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# Evaluation of almond shell as a culture substrate for ornamental plants. I. Characterisation

**(with 4 figures & 6 tables)**

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**Abstract.** Some technical and economic problems currently limit the use of substrates. The main problems include the lack of reciprocal adaptation of the cultivation technics and the substrate, the possible presence of pathogens, and the cost involved. To these we must add the ecological problems of the extraction areas, since there are no short-term renewable resources, especially in the case of peat, the classic substrate. This has motivated the search for substitutes, especially amongst indigenous materials and those easily obtained locally, such as cereals straw, rice husk and cork residues. The use of these substrates should be evaluated agronomically for: physical (total porosity, available water, air content, distribution of particles size, apparent density), chemical (cation exchange capacity, assimilable elements, salinity, pH, C/N ratio) and cultural properties. The characterisation and use of almond shell (*Prunus dulcis*) as a horticultural substrate substitute for growing ornamental plants were studied. The study involved the characterisation of the physical and chemical properties of 4 almond shell and peat mixtures (20:80,40:60, 60:40 and 80:20 in almond shell and peat volume respectively), as well as those of a control mixture consisting of peat and expanded clay (33.3: 66.6 in volume of expanded clay and peat respectively). The almond shell in the substrate increased aeration, low retention of water, low cation exchange capacity. It presents high content of K, Na and Cl, and hence E.C. and a high C/N ratio.

**Key words:** Substrate characterisation, available water, peat, expanded clay

Soilless culture can be divided into hydroponic culture and substrate culture (1). The term substrate is applied in horticulture to all solid material different from natural soil *in situ*, composed of synthesis or residual, mineral or organic substances that is placed in a container, in

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pure form or in a mixture, and which allows the anchorage of the root system, and is able to intervene (chemically active material) or not (inert) in the complex process of the mineral nutrition of the plant (2, 3 and 4).

Some technical and economic problems currently limit the use of substrates (5 and 6). The main problems include the lack of reciprocal adaptation of the cultivation technics and the substrate, the possible presence of pathogens, and the cost involved. To these we must add the ecological problems of the extraction areas, since there are no short-term renewable resources, especially in the case of peat, the classic substrate. This has motivated the search for substitutes, especially amongst indigenous materials and those easily obtained locally, such as the straw of cereals, rice husk and cork residual (2).

The almond tree, originally from Asia Minor has existed in the Mediterranean basin since before the birth of Christ. At the present time, Spain is the second largest producer (20.33% in the world production) after the USA (32.39%) (7).

The current uses of almond shell are for furfural production, fertilisers made from the residue of previous production, coal and fuels, xylose and xylitol, some bioproducts and mulching in gardens and growth substrates.

## MATERIALS & METHODS

Five mixtures of substrate were prepared, four of them composed of almond shell and peat, in different volumetric ratios, and one formed by expanded clay and peat:

T1: 20% shell + 80% peat; T2: 40% shell + 60% peat; T3: 60% shell + 40% peat; T4: 80% shell + 20% peat; Control: 33,3% expanded clay + 66,6% peat.

Cracked almond shells varying in size from 0.5 to 2 cm were obtained from one of the local companies, and the kernel was cleaned out. The peat used in all the mixtures was of Danish origin and its characteristics guaranteed by the manufacturing firm were: screening: sifter of 20 mm, pH 6.0 (in water), elements added by $m^3$: nitrate-N, 63 g; ammonium-N, 11 g; $P_20_5$, 121 g; $K_2O$, 142 g; MgO, 35 g; CaO, 300 g; and micronutrients, 200 g; FTE 3600 (slow resease).

The expanded clay used had sizes between 3 and 5 mm.

**Physical characterisation of the samples:** Ten litres of substrates were taken and divided in the laboratory by means of the spoon method (6). The moisture, ash, organic matter, particle size, total porosity and apparent density were determined according to sustrates (8), the real density, and water retention were determined according to De Boodt *et al* (9).

**Chemical characteristics of the samples:** The saturated extract was prepared according to the method described by Warncke (10). Sample pH, E.C. and assimilable elements were analysed following standard analytic techniques (11). The cation exchange capacity and C/N ratio were determined following the procedures of Brower *et al.* (12) and the official methods (13).

Data were analysed having the analysis variance and means were separated using the least significant difference (LSD) at $p<0.05$.

## RESULTS & DISCUSSION

**Physical characterisation of the samples**: Table 1 shows the results for humidity, dry weight, organic matter and ash contents of the 4 treatments and the control. The different mixtures had similar values which differed greatly from the control with a mineral component.

In table 2 the data for the granulometric analysis are presented. There is a lineal correlation between the almond shell percentage that is greater than >10mm and equal to 5-10mm respectively with negative and positive slopes. The fraction of 5-1mm is not modified substantially and the one corresponding to the size of particles <1mm presents a polynomial correlation with a very strong slope of up to 60 % of almond shell that is modified practically not when the level of almond shell in the mixture is increased. The control was higher in the 5-1mm fraction than in the other fractions. This implies that this fraction is due fundamentally to the constituent materials of peat (figure 1).

The data for apparent density, real density and total porosity are shown in table 3. The real density for control was superior to that of the other treatments, due to the contribution of the mineral component. Among the treatments the real density diminishes slightly when the shell fraction was increased, which means that the real density of peat was slightly superior to that of almond shell. For apparent density the values increased as the shell fraction increased in the mixture. The control values was next to the trial mixtures.

We found two correlations: the first one between the shell fraction in the mixture and total porosity ($R^2$= 0.98) and the second between the apparent density and total porosity of the four treatments without the control ($R^2$= 1). These relationship allows the design of a commercial substrate with the total porosity required starting from its components as a function of the objectives that should be obtained (figure 2).

The ratios air-water of the mixtures is presented in table 4. The existent correlations between the fraction of almond shell percentage and the different volumetrics fraction have been studied. Lineal relationships were found with the values of the determination coefficient of 0.93,0.84,0.91 and 0.98 for air content (0-10 cwt), easily available water

Table 1.– Humidity, dry, organic matter and ashy of the mixtures and the control.

| substrate | Humidity (%) | Dry weight (%) | Organic matter (%) | Ashy ( %) |
|---|---|---|---|---|
| $T_1$ | 25.0 b* | 75.0 c | 94.5 a | 5.4 b |
| $T_2$ | 17.0 c | 83.0 b | 94.6 a | 5.3 b |
| $T_3$ | 12.9 d | 87.0 a | 94.7 a | 5.3 b |
| $T_4$ | 13.3 d | 87.6 a | 95.0 a | 5.0 b |
| Control | 29.5 a | 70.4 d | 15.0 b | 85.0 a |

* Mean separation in columns by LSD ($p< 0.05$)

Table 2. Granulometric analysis of the mixtures and the control.

| Substrate | >10mm | 10-5mm | 5-1mm | <1mm |
|---|---|---|---|---|
| $T_1$ | 10.0 a* | 51.8 c | 20.4 b | 17.8 a |
| $T_2$ | 6.7 b | 69.5 b | 16.9 c | 6.9 c |
| $T_3$ | 4.9 c | 74.7 b | 18.1 c | 2.3 d |
| $T_4$ | 2.0 d | 87.6 a | 8.7 d | 1.7 d |
| Control | 6.3 b | 37 d | 45.5 a | 11.2 b |

* Mean separation in columns by LSD ($p< 0.05$)

Table 3. Apparent and real density of the mixtures and the control.

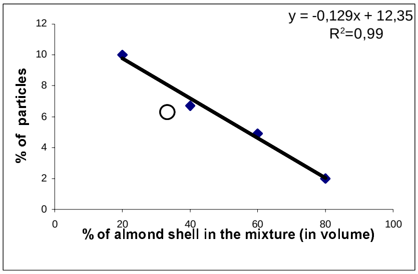
| Substrate | Apparent density ($g\ cm^{-3}$) | Real density ($g\ cm^{-3}$) | % total porosity |
|---|---|---|---|
| $T_1$ | 0.13 c* | 1.49 b | 91.5 a |
| $T_2$ | 0.21b | 1.48 b | 85.2 b |
| $T_3$ | 0.23 b | 1.47 b | 74.9 c |
| $T_4$ | 0.37 a | 1.46 b | 69.7 d |
| Control | 0.44 a | 1.78 a | 93.1 a |

* Mean separation in columns by LSD ($p< 0.05$)

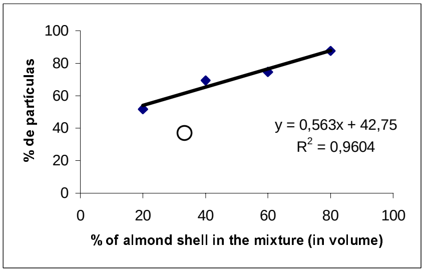
Table 4. Relationship air-water of the mixtures and the control explained of the volumetric fractions: air content (A.C.), total water. easily available water (E.A.W.), reservation water (R.W), difficultly available water (D.A.W.) and dry matter (D.M).

| Substrate | A .C. (%) | Total water (%) | E.A.W (%) | R.W % | D.A.W (%) | D.M.(%) |
|---|---|---|---|---|---|---|
| $T_1$ | 51.5 c* | 40.0 a | 8.6 a | 4.5 a | 27.0 a | 8.5 c |
| $T_2$ | 54.3 c | 30.9 b | 4.5 c | 1.2 c | 25.1 a | 14.8 b |
| $T_3$ | 61.8 b | 13.1 d | 3.9 c | 0.5 d | 8.7 c | 25.1 a |
| $T_4$ | 63.2 b | 6.7 e | 2.8 d | 0.4 d | 3.5 c | 30.1 a |
| Control | 71.8 a | 21.3 c | 5.6 b | 2.0 b | 13.7 b | 6.9 c |

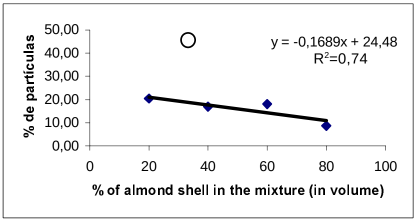
* Mean separation in columns by LSD ($p< 0.05$)



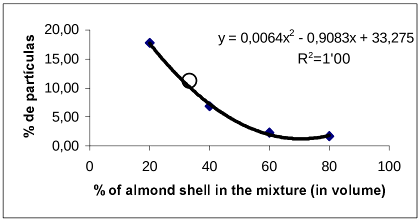

Particles >10mm




particles 10-5 mm




particles 5-1 mm




particles < 1 mm

Fig. 1.– Evolution of the percentage of particles for size in the different substrate mixtures (◆), and the control (O).

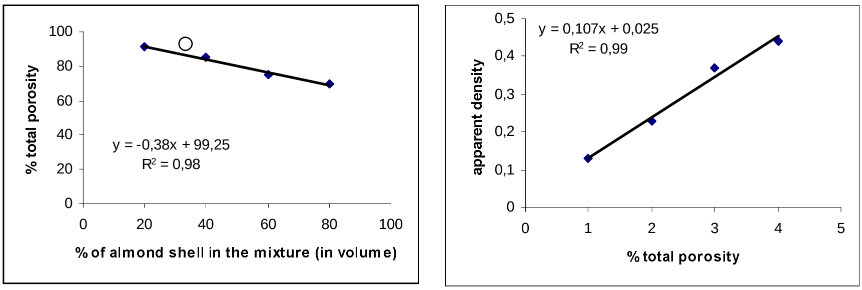



Fig. 2.– Evolutión of the total porosity in the different substrate mixtures (◆), and the control (O) (left). Relationship between apparent density and % total porosity.

(10-50 cwt), difficulty available water (>100cwt) and dry matter and a polynomial degree 2 relationship with a value of $R^2$= 0.98 for the water reserve (50-100 cwt). As shown in table 4, the control had a higher air content than all the other treatments and a smaller percentage of total water than would be appropriate according to its fraction in the mixture with the peat. The changes in the ratio air-water by tension, is presented in figure 3.

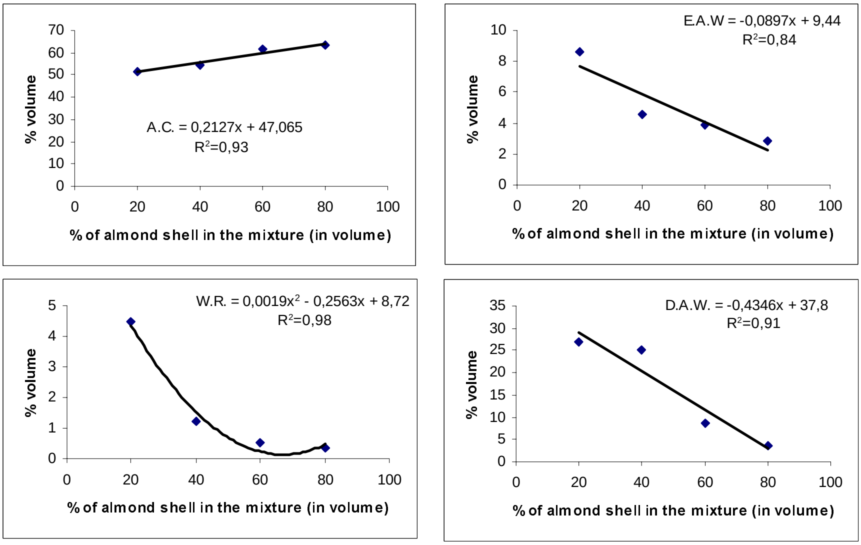



Fig. 3.– Evolution of the air content (A.C.), easy available water (E.A.W.), water reserve (W.R.) and difficulty available water (D.A.W.) in the different substrate mixtures.

The treatments and the control show a high air content with regard to an ideal substrate (20-30%) (10, 14), the percentage of easily available water was low (25% of total porosity) (9), but adequate with regard the total water available (of the 75 to 90%) (15). The percentage of dry matter should be of 15% (15) a value corresponding to the $T_2$ treatment, the control being the lowest.

The ideal values of the air-water relationships seek to provide the plant with the oxygen necessary for radical metabolic activity, as well as water at low-tension levels, however it is necessary to understand:

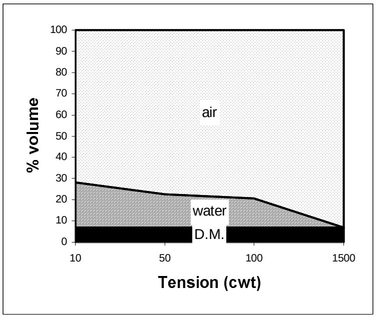
If defects exist in the water management, that is to say, there is no overlapping between the water requirements of the plant and the water application. This should be compensated by the substrate's water retention.

When the plant absorbs water, the air content is increased.

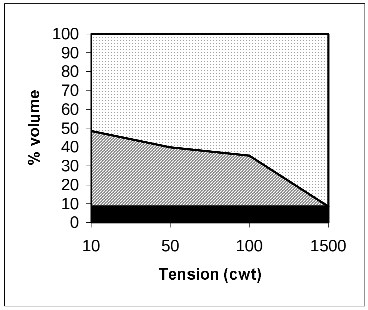
The rhythm of water absorption is a function of the environmental conditions.

With high radiation and Deficit Pressure Vapour a higher water consumption takes place per unit of time, that is to say, there is a bigger flow of transpiration than can be related to the increment of the air content in the substrate and should dominate the capacity of a substrate to store water, thus avoiding water stress situations.

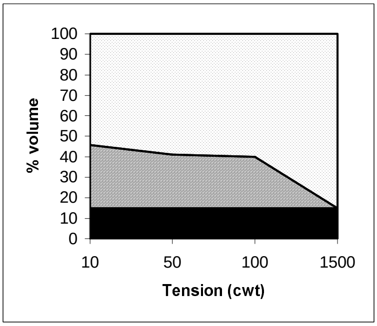
In situations of low radiation and Deficit Pressure Vapour, the water consumption per unit of time is smaller. This means that the air in



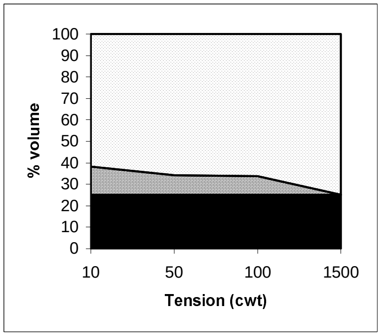
Control



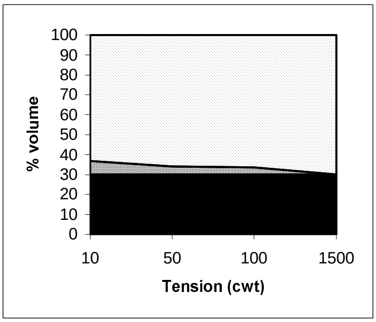
$T_1$



$T_2$



$T_3$



$T_4$

Fig. 4.– Gravimetric ratio air-water (%) at different tension levels for the control and the treatments.

the substrate sticks to the pores of air (0-10 cwt) and when this is low, anoxia conditions frequently occur (14 and 16).

Therefore in the production of ornamental plants, it is important to have 2 materials, in order to carry out a basic study of the substrates properties, generated with different mixture percentages and to choose the most appropriate mixture for this production system given the function of the species and the climatic conditions during the cultivation period.

In plants of long cycle and in passive systems culture, the environmental conditions vary and the decision making process is more complex, however the critical period of cultivation be considered as the base for the design of the substrate.

By way of example in trials carried out with *Solanum rantonetti* 057, daily consumption has been estimated in April at 300 $cm^3$ $plant^{-1}$ $day^{-1}$ and in November at 50 $cm^3$ $plant^{-1}$ $day^{-1}$ (data of authors unpublished). In this case, it was decided to use a substrate with high air content and with characteristics similar to the control that is presented in this work which enable us to have a significant increment in the watering frequency during the period of high consumption and thus anoxia situations were avoided during the winter.

**Chemical characterisation of the samples:** In table 5 the pH, Electric Conductivity, Cation Exchange Capacity and C/N ratio data are presented. We observe a neutral pH spreading to basic without significant differences in the different samples.

The E.C. is increased as the ratio of almond shell in the mixture increased, reaching the next values to 3 dS $m^{-1}$. This can be restrictive for the cultivation of species with high sensitivity to salinity (17), such as ferns and orchids (14), therefore, its use will come conditioned by the salts that generate this factor and its correction possibilities.

The C.E.C. diminished whit increasing shell percentage in the substrate, reaching values of 17.4 meq100 $g^{-1}$. Nevertheless all the obtained values were in the region of the minimum values recommended (15) (20meq 100$g^{-1}$) for cultivation in substrate.

The C/N ratio was very high, since the values recommended for organic substrates are between 20-40 (15). We must establish specific recommendations regarding fertilisation both in basal fertilisation and in fertirrigation when this substrate is used. Adding an extra nitrogen may limit the problems of "nitrogen hunger" that are generated when satisfying the hydrocarbonated demands of the substrate.

In table 6 the results for the assimilable elements of the saturated extract of the different mixtures and the control are shown. It is necessary to highlight in the control, the enrichment for expanded clay that is conferred to the solution of the substrate in calcium (4.18 mmol $L^{-1}$ in saturated extract). In the case of the treatments, there were increases in assimilable chlorides, sodium and potassium when the shell fraction increased, reaching values of 14.6, 5.2 and 6.0 mmol $L^{-1}$ of potassium, sodium and chlorides respectively.

Based on these data, the use of basal potassium fertiliser is not necessary in substrates containing almond shell seems appropriate. However, under fertirrigation a study would be necessary to determine the dynamics of potassium in the solution of the substrate, since it seems to come from very soluble salts as potassium chloride, carbonates and bicarbonates or organic salts that can be washed away very easily.

Table 5. Chemical Characterisation of the mixtures and the control.

| Substrate | pH | E.C.(dS $m^{-1}$) | C.E.C.(meq 100g) | C/N |
|---|---|---|---|---|
| $T_1$ | 7.9 a* | 0.6 c | 27.8 a | 55 cd |
| $T_2$ | 7.2 b | 0.7 c | 26.1 a | 70 c |
| $T_3$ | 7.5 b | 1.1 b | 22.6 b | 110 b |
| $T_4$ | 7.3 b | 2.9 a | 17.4 c | 165 a |
| Control | 7.5 b | 1.7 b | 27.0 a | 40 d |

* Mean separation in columns by LSD ($p < 0.05$)

Table 6. Assimilable elements in the saturated extract (mmol $L^{-1}$).

| Substrate | $NO_3^-$ | $NH_4^+$ | $H_2PO_4^-$ | $K^+$ | $Ca^{2+}$ | $Mg^{2+}$ | $SO_4^{2-}$ | $Na^+$ | $Cl^-$ |
|---|---|---|---|---|---|---|---|---|---|
| $T_1$ | 2.8 d* | 1.0 b | 0.05 c | 3.8 d | 0.5 c | 0.17 b | 0.3 b | 3.5 c | 1.7 c |
| $T_2$ | 3.6 c | 1.3 b | 0.08 b | 5.4 c | 0.4 c | 0.17 b | 0.3 b | 3.9 c | 2.0 c |
| $T_3$ | 3.5 c | 1.4 b | 0.09 b | 9.2 b | 0.6 c | 0.30 b | 0.6 b | 4.3 c | 2.5 b |
| $T_4$ | 3.9 b | 2.1 a | 0.14 a | 14.6 a | 1.3 b | 0.68 a | 0.6 b | 5.2 b | 6.0 a |
| Control | 4.2 a | 0.3 c | 0.02 d | 3.8 d | 4.2 a | 0.89 a | 3.9 a | 6.1 a | 2.9 b |

* Mean separation in columns by LSD ($p < 0.05$)

Nevertheless, the nature of these salts allows to carry out effective washings as a technique to reduce the electric conductivity during the cultivation of plants sensitive to salinity.

## CONCLUSIONS

The contribution of almond shell in the substrate was to its physical and chemical properties and, therefore, this can be the starting point for the design of the substrate´s composition. The most important characteristics of almond shell are: Increased aeration and low retention of water, making good irrigation management necessary; a low cation exchange capacity; a high content of potassium, sodium and chlorides, and hence E.C. that can be reduced by washing; a high C/N ratio which makes it necessary to increase the N fertilisation.

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