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Treated sediment as substrate component of three containerized ornamental species: effects on marketable and qualitative traits

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Abstract: Carried out within the LIFE17ENV/IT/000347-SUBSED project, this research aimed at investigating the effect of a treated sediment (TS) as substrate component on the quality and marketability of three widespread containerized ornamental species: cherry laurel (*Prunus laurocerasus*) cv. Novìta, calla lily (*Zantedeschia aethiopica*) and protea (*Protea cynaroides*) cv. Little Prince. The TS was mixed with soilless substrates as sphagnum peat, coir, and bark in different proportion (0%, 25% and 50%). In cherry laurel, the TS used in 25 - 50% proportions reduced plant height, slightly altering its attractive vibrant foliage. A positive effect of the TS was evidenced on calla lily, where both tested sediment-based mixtures allowed a copious blooming and flower quality raised as the sediment content increased (TS 50% > TS 25% > TS 0%). Post-harvest longevity and colour of flowers were not affected by substrate composition. The effect of sediment-based substrates on protea growth and blooming showed an opposite trend (TS 0% > TS 25% > TS 50%), with plants grown on 50% *v/v* TS exhibiting a considerable reduction in plant growth and production of flower clusters, with brighter tones turning towards purple. Based on sale values, the TS proved to be a sustainable alternative for the production of potted ornamentals if properly mixed with other organic matrixes, such as peat and coir.

1. Introduction

The ornamental plant industry in Tuscany is a strategic sector, representing approx. 5% of the entire national agricultural production, which derives for about 75% from potted plants and nurseries (trees and shrubs) and for the remainder from fresh cut flowers and foliages (Martorana, 2021). This segment produces a giant assortment of ornamental and flower species in about 6,500 hectares of land, concentrated in the provinces of Pistoia and Lucca. With over 3,300 nursery enterprises, 2,060 of which are ornamental producers and 1,900 flower growers, this sector has a large impact on employment and induced economy, as well as a strong export vocation (Pagliantini, 2020). The power of this sector lies in the variety of the assortment offered for sale and therefore nursery industries are constantly looking for new species and cultivars. Another important factor for the expansion of this sector is the adaptation of new production technologies to the concept of sustainable development. Great deal of the ornamental and flowering plant production is carried out in containers and depends almost entirely on the quality of soilless media derived from both organic and inorganic constituents. Indeed, since successful container cultures depend on producing a stable finished plant, different components in the growing substrate can pose significant problems if they affect growth rate, nutrition or plant shape and aesthetics (Salachna, 2022).

Its unique physical properties and large availability have led peat to be the dominant organic constituent of growing media in many parts of the world in recent decades. Nevertheless, other organic materials have been recently attracting more attention as a partial substitute for sphagnum peat in a container growing medium (Fascella, 2015; Barrett *et al*., 2016). Among these is coir, regarded as a rapidly renewable resource, as it is a by-product of coconut harvest. Moreover, especially in Europe, innovative approaches have involved an increasing use of locally available organic materials such as bark (wood fibre) and transformation of composted wastes as next-generation constituents of growing media. Perlite or vermiculite components are often used to improve drainage and aeration (Gruda, 2019).

Recent studies have focused on the possibility of reusing sediments in agriculture by combining them with standard growing media or biochar amendment (Renella, 2021). This practice could be best successfully applied to ornamental species grown in containers, where health risk due to the presence of toxic residues are minimized. Thus, in this study we investigated the effect of a treated sediment as a substrate component on the quality and marketability of three widespread containerized ornamental species: cherry laurel, calla lily and protea.

Prunus laurocerasus 'Novìta', commonly known as cherry laurel, an evergreen ornamental with a very fast growing and plant development, is one of the most commercially important outdoor ornamental species for the Italian nursery. The cultivar 'Novìta', selected in Holland, has now become widely established and has replaced the previous cultivar 'Caucasica', compared to which it has longer, thicker, and shinier leaves, and above all, is more resistant to diseases and water stress (Ilnitsky *et al*., 2019). Nowadays, container-grown cherry laurels, as all outdoor nursery plants, can be sold at any time of year with two major peaks in spring and autumn. Its commercial value is a function of the size of the plant, first of all its height.

Calla lily (*Zantedeschia aethiopica*) is a very popular flower of great world economic importance, grown as cut flower, potted or garden plant. This species flowers from late summer into spring in frost free areas and prefers partially illuminated environments (De Hertogh, 1996). Calla cultivation is spread from central to southern Italy, where it is performed indoor under greenhouse conditions to protect the crop from October to the end of April (Janowska and Andrzejak, 2022). On the market, cut flowers are classified into grades based on the size of the stem and the flower (spathe). Furthermore, the sale price varies throughout the year, reaching the highest values in the winter period and the lowest values in the month of April, when the quantity of flowers offered on the market is highest.

The protea used in this experiment was *Protea cynaroides* dwarf 'Little Prince', a patented variety, bred for flowerpot production at the National Research Council of South Africa. This cultivar differs from the well-known protea King, national flower of South Africa, for its compact habit, which makes it suitable for expanding the potted plant floral market. Protea is an unusual plant for Europe, where it is considered a niche product much appreciated by fans of exotic plants. Commercial growing of proteas for the cut flower market is increasing also in other European regions with mild winter, especially Portugal and Canary Islands (Lewis and Matthews, 2002; Claassens, 2017). At the marketing stage, protea potted plants are graded and priced according to the number of flowers.

These species were used as model plants of the ornamental plant sector (evergreen shrubs, flowerpot, cut flower) to assess the commercial potential of sediment-based growing media combined with sphagnum peat, coir and wood fibre on the existing floriculture market.

2. Materials and Methods

This study used the marine sediment dredged from Leghorn port (central Italy, 43°33'25''N, 10°17'39''E) in 2008. To reduce the level of contaminants, the sediment was recovered through three years of phytoremediation process under the frame of the AGRIPORT project (Agricultural Reuse of Polluted Dredged Sediments, Eco-innovation EU Project n. ECO/08/239065ECO/08/239065) (Masciandaro *et al*., 2014; Doni e*t al*., 2015). The phytoremediated sediment underwent landfarming, consisting in a periodical aeration by mechanical handling for three months, before using it.

The treated sediment (TS) was then used as a partial substitute of standard substrates, commonly used for ornamental and flowering crop cultivation in Tuscany. In addition to sphagnum peat, other materials that are already being used for commercial productions as an alternative to peat, such as coconut coir and bark, were employed as organic materials, while pumice was added as inorganic matrix in all mixtures. Sphagnum peat, coir, bark and pumice were mixed separately with the TS to create several media containing 25 or 50% by volume of TS (Table 1). Mixes were used as growing media for soilless cultivation of three ornamental crops: *P. laurocerasus* 'Novìta' (outdoor ornamental shrub), *Z. aethiopica* (cut flower), *P. cynaroides* 'Little Prince' (flowering potted plant). Thanks to its unique microporous properties, the standard peat-based substrate (60% peat, 40% pumice *v/v*) was used as control in all cultivation trials.

The experiments were performed in private facilities of Central Italy (Tuscany). Plants were cultivated under greenhouse conditions for one year growing season over 2020-2021 (cherry laurel and calla) and 2021-2022 (Protea) (Fig. 1). Standard commercial nursery management practices were followed, except those plants received different water amounts depending upon the species, as better specified below in the experimental design of each considered species. The efficiency of soilless cultivation was evaluated both in terms of quantity and quality of marketable products and commercial value. The commercial expected value was obtained by multiplying each product category by the corresponding sale price of a given selling season and market demand. Data on prices for the studied species were given by two Tuscan's leading ornamental trading centres (Ornamental Nursery District, Pistoia, Italy; Flora Toscana, Pescia (PT), Italy) during 2021 for potted cherry laurel plants and cut calla flowers, and during 2022 for potted proteas.

Fig. 1 - Greenhouse soilless culture of *Prunus laurocerasus* (A), *Zantedeschia aethiopica* (B), and *Protea cynaroides* (C) in Tuscany (Central Italy).

*Cherry laurel (*Prunus laurocerasus*) 'Novìta'*

Cherry laurel is a very common shrub in Italian gardens, widely used as evergreen ornamental barrier plant (hedge). It is easily propagated by cutting and sold as potted plant at different stages of growth in different pot sizes. Totally 336 cherry laurel rooted cuttings were grown in 8.5-L drip-irrigated pots. The experimental design consisted of seven growing media (GM) and two water regimes (WR) as described in Table 1. Growing media were prepared by mixing defined volumes of previously homogenized TS and standard substrates based on peat, coconut coir, and bark, each one containing a certain amount of inert pumice. GM containing commercial peat-based substrate alone was considered as the control. Plants were watered by an automated drip irrigation system providing two irrigation rates: normal (WR1 = 250 mL/day of water per pot on average) and reduced by 20% (WR2= 200 mL/day of water per pot on average). Each GM*WR combination was replicated in three blocks, each containing four pots, each one consisting of two cuttings (8 cuttings × 14 treatments × 3 blocks = 336 cuttings). All plants were supplied with a slow-release fertilizer (Nitrophoska Gold®). Growth in height of all cherry laurel plants was measured at the end of the growing cycle and the corresponding sale price was considered as index of production quality. Leaf colour (i.e., the coordi-

Table 1 - Composition of the tested growing media

GM			Peat	Treated sediment	Coir		Bark (wood fiber)	Pumice
Cherry laurel	Calla	Protea			Fiber	Peat		
LMix 1	CMix 1	PMix 1	60					40
LMix 2	CMix 2	PMix 2	45	25				30
LMix 3	CMix 3	PMix 3	30	50				20
LMix 4				25	45			30
LMix 5				50	30			20
LMix 6				25			45	30
LMix 7				50			30	20
		PMix 4		25	34.2	22.8		18
		PMix 5		50	22.8	15.2		12
		PMix 6		25	17.1	39.9		18
		PMix 7		50	11.4	26.6		12

nates L* [brightness], a* [redness], and b* [yellowness]) was measured with a colorimeter (Chromameter, Minolta CR 200) on three different leaf points shortly after growth measurements. The chroma index (Chroma) was calculated using the coordinates a* and b* (Chroma = [(a*2 + b*2) 1/2]).

*Calla lily (*Zantedeschia aethiopica*)*

Calla lily is a species of great economic importance worldwide thanks to the beauty of its flowers. In Italy, calla is grown as outdoor garden and potted plant, but also largely raised for cut flower production under greenhouse conditions. Totally 378 calla rhizomes were planted in 30-L containers placed on three raised benches. Three different GM combining different proportions of the TS with a standard peat-based substrate were tested (Table 1). Benches were served by different water regimes (WR) by a drip irrigation system: i) WR1, high water regime=WR2+30% (1220 mL/day of water per pot on average); ii) WR2, normal water regime (930 mL/day of water per pot on average); iii) WR3, low water regime=WR2-30% (650 mL/day of water per pot on average). Each GM*WR combination was replicated in three blocks, each containing seven pots, each holding 2 rhizomes (14 rhizomes x 9 treatments x 3 blocks = 378 rhizomes). Plants were fed with a nutrient solution commonly adopted for the cultivation of soilless calla and the experiment was stopped at the end of the first flower flush. Flower number and flower length were monitored during plant life cycle (once a week from September to February, and twice a week from March to May) by collecting, counting and measuring all the flowers produced in the experimental test. Moreover, flowers were graded by stem length and sale price of each flower category was calculated during the whole harvest season. Marketable senescence (number of days to get pollen on spathe) and final senescence (number of days to spathe browning) were determined by storing 15 cut flowers (5 for each replicated block) in water at room temperature. On the same flowers, spathe colour was measured on three different floral leaf points as described above.

*Protea (*Protea cynaroides*) 'Little Prince'*

National Flower of South Africa, protea is commercially relevant for the flower industry and in Italy it is extensively cultivated as flowering pot and exported all over the world. Crop protection is a fundamental requirement for its cultivation in Tuscany; moreover, water needs are high when this species is grown under soilless conditions. Totally 210 rooted cuttings were transferred in 2-L pots and cultivated until full blooming.

The TS was mixed in different proportion with peat and coir to obtain seven growing media, as described in Table 1. Each substrate mix was replicated three times with 10 pots for each replicated plot. Plants were supplied with 150 mL/day of water per pot on average. All plants were fertilized with Nutricote timed release fertilizer (NPK 18:6:8 - 360 day releasing time) and watered with daily drip irrigation. Number and length of stems, number and dimension of flowers of all experimental plants were measured after the full opening of the flowers, and the sale price of each flowering potted plant was considered. The cluster colour of all flowering plants was measured on three different bracts as described above.

Statistical analysis

Pots in the three greenhouse experiments were arranged according to a randomized complete block design. All collected data were subjected to analysis of variance (ANOVA) to determine treatment effects. Where significant effects were determined, Tukey's test was used to separate differences among treatment means at the 99% (p<0.01) level of confidence, applying SPSS v27 software (SPSS Inc., Chicago, Il, USA).

3. Results

*Cherry laurel (*Prunus laurocerasus*) 'Novìta'*

The GM had a clear effect on final plant height (Fig. 2A), while WR and GM*WR interaction were without effect on plant development. LMix 6 and LMix 7, containing TS mixed with wood fiber, were the most limiting for *P. laurocerasus* growth. Cherry laurel grown in TS and peat (LMix 2 and LMix 3) did not statistically differ from the control, while plants obtained on mixes containing TS and coir (LMix 4 and LMix 5) exhibited intermediate height values. Selling values followed the same trend as the plant development (Fig. 2B). As regards leaf blade colour, leaves of cherry laurel showed a significant yellowing compared to the control when grown mixes containing TS and bark (Table 2).

Fig. 2 - Plant height (A) and selling value (B) of *P. laurocerasus* at marketing stage. Mean separation among bars by Tukey's test. Means (n = 24) followed by different letters are significantly different (p<0.01).

Table 2 - Effect of growing media (GM) on the colour of cherry laurel leaves

GM	Chroma
LMix 1	18.5 a
LMix 2	18.8 a
LMix 3	17.6 abc
LMix 4	17.3 abc
LMix 5	17.2 abc
LMix 6	16.2 bc
LMix 7	15.8 c

Mean separation within column by Tukey's test. Means (n= 24) followed by different letters are significantly different (p<0.01).

*Calla lily (*Zantedeschia aethiopica*)*

Number of flowers and selling price were significantly affected by the GM and WR, while the GM*WR interaction did not affect productive traits. The treated sediment had a clear positive effect on plant blooming, since the number of flowers showed increasing values as the content of the sediment in the mixture increased (Table 3). Regarding water supply, a 30% water reduction diminished calla blooming, being the number of flowers per plant on average 21% smaller than that obtained under normal water supply (4.5 vs 5.7). In general, the produc-

Table 3 - Main effect of growing media (GM) and water regime (WR) on the number of calla lily flowers and their selling value

Factor	Flowers/plant (n)	Selling value/flower (€)
GM		
CMix 1	4.6 b	1.8 b
CMix 2	5.5 a	2.6 a
CMix 3	5.8 a	2.8 a
WR		
WR1	5.7 a	2.9 a
WR2	5.7 a	2.6 a
WR3	4.5 b	1.6 b

Mean separation within columns by Tukey's test. Means (n= 63) followed by different letters are significantly different (p<0.01).

tion of flowers increased over time reaching the maximum peak in March and April. Flowers were subdivided according to the stem length, which varied from 50 to 100 cm. Plants cultivated on CMix 3 produced a consistently higher number of quality flowers reaching 80, 90 and 100 cm of final length compared to the control (72 *vs* 45, 43 *vs* 6 and 29 *vs* 0, respectively). Thus, the selling value averaged over the entire harvest season was found to be greater for flowers obtained on CMix 3 consisting of 50% TS (Table 3). No differences in the colour of the spathe were evidenced (Fig. 3), whatever growth conditions (GM and WR) were used (Table 4). Regarding petal senescence, inferior cut flower performance during vase life was observed when flowers were cultivated on CMix 1 and CMix 2 with reduced irrigation (Table 4).

Fig. 3 - Calla lily cut flowers at harvest time.

*Protea (*Protea cynaroides*) 'Little Prince'*

ANOVA showed that all considered parameters of protea were significantly affected by the growth media. In particular, protea grown on the control (PMix 1) exhibited significant higher average values of stem number and length (Table 5), along with an anticipated flower induction and development (data non shown) compared to plants grown on sediment-based media. The incorporation of 50% *v/v* TS in the growing media drastically reduced plant growth and flower production in all tested mixes (Fig. 4A). On the other hand, protea grown on mixes containing 25% *v/v* TS had a more compact shape, but developed a good number of flowers, except for PMix 6 containing a higher percentage of coir dust. Selling prices of potted flowering proteas were in line with the values expressed by plant vegetative and reproductive behaviour under the different tested soilless conditions (Fig. 4B). Once flowers opened, they were similar in terms of size (Table 6; Fig. 5), except for flower length which was smaller in PMix 5, PMix 6 and PMix 7 essentially related to the lesser flower development at the time of the data collection. Some differences in the bract colour of protea clusters were perceptible as indicated by the Chroma Index reported in table 6. In general, control flowers were deep pink, while those obtained on sediment-based substrates had brighter tones and tending towards purple. In

Table 4 - Effect of GM*WR interaction on the senescence and colour of calla lily flowers

GM*WR	Flower senescence		Chroma
	Marketable	Final	
CMix 1 WR1	11.8 ab	15.0 ab	6.6 NS
CMix 1 WR2	14.8 a	19.0 a	6.1 NS
CMix 1 WR3	8.2 c	15.4 ab	6.2 NS
CMix 2 WR1	13.2 ab	16.6 ab	6.2 NS
CMix 2 WR2	13.8 ab	18.4 ab	6.1 NS
CMix 2 WR3	7.6 c	14.0 b	6.0 NS
CMix 3 WR1	13.4 ab	17.2 ab	5.9 NS
CMix 3 WR2	13.8 ab	17.2 ab	6.2 NS
CMix 3 WR3	12.0 ab	17.4 ab	6.1 NS

Mean separation within columns by Tukey's test. Means (n= 15) followed by different letters are significantly different (p<0.01). NS = not significant.

Table 5 - Effect of growing media (GM) on stem number and lenght of *P. cynaroides*

GM	Stem/plant (n)	Stem lenght (cm)*
PMix 1	2.9 a	31.6 a
PMix 2	2.8 ab	23.0 b
PMix 3	2.1 bc	15.5 cde
PMix 4	2.5 ab	18.9 bc
PMix 5	1.3 c	9.6 e
PMix 6	2.7 ab	15.8 cd
PMix 7	1.9 bc	13.9 de

*Values are the average of all plant stems.
Mean separation within column by Tukey's test. Means (n= 30) followed by different letters are significantly different (p<0.01).

Fig. 4 - Bloomed plants (A) and selling value (B) of *P. cynaroides* at marketing stage. Mean separation among bars by Tukey's test. Means (n = 30) followed by different letters are significantly different (p<0.01).

Table 6 - Effect of growing media (GM) on protea flower size and colour

GM	Flower size			Chroma
	Length (mm)^{Z}	Width (mm)^{Z}	Diameter (mm)^{Y}	
PMix 1	97.3 a	38.7 a	22.5 NS	32.7 a
PMix 2	97.3 a	38.4 a	22.3 NS	30.0 ab
PMix 3	97.9 a	39.3 a	21.4 NS	28.3 ab
PMix 4	97.8 a	40.3 a	23.1 NS	32.2 a
PMix 5	81.0 b	32.9 b	22.7 NS	27.5 b
PMix 6	74.7 b	38.6 a	22.3 NS	30.9 ab
PMix 7	81.6 b	33.9 b	22.0 NS	28.9 ab

$^{(z)}$ measured with closed flower on March 2022; $^{(y)}$ measured with fully open flower on May 2022.
Mean separation within columns by Tukey's test. Means (n = 30) followed by different letters are significantly different (p<0.01). NS = not significant.

particular, the flowers collected on PMix 5 exhibited the lowest chroma index mainly associated to the a* component more shifted towards green and the b* component towards yellow.

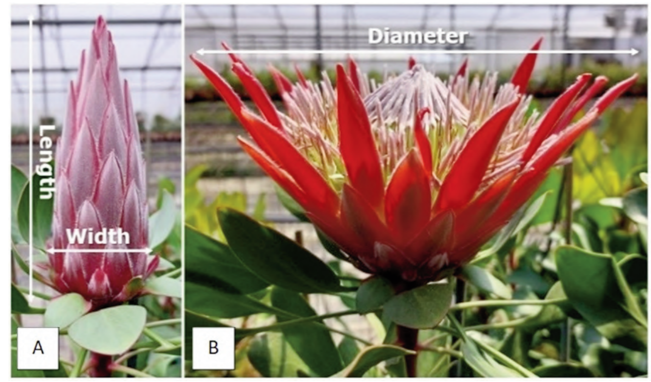

Fig. 5 - Size measurement on Protea flower. Length and width (A), diameter (B).

4. Discussion and Conclusions

Results showed that the incorporation of the treated sediment into growing media for soilless cultivation affected both plant growth and blooming differently according to the considered ornamental species.

In the case of evergreen cherry laurel, the TS used in proportions of 25-50% reduced plant height growth, especially when combined with wood fibre, slightly altering its attractive vibrant foliage. This species is easy to care and adapts to most types of soils, from light and sandy to heavy clay; thus, the reduced plant development was assumed to be primarily associated to the combined properties of the used matrices (Tozzi *et al*., 2022).

A positive effect of the TS was evidenced on calla lily, notoriously known as a water demanding species. In fact, due to its clayey silt composition, the sediment can increase water retention capacity when added to traditional soilless growing media, although the effect appears to depend primarily on the amount of sediment added to the medium (Martínez-Nicolás *et al*., 2021). In our study, both tested sediment-based mixtures allowed a copious blooming, while a 30% water reduction determined a highly significant decrease in flower production. The highest number of flowers and of best quality (stem size between 80-100) were obtained from plants grown in the presence of 50% of TS. On the other hand, petal senescence appeared to be mainly influenced by the water amount that plants receive during cultivation, while no significant differences were detected in the colour of calla flowers among the considered treatments.

The effect on protea plants grown on different sediment-based substrates was almost opposite. Plants grown on mixes containing 50% *v/v* TS exhibited a considerable reduction in plant growth and flower production (Fig. 6). Nevertheless, when 25% *v/v* TS was added to peat and coir fibre, only 7-13% of potted plants failed to bear flowers and displayed a nice compact habit. In this regard, it should be noted that a compact behaviour might represent a valuable feature for this species, when cultivated as a flowering pot, since growth regulators are being used to induce branching and improve compactness (Ben-Jaacov and Silber, 2007). Suggested factors limiting plant development and flower production could be related to high pH values and nutrient content, especially phosphorus, inherited from the sediment matrix. In fact, this perennial flowering species develops proteoid roots to increase nutrient absorption, being therefore adapted to poor soils of low nutritional status, particularly phosphorus, with a pH 4-6, and a clay content of less than 20% (Griebenow *et al*., 2022; Walter *et al*., 2022). Concerning other aesthetic aspects of the plant, the amount of TS incorporated in the substrate mixes affected the colour of clusters but not their size.

Ultimately, based on sale values, the TS can be a sustainable alternative for soilless production of ornamental crops, both for environmental protection and economic development. Recommended for calla cut flower production, the TS can be also used successfully for potted cherry laurel and protea cultivation if properly combined in the correct proportions (up to a maximum of 50% and 25%, respectively) with other organic matrixes, such as peat and coir.

A large number of consumers are changing their way of life and the products they buy in an effort to live more sustainably. It's clear that nursery industries need to place sustainability in the heart of their business strategy. However, the cost of eco-friendly plants is often higher than conventional products, due to expensive raw materials which are necessary to produce with lower environmental impact. So, the issues are: is such discrepancy really that significant? Are costumers willing to pay more for a plant obtained with the utmost respect for the environment?

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Fig. 6 - Protea plants grown on control substrate (1 = PMix 1), mixes containing 25% TS (2 = PMix 2, 4 = PMix 4, 6 = PMix 6), and mixes containing 50% TS (3 = PMix 3, 5 = PMix 5, 7 = PMix 7

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