the lack of significant differences in spring cycle could be due to the properties evolution that tends to be similar in relation to AV and EAW. All the quality parameters measured were within the optimal range given by Aguayo and Artés (2004) for optimum aroma and flavour tomatoes.

In spite of all wood fibre substrates had very similar properties and their yields were not significantly different, the granulated substrates showed slightly higher yield values than original WF. Likewise, the adhesive addition made decrease the yield compared with their homologue without adhesive, except for G4 at spring cycle.

In conclusion, the new variants of wood fibre substrates were suitable for hydroponic tomato greenhouse culture showing yield values similar to control substrates and increase slightly the yield values of original wood fibre substrates. Their initial properties are suitable for soilless culture. These properties change throughout crop cycles but these changes had not detrimental effects in crop, if even seems to be beneficially because the properties become more adequate. Moreover, the visual appearance of bags of new variants granulated throughout crop cycles was better than the appearance of original wood fibre bags.

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