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Research Report

The Effect of Biobased Plastic Resins Containing Chicken Feather Fibers on the Growth and Flowering of *Begonia boliviensis*

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Abstract. This study was conducted to evaluate the growth and flowering of *Begonia boliviensis* A. DC. 'Bonfire' when grown in the growing medium mixed with pellets from biobased plastic resins containing chicken feather fibers, and analyze macro- and micro-elements in soil and leaf tissues during different developmental stages of begonia. Growth, flowering, and foliar analysis of plants grown in 10 cm pots containing 95 grams medium mixed with 6 grams each of pellet 29 (P 29), 32 (P 32), 37 (P 37), or 40 (P 40), 3 grams of Na (P NaS), or 9 grams of 45 (P 45) were similar to the control plants. Extra nitrogen was available from P 32 and P 37 based on the growing medium and foliar analysis of plants grown in P 32 (P 32 plant) and P 37 plant during the first 59 days after planting (DAP). Slow growth, low flowering percentage, or even the death of *B. boliviensis* 'Bonefire' grown in P NaS medium is attributed to high pH and high sulfur concentration. Based on the pH, soluble salts level, and the concentrations of macro- and micro-elements in the medium and leaves, P 45 pellet is the suitable source, if nitrogen is supplied constantly to the optimum level. Pellets prepared following mixing > 30 feather fibers without using glycerol should be further tested.

***Additional key words*:** availability of nitrogen, chicken feather pots, foliar analysis, growing medium

Introduction

Currently about 1.8 trillion nursery pots are used by the nursery and greenhouse industries and most are made with petroleum based plastic (Hodges and Haydu, 2001). An effective and profitable utilization of feather wastes will be helpful if feathers can be utilized to make nursery growing containers. There was a limited number of research related to plant production utilizing feather fibers. When a biodegradable pot containing processed feathers was compared with a plastic and peat pot, dry shoot weight of 'Better Boy' tomato (*Lycopersicum esculentum* L.) grown in feather pots was similar to that in peat pots and had higher tissue nitrogen (N) concentration. The nitrogen concentration was higher in tomato plants when grown in feather containers which may release additional nitrogen, resulting in plants with higher dry weight as compared to those grown in plastic or peat pots (Evans, 2004).

Based on the chemical analysis of six pellets mixed in media, P 32, P 37, P 40, P NaS which contains > 20% glycerol were not suitable and not recommended for future evaluation. Pellets containing glycerol at 10% were not suitable for use as an ingredient for commercial growing media. Based on this study, glycerol even at 10% is considered not suitable to use as an ingredient to process pellets and the use of P 45 is the best source of pellets (Roh et al., 2012). However, there is no report on how pellets may affect the chemical properties of the medium and plant growth and development. The objectives of this study were to evaluate the growth and flowering of *Begonia boliviensis* 'Bonfire' with pellets mixed in the medium, and to analyze the concentrations of macro- and micro-elements in the growing medium and plant tissues.

Materials and Methods

Stock Plants and Propagules Preparation

Begonia boliviensis 'Bonfire' (Gro-N-Sell Inc., Chalfont,

PA, USA) stock plants were grown in as described (Roh et al., 2012). Rooted cuttings planted in 10 cm plastic pots were used in the following growth and flowering experiments.

Optimum Level of Six Different Pellets Mixed in a Growing Medium on Growth, Flowering and Foliar Analysis over a Long Term Evaluation (Expt. 1)

Cuttings with two lateral shoots visible at the bottom of shoots were selected and rooted under a mist then transplanted individually on June 7, 2010 into pots mixed with six pellets: pellet 29 (P 29), P 32, P 37, P 40, P 45, or P NaS (Roh et al., 2012). Each medium contained 0, 3, 6, or 9 grams of pellets mixed in 95 grams of soilless medium as described (Roh et al., 2012) and was then placed in plastic pots. At planting, 0.8 grams of controlled release fertilizer (14N-6P-11.3K) was mixed with the medium.

Each treatment consisted of 15 rooted cuttings, and all randomized by treatments during culture in the air-conditioned greenhouse maintained at 21°/18.3℃ (day/night) (Lee and Roh, 2001). The number of flowers that reached anthesis was recorded on Monday and Friday each week. Length of the main shoots, the longest lateral shoots, number of nodes on the main shoot, and the number of lateral shoots that produced flowers were recorded 40 days after planting (DAP). Five fully matured leaves from the main shoots were collected in duplicate for analysis (Roh et al., 2012) (Expt. 1A).

Following the completion of evaluation described above (Expt. 1A), all plants were pruned on Aug. 4, leaving two uniform lateral shoots which were cut back to 5 cm long. Ten plants were randomly selected from 15 plants and grown without additional fertilizer during this period of evaluation (Expt. 1B). The number of total flowers from primary and secondary shoots was recorded, and cumulative number of flowers was calculated 27 DAP. The number of secondary and tertiary shoots with flower buds and the length of the longest shoot with flowers was recorded 27 DAP when the experiment was terminated.

Data were analyzed in one-way analysis including controls, and then analyzed again without including pellets as a variable using SAS Software (SAS Proprietary Software Version 9.00, 2002). Means were compared separately in a given pellet by highly significant difference (HSD) at 1% level.

Evaluation of Three Selected Pellets Mixed in a Growing Medium on Growth, Flowering, and Soil and Foliar Analysis (Expt. 2)

Rooted cuttings were transplanted individually into pots filled with a medium mixed with 8 grams of each of P 32, P 37, and P 45 made of chicken keratin. One week after transplanting (Aug. 20, 2010), plants were fertilized weekly with 200 mg·L^{-1} N from a 20N-8.6P-11.7K water soluble fertilizer. There were 12 single plant replications of each pellet medium under a completely randomized design during greenhouse culture.

The numbers of flowers that reached anthesis were counted 24, 38, 47, 59, 68, and 77 DAP. Samples for soil and foliar analysis of macro- and micro- elements and pH and soluble salts from soil samples were collected 24 DAP, 59 DAP, and 77 DAP from 4 pots at each sampling dates. All plant parts above the soil level were sampled from three pots and combined for analysis in triplicate for growing medium and foliar analysis as described (Roh et al., 2012). Data were analyzed at each sampling date with pellets as a variable for flowering data or with sampling date and pellets as variables.

Results

All cuttings grown in a medium without pellets (P con plant) flowered, and the length of the main shoot ranged from 29.5 to 31.4 cm (Expt. 1A; Table 1). No significance differences among the three controls were observed in all variables (data not presented). Therefore, only the means of three controls are presented. When grown in a medium mixed with various pellets, growth and flowering responses were significantly affected by pellet types, amount of pellets mixed in a medium, and their interaction. Therefore, the effect of the amount of pellets mixed in a medium was analyzed by individual pellet.

When 3 grams of each pellet type were mixed with the medium, growth and flowering responses were not significantly affected as compared to the control. One exception was the number of days between the first and the last flower opening (no. of days FF - LF) (16.9 vs. 12.5 days) when plants were grown in 3 grams of P NaS-3g (pellets-weight of pellets mixed in a growing medium) plant and P 32-3g plant (15.7 vs. 12.6 days) (Table 1). Significant growth inhibition of the main shoot was observed with P 32-6g, P 37-6g, P40-6g, P NaS-6g plant.

Generally growth and flowering response to the amount of pellets mixed in the medium was similar between P 32, P 37, P 40, and P NaS plant and also between P 29 and P 45 plant. For example, the number of days to the first flower (FF) opening was not affected by the amount of pellets mixed in the medium; P 29 plant and also in P 45 plant that ranged from 28 to 30 days, and the no. of days FF - LF which lasted about 16 days in P 29 plant and about 17 days in P 45 plant. However, in P 32, P. 37, P 40, and P NaS plant, mixing 6 or 9 grams of pellets significantly shortened the number of days to FF and the number of days of FF - LF.

Significant inhibition of growth and flowering response

Table 1. Growth and flowering of *Begonia*, 'Bonfire' in a growing medium mixed with different amount of pellets (Expt. 1A).

Pellet	Wt[z] (g)	Main shoot length (cm)	Lateral shoot		No. of[y]			Flowering (%) (remarks)[x]
			no. of shoots	length (cm)	days to FF	TF	days FF - LF	
P con[w]	0	30.7	7.7	26.9	28	5.0	17.7	100 F
P 29	0	32.6a[v]	6.5a	28.1a	28a	4.8a	16.1a	100 F
	3	31.7a	5.9a	27.6a	30a	4.4a	15.3a	100 F
	6	31.2a	6.5a	24.2b	29a	4.3a	16.2a	94 F (6 D)
	9	26.4b	7.1a	23.2b	30a	4.3a	15.9a	94 F (6 D)
P 32	0	30.3a	7.9a	24.1a	29b	4.5a	15.7a	100 F
	3	26.5a	7.1a	22.5a	30ab	3.7a	12.6b	94 F (6 P)
	6	21.2b	5.7ab	15.3b	32a	3.3a	11.8b	94
	9	11.5c	4.4b	7.5c	35a	1.5b	8.3c	80 F (20 D)
P 37	0	30.2a	6.9a	28.3a	27a	4.8a	18.3a	80 F (20 P)
	3	28.4a	7.8a	24.5a	30a	4.7a	15.3a	87
	6	18.4b	6.5a	16.5b	32a	3.2b	7.3b	87 F (13 P)
	9	11.5c	3.7b	7.8c	5b	1.4c	7.7b	80 F (20 D)
P 40	0	29.0a	7.2a	25.7a	28b	4.8a	17.5a	94 F (6 P)
	3	25.7a	7.6a	22.1a	30b	4.5a	16.0a	100 F
	6	21.2b	6.3a	17.1b	30b	3.5a	13.6b	100 F
	9	9.9c	3.2b	6.1c	37a	1.8b	6.2c	87 F (13 D)
P 45	0	28.3a	7.3a	26.0a	28a	4.9a	18.3a	100 F
	3	30.4a	6.9a	25.9a	30a	4.6a	16.3a	94 F (6 P)
	6	28.5a	8.4a	24.8a	28a	4.5a	16.9a	100 F
	9	31.1a	7.1a	27.4a	28a	4.7a	18.0a	100 F
P NaS	0	31.1a	7.1a	26.5a	28a	4.5a	16.9a	100 F
	3	27.9a	7.3a	21.4a	32a	3.9a	12.5b	94 F (6 D)
	6	26.6a	6.2a	21.6a	32a	4.0a	13.0b	94 F (6 P)
	9	8.8b	1.8b	7.0b	33a	0.8b	0.0c	33 F (67 D)
Level of significance[u]								
Pellet		**	*	*	ns	*	***	
Weight (Wt)		***	*	***	**	**	***	
Pellet × Wt		***	***	***	ns	ns	*	

[z]Wt: weight of pellets mixed in a growing medium.
[y]The number of days to first flower open (FF), total flowers (TF), and from first flower to last flower to open (FF - LF).
[x]Percentage of plants that flowered (F), pinched during culture accidently (P), and died (D).
[w]No significance was observed in three controls, so, only the means of three controls are presented. Means are not significantly different from those of plants grown in the medium without pellet mixed.
[v]Means with the different letter in a column is not significantly different with each other at $P < 0.05$ or 0.01, by HSD.
[u]Non-significant (ns) and significant difference at 5% (*), 1% (**), and 0,1% *(***), F-test.

were observed particularly in P 32-9g plant, but not in P 45-9g plant (Table 1). The number of lateral shoots (4.4) were reduced in P 32-9g plant and the number of days for the FF to reach anthesis (35), the number of total flowers (TF) (1.5), and the no. of days FF - LF (8.3) was significantly affected as compared to P 32-0g, PD 32-3g, and P 32-6g plant. However, growth and flowering responses were not affected by the amount of P 45 mixed in a medium. Except for a few plants that did not survive or failed to flower due to a accidental pinching of the main shoots, flowering percentage was > 94% when P 29 and P 45 were mixed, regardless of the amount of pellets mixed in a medium. Lowest flowering percentage (33%) was observed in P NaS-9g medium.

Macro- and micro-elements in leaves was also affected by pellets, weight of pellets mixed in a medium, and their interaction (Table 2). Total nitrogen (N) concentration in the P control medium (P con medium) when cuttings were

Table 2. Analysis for macro- and micro-elements in a growing medium mixed with different pellets to grow *Begonia* 'Bonfire'. (Expt. 1A).

Pellet	Wt[z] (g)	Concentration of macro- and micro-elements											
		N	P	K	Ca	Mg	B	Fe	Mn	Cu	Zn	Mo	Na
		(%)					(mg·kg^{-1})						
P control	0	2.9	0.17	0.99	0.82	0.39	46.4	57.6	44.1	9.83	24.9	0.48	2,078
P 29	0	3.1b[y]	0.31b	1.11ab	0.87a	0.39a	49.3b	60.6b	44.7a	10.72a	27.2a	0.39a	2,017b
	3	3.3b	0.29b	0.88b	0.72a	0.36a	49.0b	59.4b	41.6a	10.65a	27.0a	0.28b	1,940b
	6	4.2a	0.44a	1.25a	0.83a	0.35a	60.7a	66.9a	48.3a	11.45a	29.6a	0.14c	2,542a
	9	4.7a	0.43a	1.32a	0.81a	0.33a	58.7a	74.5a	42.4a	11.20a	27.8a	0.08c	2,191b
P 32	0	4.1b	0.36c	1.34b	0.88a	0.41a	56.6a	74.5a	53.4ab	14.25a	30.7a	0.24a	2,451a
	3	4.9b	0.53b	1.33b	0.81ab	0.31b	64.8a	85.2a	52.2ab	14.50a	32.4a	1.19b	2,393a
	6	5.0b	0.65a	1.47b	0.90a	0.30b	55.4a	90.2a	60.0a	14.00a	31.4a	0.13b	2,321a
	9	6.3a	0.67a	1.72a	0.78b	0.33b	33.2b	85.3a	45.3b	13.50a	26.9a	0.28a	2,239a
P 37	0	3.8b	0.31c	1.15b	0.83a	0.44a	48.8a	62.1b	49.2a	12.55a	27.5a	0.33a	2,067a
	3	4.2b	0.47b	1.22b	0.70ab	0.30b	52.5a	73.5ab	53.2a	13.80a	26.9a	0.08b	2,053a
	6	4.6b	0.51b	1.32b	0.67b	0.24b	44.2ab	76.5a	47.7a	13.40a	24.6a	0.05b	1,826a
	9	6.4a	0.62a	1.53a	0.74ab	0.30b	40.9b	82.9a	53.5a	13.90a	23.1a	0.20a	2,219a
P 40	0	3.4d	0.34b	1.18b	0.71b	0.34a	48.4a	59.9c	42.1b	10.66b	25.4b	0.36a	2,021a
	3	4.8c	0.47b	1.53a	0.70b	0.27a	55.2a	75.2b	37.1b	12.65b	33.3a	0.10b	2,152a
	6	5.3b	0.65a	1.49a	0.96a	0.32a	57.1a	91.9a	64.7a	15.30a	31.0a	0.20b	2,309a
	9	6.2a	0.44b	1.34ab	0.67b	0.34a	34.3b	78.3b	39.1b	11.70b	32.7a	0.43a	2,113a
P 45	0	2.9b	0.28b	0.96a	0.69a	0.36a	40.7a	51.5a	41.3a	10.44a	23.85b	0.46a	1,942a
	3	2.8b	0.25c	0.96a	0.65a	0.32a	40.7a	50.0a	35.6a	10.16a	24.85b	0.34b	1,935a
	6	2.9b	0.28b	1.13a	0.72a	0.36a	46.9a	55.7a	42.6a	10.16a	25.25b	0.33b	1,994a
	9	4.3a	0.30a	1.08a	0.74a	0.34a	45.7a	59.9a	38.2a	11.15a	31.80a	0.31b	2,254a
P NaS	0	2.7c	0.37b	1.30a	0.74a	0.36a	50.8a	63.1b	44.9b	10.75b	25.5b	0.21a	1,947c
	3	4.7b	0.53a	1.36a	0.76a	0.28b	58.8a	79.3a	47.9b	13.45a	30.1a	0.06b	3,523b
	6	4.4b	0.53a	1.41a	0.89a	0.36a	58.1a	84.1a	59.1a	12.05a	26.4b	0.08b	3,706b
	9[x]	5.9a	0.50a	1.08b	0.74a	0.29b	40.3b	83.3a	47.1b	13.28a	29.5a	0.25a	7,116a
Level of significance[w]													
Pellet		***	***	**	**	ns	***	***	***	***	*	**	***
Weight (Wt)		***	***	**	ns	ns	**	**	**	***	**	**	**
Pellet × Wt		***	*	**	ns	*	**	**	*	ns	*	**	**
Suggested ranges[v]		3.5 - 5.5	0.35 - 1.0	2.0 - 8.8	0.8 - 3.0	0.20 - 1.50	30 - 150	60 - 200	50 - 200	5 - 20	30 - 150	0.5 - 5.0	-

[z]Wt: weight of pellets mixed in a growing medium.
[y]Means with the different letter in a column is not significantly different with each other at $P < 0.05$ or 0.01, by HSD
[x]Leaf samples were not sufficient, and therefore pieces of stem were included for foliar analysis.
[w]Non-significant (ns) and significant difference at 5% (*), 1% (**), and 0,1% *(***), F-test. Data from P control was not included in the analysis.
[v]General suggested range set by JR Peters Laboratory.

obtained from plants grown in P con medium was 2.9%, which was similar to the concentration in P 29-0g (3.1%) and P 45-0g (2.9%), P 45 CD-3g (2.8%), and P 45 CD-6g (2.9%), and P NaS CD-0g (2.7%) medium. Nitrogen concentration was significantly increased in P 29-6g, P 32-6g, P 37-6g, P 40-6g, and P NaS-6g medium, except in P 45-6g medium. For example, N concentration of P 37-9g medium was 6.4% which is the highest among all treatments.

Concentrations of phosphorus (P), potassium (K), and calcium (Ca) were also increased in general when 9 grams of pellets were mixed in a medium and of magnesium (Mg) when > 3 grams of P 32 and 37 were mixed in a medium (Table 2). For micro-elements, boron (B) concentration except P NaS-9g medium, iron (Fe) concentration except P 29-6g or 9g medium, and Mn concentration except P 32-6g, P 40-6g medium was significantly higher than other treatments (Table 2). The concentration of copper (Cu) and zinc (Zn) was not affected by the amount of pellets mixed in a medium. The concentration of sodium (Na) was affected by the amount of pellets in a medium, but increased particularly in P 29-9g and P NaS-3g, -6g, and -9g medium. In general, all elements fell within the suggested ranges for each element (JR Peters Lab., Allentown, PA, USA).

The number of primary buds when pellets were mixed at 3 g or 6 g as compared to those without pellets mixed (control) except for P 29-3g and P29-6g plant was increased 27 DAP (Table 3). However, the number of secondary shoots was significantly reduced when plants were grown in a medium mixed with 9 grams of pellets except P 45-9g plant. A significant increase in the secondary flower buds in P

Table 3. Growth and flowering of *Begonia*, 'Bonfire' grown in a growing medium mixed with different amount of pellets (Expt. 1B).

Pellet	Wt[z] (g)	Number of flowers[y] Pri.	Number of flowers[y] Sec.	Number of shoots with flower buds Sec.	Number of shoots with flower buds Ter.	Shoot length (cm)	Leaf color, visual[x]
P 29	0	10.2a[w]	5.2b	3.0ab	0.0b	18.8b	10Y
	3	10.7a	7.3ab	4.4ab	0.2ab	22.4a	10Y
	6	10.7a	8.4a	4.6ab	0.4a	25.7a	10YG
	9	1.7b	1.1c	5.1a	0.6a	23.4a	10YG
P 32	0	9.9a	3.1ab	3.1b	0.0b	19.0b	10Y
	3	10.6a	6.6a	4.0ab	0.0b	22.1ab	10Y
	6	11.3a	9.5a	7.0a	0.6a	24.4a	10Y
	9	-[v]	-	-	-	-	-
P 37	0	10.7a	3.3bc	3.3ab	0.0b	21.3b	10Y
	3	10.8a	5.5b	3.7ab	0.0b	20.3b	9Y, 1YG
	6	11.8a	8.5a	5.7a	1.7a	28.2a	8Y, 2YG
	9	6.0b	1.8c	3.0b	0.1b	17.2b	5G
P 40	0	12.7a	4.5bc	3.2b	0.3b	22.8b	10Y
	3	11.0ab	6.3b	4.3ab	0.1b	23.3b	4Y, 6YG
	6	10.6ab	8.8a	4.8a	2.3a	29.3a	3YG, 7G
	9	8.6b	3.3c	4.8a	0.3b	19.5b	4G
P 45	0	9.6a	2.6a	2.0b	0.2a	18.6a	10Y
	3	10.8a	4.0a	2.9ab	0.3a	19.9a	8Y, 2YG
	6	9.5a	3.7a	2.3b	0.1a	18.1a	10Y
	9	10.6a	2.9a	3.9a	0.3a	18.3a	10Y
P NaS	0	9.7a	3.2b	3.4a	0.0a	17.9b	10Y
	3	11.9a	7.9a	4.2a	0.2a	23.8a	8Y, 2YG
	6	11.5a	7.2a	4.1a	0.4a	23.5a	8Y, 2YG
	9	-	-	-	-	-	-
Level of significance[u]							
Pellet		***	***	**	ns	*	-
Weight (Wt)		***	***	*	ns	*	-
Pellet × Wt		**	**	*	ns	ns	-

[z]Wt: weight of pellets mixed in a growing medium.
[y]Pri. and Sec.: Primary and secondary flowers, respectively, reached to anthesis.
[x]The number of plants with foliage color visually grouped yellow (Y), yellow green (YG), and green (G).
[w]Means with the different letter in a column is not significantly different with each other a at $P < 0.05$ or 0.01, by HSD.
[v]Plants died.

29-6g (8.4 secondary flowers) or P 37-3g (5.5 secondary flowers) or P 37-6g (8.5 secondary flowers) plant as compared to those in P 29-0g or P 37-0g was observed. The number of shoots with the secondary buds was increased in a few treatments, such as P 29-9g (5.1 shoots). However, tertiary shoots with flower buds present did not show a clear trend related to the amount of pellets mixed in a medium. At the termination of the experiment, the length of shoots increased when 6 grams of pellets were mixed, except the P 45-6g plant. Leaf color was greener for P 29-9g, P 32-6g, P 37-6g, and P 40-6g and P 40-9g plant compared to leaf color on plants with or without the 3 grams/pot rate of pellets (Table 3 and Fig. 1). Leaf color of P 45 plant regardless of the amount of pellets mixed in was a more pale green.

The concentration of macro- and micro-elements in leaves except Ca and Mg was not affected by type of pellets and the amount of pellets mixed in a medium and their interaction (Table 4). When pellets were mixed at 6 or 9 g, the total N concentration in P 45 and P NaS was not affected by the amount of pellets mixed in a medium and increased in P 29, P 32, P 37, and P 40 medium. The level of K, Fe, Mn, Cu, and Zn in P 29, P 32, P 37, and P 40 plant was increased significantly when 6 or 9 grams of pellets were mixed in a medium. For example, in P 37-9g plant, the concentration of Fe (62.1 $mg \cdot kg^{-1}$), Mn (36.2 $mg \cdot kg^{-1}$), and Cu (8.51 $mg \cdot kg^{-1}$) was significantly higher when compared to the P 37-0g control plant. Also Fe, Mn, and Cu concentration in P 40-9g plant were also significantly higher than the control. In general, the concentration of N, B, Fe, Mn, Cu, Zn, and molybdenum (Mo) was lower than the lower level of suggested ranges (Expt. 1B).

The number of flowers in the P con plant that reached

Table 4. Analysis data for macro- and micro- elements in a growing medium mixed with different pellets to grow *Begonia* 'Bonfire' (Expt. 1B).

Pellet	Wt[z] (g)	Macro- and micro-elements										
		N	P	K	Ca	Mg	B	Fe	Mn	Cu	Zn	Mo
		(%)					(mg·g^{-1})					
P 29	0	1.09b[y]	0.13a	0.58a	0.52a	0.27a	15.4a	16.5b	16.6a	6.44b	16.0a	0.07b
	3	1.26ab	0.11a	0.44b	0.61a	0.30a	13.5b	19.4b	18.9a	7.61a	15.2a	1.01a
	6	1.46a	0.08a	0.29c	0.57a	0.28a	13.2b	24.4a	21.6a	6.81b	16.7a	0.00b
	9	1.50a	0.09a	0.31c	0.53a	0.23a	13.8b	24.0a	20.7a	8.21a	14.8a	0.04b
P 32	0	0.81b	0.13a	0.49a	0.57a	0.27a	19.1a	18.6b	18.9a	5.73a	18.9a	0.13a
	3	0.96b	0.11a	0.43a	0.60a	0.28a	14.3b	21.5b	20.1a	5.72a	13.9b	0.00b
	6	1.61a	0.10a	.051a	0.51a	0.21a	14.1b	31.0a	20.4a	6.18a	14.7b	0.02b
	9	-[x]	-	-	-	-	-	-	-	-	-	-
P 37	0	1.16c	0.13b	0.53b	0.52b	0.26ab	15.6c	17.8c	18.5b	6.39b	34.2a	0.05a
	3	1.17c	0.10b	0.39b	0.57b	0.30a	12.9c	18.4c	20.1b	6.49b	12.9c	0.03a
	6	2.22b	0.16b	0.53b	0.52b	0.22b	19.5b	39.1b	20.7b	7.17b	15.5c	0.01a
	9	3.80a	0.26a	1.15a	0.73a	0.34a	26.3a	62.1a	36.2a	8.51a	21.0b	0.00a
P 40	0	0.83b	0.13b	0.41c	0.51b	0.26b	16.3b	16.0c	15.4c	5.60b	13.5c	0.04a
	3	0.86b	0.12b	0.37c	0.56b	0.26b	15.1b	18.9c	18.1b	6.98b	16.4b	0.03a
	6	1.41b	0.10b	0.56b	0.51b	0.22b	15.5b	29.4b	19.0b	7.61b	16.0b	0.02a
	9	4.07a	0.31a	1.32a	0.78a	0.36a	31.4a	65.1a	37.8a	18.82a	26.0a	0.00a
P 45	0	0.81a	0.13a	0.60a	0.49a	0.27a	15.6b	14.7a	16.0a	7.01a	13.3b	0.06b
	3	0.83a	0.13a	0.58a	0.46a	0.25a	16.1b	16.7a	15.1a	6.39a	20.1a	0.12a
	6	0.86a	0.13a	0.63a	0.54a	0.30a	19.1a	17.1a	18.3a	6.31a	21.5a	0.02b
	9	0.79a	0.12a	0.49b	0.54a	0.27a	16.6b	15.4a	17.4a	6.27a	12.7b	0.06b
P NaS	0	0.86a	0.13a	0.54a	0.60a	0.29a	18.1a	19.0a	23.6a	5.78a	18.4a	0.10b
	3	0.98a	0.11a	0.46a	0.66a	0.31a	14.8a	20.2a	24.2a	5.90a	15.4b	0.17a
	6	0.92a	0.09a	0.48a	0.62a	0.30a	16.8a	20.7a	22.4a	5.74a	14.6b	0.07b
	9	-	-	-	-	-	-	-	-	-	-	-
Level of significance[w]												
Pellet		***	*	***	ns	ns	**	***	***	***	**	**
Weight (Wt)		***	**	**	ns	ns	**	***	*	*	***	ns
Pellet × Wt		***	*	***	ns	ns	***	***	*	ns	**	ns
Suggested ranges[v]		3.5 - 5.5	0.35 - 1.0	2.0 - 8.8	0.8 - 3.0	0.20 - 1.50	30 - 150	60 - 200	50 - 200	5 - 20	30 - 150	0.5 - 5.0

[z]Wt: weight of pellets mixed in a growing medium.
[y]Means with the different letter in a column is not significantly different with each other at $P < 0.05$ or 0.01, by HSD.
[x]Plants died.
[w]Non-significant (ns) and significant difference at 5% (*), 1% (**), and 0,1% *(***), F-test.
[v]General suggested range set by JR Peters Laboratory.

anthesis was the highest compared to those plants in media mixed with pellets, particularly pellet 32 (P 32 plant) and P 37 plant (Expt. 2; Table 5). For example, the number of flowers open between 24 and 38 DAP was 3.9 on the P con plant and was 1.6 and 1.3 on P 32 and P 37 plant, respectively. The number of flowers open on P 45 plant did not differ greatly from those on the P control plant. The P 32 plant produced the least number of open flowers at each recording period as compared to the P control and P 37 and P 45 plant. P 32 plant produced only 15.0 flowers in 77 DAP that reached anthesis, which was significantly less than the three other treatments.

The number of secondary and tertiary shoots was also low in P 32 plant, particularly at the early growth period between 24 and 59 days (Table 5). However, on Nov. 15, the second shoot length did not differ significantly among the 4 treatments. The fresh and dry weight of the P 32 plant, 28.7 g and 3.0 g was significantly less than those of the control

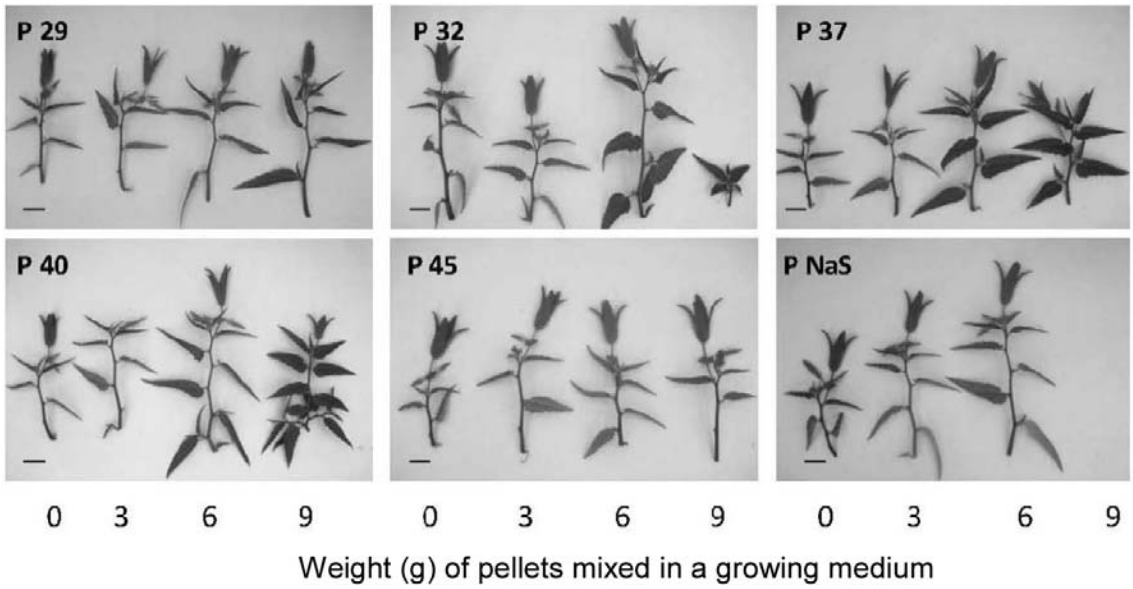

Fig. 1. Growth and flowering response of *Begonia* 'Bonfire' as influenced by pellets and controlled release fertilizer treatment. Plants were grown in P 29, P 32, P 37, P 40, P 45, and P NaS medium. Pellets at 0, 3, 6, and 9 g per 10 cm pot were mixed in a growing medium on June 7 (Expt 2A), and pinched on Aug. 4 (Expt. 1B). Note dark foliage in plants grown in P 32 pellets with 6 grams of controlled release fertilizer (P 32-6g plant), P 37-6g and P 37-9g plant, and P 40-6 and P 40-9 plant. Plants grown in a growing medium mixed with pellet NaS-9 failed to grow. Photographed on Sept. 7, 2010. Bar = 2 cm.

Table 5. Growth and flowering response of *Begonia* as influenced by different pellets mixed with a growing medium. (Expt. 2).

Samp. date (DAP[z])	Pellet (P[y])	Number of Flowers reached to anthesis (DAP)						Number of Shoots[w]		Second shoot length (cm)	Weight (g)[x]	
		24[x]	38	47	59	68	77	Second	Third		fresh	dry
Sept. 13	P con	3.3a[v]						3.3a	0 a	11.9ab	-	-
(24 DAP)	P 32	1.3b						2.7b	0 a	5.4b	-	-
	P 37	2.3ab						2.3b	0 a	9.8ab	-	-
	P 45	0.0b						3.3a	0 a	13.0a	-	-
Oct. 19	P con	2.7a	3.9a	2.1a	2.8b			8.0a	0.3a	26.0a	66.0a	6.4a
(59 DAP)	P 32	0.8b	1.6b	1.7a	2.2b			1.7b	0 a	18.6b	28.7c	3.0b
	P 37	0.0b	1.3b	2.2a	2.2b			6.0a	0 a	19.1b	45.9b	3.4b
	P 45	2.0a	3.4a	2.3a	3.6a			7.3a	0 a	23.1a	68.9a	6.7a
Nov. 15	P con	2.2a	3.0a	3.8a	6.4a	10.1a	34.3a	15.0b	5.3c	34.4a	132.5b	14.5a
(77 DAP)	P 32	0.4b	0.1b	1.0b	3.9c	5.0b	15.0b	14.0b	7.7b	30.1a	109.8c	10.4b
	P 37	0.0b	0.5b	3.0a	7.0a	9.5a	26.3ab	19.3a	9.7a	34.7a	159.5a	16.3a
	P 45	1.8a	3.8a	2.7a	5.3bc	7.8ab	34.3a	16.3b	8.0b	35.6a	150.6a	16.4a
Level of significance[u]												
Samp. Date (SD)		**	*	*	**	-	-	***	***	***	***	***
Pellet (P)		**	**	*	**	**	**	***	***	***	***	***
SD × P		ns	ns	ns	ns	-	-			*	*	*

[z]Days after transplanting. Plants were collected for foliar analysis, and therefore, no further flowering data could be collected.
[y]Growing medium mixed with pellets. P con: control without containing pellet.
[x]Other data were collected when soil and foliar samples were collected; 12, 8, and 4 plants on 24 DAP, 59 DAP, and 77 DAP.
[v]Mean separations is within each sampling date, and means with the same letter are not significantly different from each other at $P < 0.05$ or 0.01, by HSD.
[u]Non-significant (ns) and significant difference at 5% (*), 1% (**), and 0,1% *(***), F-test.

plant, 66.0 g and 6.4 g, respectively, and of the P 37 plant. However, the fresh weight and dry weight of P 37 plant did not differ significantly from those of the control and P 45 plant. The weight of P 32 plant, however, was significantly less than the P control and P 45 plant.

Soil and foliar analysis was presented by the means of three sampling dates (24, 59, and 77 DAP) and four media mixed with pellets. At 24 DAP, the pHs of the media mixed with P 32 and P 37 were 6.1 and 5.8, respectively, and were lower than pH 7.1 in both of the P control and P 45 media

(Table 6). However, at 77 DAP, there was no significant difference in pH among three pellet-mixed media, although it was slightly lower than that of the control. The total soluble salts were higher in P 32 (1.67 dS·m^{-1}) and the P 37 medium (1.71 dS·m^{-1}) as compared to the P control and P 45 medium which was 0.21 and 0.23 dS·m^{-1}, respectively.

The concentration of NO_3-N, K, Ca, Mg, and S was higher in P 32 and P 37 medium than the level of P con medium and P 45 medium 24 DAP. At 24 DAP and 59 DAP, the concentration of NO_3-N, Ca, and S was higher with P 32 and P 37 medium compared to P control and P 45 medium; and at 77 DAP (Nov. 15) (Table 6). However, except for Ca and S, the pH, soluble salts, and most of the macro- and micro-elements did not differ significantly among all media.

Table 6. Analysis for soluble salts (SS) and macro- and micro- elements in a growing medium mixed with different pellets to grow *Begonia* 'Bonfire' (Expt. 2).

Sampling date (DAP[z])	Pellet (P[y])	pH, total soluble salts (SS), and macro-elements (%)								
		pH	SS (dS·m^{-1})	NO_3-N	NH_4-N	P	K	Ca	Mg	S
Sept. 13	P con	7.1	0.21	2	0.8	2.1	13	17	3.5	17
(24 DAP)	P 32	6.1	1.67	128	41.3	5.1	38	170	28.6	82
	P 37	5.8	1.71	158	8.4	5.0	41	220	36.7	68
	P 45	7.1	0.23	2	1.5	2.5	19	18	3.5	16
Oct. 19	P con	6.9	0.23	2	1.0	15.2	53	10	1.4	8
(59 DAP)	P 32	5.6	1.84	172	1.1	11.9	112	210	33.2	55
	P 37	6.1	0.91	73	0.9	9.1	87	85	14.3	36
	P 45	6.5	0.70	49	0.9	8.9	78	58	10.0	26
Nov. 15	P con	6.9	0.09	2	1.7	5.0	22	5	0.4	1
(77 DAP)	P 32	6.2	0.20	2	1.8	1.6	14	15	1.6	17
	P 37	6.3	0.16	2	1.5	2.9	16	16	1.0	14
	P 45	6.5	0.10	5	1.9	3.6	20	6	0.5	3
Level of significance[x]										
Samp. Date (SD)		ns	***	***	***	***	***	***	***	***
Pellet		***	***	***	***	ns	ns	***	***	***
SD × Pellet		ns	***	***	***	***	***	***	***	*

[z]Days after transplanting.
[y]Growing medium mixed with pellets. P con: control without containing pellets.
[x]Non-significant (ns) and significant difference at 5% (*), 1% (**), and 0,1% *(***), F-test.

Table 7. Foliar analysis data for macro- and micro-elements in *Begonia* 'Bonfire' grown in a growing medium mixed with different pellets (Expt. 2).

Sampling date (DAP[z])	Pellet (P[y])	Macro- and micro-elements								
		N	P	K	Ca	B	Fe	Mn	Cu	Mo
		(%)				(mg·kg^{-1})				
Sept. 13	P con	1.4	0.22	1.32	0.62	27.9	35.3	70	9.2	0.56
(24 DAP)	P 32	4.7	0.22	1.18	0.64	25.0	46.4	75	12.4	1.50
	P 37	4.7	0.17	1.70	0.78	31.8	52.9	82	11.5	0.44
	P 45	1.8	0.20	1.13	0.66	28.7	35.8	69	8.9	0.42
Oct. 19	P con	2.2	0.27	2.04	0.61	30.5	40.0	83	8.0	0.52
(59 DAP)	P 32	4.4	0.38	2.43	0.90	35.1	53.5	77	9.4	0.02
	P 37	4.2	0.42	2.78	0.99	41.2	64.0	98	11.1	0.03
	P 45	2.5	0.29	1.93	0.64	32.6	43.2	72	9.7	0.52
Nov. 15	P con	1.4	0.23	1.44	0.62	16.9	43.0	52	9.1	0.64
(77 DAP)	P 32	2.6	0.27	1.49	0.80	23.2	56.5	54	10.9	0.06
	P 37	1.6	0.24	1.59	0.78	17.9	51.3	53	11.1	0.21
	P 45	1.9	0.21	1.35	0.70	16.4	47.4	45	10.2	0.52
Level of significance[x]										
Sampling date (SD)		***	***	***	ns	***	*	***	ns	***
Pellet		***	ns	*	***	ns	***	ns	***	*
SD × Pellet		***	*	ns	ns	ns	ns	ns	ns	***

[z]Days after transplanting.
[y]Growing medium mixed with pellets. P con: control without containing pellets.
[z]Non-significant (ns) and significant difference at 5% (*), 1% (**), and 0,1% *(***), F-test.

Generally the level of NO_3-N (172 mg·L^{-1}), K (11.87 mg·L^{-1}), Ca (112 mg·L^{-1}, and Mg (210 mg·L^{-1}) in P 32 medium was higher 59 DAP as compared to those in other media (Table 6). However, this difference was not observed 77 DAP and the concentration of all macro- and micro-elements fell in the suggested ranges.

Foliar analysis data indicated that N level in P 32 plant and P 37 plant was higher than the level in P control and P 45 plant 24 at 59 DAP; and remained high in P 32 plant at 77 DAP (Table 7). Phosphorus and Mn in P 37 plant was higher 59 DAP. Molybdenum (Mo) showed an elevated level only in P 32 plant at 24 DAP, but decreased at 59 and 77 DAP when compared to plants in other media.

When mean values for soil analysis were calculated and compared, pH was not affected by sampling dates, but by medium types. P 32 (6.0) and P 37 (6.1) medium had low pH values compared to P control and P 45 medium (data not presented). Except for pH and Mo concentration, soluble salts and other macro- and micro-elements in soils sampled 77 DAP were lower than previous sampling dates. P 32 medium had higher soluble salts, NH_4-N, P, K, Ca, and B concentration than P control, P 37, and P 45 medium. The level of pH, soluble salts and levels of elements between P control and P 45 medium did not differ significantly.

When mean values for foliar analysis were calculated and compared, mean N concentrations were higher when sampled on 24 DAP (3.14%) or 59 DAP (3.32%) compared to 77 DAP (1.87%). P 32 (3.89%) or P 37 plant (3.50%) Mean N concentrations were higher in P 32 plant (3.89%) or P 37 plant (3.50%) compared to P control (1.66%) and P 45 (2.06%) plant. The concentration of P, K, B, and Mn in plants sampled at 59 DAP was higher than those sampled at 24 and 77 DAP (data not presented). For example, the concentration of K was higher when sampled on Oct. 19 (2.29%) than on Sept. 13 (1.3%) or on Nov. 15 (1.49%). Although some differences are observed in Fe (> 52.1 mg·L^{-1} in P 32 and P 37 plant compared to < 41.2 mg·L^{-1} in P control and P. 45 plant), the concentration of elements were not significantly different among the 4 media (Expt. 2).

Discussion

Most large scale greenhouse floral and nursery crops are grown in petroleum based plastic pots. Recently, physical properties of several types of biodegradable pots such as rice-hull based pots and containers have been evaluated (Evans et al., 2010). These reports indicated that plants were grown successfully in media containing up to 30% feather fiber (Evans, 2004; Evans and Hensley, 2004). Tomato plant grown in pots with ground feathers (Tyson, Inc., Springdale, AR) had higher N concentration in the tissue and higher dry weight (Evans, 2004). However, production of the prototype models has been discontinued. (Personal communication, Hickman, 2011).

No information is available concerning how various pellets mixed into a medium affect plant growth and flowering, let alone pots made of these pellets. It is desirable to find whether or not macro- and micro-elements may be released from pellets during the course of culture. Therefore, chemical properties of 6 different pellets, P 29, P 32, P 37, P 40, P 45, and P NaS was investigated (Roh et al., 2012) and of medium mixed with above pellets were evaluated by observing the growth, flowering, and analyzing foliar analysis of begonia.

Considering a high concentration of NH_4-N in P 32, P 37, and P 40 containing > 20% glycerol and also high P and K level in P 37, P 29 and P 45 containing < 10% glycerol can be considered suitable for plant growth when mixed in medium at the rate of 8 grams of pellets per 95 grams of medium. Glycerol, due to its hydroxyl groups, is miscible with water (http://www.dow.com/glycerine/resources/solubility.htm; accessed on July 5, 2011) and glycerol released from P 32, P 37, and P 40 may be the cause of poor growth, particularly at an early growth and development stage of begonia, if glycerol is rapidly released to a medium. The growth of wheat grass in soil/composed mixture containing 60 grams of 10% spiked glycerine mixed with 120 grams of soil is, however, better than that without glycerine (Wee and Obbard, 2011). The addition of 10^{-1}M glycerol with auxin promotes shoot formation per cell mass of *Grateloupia doryphora* in vitro (Garcia-Jimenez et al., 1998). Therefore, poor growth of begonia may not be attributed only to the level of glycerol in the pellets. The inhibitory effect in P 37 medium on plant growth could also be related to the addition of Biomax as a strengthening additive which improves the performance of compostable polylactic acid (PLA) (http://www2.dupont.com/Biomax/en_US/assets/downloads/Biomax%20Strong.pdf). However, no information is available about how these additives might affect growth and development of plants.

The low pH of P NaS medium, which is outside of the suggested range, is also considered responsible for poor growth. The low pH may result from acidification by available NH_4-N in the medium. Increased soil concentration of NH_4-N following drip irrigation with ammonium based fertilizer acidified soil pH from 5.8 to 4.5 in gravelly sandy loam soil (Parchomchuk et al., 1993). The source of NH_4-N and NO_3-N should be from feather fibers which contains > 13% of total nitrogen (Choi and Nelson, 1996b). However, the pH of P control and P 45 medium, which is higher than the upper limit by about 0.5 pH unit of the suggested range, did not affect plant growth. Therefore, *Begonia boliviensis* can be grown well in pH around 6.8. Although pH > 6.0 reduced the number of inflorescences in *Begonia albopicta* W. Bull., but not in *B. holtonis* A. DC., it was concluded that six

Begonia species were not susceptible to high pH rather than low medium pH and (Jeong et al., 2010). High N concentration in leaves grown in pellet mixed medium was > 5.7% and high in copper (Cu) concentration in P 29, 32, 37, and P 40 medium may require adjustment of fertilizer application, if the pellets release these elements. Although the concentration of molybdenum (Mo) is low, there was no any Mo deficiency symptoms noticed.

Based on the foliar analysis of P 29, P 32, P 37, P 40, and P NaS plant as compared to P 45 plant, > 6 grams of pellets may release nitrogen to the medium evidenced by increased N concentration in the leaves, which may be derived from the slowly released N from feather fibers (Choi and Nelson, 1996a, 1996b), the release of N from P 45 is considered minimal. Although all other elements fall in the suggested ranges, care may be needed to supplement K and Ca, although no deficiency symptoms in begonia were observed for K and Ca, except for yellow leaves resulting from low N concentration optimum ranges for begonia should further be defined. In *Begonia* × *semperflorenscultorum*, Jeong et al. (2010) reported that 4.0% N concentration is considered an optimum level in *B. boliviensis*; if so, additional N fertilizer is needed with P 29-3g, P 45-3g and -6g.

Due to the presence of controlled release fertilizer in the medium, availability of elements from pellets could not be analyzed in Expt. 1A and 2B. and during these 67 days after application of controlled release fertilizer in Expt. 1A, the amount of nutrients from the pellets could not be evaluated. Therefore, controlled release fertilizer was not applied in Expt. 2 and only water soluble fertilizer was supplied; with soil and foliar analyses performed over the period of evaluation, i. e., 24, 59, and 77 DAP. The foliar analysis of begonia grown in various pellet mixed media was higher when leaf tissues were collected 40 DAP (Expt. 1A).

Slow growth and delay in the flowering of P 32 and P 37 plant at the early 24 DAP stage could not be solely explained in terms of pH of the medium as discussed above. Plants can absorb both NH_4-N and NO_3-N at equal rates at a pH of 6.8 (Michael et al., 1965), and high NO_3-N concentration in P 32 and P 37 medium may be responsible for an initial poor growth at pH around 6.0 in this study since NO_3-N levels in P 32 medium remained high 59 DAP (8 weeks after transplanting). High NO_3-N level in P 32 medium may suggest that P 32 could be the source of NO_3-N since the level in other media is low. In three leafy vegetables, including spinach, (*Spinacia oleracea* L.), significant growth inhibition was observed when NO_3-N supply was higher than 0.45 g N·kg^{-1}. Soluble salts levels at all sampling dates were < 1.84 (P 37 medium, which is lower than the maximum level of non-saline conditions (http://www.extension.umn.edu/distribution/horticulture/components/1731-5-solublesalts.pdf) for seed germination, plant growth and flowering. Therefore, the delay in flowering in P 32 and P 37 plant is considered not related to the total soluble salts level. The optimum medium pH for six *Begonia* was reported between 5.7 and 6.3, with pH below 5.2 (Jeong et al., 2010), or 5.5 should be avoided to prevent necrosis and small leaves in *B. echinosepala* var. *elongatifoliosa* (Cavins et al., 2000). The pH level of P control medium 24 DAP, which corresponds to the early growth, was 7.1, which is higher than the optimal level for most begonias, and the pH level of Pro-Mix BX (5.2-6.2) (Anonymous, 2011). No physiological disorders or malformation in growth of leaves were observed at all, and pH level falls in the acceptable range by 24 DAP; however, vegetative and reproductive growth was still poor 59 DAP, as compared to the P control plant.

The high N concentration in P 32 and P 37 plant indicate that NH_4 and NO_3 are absorbed at the early stage of growth (during the first 8 weeks of culture), and then leached out to a level similar to P control and P 45 medium at a later stage of growth. Since the level of NH_4 and NO_3-N in the medium did not differ significantly regardless of the addition of three pellets, it is concluded that conversion of NH_4-N to NO_3-N and leaching of NO_3-N from the medium may occur 59 DAP. Leaching of NH_4-N to NO_3-N and other elements from pellets and pots made of pellets will be reported in a subsequent publication.

In conclusion, based on the physical and chemical analysis of six pellets, P 32, P 37, and P 40 which contain 20% of glycerol and P NaS containing sodium sulfite and 30% glycerol is not recommended for future evaluation and should be excluded to utilize pellets to prepare pots. Poor growth and development of *Begonia* 'Bonefire' grown in P NaS medium is not solely considered responsible for high pH and particularly K and S concentration among other macro-micro elements. Mixing P 45 which does not contain glycerol with 30% feather fibers with a medium is recommended for further evaluation. Based on this study, glycerol even at 10% is considered not suitable to use as an ingredient to process pellets. Based on the pH, soluble salts level, and macro- and micro-elements in P 45 medium and subsequent plant growth, the use of P 45 is the best source of pellets, if nitrogen is supplied constantly to support plant growth. Pellets prepared following mixing > 30 feather fibers without using glycerol should be further tested.

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58-3K95-6-1146. Mention of a trade, name, proprietary product, or specific equipment does not constitute a guarantee or warranty by the US Department of Agriculture and does not imply its approval to the exclusion of other products that may be suitable.

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