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Biodegradable pots for Poinsettia cultivation: Agronomic and technical traits

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ABSTRACT

A large quantity of plastics is utilized by floriculture and especially for the production of flowering potted plants, where the pot is a very important component of the whole marketable product. Among these, poinsettia (*Euphorbia pulcherrima* Willd. ex Klotzsch) is a typical example of ornamental potted-plant characterized to have a relatively long crop cycle, a strong demand, especially in Europe and North America, concentrated in the Christmas period and a short shield life. Its cultivation produces a huge quantity of plastic pots to be managed in the right way to avoid environmental risks. A solution of this problem could be the use of biodegradable pots instead of traditional ones. Nevertheless, it is necessary to verify if these materials, although having biodegradability properties, are able to ensure comparative levels of technical use as traditional plastic materials.

In this paper, three different kinds of biodegradable pots (biodegradable polyester, plain or added with plant fibers) plus a traditional one (polypropylene, PP) were tested in two cultivation cycles of poinsettia (*E. pulcherrima* cv Premium red). The trial was carried out in a heated greenhouse located in Southern Italy (40° 38′N; 14° 55′E; 50 m a.s.l.). Agronomical response of plants as well as the mechanical and colorimetric behavior of pots over time were studied.

Result have shown that poinsettias growth in pots charged with plant fiber have had good values of some agronomical qualitative and quantitative indexes. Mechanical tests have pointed out that pots made by 100% biodegradable polyesters have a good mechanical resistance, with a decrease of the maximum tensile strength (σ_{max}) of just 32.2% during the trial, and a fixed color over time. Pots made of biodegradable polyesters variously added with plant fibers do not seem appropriate for poinsettia cultivation especially for the fast falling of the σ_{max} that, in the case of the biodegradable pot added with 20% of plant fibers, that decreased of 81.3% during the trial.

1. Introduction

Modern agriculture is characterized by a large use of non-renewable petroleum based plastics items. A recent study pointed out that in Europe about 2.8 million tons of plastics, that is approximately 5% of the whole year production, are for agricultural uses (Briassoulis et al., 2013).

This huge quantity of plastics, although characterized by technical performances (mechanical strength, chemical stability, microbial degradation resistance and durability, etc.), that perfectly fit with the applications they are destined, at the end of their technical life become a waste that must be properly collected and managed before to be sent to landfills or to be recycled. Inappropriate management, due to high costs of proper disposal or recycling, can cause serious environmental hazards (Candido et al., 2007; Vox et al., 2010; Giacomelli et al., 2012; Santagata et al., 2014), due principally by uncontrolled burns, or by discarding in unauthorized and uncontrolled landfills (Schettini et al., 2013).

A valid alternative to conventional plastics could be the use of biodegradable materials (Evans et al., 2010; Candido et al., 2011a,b; Kasirajan and Ngouajio, 2012; Schettini et al., 2012; Sartore et al., 2013), having technical performances suitable for agricultural applications, that can be easily degraded by naturally occurring microorganisms (Candido et al., 2001; Kyrikou and Briassoulis, 2007; Lucas et al. 2008) in biomass and inorganic products, such as carbon dioxide and water.

Biodegradable pots (biopots) can be divided in two categories: plantable and compostable (Koeser et al., 2013). The formers can

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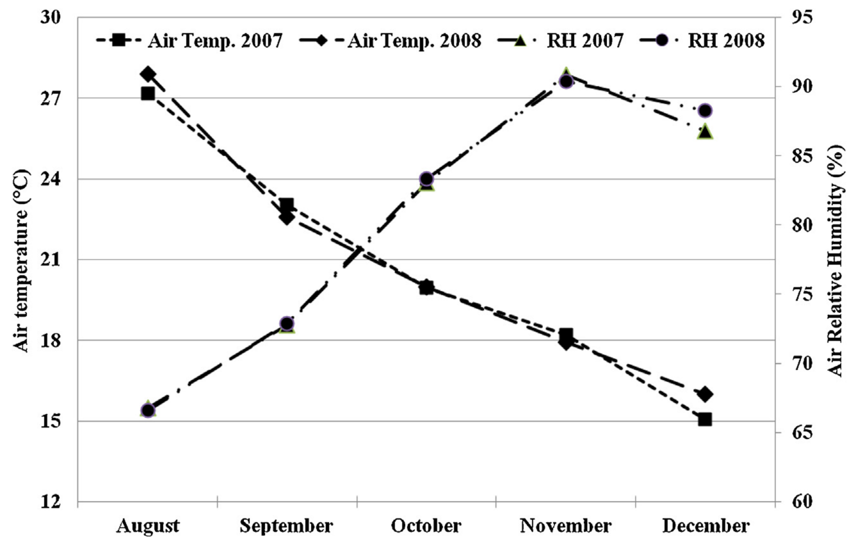

Fig.1. Monthly average air temperature [°C] and air relative humidity [%] in greenhouse.

be directly buried in the soil with the plant because their capacity to be easily crossed by plant roots; the latters, on the other hand, are characterized by a structure strength that prevent plant root to growth through their walls. Therefore, plantable biopots can biodegrade directly in the field while compostable biopots have to be removed before planting and placed in a compost pile to biodegrade. Plantable biopots can be made of different kinds of organic matrix, such as coconut fiber, manure, paper, peat, straw, wood fiber, etc., while compostable pots are generally made by bioplastic based on starch, rice hulls and polylactic acid. Other Researchers evaluated nine commercially available biocontainers to determine the irrigation interval and total water required to grow a crop of 'Cooler Grape' vinca (*Catharanthus roseus*) with or without the use of plastic shuttle trays (Evans et al., 2015). The study highlighted that containers made by water-permeable materials (i.e., slotted rice hull, coconut fiber, peat, wood fiber, dairy manure, and straw) increased the loss of water and determined shorter irrigation intervals respect to biocontainers made with more impermeable materials such as solid rice hull. The use of plastic shuttle trays reduced the rate of water loss of permeable biopots but, however, these containers needed higher irrigation demand than plastic control containers. Beeks and Evans, (2013) analyzed the behavior of nine bio containers, three compostable and six plantable, compared with a traditional petroleum-based plastic one for the production of a long term greenhouse crop as cyclamen (*Cyclamen persicum* L.) cv 'Rainer purple' irrigated with an ebb and flow system. The researchers pointed out that compostable containers, as conventional plastic ones, are compatible for long term greenhouse crops whilst most plantable containers are not suitable for this aim.

Among the various agricultural activities, nursery and floriculture, because of their heavy use of plastics, are sectors in which the need for biodegradable items is very important also to cope with the ever-increasing customer demand for sustainable productions. Recent studies demonstrate that pot type has a great impact on consumer's perception of product sustainability. In particular, it was found that biopots were preferred to pots made of recycled plastic (Yue et al., 2011; Hall et al., 2010). Potted flowering crops are the most suitable products to beneficiate of the use of biopots not only for the added value they give, but also for their environmental positive impact.

Among potted plants, poinsettia (*Euphorbia pulcherrima* Willd. ex Klotzsch) is one of the most important species both for the number of plant yearly produced and for the value of its market (Islam et al., 2014). Poinsettias have a long cropping period, depending mostly on the pot dimensions, and its utilization is concentrated during the Christmas period. Moreover, their short shelf life made them items entirely disposable determining a production of large amount of waste in a relative short time (Candido et al., 2008). Therefore, some researchers studied the agronomical behavior of biopots used for a long-term growing crop such as the poinsettia (Lopez and Camberato, 2011) but no information about mechanical performances over time of containers and their colorimetric parameters were analyzed.

The aim of this paper is the evaluation of agronomical and technical behavior of three different kinds of biopots, compared to a conventional one, for the production of potted poinsettia, also reporting their mechanical and colorimetric performances over time. Therefore, during a two-year research, the biometrical characterization of plants, the colorimetric characterization of leaves, bracts and containers as well as the mechanical resistance performance of pots were carried out.

Table 1
Tested pots for the poinsettias cultivation.

Pot abbreviation	Composition
Bio 100	100% biodegradable polyester
Bio 90–10	90% biodegradable polyester + 10% plant fibers
Bio 80–20	80% biodegradable polyester + 20% plant fibers
PP	Polypropylene

2. Materials and methods

Experimental trials were undertaken at Montecorvino Pugliano (40° 38′N, 14° 55′E; 50 m a.s.l., Province of Salerno, Campania Region, Southern Italy) in a climatized greenhouse with a metal structure covered by a low density polyethylene (LDPE) single layer plastic film having a thickness of 0.2 mm. The greenhouse, 90.0 m long and 77.6 wide, equipped with an automatic roof opening device and subdivided into eight spans (each one 90 m long and 9.7 m wide), had a 4.2 m^3 m^{-2} volume/surface index.

Two summer–autumn cycles (2007 and 2008) of potted poinsettia (*E. pulcherrima* cv. Premium red) cultivations were considered. Three different kinds of biopots, made of biodegradable polyester differently added with plant fibers, plus a commercial one made of polypropylene (PP), as a control, were used (Table 1). Pots were light brown in color and trunk conical shaped with a height of 11.8 cm and having the major and minor diameters, respectively, equal to 14.0 and 9.5 cm. Moreover, 8 drainage holes with a diameter of 1 cm were present in the bottom of every pot.

Transplanting took place on 4th and on 7th August, respectively for 2007 and 2008, using a three to four-leaved plants of poinsettia cv. Premium red for each pot that were previously filled with 1.08 l of substrate made of blond and brown peat, equally dosed, plus a 20–20–20 ternary fertilizer with microelements.

After the transplant, pots were placed directly on the greenhouse floor spaced 16 cm on and between rows, in order to have a density of 40 plants m^{-2}. A crop topping above the 4th leaf was carried out 20 days following the transplant. A second spacing was done 10 days after the topping to have a density of 9.2 plants m^{-2} (33 cm on and between rows).

For each crop cycle, four experimental treatments (i.e., pot typologies) replicated four times, according to a randomized block design, were performed. Each replicate was made of 20 plants in order to have 80 poinsettias per treatment.

At the end of September of both year a phyto regulator treatment, using cycocel 5C (Basf Crop Protection Italy) at the dose of 100 ml 100 l^{-1} of water, was carried out.

After the crop topping, fertirrigation started through a drip irrigation system placing two drippers (3 l h^{-1} flow rate) per pot. Each day, depending on the weather condition, one or two fertirrigations were carried out, dispensing 250 ml of nutrient solution per each pot.

From the transplanting to the first ten-day of October of each year, a black shadow net (50% shading) was used to cover the greenhouse, later the heating system was activated to have always the minimum temperature of the air in the greenhouse above 16 °C until the end of the crop cycle.

At beginning of poinsettia marketing period, on 12th and 10th December, respectively for the 2007 and the 2008, ten plants per each pot type undergone to agronomic characterization and for this purpose biometrical parameters (plant height, inflorescence number, stem fresh and dry weights, leaf fresh and dry weights, bract fresh and dry weights, bract number and area, leaf number and area, color of bracts and leaves) were recorded. Dry weights were calculated drying samples to constant weight by using a ventilated heater. Bract and leaf number and surface were determined by using an area meter LI-Cor Model 3100 (LI-Cor, Inc., Lincoln, NE, USA). Besides, color of bracts and leaves was measured by means of a Minolta CR-400Chroma Meter (Minolta Corp., Osaka, Japan), coupled to a Minolta DP-301 data processor. The CIE standard illuminant D65 (Alcalde-Eon et al., 2014) were used to assess the measurements of the L^* (lightness), a^* (green–red direction) and b^* (blue–yellow direction) color coordinates in the CIELAB color system (Konica Minolta, 2003).

Chroma ($C_{ab}{}^*$) and hue angle (H_{ab}) were calculated by means of the following equations (Konica Minolta, 2003):

$$C_{ab}* = \sqrt{(a*)^2 + (b*)^2} \quad (1)$$

$$H_{ab} = \tan^{-1}\left(\frac{b*}{a*}\right) \quad (2)$$

In order to evaluate mechanical behavior of pots and their color change over time, in particular from transplanting (new pots) to the beginning of poinsettias marketing period (used pots), bioplastic and PP samples were mechanically tested and chromatically measured in both trial years. Mechanical tests have been carried out by using a Galdabini PMA 10 (Galdabini S.p.A., Italy) universal computerized press according to the ISO 5893 (ISO 5893, 2002). Furthermore, at the end of poinsettia shelf life, for each crop cycle visual reliefs of the pots degradation index, according to a qualitative rating scale (Martin-Closas et al., 2008) variable from 0 (completely intact material and perfect sealing of the pot) to 5 (completely degraded material with poor sealing of the pot), were carried out.

Moreover, color was detected in the same way as described above for poinsettia leaves and bracts; in addition hue differences over time were determined using the following formula (Konica Minolta, 2003):

$$\Delta E_{ab}* = \sqrt{(\Delta L*)^2 + (\Delta a*)^2 + (\Delta b*)^2} \quad (3)$$

$$\Delta H_{ab}* = \sqrt{(\Delta E*_{ab})^2 - (\Delta L*)^2 - (\Delta C*_{ab})^2} \quad (4)$$

in which:

$$\Delta L* = L*_{\text{used pots}} - L*_{\text{new pots}}$$

$$\Delta a* = a*_{\text{used pots}} - a*_{\text{new pots}}$$

$$\Delta b* = b*_{\text{used pots}} - b*_{\text{new pots}}$$

$$\Delta E^*_{ab} = E^*_{\text{abusedpots}} - E^*_{\text{abnew pots}}$$

$$\Delta C^*_{ab} = C^*_{\text{abusedpots}} - C^*_{\text{abnew pots}}$$

During the trials, greenhouse air temperature and relative humidity were recorded, with a sampling interval of 30 min each day, by air temperature and relative humidity probes (CS500-L—modified version of Vaisala's 50Y Humitter, Campbell Scientific Inc, Utah, USA) and data were recorded by a CR 10× data-logger (Campbell Scientific Inc., Utah, USA).

All collected data were statistically analyzed by ANOVA procedure, considering years and the different types of pots as sources of variation. Mean values were separated by the Student–Newman–Keuls (SNK) test at $P \leq 0.05$.

3. Results

3.1. Climatic data

Climatic data, showed as the monthly average of the mean value for each day, pointed out that air temperature and air relative humidity were nearly similar during the poinsettia cultivation in 2007 and 2008. In particular, as shown in Fig. 1, air temperature values were slightly higher in 2007 till the end of November after that the temperature was lower than in 2008. Values of relative humidity of air were almost equal in 2007 and 2008 and just at the end of the cultivation the value of 2008 was slightly higher than the value of 2007. However, the recorded values of temperature and relative humidity of air showed that the conditioning of the greenhouse was conducted in equal measure in both years of trials.

3.2. Morphological traits of plants

As shown in Table 2, statistically significant differences in plant morphological traits between 2007 and 2008 poinsettia cultivation were observed. In particular, 2008 plants ready for commercialization were 8.3 cm higher and had meanly one inflorescence more than those cultivated in the 2007. On the contrary, 2007 poinsettias showed higher values of some parameters such as: fresh weight (+25.8 g), bracts/leaves ratio (+0.6), distance between bracts (+0.2 cm). Pots typology has significantly influenced all the morphological parameters, except for plant height that remained statistically unvaried. Among biopots, those charged with plant fibers, have positively influenced the development of poinsettias determining significant increases of the number of inflorescences, distance between bracts, dry matter and fresh weight of stems

Table 2
Effects of pots on some morphological traits of Poinsettia plants in two years.

Treatments	Plant traits[a]							
	Plants			Bracts		Inflorescence	Stems	
	Height (cm)	Fresh weight (g)	Dry weight	Distance between bracts (cm)	Ratio bracts/leaves (n./n.)	(n.)	Fresh weight (g)	Dry matter (%)
Years (Y)								
2007	28.6	155.9	21.8	1.8	2.4	5.1	44.4	16.8
2008	36.9	130.1	17.6	1.6	1.8	6.3	42.1	13.4
Significance[b]	**	**	**	**	**	*	ns	**
Pots (P)								
Bio 100	31.6	136.2 c	18.2 c	1.4 b	2.4 a	5.2 b	38.6 c	14.4 b
Bio 90–10	34.3	147.2 b	20.5 b	1.8 a	2.0 b	5.7 b	45.8 b	15.6 a
Bio 80–20	30.9	163.2 a	22.5 a	1.9 a	2.1 ab	6.7 a	49.8 a	15.5 a
PP	34.4	125.5 d	17.5 c	1.7 ab	1.8 c	5.4 b	39.0 c	14.7 b
Significance	ns	**	**	**	**	**	**	**
Interaction Y × P								
Significance	ns	**	**	ns	**	ns	**	**

[a] For each column and treatments, mean values followed by a different lower-case letter are significantly different at $P \leq 0.05$ according to Student–Neuman–Keul's test.
[b] * = Significance at 0.05P; ** = Significance at 0.01P; ns = not significant differences.

(Table 2). On the contrary, bio 100 pots have had a behavior somewhat similar to the PP ones. Furthermore, more compact bracts (less distance between them) and a more favorable bracts/leaves ratio was given by their use. At last, the fresh and dry weight of plants such as the bracts/leaves ratio, the fresh weight and the dry matter of stems have been influenced by the type of pots and were different in the two years of trials, as evidenced by the significance of the interaction "Years × Pots" (Table 2).

3.3. Morphological and colorimetric traits of bracts

Bracts morphological and color characteristics have been changed significantly in the two years of trials and have been influenced also by pots typology.

Plants obtained in 2007 had a greater development of the bracts although their number remained statistically unchanged. In particular, fresh weight of hypsophylls was higher of 22.9 g plant^{-1} respect to 2008. Moreover, 2007 poinsettias had both a greater leaf surface area per plant (+495 cm^2) and for the single bract (+5.4 cm^2). On the other hand, in 2008 bracts showed higher values of the chromatic characters (Table 3).

Poinsettias cultivated in biopots showed bracts with significantly higher values in terms of number, biomass and surface per plant compared to those of the plants cultivated in the PP ones.

Among biopots, the bio 80–20 one had the best performance, while no significant differences were observed for the other biopots (Table 3).

In 2007 bracts were characterized by lower color performances compared to those of 2008 (Table 3).

Regarding pots, the best color of bracts was reached by poinsettias cultivated in the bio 90–10 followed by the ones of the bio 80–20, bio 100 and PP ones (Table 3).

The number of bracts per plant as well as their fresh and dry weight, surface area, b^* color coordinate and hue angle were influenced by the interaction Years × Pots (Table 3).

3.4. Morphological and colorimetric traits of leaves

In 2008, plants have produced in average 12 leaves more than the previous year but these were 8.7 cm^2 smaller and with lower chromatic values (Table 4). On the other hand, leaves of plants cultivated in 2007 had better chromatic performances.

Table 3
Effects of pots on some morphological and colorimetric traits of Poinsettia bracts in two years.

Treatments	Bracts traits[a]										
	Per plant	Weight		Dry matter	Surface area		Color				
		Fresh	Dry		Per plant	Average	Coordinates			Chroma	Hue angle
							L^*	a^*	b^*		
	(n.)	(g)	(g)	(%)	(cm^2)	(cm^2)				(C^*_{ab})	(H_{ab})
Years (Y)											
2007	80.7	70.0	8.0	11.5	2745	34.3	32.3	51.5	19.4	55.0	20.6
2008	78.8	47.1	5.8	12.3	2250	28.9	33.8	54.7	27.5	61.2	26.7
Significance[b]	ns	**	**	**	**	**	*	**	**	**	**
Pots (P)											
Bio 100	80.2 b	60.2 b	6.9 b	11.5 b	2619 b	33.0 a	33.1	52.4	22.5 c	57.0	23.2 b
Bio 90–10	80.8 b	59.0 b	6.9 b	11.7 b	2484 b	31.0 b	32.6	53.4	24.5 a	58.7	24.6 a
Bio 80–20	98.0 a	67.1 a	8.0 a	12.0 a	2884 a	29.4 c	33.0	52.9	23.5 b	57.9	23.9 b
PP	60.1 c	47.7 c	5.9 c	12.2 a	2002 c	33.0 a	33.4	53.8	23.2 c	58.6	23.3 b
Significance	**	**	**	*	**	**	ns	ns	**	ns	**
Interaction Y × P											
Significance	**	**	*	ns	**	**	ns	ns	**	ns	**

[a] For each column and treatments, mean values followed by a different lower-case letter are significantly different at $P \leq 0.05$ according to Student–Neuman–Keul's test.
[b] * = significance at 0.05P; ** = significance at 0.01P; ns = not significant differences.

Table 4
Effects of pots on some morphological and colorimetric traits of Poinsettia leaves in two years.

Treatments	Leaf traits[a]										
	Per plant	Weight		Dry matter	Area		Color				
		Fresh	Dry		Per plant	Average	Coordinates			Chroma	Hue angle
							L^*	a^*	b^*		
	(n.)	(g)	(g)	(%)	(cm^2)	(cm^2)				(C^*_{ab})	(H_{ab})
Years (Y)											
2007	33.9	41.0	6.3	15.3	1474	43.7	28.1	−7.0	5.6	9.0	-38.6
2008	45.9	41.1	6.0	15.0	1606	35.0	28.0	−4.8	6.0	7.7	-51.3
Significance[b]	**	ns	ns	ns	ns	**	ns	**	ns	*	**
Pots (P)											
Bio 100	34.0 b	37.4 b	5.6 b	15.1	1369 c	40.4	26.1 b	−4.8 b	5.0 b	6.9 b	−46.2
Bio 90–10	42.2 a	42.9 a	6.3 a	15.1	1644 ab	39.8	27.4 b	−5.7 b	5.8 b	8.1 b	−45.5
Bio 80–20	47.6 a	46.1 a	6.8 a	15.1	1723 a	37.0	27.7 b	−5.6 b	5.2 b	7.6 b	−42.9
PP	35.7 b	37.8 b	5.7 b	15.2	1424 bc	40.3	30.9 a	−7.5 a	7.3 a	10.5 a	−44.2
Significance	**	**	**	ns	*	ns	**	**	**	**	ns
Interaction Y x P											
Significance	*	*	ns	ns	*	ns	ns	ns	ns	ns	ns

[a] For each column and treatments, mean values followed by a different lower-case letter are significantly different at $P \leq 0.05$ according to Student–Neuman–Keul's test.
[b] * = significance at 0.05P; ** = significance at 0.01P; ns = not significant differences.

Significant differences in the number, weight and surface of the whole biomass of leaves were found in the plants cultivated in different pots. In particular, bio 80–20 and bio 90–10 have obtained the best performance followed by bio 100 and PP pots (Table 4).

Good values of the color characterization were found in leaves of plants grown in PP pots compared to those observed in all the different biopots that did not show statistically differences between them (Table 4).

The interaction between years and pots was significant only for the number of leaves per plant, their fresh weight and surface area per plant (Table 4).

3.5. Mechanical behavior, degradation and colorimetric traits of pots

Maximum tensile strength (σ_{max}), elongation at break (*E*%) and degradation index of both new and used pots utilized in 2007 and 2008 did not statistically differ from each other (Table 5). On the other hand, a decrease of σ_{max} and *E*% was recorded for all biopots (Table 5). In particular, new bio 100 pots had a value of 21.4 N mm^{-2} that reduced to 14.5 N mm^{-2} at the end of the trial, nevertheless the latter value did not compromise the handling capability of these pots. Instead, bio 90–10 and bio 80–20 pots showed a severe decrease of the σ_{max}, that has fallen from values from 20.2 and 19.8 (new pots) to 4.5 and 3.7 N mm^{-2} (used pots) respectively, that made them unhandled and so not marketable. PP pots have had an increase of the σ_{max} from 26.8 (new pots) to 29.5 N mm^{-2} (used pots); this behavior can be explained considering a crystallization of the PP matrix that made during the first time period this compound stronger but more fragile (Table 5). Relatively to the *E*%, tests have shown that PP pots have undergone to a considerable decrease of the elasticity, likely for the crystallization of the plastics, passing from 69.7% to 16.0%, recorded respectively at the beginning and at the end of the trial. Among biopots, new Bio 100 pots showed the highest value of *E*%, equal to 78.2%, but at the start of poinsettia marketing period, it was reduced to 8%. Moreover, bio 90–10 and bio 80–20 showed the lowest elongation at break both at the start and at the end of trials (Table 5). Bio 100 and PP pots were characterized by a degradation index equal to zero, whilst bio 90–10 and bio 80–20 pots had value equal to 1.8 and 2.8

Table 5
Mechanical behavior and degradation traits of pots.

Treatments	Pots traits[a] Machanical characterization				
	σ_{max}		*E*%		Degradation
	New pots (N mm^{-2})	Used pots	New pots (%)	Used pots	index[b] (0–5)
Years (Y)					
2007	21.8	11.8	48.7	8.5	1.1
2008	22.3	14.3	48.5	7.3	1.2
Significance[c]	ns	ns	ns	ns	ns
Pots (P)					
Bio 100	21.4 b	14.5 b	78.2 a	8.0 b	0.0 c
Bio 90–10	20.2 b	4.5 c	26.3 b	3.9 c	1.8 b
Bio 80–20	19.8 b	3.7 c	19.7 b	3.7 c	2.8 a
PP	26.8 a	29.5 a	69.7 a	16.0 a	0.0 c
Significance	**	**	**	**	**
Interaction Y x P					
Significance	ns	ns	ns	ns	ns

[a] For each column and treatments, mean values followed by a different lower-case letter are significantly different at $P \leq 0.05$ according to Student–Neuman–Keul's test.
[b] 0 = pots without visual degradation damages; 5 = pots with strong degradation damages.
[c] * = significance at 0.05P; ** = significance at 0.01P; ns = not significant differences.

Table 6
Colorimetric traits of tested pots in two years.

Treatments	Pots traits[a] Colorimetric characterization											
	New pots					Used pots						
	Color coordinates			Chroma	Hue angle	Color coordinates			Chroma	Hue angle	Color Δ	
	L^*	a^*	b^*	C^*_{ab}	h_{ab}	L^*	a^*	b^*	C^*_{ab}	h_{ab}	$\Delta E_{ab}{}^*$	$\Delta H_{ab}{}^*$
Years (Y)												
2007	42.0	20.5	21.7	29.9	46.6	41.9	20.9	22.7	30.9	47.3	1.7	0.5
2008	42.1	20.9	21.7	30.1	46.2	43.8	20.2	22.0	29.9	47.6	3.0	1.3
Significance[b]	ns	ns	ns	ns	ns	**	**	**	*	**	**	**
Pots (P)												
Bio 100	43.0 a	21.2 a	22.9 a	31.2 a	47.1 a	42.3 b	21.2 a	23.1 a	31.4 a	47.5 b	1.2 c	0.5 b
Bio 90–10	42.4 b	21.3 a	22.5 a	30.9 a	46.6 a	42.2 b	20.9 a	22.7 a	30.9 a	47.3 c	0.8 c	0.5 b
Bio 80–20	41.7 c	19.3 b	21.5 b	28.9 b	48.0 a	42.5 b	21.3 a	23.0 a	31.4 a	47.2 d	2.8 b	0.7 b
PP	41.2 d	21.0 a	20.1 c	29.0 b	43.8 b	44.5 a	18.8 b	20.6 b	27.9 b	47.7 a	4.6 a	1.9 a
Significance	**	**	**	**	**	**	**	**	**	**	**	**
Interaction Y x P												
Significance	ns	ns	ns	ns	ns	**	**	**	ns	**	**	**

[a] For each column and treatments, mean values followed by a different lower-case letter are significantly different at $P \leq 0.05$ according to Student-Neuman-Keul's test.
[b] * = significance at 0.05P; ** = significance at 0.01P; ns = not significant differences.

respectively, then demonstrating again their incapability to undergone to long crop cycles. Not significant differences of the interaction Years × Pots have been found.

Both in 2007 and 2008, no significant differences were found in color coordinates, chroma and hue angle for new pots, however, statistical differences were found in used pots and delta indexes (Table 6).

Colorimetric measurements on pots pointed out that values of L^* decreased for the bio 100 pots, did not statistically differ for the bio 90–10 and increased both for bio 80–20 and PP ones; a^* values showed no significant differences from bio 100 and bio 90–10 pots, increased for the bio 80–20 pots and decreased for the PP ones; the same trend has been observed for b^* values except for the PP pots that had an increase of this colorimetric coordinate over time (Table 6). Chroma did not change between bio 100, bio 90–10 and PP pots, only the bio 80–20 containers showed an increase of this colorimetric index. Hue angle values decreased for all bio pots, especially for the 80–20 ones; only the PP showed hue angle values that increased during the trial. Moreover, $\Delta E_{ab}{}^*$ and $\Delta H_{ab}{}^*$ values were lower for bio pots respect to PP ones (Table 6).

4. Discussion

The reduction of plastics use in nursery and greenhouse production practices can increase consumer interest in these sustainable productions (Nambuthiri et al., 2015). In this view, the use of non-petroleum based inputs could gain the sustainability of the existing greenhouse productions making them more environmentally friendly (Brumfield et al., 2015). Between alternative inputs, biodegradable and compostable containers for short, medium or long term cultivation can be an important issue to arrange sustainable production of potted crops (Conneway et al., 2015). This is even more important for crops, such as potted poinsettias, whose production being concentrated in short periods of the year can give problem for the correct disposal of petroleum-based plastic containers (Candido et al., 2011a,b). Nowadays the cost of biopots is still too high than traditional ones to made them utilizable by growers in large scale (Brumfield et al., 2015). According to Minuto et al. (2008) the cost of biopots is about twice the cost the traditional ones but it can strongly decrease in the case of markets that force growers to made a repotting of the plants in biopots before deliver the goods.

Tested bio 80–20 and bio 90–10 pots had favored the development of plants by determining, compared to bio 100 and PP containers, significant increases in aerial biomass of leaves and bracts. Relatively to bracts traits (Table 3), poinsettias grown in bio 80–20 pots showed a high number of bracts with good traits respect to the plants cultivated in the other pots (Table 3). On the other hand, both bio 80–20 and bio 90–10 have suffered of a quick degradation rate of walls determining their poor mechanical performances over time (Table 5). This caused severe problems of handlings during the marketing phase due to the fragility of these pots. Even if the mechanical results appear in general agreement with the behavior of biodegradable materials, the lower values showed by biopots incorporating plant fibers (bio 90–10 and bio 80–20) are probably connected to a not yet well-homogenized mix, since it is known that, in heterogeneous materials where some fibers are included, due to their increased aspect ratio (length/diameter) compared to non fibrous filler, fibers can improve mechanical properties of composites (Schettini et al., 2013). Therefore, these containers were not found fully suitable for the 18-week potted poinsettia production cycle.

Poinsettias cultivated in bio 100 pots had agronomical responses similar to those grown in PP containers as well as the degradation rate and the mechanical performances were similar between them. A similar behavior was found by Lopez and Camberato (2011) that tested seven different types of biodegradable containers, plus a traditional one for 14-week poinsettia production cycle; the study, regarding specially the agronomic response of the plants and their degradation rate measured by a visual quality rating scale, demonstrated that innovative pots made by Canadian sphagnum moss and wood pulp, composted cow manure, straw and coconut coir containers were unsuitable because of algal and fungal growth and breakage problems. The same Authors found that containers made of molded fiber, rice hull, and wheat starch-derived bioresin have proved to be comparable to conventional containers and thus promising for commercial long-term poinsettia production.

Color of leaves and bracts of poinsettia is characterized by the predominance of different group of pigments: chlorophylls for green leaves and anthocyanins for red bracts (Slatnar et al., 2013). The relationship found in this paper between the typology of pot, in which the poinsettias have been grown, and the color of bract and leaves has shown that for leaves the PP container gave the best performance giving the better values of L^* and a^* whilst all biopots gave similar values of L^*, a^* and b^*. Instead, for bract no significant differences in L^* and a^* values were observed between pots, only b^* values were statistically different for bracts, having a lighter red for poinsettias grown in PP and bio 100 containers. Color characterization of pots over time pointed out that the bio 100 and the bio 90–10 have had a different behavior than bio 80–20; in fact, the latter had a color that become slightly darker over time than the others that showed a color becoming lighter during the trial. This can be due to the different charge of plant fiber and thus to the different rate of biodegradation. The color stability over time of bio 100 and bio 90–10 containers can be a good quality characteristics of these biopots because consumers assume the pot as an important part of the whole product.

5. Conclusions

Poinsettia cultivated in bio pots presented biometrical traits and colorimetric characteristics of leaves and bracts similar and in some cases higher than those grown in PP conventional containers. Nevertheless, the mechanical characterization of pots confirmed that containers made of 100% biodegradable polyester are suitable for the 18-week poinsettia cultivation cycle. On the other side, the pots with the addition of plant fiber, especially the bio 80–20 ones, because of their quick degradation rate and thus of mechanical poor performances over time, are not usable especially for breakage problems during the handling of the marketing phase.

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