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Effect of block co-polymer blended surfactants on substrate wettability and relative phytotoxicity of impatiens and pansy

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Abstract

Surfactant formulations consisting of proprietary blends containing sulfonic acid ester ethylene oxide/propylene oxide block co-polymer blend (ACA3204-R and ACA3204-P); sulfonic acid ester ethylene oxide/propylene oxide block copolymer blend with polyethylene glycol addition (ACA3204-2a), and ethoxylated alkylphenol (ACA160) were tested for wettability of peat-based substrates and for relative phytotoxicity. Substrate incorporation rates used in this study were 116 mL m^{-3} (a low recommended rate), 232 mL m^{-3} (a moderate recommended rate), and 464 mL m^{-3} (a supra-optimal rate). After a third wetting cycle, substrates incorporated with ACA3204-R, ACA3204-P, or ACA160 at 232 mL m^{-3} had higher wettability ratings than the Pro-Mix HP control (Premier Horticulture Inc., Quakertown, PA). There were no differences in shoot dry weight (SDW) or visual root health rating (VRHR) among treatment groups of impatiens (*Impatiens walleriana*) compared to the control. For pansy (*Viola* × *wittrockiana*), Pro-Mix-HP control-grown plants had higher SDW (0.8632 g $shoot^{-1}$) than ACA3204-R at 464 mL·m^{-3} (SDW = 0.6266 g $shoot^{-1}$) but SDWs for ACA3204-P, ACA3204-2a and ACA160 were similar to the control at all rates. Compared to the control, pansy VRHRs declined at 464 mL m^{-3} for all surfactants except for ACA160. In general, higher rates of surfactant increased mean days to 50% germination (D_X; an inverse measure of germination rate) compared to distilled water control for pansy but this effect was less pronounced for impatiens. There appeared to be a stimulatory seedling effect on mean pansy root length for ACA3204-R and ACA3204-P (rates = 300-1200 ppm) and for ACA3204-2a (rates = 600-1200 ppm). In conclusion, surfactant formulations ACA3204-R, ACA3204-P, ACA3204-2a, and ACA160 were comparatively non-phytotoxic at moderate rates of substrate incorporation (mature plant growth) but laboratory seed germination was affected by low concentrations. ACA3204-R had similar wettability rating to that of ACA160 following the third wetting cycle. Further testing with additional plant species and substrates would aide in evaluating the usefulness of newer horticultural surfactants.

Key words: Growing media, wetting agent, hydrophobicity, peat, bark, mix manufacturers

Introduction

Horticultural surfactants are routinely added by professional potting mix manufacturers to enhance hydration properties of plant growing media. Although there is limited research in this field of study, surfactants (~ wetting agents) are thought to enhance plant quality, increase plant survivability and/or reduce evaporative water loss (Bhat *et al*., 1989; Bhat *et al*., 1990; Boodley and Newman, 2009; Blodgett *et al*., 1993; Million *et al*., 2001). Non-ionic surfactant addition delayed wilting and increased water retention for petunia (*Petunia* × *hybrida)*, chrysanthemum (*Dendranthema grandiflora*) and impatiens (*Impatiens walleriana*) (Million *et al*., 2001). Some surfactant applications may result in cell necrosis, browning and/or general phytotoxicity (Czarnota and Thomas, 2013; Knoche *et al*., 1992). The widespread use of surfactants in multiple industries and subsequent biological and environmental effects are a significant concern (Rebello *et al*., 2014).

Patented surfactant technologies includes non-ionic alkylene oxide copolymer plus minor amounts of terpenic alkoxylate (Stock *et al*., 2015), alkyl polyglycoside plus ethylene oxide-propylene oxide block copolymer (Kostka and Bially, 2005), polyoxyethylene alkylphenol, polyoxyethylene glycol, polyoxyethylene monofattyacid ester, polyoxyethylene-polyoxypropylene glycol ethylenediamine and polyoxyethylene-polyoxypropylene-polyoxyethylene glycol (Ogawa *et al*., 1999). Many media 'wetting agents' consist of polyoxyethylene esters, ethoxy sulfates or a variation of these components (Czarnota and Thomas, 2013). Polyoxyethylene (=alkylphenol ethoxylate) and block co-polymers may also be used (Zontek and Kostka, 2012). An example of a common block copolymer is polyethylene oxide and polypropylene oxide (Alexandridis, 1997). Wetting agents are added to substrates to increase water lateral movement and overcome hydrophobicity by improving penetration and water-holding capacity (WHC) of the growing media (Blodgett *et al*., 1993). Some of the direct benefits include improving physical properties of the substrates, enhancement of wetting ability of peat-based mixes, rapid drainage, and reduction of evaporation (Boodley and Newman, 2009; Urrestarazu *et al*., 2008). A wetting agent increased effective water holding capacity in rockwool-peat substrates (Elliott, 1992). The efficacy of an alkyl polyglucoside/polyalkylene block copolymer blend in several bark-based nursery substrates was evaluated and, after observing increases in wettability for some substrates, it was concluded that blends have potential uses within the horticultural industry (Olszewski *et al*., 2008).

The objective of this research was to investigate proprietary surfactant (wetting agent) blends for use in commercial peat-based mixes, specifically, wettability and phytotoxicity in pansy (*Viola* × *wittrockiana*) and impatiens (*Impatiens walleriana*).

Materials and methods

Plant materials and test surfactants: Three proprietary surfactant blends from Aquatrols Corporation of America (Paulsboro, NJ) were evaluated for substrate wetting capabilities and relative phytotoxic effects. ACA160, an alkyl phenol ethoxylate-derived product sometimes used in horticultural mixes, was used as a control. See Table 1 for list of surfactants. The phytotoxicity study analyzed plug transplants of impatiens (*Impatiens walleriana* 'Super Elfin White'); grown from seed (Park Seed; Greenwood, SC) and pansy (*Viola* × *wittrockiana* 'Majestic Giants II Clear Purple'); plugs (obtained from C. Raker & Sons, Inc.; Litchfield, MI). Pansy Majestic Giants II Clear Purple' pansy (*Viola* x *wittrockiana*) plug transplants were selected based on time-of-year commercial availability. Seed used in germination experiments included impatiens and pansy (*Viola* × *wittrockiana* 'Colossus hybrid neon violet with blotch') which were obtained from Park Seed (Greenwood, SC).

Substrate materials and preparation: Test substrates consisted of 3:2 peat:coarse perlite mix blended with dolomitic limestone (6.526 kg m^{-3}), 0-45-0 superphosphate pulverized powder (0.297 kg m^{-3}), calcium sulfate (0.543 kg m^{-3}), MicroMax micronutrients (0.543 kg m^{-3}), calcium nitrate (0.297 kg m^{-3}), potassium nitrate (0.297 kg m^{-3}), and surfactant (116, 232 or 464 mL m^{-3}). Surfactants were mixed with distilled water and sprayed on media spread on a rectangular plastic sheet; media were hand-mixed during surfactant spray applications. Soilless media mixes were prepared in 10 liter batches and were blended for a total of six minutes within a cement mixer. Promix-HP (Premier Tech Horticulture; Quakertown, PA) was used as a commercial mix control. Six week old impatiens plugs and purchased pansy plugs were transplanted into pots containing surfactant-treated test substrate. All treated test media had pH values between 5.5 to 5.9 and electrical conductively (EC) between 600 to 900 µS cm^{-1}. The pH of the commercial medium was 6.6 and the EC was 677 µS·cm^{-1}.

Wettability of substrates: Surfactant efficacy in substrates was determined by a modification of Walden *et al*. (2000). All evaluations took place when media moisture content was approximately 30% (weight:weight basis) as determined using an IR-35 moisture analyzer (Denver Instrument Company, Denver, CO). Surfactant-treated substrate contained within a 8.7 cm (length) x 10.0 cm (outside rim diameter) standard round pot was irrigated with 300 mL distilled water and, following drainage, substrate leaching fraction (LF) was calculated as the volume of water leached divided by 300 mL and, then, multiplication by 100. Visible wetting ratings of substrates were evaluated as per Olszewski *et al*. (2008). Irrigated substrates were dried back at laboratory conditions to original moisture content to determine the cumulative effect of successive dry-back events on media efficacy. Subsequent evaluations were similar to the first wetting cycle.

Table 1. List of surfactants tested and experimental designations

Test Surfactant	Designation
Sulfonic acid ester and EO/POblock copolymer proprietary blend#1	ACA 3204-R
Sulfonic acid ester and EO/POblock copolymer proprietary blend#2	ACA 3204-P
Sulfonic acid ester and EO/POblock copolymer with propylene glycol proprietary blend#3	ACA 3204-2a
Ethoxylated alkylphenol (99%)	ACA 160

Phytotoxicity experiment #1 (Surfactant effects on plug transplants): Substrates were treated with surfactants as previously described at concentrations of 116, 232, or 464 mL m^{-3}. Plugs (size = 288 cells per tray) were grown as described previously and transplanted into standard 3.5 inch tall x 4 inch diameter (8.89 x 10.16 cm) pots. Shoot dry weight (g $shoot^{-1}$) and root health rating (1 to 5; 5 = Excellent root health; 4 = good root health; 3 = moderate root health; 2 = poor root health; 1 = dead) of pansy and impatiens were evaluated at 52 and 58 days, respectively, after transplanting plugs.

Phytotoxicity experiment #2 (Surfactant effect on seed germination: Germination blotters (Seedboro Equipment Company; Des Plaines, IL) were moistened with 20 mL of distilled water or test surfactant and contained in 125 x 80 x 20-mm transparent polystyrene boxes with tight-fitting lids at constant temperatures. Surfactants solutions included 150, 300, 600 and 1200 ppm (vol.:vol. basis) dilutions. Germination conditions of 20 °C and light were selected based on International Seed Testing Association (2010) recommendations for impatiens. Germination conditions of 20 °C and dark incubation were selected based on Park Seed (Greenwood, SC) recommendations for pansy. Each polystyrene box contained 50 seeds and there were three replications (boxes) per treatment arranged in a completely randomized block design. The number of seeds germinated (those having a visible radicle) were counted daily and removed. From these counts, final germination percentage (FGP) was determined and square root transformation performed according to Gomez and Gomez (1984). Mean days to 50% germination was calculated (Orchard, 1977) using the equation $D_x = \sum fx/\sum f$ where D_x = mean days to 50% germination; where 'f' number of seeds germinate on day 'x'. Data, where appropriate, were subjected to analysis of variance (ANOVA) using PROC GLM (SAS 9.3; SAS Institute, Inc., Cary, North Carolina, USA) with mean separation by Duncan's Multiple Range Test.

Phytotoxicity experiment #3 (Surfactant effect on early seedling root length): Slant test modification of Smith *et al.* (1973) was used to assess the effect of surfactants on early seedling root growth. One cut germination blotter No. 385 was placed into a polystyrene box. Each blotter was soaked in 150, 300, 600 or 1200 ppm surfactant solution (vol.:vol. basis) until saturation. Fifteen impatiens or pansy seed were placed about 1 to 2 cm from the top of each box and oriented such that radicular embryo end was oriented in a downward direction. Then, polystyrene boxes were placed at an approximately 70° angle throughout the test. Incubation chamber conditions were similar to that described previously. There were three replicates per treatment.

Statistical analysis: Growth chamber experiments were designed as randomized complete block design (RCBD) with three replications for each treatment. Greenhouse potted plant experiments were designed as RCBD with six replications for each treatment (single pot replicates). All data were subjected to analysis of variance. Percentage data were square root or arc sine square root transformed (arc sine √%) according to Gomez and Gomez (1984) and means were separated by Duncan's Multiple Range Test ($P \leq 0.05$), where appropriate. For the media wetting test, significances were analyzed as a 4 × 3 × 3 factorial (surfactant × rate × wetting cycle) experiment.

Results and discussion

Irrigation of prepared substrates treated with test surfactants indicated that there was a significant interaction ($P \leq 0.001$) of surfactant × rate of surfactant × wetting cycle for leaching fraction and for wettability rating (Table 2). Among test surfactants, ACA3204-R displayed the highest wettability over three successive wet-dry cycles. Following three successive drying cycles, leaching fraction and wettability rating for ACA3204-R was similar to that of ACA160. Excessive leaching occurred when ACA3204-2a was used, and treatments resulted in nonuniform wetting after the second wetting cycle (54% and 45% leaching fraction at 232 and 464 mL·m^{-3}, respectively). Relative humidity is a factor affecting water repellency of soils (Doerr *et al*., 2002). Higher water holding capacities were noted at lower concentrations in new coir waste and rockwool (Urrestarazu *et al*., 2008). Leaching fraction was consistently lower for ACA3204-R at 116 to 464 mL·m^{-3} (range = 20 to 36%) than to other surfactants tested. Wettability of different sources of bark-based substrate had different wettability ratings when similar surfactants were applied; leaching fractions also can be variable and trends can be linear or quadratic with concentrations of surfactant (Olszewski *et al*., 2008).

There were no impatiens shoot dry weight or visual root health rating differences between Pro-Mix HP (control) and any treatment (Table 3); however, at the 464 mL·m^{-3} rate, only ACA1 60 had visual root health ratings similar to the control in pansy. Among the test surfactants, ACA3204-2a displayed phytotoxic effects to roots (lowered VRHR) at a moderate rate (232 mL·m^{-3}) of substrate incorporation compared to Pro-Mix BX control while pansy shoot dry weight declined at a high rate (464 ml·m^{-3}) of ACA3204-R incorporation. Poinsettia (*Euphorbia pulcherrima* Willd. ex Klotzsch) plant growth parameters including height, spread, and rooting declined linearly with increasing concentrations of a surfactant consisting of 0.47:0.06:0.47 polyoxyethylene esters of alkylated phenols : silicone antifoam emulsion : other components (Bhat *et al*., 1992).

Surfactants at any rate had no effect on pansy seed final germination (Table 4). Compared to distilled water control, all surfactant treatments at 600-1200 ppm slowed the rate of pansy germination (increased $D_{\bar{x}}$). At all solution rates, ACA160 surfactant affected final germination percentage of impatiens while all other treatments had no effect on this parameter. ACA3204-P did not affect impatiens $D_{\bar{x}}$ at any treatment rate while ACA160 increased $D_{\bar{x}}$ at all test rates. Tomato (*Lycopersicon esculentum*) seed germination decreased following incubation in 2000 mg L^{-1} test solutions of polyethylene glycol nonyl-phenol compared to the control (Urrestarazu *et al*., 2008). Interestingly, all test surfactant formulations enhanced mean root length for germinated pansy seedlings compared to seeds germinated in distilled water (Table 5). Evaluation of impatiens seedling mean root length indicated that ACA3204-P at 150-600 ppm and ACA3204-2a at 150-1200 ppm were similar to that of the control, ACA3204-R additions resulted in decreased mean root length at any concentration, and ACA160 was similar to that of the control at 150 ppm. For cress (*Lepidium sativum* L.), seedling root length measurement was a more sensitive measure

Table 2. Effects of ethoxylated alkylphenol (ACA160) and blended surfactants (ACA3204-R, -P, and -2a) on leaching fraction percentage (%) and wettability rating (1 to 5; 1 = less than 10% of substrate wetted following irrigation; 5 = all or nearly all of substrate wetted following irrigation) following 116, 232 and 464 mL m^{-3}, respectively; incorporation and three successive wetting cycles

Surfactant	Rate (mL m^{-3})	Leaching fraction percentage Wetting cycle			Wettability rating number (1 to 5) Wetting cycle		
		1	2	3	1	2	3
Pro-Mix HP (control)	---	43 (41) c	42 (40) bc	44 (42) abc	4.0 c	4.3 ab	3.0 bc
ACA3204-R	116	26 (31) efg	29 (32) de	36 (37) cd	5.0 a	5.0 a	4.0 ab
	232	25 (30) efg	26 (31) de	28 (32) de	5.0 a	5.0 a	5.0 a
	464	21 (27) g	20 (27) e	26 (30) ef	5.0 a	5.0 a	4.7 a
ACA3204-P	116	59 (50) a	40 (39) bc	47 (43) ab	3.0 d	4.3 ab	2.7 c
	232	23 (29) g	22 (28) e	40 (39) bc	5.0 a	5.0 a	4.3 a
	464	24 (29) fg	21 (27) e	29 (32) de	5.0 a	5.0 a	5.0 a
ACA3204-2a	116	36 (37) cd	23 (29) de	18 (25) f	4.3 bc	5.0 a	5.0 a
	232	32 (34) de	54 (47) a	52 (46) a	5.0 a	3.0 c	2.7 c
	464	24 (30) fg	45 (42) ab	49 (44) ab	5.0 a	4.0 b	2.7 c
ACA160	116	51 (45) b	33 (35) cd	41 (40) bc	4.0 c	5.0 a	4.0 ab
	232	39 (38) c	23 (29) de	22 (28) ef	4.7 ab	5.0 a	4.7 a
	464	30 (33) def	42 (40) bc	23 (28) ef	5.0 a	4.3 ab	5.0 a
Significances							
Surfactant (SF)		(ns)	-----	-----	***	-----	-----
Rate (RT)		(***)	-----	-----	**	-----	-----
Wetting Cycle (WC)		(***)	-----	-----	***	-----	-----
SF x RT		(***)	-----	-----	***	-----	-----
SF x WC		(***)	-----	-----	***	-----	-----
RT x WC		(***)	-----	-----	***	-----	-----
SF x RT x WC		(***)	-----	-----	***	-----	-----

Leaching fraction and wettability rating determined for 8.89 cm tall x 10.16-cm diameter pots following addition of 300 mL distilled water. Substrates were dried back to 30% moisture (wt:wt) before commencing test at each wetting cycle. Leaching fraction was calculated based on the volume percentage leached through the container after adding 300 mL distilled water. Wettability rating was ratings by Olszewski *et al*. (2008) where '1' equals less than 10% aggregated substrate following irrigation and '5' equals all or nearly all substrate wetted following irrigation.

ns: not significant; *** $P < 0.001$; ** $P < 0.01$.

Table 3. Shoot dry weight (g shoot^{-1}) and root health rating (1 to 5) of 'Majestic Giants II Clear Purple' pansy '(*Viola* x *wittrockiana*) and 'Hybrid Super Elfin White' impatiens (*Impatiens walleriana*) 52 and 58 days, respectively, after transplanting 288-size plugs treated with ethoxylated alkylphenol (ACA160) or blended surfactants (ACA3204-R, -P, and -2a)

Surfactant	Media incorporation rate (mL m^{-3})	Pansy		Impatiens	
		Shoot dry weight (g·shoot^{-1})	Visual root health rating (#)	Shoot dry weight (g·shoot^{-1})	Visual root health rating (#)
ACA3204-R	116	0.8415 abc	4.0 ab	1.4231 a	3.7 b
	232	0.8769 ab	3.7 abc	1.6654 a	4.3 ab
	464	0.6266 c	2.8 bcd	1.3105 a	4.0 ab
ACA3204-P	116	0.7955 abc	3.7 abc	1.7257 a	4.8 a
	232	0.9403 a	3.7 abc	1.7458 a	4.8 a
	464	0.6997 bc	2.5 cd	1.3935 a	4.2 ab
ACA3204-2a	116	0.9258 a	3.7 abc	1.4595 a	4.5 ab
	232	0.6763 bc	2.3 d	1.4917 a	4.8 a
	464	0.7427 abc	2.3 d	1.8484 a	4.8 a
ACA160	116	0.8111 abc	4.0 ab	1.9039 a	5.0 a
	232	0.7660 abc	3.5 abcd	1.3840 a	4.2 ab
	464	0.8538 ab	3.2 abcd	1.4486 a	4.3 ab
Pro-Mix HP (control)	-----	0.8632 ab	4.2 a	1.1481 a	4.2 ab

Peat-perlite mix consisted of 3:2 peat:coarse perlite mix blended with dolomitic limestone (6.5 kgm^{-3}), 0-45-0 superphosphate pulverized powder (0.3 kg m^{-3}), calcium sulfate (0.6 kg m^{-3}), MicroMax micronutrients (0.6 kg m^{-3}), calcium nitrate (0.3 kg m^{-3}), potassium nitrate (0.3 kg m^{-3}), and test surfactant (116, 232, or 464 mL m^{-3}). Six single plant replicates were used to determine each mean. Duncan's multiple range test was used to separate means; a similar letter indicates no statistical significance. Dry weights were determined by convection oven at 70 °C for two days.

Table 4. Final germination percentage (FGP) and its angular transformation (degrees) or square root transformation (√) and mean days to 50% germination (D_x) of pansy 'Colossus Hybrid Neon Violet with Blotch (*Viola wittrockiana*) and impatiens 'Hybrid Super Elfin White' (*Impatiens walleriana*) after incubation for 20 days at 20 °C under light (impatiens) or dark (pansy) conditions grown in ethoxylated alkylphenol (ACA160) or blended surfactant (ACA3204-R, -P, and -2a) solutions

Surfactant	Concentration (ppm)	Pansy		Impatiens	
		FGP % (√)	$D_{\bar{x}}$ (days)	FGP % (√)	$D_{\bar{x}}$ (days)
ACA3204-R	150	98 (9.8995) ab	5.5 efg	93 (75) ab	5.9 cd
	300	99 (9.9638) a	6.4 defg	91 (72) ab	6.8 bc
	600	99 (9.9300) ab	6.3 defg	92 (74) ab	6.7 bc
	1200	96 (9.7952) ab	6.5 defg	95 (78) ab	6.3 cd
ACA3204-P	150	96 (9.7956) ab	4.9 gh	91 (73) ab	5.8 cd
	300	98 (9.8978) ab	5.9 efgh	95 (79) ab	6.1 cd
	600	95 (9.7610) ab	6.8 cdefg	95 (80) ab	5.9 cd
	1200	95 (9.7249) ab	8.5 bcd	87 (69) bc	6.2 cd
ACA3204-2a	150	99 (9.9638) a	6.2 defg	92 (74) ab	6.0 cd
	300	97 (9.8636) ab	5.3 fgh	91 (73) ab	5.8 cd
	600	96 (9.7952) ab	7.0 cdefg	97 (81) a	6.2 cd
	1200	93(9.6562) ab	8.9 abc	96 (79) ab	6.9 bc
ACA160	150	98 (9.8958) ab	7.4 cdef	77 (62) cd	6.7 bc
	300	95 (9.7630) ab	10.4 ab	71 (58) d	7.8 ab
	600	95 (9.7281) ab	7.7 cde	44 (42) e	8.2 a
	1200	91 (9.5501) b	10.9 a	24 (29) f	8.7 a
Distilled water (control)	---	98 (9.8995) ab	3.9 h	93 (75) ab	5.3 d

Concentration calculated on vol.:vol. basis. Transformations as per Gomez and Gomez (1984). Mean separation by Duncan's Multiple Range Test by column indicated by a different letter. $D_x = \sum fx/\sum f$ where D=estimated mean days to 50% germination and f = number of seeds germinated on day x (Orchard, 1977).

of phytotoxicity than percentage seed germination; cress root length decreased following growth in 20 mg·L^{-1} test solutions of polyethylene glycol nonyl-phenol compared to the control (Urrestarazu *et al.*, 2008).

Some surfactants such as dioctyl sodium sulfosuccinate impart excellent wetting qualities to bark substrates but were more phytotoxic to cucumber (*Cucumis sativus*) germination than other surfactants (Airhart *et al.*, 1980). Alkylphenol ethoxylates are widely used and may have environmentally toxic properties (Rice *et al.*, 2003; Renner, 1997). Thus, there is a need for less toxic chemicals, including reduced phytotoxicity and reduced environmental toxicity, and increased or equivalent efficacy

Table 5. Mean root length (mm) yield measurements of pansy 'Colossus Hybrid Neon Violet with Blotch (*Viola wittrockiana*) and impatiens 'Hybrid Super Elfin White' (*Impatiens walleriana*) following slant test incubation for 15 and 17 days, respectively, at 20 °C under light (impatiens) or dark (pansy) conditions grown on ethoxylated alkylphenol (ACA160) or blended surfactant (ACA3204-R, -P, and -2a) treated blotters

Surfactant	Concentration (ppm)	Pansy mean root length (mm)	Impatiens mean root length (mm)
ACA3204-R	150	13 ± 2	5 ± 1
	300	14 ± 1	6 ± 1
	600	15 ± 3	6 ± 1
	1200	14 ± 1	5 ± 2
ACA3204-P	150	12 ± 2	8 ± 2
	300	15 ± 3	7 ± 2
	600	16 ± 1	7 ± 1
	1200	14 ± 2	6 ± 1
ACA3204-2a	150	11 ± 1	9 ± 1
	300	12 ± 2	10 ± 1
	600	14 ± 1	7 ± 1
	1200	18 ± 1	8 ± 2
ACA160	150	12 ± 3	8 ± 3
	300	7 ± 1	4 ± 1
	600	5 ± 1	2 ± 1
	1200	4 ± 1	1 ± 0
Control	---	10 ± 1	8 ± 0

Concentration calculated on vol.: vol. basis. Mean ± standard deviation. Mean root lengths were determined by using three replicates. The mean for each replicate was determined by sowing 15 seed on a slanted blotter and measuring root length after approximately two weeks; then, root lengths within each replicate were averaged. During the experiment and following initial saturation of blotters with test solutions, any dried blotters were replenished with distilled water. All test surfactants were dissolved in distilled water prior to adding to single layer blotters contained in rectangular polystyrene boxes.

within substrates. Considering the results of this study, test surfactants ACA3204-P and ACA3204-2a were as safe or safer than ACA160 to impatiens and pansy. Results for ACA3204-R indicated that it was more phytotoxic than either ACA3204-P or ACA3204-2a. Conversely, ACA3204-R was more effective at wetting and leaching reduction than either ACA3204-P or ACA3204-2a; ACA3204-R had similar wetting properties as ACA160 but had less leaching after the first and second wetting cycles.

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