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Efficacy of Flurprimidol and Peat Alternatives on Growth Control of Potted Camellias

Andrea Berruti, Valentina Scariot[1]

E-mail: andrea.berruti@unito.it, valentina.scariot@unito.it

Department of Agricultural, Forest and Food Sciences, University of Turin, Via Leonardo da Vinci, 44 – 10095 Grugliasco, Turin, Italy

[1]Corresponding author: e-mail - valentina.scariot@unito.it

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Abstract

Potted camellias tend to grow more than desired and sometimes in association with poor flowering. Growth regulators of the triazole group have been successfully applied to overcome these issues in the past; however, recent restrictions on the group indicate that new growth retardants must be considered and tested. Concurrent with this change is the need to reduce the horticultural use of peat (potting mixture), a world resource being quickly depleted. Given these two aims, we evaluated the efficacy of flurprimidol, in combination with three peat alternatives (reused nutshells, rice husk, coconut fibres), to control the growth of four *Camellia japonica* cultivars. Results showed that all considered peat alternatives, especially rice husk, were suitable as partial substitutes. Results also showed that at low concentrations, flurprimidol controlled height (12-13% reduction) and enhanced flowering (three flowers per plant *versus* two). However, we suggest that the growth regulator input be adjusted based on the cultivar and substrate type, as the three factors interact strongly.

Introduction

In ornamental potting plant cultivation, growth control is key to a marketable final product. The tendency of the plants to grow taller and larger than desired, along with poor flowering, represent challenges in ornamental greenhouse production (Halevy 1985), and especially in camellia cultivation (Keever & McGuire 1991). Not surprisingly, the world-renowned ornamental flower *Camellia japonica* L., with more than 3,000 cultivars, represents a large economic interest (Mondal 2011). The growth pattern of camellias requires that their production be carefully managed. Once rooted, cuttings often grow so vigorously that pruning is required to maintain a compact and globular shape and/or the weight of opening flowers bends their long, thin stems (Wilkinson & Richards 1988). In some cultivars, young plant vigorous growth causes few flower buds to set while in others, the growth slows the number of vegetative buds converted to flower buds (Keever & McGuire 1991). Effective control of these phenomena in potted plants and several woody landscape species (Rademacher & Brahm 2010) has been application of chemical growth retardants to suppress stem elongation and to produce a compact size. Secondary to the reduced growth rate, retardants also increase flower initiation in acidophilic plants, such as camellias (Wilkinson & Richards 1988).

Historically, triazoles have been the best compounds to ensure suitable growth control on a wide range of crops (Davis et al. 1988). However, several chemicals used in agriculture have recently been banned, indicating the need to test new compounds. Flurprimidol, a plant growth regulator (PGR) previously untested on camellias, was known for its effect on other woody ornamentals including the acidophilic species *Rhododendron catawbiense* (Banko & Stefani 1995). A new screening of the compound has shown its potential to regulate camellia growth (Berruti et al., 2012).

Finding alternative growth regulators must go hand in hand with the ambitious target to reduce horticultural use of peat as a potting mixture. Peatlands constitute the top long-term carbon stock in the terrestrial biosphere. Their slow renewal rate implies that peat should not only be treated as a non-renewable resource (Joosten & Couwenberg 2008), but also that alternatives research is important. Several highly available food industry byproducts have been identified as suitable growing media alternatives (Dede et al. 2010; Di Benedetto et al. 2010; Hernàndez-Apaolaza et al. 2005; Jayasinghe et al. 2010; Larcher & Scariot 2009). In fact, ornamental nurseries have already incorporated coconut fibres as a partial peat substitute (Hernandez-Apaolaza et al. 2005). Rice husk, a byproduct of one of the world's main food crops (http://www.fao.org/), is also right now in nurseries (Shinohara et al. 1999; van Schie 1999). This newly identified "use" of the husks reduces waste disposal and supports recycling and environmental protection. Hazelnuts, a major agricultural product in many countries, represent an opportunity like rice, given its large quantity of husk and shell waste.

Peat alternatives vary physicochemically (Dede et al. 2010), and possibly in their capacity to make growth regulators available to their root systems. Potting mixture differences may not only affect plant growth regulation (Million et al. 1998), but also may interfere with the response of the plant to growth regulators (Larcher & Scariot 2009). Consequently, our study aimed to assess the growth regulatory efficiency of flurprimidol, and the growth-related effects of three peat alternatives (readily available, eco-friendly recycled materials) on four cultivars of *C. japonica*. Our goals were to define the introduction suitability of flurprimidol and reuse substrate materials into the *C. japonica* cultivation cycle, and to detect interactions among genotype, substrate mixture, and growth regulator treatment.

Materials and Methods

Experimental design

We selected four *C. japonica* cultivars according to their commercial, trade, and ornamental value: 'Nuccio's Pearl,' 'Hagoromo' (white-pinkish flowers), 'Charles Cobb's,' and ‘Dr. Burnside’ (red flowers). Their cultivation cycle lasted 27 months (February 2008 - May 2010) and was conducted in a commercial nursery in Fondotoce (+45° 55' 41.49", +8° 28' 2.32" Italy). The cultivation occurred in a frost-free greenhouse with 30% steady external shade, to which 40% internal shade was automatically supplemented when natural irradiation exceeded 87.85 W m^{-2}. Temperatures averaged 16.1°C, with a minimum of 2.4°C (January/February 2009) and maximum of 29°C (July 2009).

In February 2008, a total of 3,000 rooted camellia cuttings (750 per cultivar) were planted, three per pot (9 cm in diameter). The pots were then divided into five equal experimental groups: three were cultivated in one of three peat alternative substrate mixtures (nutshells, rice husks, coconut fibres), one served as a negative control mixture of green compost (phytotoxic for camellias, Larcher et al. 2011), and the standard substrate (*Sphagnum* peat-based) acted as the positive control (Table 1). To all substrate mixtures was added the following fertiliser dose: 2.25 kg m^{-3} $CaCO_3$, 1.12 kg m^{-3} of 15N-3.9P-7.5K + micronutrients and 0.5 kg m^{-3} of phosphatic inorganic fertiliser. During cultivation, plants received rainwater from collection wells as needed, and were fertigated with 20N-8.7P-16.6K hydrosoluble fertiliser at 0.8-0.9 g l^{-1} about every two weeks during the March–October period each year.

After nine months in cultivation (October 2008), plants were transplanted into 15 cm diameter pots containing the same substrate mixtures and pruned. Then, on June 5 and 12, 2009, plant growth regulation was carried out. Three different flurprimidol (IUPAC chemical name: [RS]-2-methyl-1-pyrimidin-5-yl-1-[4-trifluoromethoxyphenyl]propan-1-ol) doses and one paclobutrazol (IUPAC chemical name: [2RS, 3RS]-1-[4-chlorophenyl]-4,4-dimethyl-2-[1H-1,2,4-triazol-1-yl]pentan-3-ol) positive control were compared to a water negative control. Application methods and doses are displayed in Table 1. Plant growth regulators (PGRs) were applied in a completely randomised design, treating 10 replicate plants per each cultivar-substrate combination. The cultivation ended in late May 2010 after all plants had completed flowering.

Substrate properties and plant growth assessment

Before planting (January 2008) and after removing root residues at the end of cultivation (May 2010), substrate physical and chemical characteristics were assessed. Bulk density, particle density, porosity, pH, electrical conductivity, and soluble chemical elements (N-NO_3. P_2O_5, K^+, Ca^{2+}, Mg^{2+} and N-NH_4) were determined per European (EN) standards.

We evaluated plant growth at the end of cultivation (May 2010). Plant height (H, from substrate level to highest leaf), longest shoot length (SL, from axil to terminal bud), and foliage diameter (Ø, across widest side of plant) were measured and recorded for each plant. Chlorophyll Meter SPAD-502 Konica Minolta sensor (Nieuwegein, The Netherlands) was used to indirectly measure leaf chlorophyll content and plant health. Measurements were performed on each replicate plant, such that each measure represented the mean value of three technical replicates of a chosen mature leaf. Total leaf dry weight (LDW) and total branch dry weight (BDW) was calculated from oven-dried (90°C for two days) plant tissues and mortality rate (MR) came from a dead plant count.

Finally, aesthetic parameters were assessed post cultivation. The plant height/diameter ratio (H/Ø) was used as a proxy ornamental parameter. Colour variation was measured by means of spectrophotometer CM-2600 Konica Minolta Sensing, Inc. (Osaka, Japan). At full bloom (mid-March 2010), three colour-related parameters (L*, a*, b* space) were measured on four randomly sampled leaves and petals. Chroma (C*) and hue angle (h°) were calculated according to Onozaki et al. (1999). At last, total flowers produced per plant (FN) during the entire flowering period (late December 2009 – late May 2010) were counted.

Statistical analysis

All observations were subjected to a Between-Subjects Effects' Test by either three-way analysis of variance (ANOVA), two-way ANOVA, or one-way ANOVA using SPSS statistical package (version 16.0; SPSS Inc. (Chicago). Data were then post-hoc tested using the Ryan-Einot-Gabriel-Welsch-F test (REGW-F) or the Tamhane test when variance homogeneity was not assumed.

Results

Substrate physicochemical properties

Tables 2 and 3 indicate the substrate physicochemical properties assessed before cultivation. Physical analyses (Table 2) showed substrates were generally acidic; the rice husk mixture (SRH) was most acidic (lowest pH). The green compost substrate (SGC) was most electrically conductive and saline. SGC and the nutshell substrate mixture (SNS) were highest in both bulk and particle densities, while the standard substrate (S) was lowest. Porosity was statistically similar across all substrate mixtures. Chemical analysis results (Table 3) highlighted that SGC had the highest macronutrient concentrations (total N, P_2O_5, Ca^{2+}, Mg^{2+}, K^+). Total carbon was the highest in SNS and ammonium nitrogen the highest in S.

Mean values for substrate physical and chemical analyses done at the end of cultivation (Tables 2 and 3) showed that the cultivars negatively affected substrate characteristics. Overall, pH, electrical conductivity, and salinity all increased. Only in SGC, did electrical conductivity and salinity trend lower. As bulk density increased in all, particle density and porosity decreased drastically. Carbon declined also. While total nitrogen did not vary, ammonium nitrogen increased in each, with SGC always characterised by the highest percentages. Nitric nitrogen decreased to non-detectable levels; total phosphorous was also highly reduced in all. Potassium content decreased or remained very low in all substrates, except in SRH where it increased. Other macronutrient concentrations generally increased.

Effect of plant growth regulator treatments

Plant growth regulator (PGR) treatment effects are displayed in Table 4. In general, flurprimidol treatments (FPD1, FPD2, FPD3; Table 1) caused reduced height and shoot length in the negative control (W) and paclobutrazol application (PBZ). FPD1 and FPD2 promoted lower LDW; only FPD2 slightly reduced BDW. All flurprimidol (FPD) treatments enhanced flower number, which equalised the PBZ effect. Mortality rate, plant diameter, and leaf lightness were not statistically affected, leaf hue angle increased only slightly, and chlorophyll content differed negligibly. Flurprimidol treatments promoted darker (except FPD3), more vivid, and redder (except FPD2) petals than did treatment W.

Effect of the growing media

Substrate mixtures influenced most growth related parameters (Table 4). SGC caused phytotoxic symptoms and stunted development evidenced by excessive height, shoot length, and dry weight reductions. While chlorophyll content and leaf hue angle, and flower number, were highest, these effects were offset by flower volume and buds that failed to complete anthesis (data not shown). Leaf dry weight was slightly reduced in all other peat alternatives, while shoot length was restrained in SRH and SCF. Low chlorophyll content and few flowers were noted in plants grown in SCF, whereas SRH performed equal to S in these and leaf hue angle. Substrate type did not significantly affect other parameters.

Genotypic effect

Growth parameters differed among the tested cultivars (Table 4). ‘Hagoromo’ had the highest mortality rate, as well as the lowest height, shoot length, and leaf and branch dry weights. No disease symptoms were detected on dying specimens, so the high mortality was attributed to its inability to adapt to the adopted cultivation cycle. ‘Nuccio’s Pearl’ had the highest height/diameter ratio and lowest flower number. In both these cultivars, SPAD values were higher than for ‘Charles Cobb’s’ and ‘Dr. Burnside’, whereas the reverse was true for foliage diameter. Flower colour parameters (lightness, chroma, hue angle) differed remarkably across the tested cultivars. Other parameters differed only slightly.

Interactions

Between-factor interaction significance is shown in Table 5. Genotype interacted with PGR treatments (shoot length, height/diameter ratio, leaf and flower lightness, hue angle) and substrate mixtures (mortality rate, shoot length, flower colour). Significant interaction was also found between PGR treatments and substrate mixtures (chlorophyll content, flower colour), and several three-way interactions (height, leaf and branch dry weights, chlorophyll content, flower number, leaf hue angle, flower colour) were detected.

Further statistical analysis of the main morphological parameters (height, chlorophyll content, flower number) considered all cultivars separately to remove the genotypic factor effect (data not shown). Substrate mixture strongly affected the growth of all cultivars and different cultivars varied in their response to PGR application. In ‘Charles Cobb’s’, height, chlorophyll content, and flower number were all affected by PGR treatments, with the sharpest effect seen after FPD2 treatment with SRH. FPD1 controlled height better when combined with S or SCF, and SNS worked better in combination with FPD3. In ‘Nuccio’s Pearl’, PGR treatments had a significant effect on plant morphological traits but a significant interaction between PGR and substrate mixtures was seen only on plant height. FPD2 also performed best in ‘Nuccio’s Pearl’ except for plants cultivated in SNS. Contrary to PBZ, FPD did not enhance the flowering of this cultivar. Non-treated ‘Nuccio’s Pearl’ plants failed to flower when cultivated in S, but flowered successfully with alternative substrate mixtures. With respect to S, SNS also caused some size restraint. In ‘Dr. Burnside’, PGR treatments resulted in varied chlorophyll content and flower number, and interacted with the substrate only in flower production. No size restraint was observed. Flower number was higher in plants cultivated in S and SRH, when treated with FPD2 and PBZ, respectively. Finally, ‘Hagoromo’ plants responded poorly to PGR and no interaction occurred between the two fixed factors. The best flowering occurred in S, although all substrate mixtures, save SGC, suited this cultivar.

Discussion

Unlike paclobutrazol (PBZ), flurprimidol (FPD) was generally effective in controlling plant growth at the tested concentrations (12-13% height reduction and 14-17% shoot length decrease), as seen in earlier shrub and herbaceous plant studies (*Euphorbia pulcherrima*: Currey & Lopez 2011; *Lilium longiflorum*: Currey et al. 2012; *Salvia ×microphylla*: Fair et al. 2012). FPD caused branch compactness, which made the camellias able to support the increased flower numbers observed. This might be of particular interest for ‘Nuccio’s Pearl,’ which often presents long, downward curved branches from flower and leaf weight. In some cases, FPD promoted a more greenish leaf colour as also observed by Banko and Stefani (1995), and more vivid reddish petals. Previous experiments on woody landscape species had been less encouraging as FPD decreased inflorescence numbers in *Buddleia davidii* ‘Royal Red’ (Keever & Gilliam 1994) and reduced flowering quality (Pobudkiewicz 2008). In many container grown woody ornamentals, including *Rhododendron catawbiense* Michx. 'Nova Zembla', FPD was effective only at 100 times our concentrations (Banko & Stefani 1995).

Overall, the best treatment was FPD2, which combined a 15 mg l^{-1} spray application (ca 10 ml) and a 2 mg l^{-1} drench application (70 ml). FPD dosing in this manner, as opposed to PBZ, ensures less plant growth regulator (PGR) is released into the environment. The half-life ranges of the two PGRs can differ greatly. Depending on soil type, flurprimidol has a soil DT_{50} of 119 to 187 days *versus* paclobutrazol with a soil DT_{50} of 182 to 365 days (http://www.agropages.com and http://www.epa.gov). Hence, FPD is not only an effective alternative to PBZ, but also less harmful to the environment.

Physically and chemically, the tested substrate mixtures were quite similar. The physical features of the coconut fibre substrate mixture (SCF) made it the most “peat-like.” All three mixtures had acceptable electrical conductivity and salinity for acidophilic plant cultivation (Abad et al. 2001), and as expected, the green compost substrate mixture (SGC) had remarkably high values for both. Particle densities and porosities for all, even the standard substrate (S), were lower than described by Abad et al. (2001). The hemical characteristics of all substrate mixtures were similar to S as well. At the end of cultivation, all had increased pH and electrical conductivity as others have shown (Hernàndez-Apaolaza et al. 2005; Larcher & Scariot 2009). We observed increased bulk densities while particle density and porosity drastically decreased in all substrates, likely due to normal decomposition. Accordingly, a slight decrease of total carbon was detected. We also found ammonium nitrogen increased in every substrate, probably due to the part-ammonia nitrogen fertiliser used. Alternatively, it might indicate that nitrogen fixation occurred in the peat-based substrates that are retrieved from nitrogen-fixing bacteria environments (Limpens et al. 2006). Nitric nitrogen levels varied most dramatically; they became non-detectable during the cultivation cycle, given its easy absorption by plants. Interestingly, total phosphorous was not completely depleted at the end of cultivation in nutshell (SNS) and rice husk substrates (SRH). SRH potassium actually increased during cultivation, which might indicate that rice husks trapped these important macroelements during fertigation for root availability throughout the cultivation cycle.

Plant growth results showed all three alternative materials were good partial peat substitutes. Among the tested materials, rice husk was best, as has been borne out in reports of its use in horticultural and ornamental plants (Shinohara et al. 1999; van Schie 1999; Evans and Gachukia 2004; Blok & Verhagen 2009; Gomez and Robbins 2011) and in forest plants (Tsakaldimi 2006). When we compared our results to the standard substrate, rice husk use yielded a slight reduction in shoot length and dry weight, both positives for the camellia shape. Only SRH ensured leaf chlorophyll content and leaf colour of S. In addition, as with SNS, it promoted flower production like that of S. In contrast to previous *C. japonica* research (Larcher & Scariot 2009), we found that coconut fibres reduced flowering and chlorophyll content, a factor potentially related to our use of 20% more alternative material in the substrate. Consistent with others (Larcher & Scariot 2009; Larcher et al. 2011), *C. japonica* plants grown on SGC (negative control) raised phytotoxic symptoms.

To standardise cultivation practises, interactions between cultivars and cultivation protocols must be understood. As with others, we detected many interactions: genotype-PGR treatment (Meijon et al. 2009; Larcher et al. 2011), genotype-substrate mixture (Hernàndez-Apaolaza et al. 2005; Larcher & Scariot 2009; Ameri et al. 2012), and PGR treatment-substrate mixture (Larcher et al. 2011). We also found three-way interactions, as did Larcher et al. (2011). We diverged, however, from Currey et al. (2010) by demonstrating PGR treatment efficacy might vary with a single cultivar when combined with different substrate mixtures. This finding does not mesh well with a grower's desire to balance demand and economics, which aims for simultaneous cultivation of a spectrum of cultivars with a standardised cultivation protocol.

In conclusion, our study proved the suitability of flurprimidol to control *C. japonica* growth, and three eco-friendly materials (rice husk, nutshells, coconut fibres) as partial peat replacements to produce high quality marketable plants. The best result was achieved with repeated application of flurprimidol (15 mg l^{-1} spray + 2 mg l^{-1} drench) in combination with rice husks (30%) as a partial peat alternative.

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Table captions

Table 1. Experimental design conducted on four camellia cultivars. On the left is substrate (Sub) composition. On the right is plant growth regulator (PGR) treatment active ingredients and application method and dose. Spray application was performed with ca 10 ml per plant. Drench application used 70 ml per pot.

Table 2. Physical properties of the substrates (S: standard substrate, SGC: substrate with green compost, SNS: substrate with nutshells, SRH: substrate with rice husk, SCF: substrate with coconut fibres) before and at the end of cultivation. The influence of the different cultivars (cv) is also provided.

Table 3. Chemical properties of the substrates (S: standard substrate, SGC: substrate with green compost, SNS: substrate with nutshells, SRH: substrate with rice husk, SCF: substrate with coconut fibres) before and at the end of cultivation. The influence of the different cultivars (cv) is also provided.

Table 4. Overall effects of plant growth regulator (PGR) treatments: (W: water control, PBZ: paclobutrazol treatment, FPD1, FPD2, and FPD3: flurprimidol treatments) and substrate (S: standard substrate, SGC: substrate with green compost, SNS: substrate with nutshells, SRH: substrate with rice husk, SCF: substrate with coconut fibre) on growth characteristics of four camellia cultivars (CC: 'Charles Cobb's'; NP: 'Nuccio's Pearl'; DB: 'Dr. Burnside'; HA: 'Hagoromo'). Abbreviations and symbols: MR: mortality rate; H: height; Ø: diameter; SL: shoot length; LDW, BDW: leaf and branch dry weight; H/Ø: height/diameter ratio; SPAD : chlorophyll content; LL, Lh°: leaf lightness and hue angle; FN, FL, FC*, Fh°; flower number, lightness, chroma, and hue angle.

Table 5. Statistic relevance of the interactions among the fixed factors (PGR: plant growth regulator treatment, Sub: substrate mixture, and cv: cultivar). Abbreviations and symbols: MR: mortality rate; H: height; Ø: diameter; SL: shoot length; LDW, BDW: leaf and branch dry weight; H/Ø: height-diameter ratio; SPAD: chlorophyll content; LL, Lh°: leaf lightness and hue angle; FN, FL, FC*, Fh°: flower number, lightness, chroma and hue angle.

Tables

Table 1

Sub code	Composition
S	*Sphagnum* peat + agrilite 89:11
SGC	S + Green Compost 70:30
SNS	S + Nutshell 70:30
SRH	S + Rice Husk 70:30
SCF	S + Coconut fibre 50:50

PGR code	Active ingredient	Method of application	Dosage (mg l^{-1})
W	Water control	Spray	-
PBZ	Paclobutrazol	Spray	50
FPD1	Flurprimidol	Drench	2
FPD2	Flurprimidol	Spray+Drench	15+2
FPD3	Flurprimidol	Spray+Spray	15+15

Table 2

Sub code	pH	Electrical Conductivity (µS/cm)	Salinity (meq/100g)	Bulk Density (Kg/m^3)	Particle Density (Kg/m^3)	Porosity (%)
Before cultivation						
S	5.0bc[z]	44d	1d	67b	183d	62
SGC	5.5ab	913a	21a	153a	407b	62
SNS	5.1abc	157c	3c	110ab	507a	78
SRH	4.6c	272b	5b	80b	293c	73
SCF	5.6a	38d	1d	73b	250c	71
P	**	***	***	*	***	NS
End of cultivation						
S	5.6c	369a	14a	98c	122b	18
SGC	6.2a	288ab	8bc	221a	298a	25
SNS	6.0ab	187b	5d	176ab	298a	40
SRH	5.7bc	393a	12ab	97c	142b	31
SCF	5.9b	258ab	10b	91c	123b	21
P	***	***	**	***	***	-
cv	NS	**	NS	NS	NS	-

[z]Means followed by the same letter do not differ significantly at $P < 0.05$, according to the REGW-F test or the Tamhane test when the homogeneity of variances was not assumed. The statistical relevance (p-value, $P < 0.05$ = *, $P < 0.01$ = **, $P < 0.001$ = ***, NS = non-significant) of Between-Subjects Effects' Tests is provided.

Table 3

Sub code	Total Carbon (%)	Total Nitrogen (%)	N-NH4 (%)	$N-NO_3$ (mg Kg^{-1})	P_2O_5 (%)	Ca^{2+} (%)	Mg^{2+} (%)	K^+ (%)
Before cultivation								
S	44c[z]	0.7b	0.2a	24b	ND[w]	0.2c	0.1b	0.1c
SGC	32e	1.6a	0.1c	16237a	0.20	3.3a	0.9a	0.5a
SNS	49a	0.6b	0.1c	25b	ND	0.4b	0.1b	0.3b
SRH	41d	0.7b	0.2ab	33b	ND	0.1c	0.1b	0.3b
SCF	46b	0.6c	0.1b	17b	ND	0.4b	0.1b	0.1c
P	***	***	***	***	-	***	***	***
End of cultivation								
S	40c	0.7d	0.9b	ND	ND	0.6c	1.3b	0.1c
SGC	28e	1.5a	2.4a	5.3	0.28a	9.5a	9.1a	0.3b
SNS	48a	0.6e	0.5c	ND	0.03c	0.3d	1.3b	0.1c
SRH	38d	0.8c	1.1b	ND	0.11b	0.7bc	1.2b	0.5a
SCF	45b	0.9b	0.8b	ND	ND	0.8b	1.7b	0.1c
P	***	***	***	-	***	***	***	***
cv	NS	NS	NS	*	NS	NS	NS	NS

[z]Means followed by the same letter do not differ significantly at $P < 0.05$, according to the REGW-F test or the Tamhane test when the homogeneity of variances was not assumed. The statistical relevance (p-value, $P < 0.05$ = *, $P < 0.01$ = **, $P < 0.001$ = ***, NS = non-significant) of Between-Subjects Effects' Tests is provided. [w]ND = non-determinable.

Table 4

		MR (%)	H (cm)	Ø (cm)	SL (cm)	LDW (g)	BDW (g)	H/Ø	SPAD	FN	LL	Lh°	FL	FC*	Fh°
PGR	**W**	11	41a[z]	31	28a	17a	11a	1.4a	69b	2.0b	37	119b	69a	24d	29a
	PBZ	10	40a	30	26ab	17a	10ab	1.4ab	73a	2.8a	36	120a	61d	35a	23b
	FPD1	5	35b	30	24bc	14b	9ab	1.2d	71ab	2.5ab	36	120a	65c	31b	19bc
	FPD2	9	35b	29	23c	15b	8b	1.3cd	70b	3.0a	37	120ab	67b	27c	31a
	FPD3	5	37b	30	24bc	17a	10a	1.3abc	72ab	2.9a	37	120ab	69a	27c	17c
	P	NS	***	NS	***	***	*	***	***	***	NS	*	***	**	***
Sub	**S**	6	39a	29	27a	19a	11a	1.4a	73b	2.4bc	36abc	120b	64	31	25
	SGC	13	32b	28	21d	13c	7b	1.2b	77a	4.2a	35c	122a	65	30	24
	SNS	7	39a	32	27ab	15b	10a	1.3a	66c	2.2cd	38ab	119c	71	25	20
	SRH	6	40a	31	23c	16b	10a	1.3a	73b	2.9b	36bc	120b	66	29	23
	SCF	7	38a	29	25bc	17b	10a	1.3a	67c	1.7d	38a	119c	63	32	27
	P	NS	***	NS	***	***	***	***	***	***	***	***	NS	NS	NS
cv	**CC**	6b	39a	31a	25a	17ab	11a	1.3b	69b	4.1a	38b	119b	43b	52a	20b
	NP	5b	41a	29b	25ab	16b	10b	1.4a	74a	1.3b	36b	121a	85a	10b	22b
	DB	6b	39a	32a	26a	18a	11ab	1.3b	68b	2.5a	38a	119b	41c	53a	20b
	HA	14a	32b	27b	22b	11c	6c	1.2b	74a	2.7a	36b	121a	86a	9b	32a
	P	***	***	**	***	***	***	***	***	***	***	***	***	***	***

[z]Means followed by the same letter do not differ significantly at $P < 0.05$, according to the REGW-F test or the Tamhane test when the homogeneity of variances was not assumed. The statistical relevance (p-value, $P < 0.05$ = *, $P < 0.01$ = **, $P < 0.001$ = ***, NS = non-significant) of Between-Subjects Effects' Tests is provided.

Table 5

Interaction	MR	H	Ø	SL	LDW	BDW	H/Ø	SPAD	FN	LL	Lh°	FL	FC*	Fh°
Sub*cv	*[z]	***	NS	**	***	NS	NS	***	***	NS	NS	**	**	*
PGR*Sub	NS	NS	NS	NS	NS	NS	NS	**	NS	NS	NS	***	***	**
PGR*cv	NS	NS	NS	*	NS	NS	*	NS	NS	*	NS	***	NS	***
PGR*Sub*cv	NS	**	NS	NS	**	*	NS	*	*	NS	**	***	***	**

[z]The statistical relevance (p-value, $P < 0.05$ = *, $P < 0.01$ = **, $P < 0.001$ = ***, NS = non-significant) of Between-Subjects Effects' Tests is provided.