Adventitious Rooting of *Lavandula* x *intermedia* Cuttings[1]

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Abstract

Due to challenges associated with lavender propagation, Texas hybrid lavender (lavandin) growers require revised propagation information. Therefore, experiments investigated effects of media and plant growth regulators (PGR) on rooting of three different lavandin (*Lavandula* x *intermedia*) cultivars. PGRs applied to cuttings were naphthaleneacetic acid (NAA), or indole-3-butyric acid (IBA) at three concentrations. In addition, four rooting media were examined. Cuttings exposed to a peat moss/sand medium had the greatest mean overall rooting percentage, number of roots, and regardless of cultivar, cuttings exposed to the peat moss/sand medium had the longest roots. In general, mean rooting data were also greatest for cuttings dipped in NAA at 0.5 and 1.0 $g \cdot L^{-1}$ (500 and 1000 ppm, respectively). Overall, across all media and PGR treatments 'Grosso' cuttings tended to have the greatest rooting percentage and longest roots. In addition, compared to the no PGR treatment, 'Provence' and 'Hidcote Giant' cuttings exposed to the peat moss/sand medium and greater PGR concentrations produced cuttings with an increased mean rooting percentage and longer roots. When rooting lavandin cultivars, results indicate correct media selection**,** PGR formulation, and PGR concentration determine propagation success.

Index words: lavandin, *Lavandula* x *intermedia* Emeric ex Loisel, peat moss, perlite, rooting percentage, root quality, sand.

Chemicals used in this study: indole-3-butyric acid (IBA; 0.5, 1.0, and 1.5 $g \cdot L^{-1}$); naphthaleneacetic acid (NAA; 0.5, 1.0, and 1.5 $g \cdot L^{-1}$).

Species used in this study: 'Grosso', 'Provence', and 'Hidcote Giant' lavandin (*Lavandula* x *intermedia* Emeric ex Loisel.).

Significance to the Horticulture Industry

Lavender production for essential oil is a growing industry within West Texas. However, due to costs associated with propagation of lavender cuttings, economics often limits grower expansion. Therefore, this research investigated asexual propagation methods designed to increase rooting percentage and root quality of hybrid lavender (lavandin) cuttings. Tip cuttings of three lavandin cultivars ('Grosso', 'Provence', and 'Hidcote Giant') were exposed to differing media, plant growth regulators (PGR), and PGR concentrations. Results indicate rooting these lavandin cuttings in a peat moss/sand medium produced cuttings with the greatest rooting percentage, and the longest roots. However, although rooting percentage and root quality response of 'Grosso', 'Provence', and 'Hidcote Giant' cuttings generally increased in response to exposure to PGR and greater PGR concentrations, overall response of lavandin cuttings to PGR, and PGR concentration varied with cultivar. Currently, there is limited literature available which discusses propagation of lavandin by cuttings. However, this research adds critical information to this insufficient body of work, and updates propagation practices which will greatly increase adventitious rooting success of these lavandin cultivars.

Introduction

Lavender (*Lavandula spp*.) has been grown for medicinal properties and essential oils since ancient times (Jianu et al. 2013, Upson and Andrews 2004). Native to regions of the Mediterranean, Africa, and India, lavender is a member of the *Lamiaceae* family, and the genus is thought to include nearly 40 species, numerous hybrids, and approximately 400 cultivars (Hanamanthagouda et al. 2010, Paton et al. 2004, Upson and Andrews 2004). In the modern era of health awareness, demand for lavender oil for use in pharmaceuticals (local anesthetic, sedative, antispasmodic, anticonvulsant, analgesic, antioxidant, etc.), perfumes, colognes, cosmetics, and skin lotions is on the rise (Hassiotis et al. 2010, Koulivand et al. 2013, Kovatcheva et al. 2001). Lavender essential oils are volatile compounds primarily synthesized in secretory oil glands located on the surface of the calyx, and to a lesser extent on leaves (Hassiotis et al. 2010). Essential oils are comprised of a number of monoterpenes and sesquiterpenes, and inflorescences are harvested at the maximum flowering stage (Gökdogan 2016, Jianu et al. 2013, Zheljazkov et al. 2013). Recent estimates indicate over 200,000 ha (over 494,000 acres) of lavender is cultivated in Europe for essential oil, medicinal, aromatherapy, and pharmaceutical practices (Hassiotis et al. 2010).

Lavandin (hybrid lavender) is a sterile cross between true lavender (*L. angustifolia* L.) and spike lavender (*L. latifolia* Miller) (Jianu et al. 2013). Lavandin is thought to be cold hardy from -15 C to -20 C (5 F to -4 F) (United States Department of Agriculture Hardiness Zones 7b – 6a) (Upson and Andrews 2004, United States Department of Agriculture 2012), and is prized for abundant essential oil production (Jianu et al. 2013, Upson and Andrews 2004). Recently, with

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Fig. 1. **Examples of lavandin (*Lavandula x intermedia*) stock plants. Cultivars include 'Grosso' (A), 'Provence' (B), and 'Hidcote Giant' (C).**

an increase in small businesses and agro-tourism farms, lavender production has found popularity within the United States (Zheljazkov et al. 2013). Therefore, with increasing demand for essential oils, the addition of lavender as a specialty crop in Texas may broaden agricultural crop selection, and potentially produce new employment opportunities (Karelakis et al. 2017, Texas Lavender Association (https://texaslavenderassociation.org/) personal communication 2019, Usano-Alemany et al. 2011). Although a great number of lavender species and cultivars are grown worldwide (Jianu et al. 2013, Paton et al. 2004), three adapted and commonly grown lavandin cultivars in West Texas are 'Grosso', 'Provence', and 'Hidcote Giant' (Texas Lavender Association personal communication 2019) (Fig. 1).

Common methods of lavender propagation include sexual (seed germination) and asexual (micropropagation and cuttings) (Andrade et al. 1999, Upson and Andrews 2004). However, lavandin produces sterile flowers (Jianu et al. 2013), and therefore cannot be propagated sexually. Asexual (vegetative) propagation results in plants which have the identical genotype of the parent plant, and provide required uniformity (Davies et al. 2018, Mabizela et al. 2017). In vitro micropropagation produces genetic clones of the source plant, and is currently the primary method of lavender propagation (Andrade et al. 1999, Goncalves and Romano 2013, Mitrofanova et al. 2017). However, micropropagation requires specialized skills and equipment, and cost for each plantlet is typically greater when compared to asexual propagation through cuttings (Chen 2016, Tomar et al. 2007).

Asexual propagation success of cuttings often depends upon a number of endogenous and exogenous factors (Zheng et al. 2020). For example, plant genotype, hormone synthesis and transport, time of year when cuttings are collected, maturity of stock plants, type of cutting, size of cutting, media temperature, media oxygen and water availability, and plant growth regulator (PGR) (Davies et al. 2018, Fox and Montague 2004, King et al. 2011, Mabizela et al. 2017, Pacurar et al. 2014, Swamy et al. 2002, Zheng et al. 2020) may influence adventitious rooting, and root growth. Rooting ability of cuttings may also differ among cultivars or clones within the same species (Epstein and Ackerman 1993, Epstein et al. 1993, Mabizela et al. 2017, McIvor et al. 2014). Previous research indicates asexual propagation of lavender by cuttings is challenging (Andrade et al. 1999, Nobre 1996). Therefore, when expanding for future production, rather than propagate cuttings from their own stock plants, most Texas lavender growers choose to pay greater costs, and purchase pre-rooted micropropagated plugs (Texas Lavender Association personal communication 2019). Lack of growers propagating their own plants is likely due to limited grower understanding of propagation methodology, and challenges associated with rooting lavender cuttings (Nobre 1996, Texas Lavender Association personal communication 2019).

Media selection will also influence cutting rooting success (King et al. 2011, Mabizela et al. 2017, McIvor et al. 2014, Szczepaniak et al. 2016). Zheng et al. (2020) exposed carnation (*Dianthus caryophyllus* L.) cuttings to three cocopeat/perlite formulations (1:1, 1:2, 1:3) (throughout this paper, media mixing ratios will be expressed on a volumetric basis). They report carnation rooting percentage did not differ among media treatments. However, root length, fresh weight, and dry weight were greatest for carnation cuttings rooted in the cocopeat/perlite (1:1) medium (Zheng et al. 2020). Zheng et al. (2020) concluded the best rooting medium for carnation cuttings should have a balance between bulk density, water holding capacity, and air water permeability. Baldcypress (*Taxodium distichum* L.) cuttings were exposed to several IAA treatments, and rooted in peat moss, perlite, and a 1:1 peat moss/perlite medium (King et al. 2011). Rooting medium treatment results indicate differences were found for baldcypress cuttings rooting percentage and root quality data (root to shoot ratio, root length, number of primary and secondary roots, etc.). King et al. (2011) suggest for the greatest rooting percentage, rooting media for baldcypress cuttings should provide greater aeration. However, root quality parameters were greater in media with greater water holding capacity.

As a growing medium, peat moss (organic component) provides water-holding capacity, reduced pH, and increased cation exchange capacity (CEC). Perlite (inorganic component) is known to have low CEC, low bulk density, high porosity, and provide aeration in soilless media (Pascual et al. 2018, Zheng et al. 2020). Sand (inorganic component) has low CEC, high bulk density, and low to moderate porosity (Lemaire 1995, Mazare et al. 2007, Pascual et al. 2018). Therefore, each media might be considered suitable for rooting certain species (Adugna et al. 2015, Davies et al. 2018, King et al. 2011, Kukkonen and Vesterg 2009). However, adding sand to peat moss increases medium permeability, and may potentially improve medium quality for rooting of cuttings (Kukkonen and Vesterg 2009, Szczepaniak et al. 2016, Westervelt 2003).

Updated, replicated information is lacking for asexual propagation of lavender by cuttings. Nobre (1996) indicates lavender cuttings have an inherent resistance to rooting. In addition, Andrade et al. (1999) found the presence of a PGR greatly increased true lavender 'Vera' plantlet rooting, especially at greater PGR concentrations. Therefore, when rooting lavender cuttings, use of a PGR may increase rooting percentage and rooting uniformity (Blythe et al. 2007, Davies et al. 2018). Improved lavender stem cutting propagation techniques would potentially increase lavender propagation success, allow growers to propagate lavender from their own stock plants, and potentially reduce production costs for Texas lavender flower and oil producers. Therefore, this research investigated rooting success of lavandin cuttings rooted in four differing media, exposed to three concentrations of two PGRs, and removed from stock plants of three different cultivars.

Materials and Methods

Collection of cuttings. Two experiments were conducted. Experiment 1 (Expt. 1) began late summer 2019, and experiment 2 (Expt. 2) was initiated early spring 2020. Each experiment continued for a period of approximately eight weeks. Greenhouse experiments were conducted at the Texas Tech University Plant and Soil Science Greenhouse complex (Lubbock, TX). Tip cuttings (mean cutting length 12.5 cm (4.9 in)) of three hybrid lavandin cultivars ('Grosso', 'Provence', and 'Hidcote Giant') were taken from stock plants of a local lavender farm (Fig.1). Cuttings were collected from multiple stock plants the morning of 16 August, 2019 (Expt. 1), and 28 February, 2020 (Expt. 2). Following removal from stock plants, cuttings were placed in twenty-liter (5.2 gal) buckets filled with water, and immediately transported to the greenhouse facility.

Cutting preparation and treatments. Upon arrival at the greenhouse complex, cuttings were rinsed with tap water, and leaves from the basal 5.0 cm (2 in) of the stem were removed. Prior to application of PGR, each cutting was wounded by making a 5 cm (2 in) length incision along the stem axis to the basal end of the cutting (Fig. 2) (Davies et al. 2018, King et al. 2011). Cuttings from each cultivar were then randomly divided into seven groups, each group to be treated with a different auxin-based PGR, and PGR concentration. Investigated PGRs included naphthaleneacetic acid (NAA, Caisson Labs, CAS# 86-87-3, Smithfield, UT), and indole-3-butyric acid (IBA, Phytotronics Inc., Earth City, MO) soluble salts. For each PGR, cuttings were assigned one of four treatments: 0, 0.5, 1.0, and 1.5 $g \cdot L^{-1}$ (0, 500, 1,000, or 1,500 ppm). Using a total immersion method (Blythe et al. 2007, Davies et al. 2018), entire cuttings were soaked in each treatment for 30 seconds. Prior to inserting into media and placing under mist, cuttings were set aside to dry for 10 minutes. For each

Fig. 2. Example of a lavandin (*Lavandula x intermedia*) cutting with leaves detached from the basal 5.0 cm (2.0 in) of stem, and the outer most layer of bark removed in the wounding process.

experiment, a single cutting was placed into a 10 × 10 × 10 cm (4 × 4 × 4 in) container. Containers were then placed into flats (18 containers in each flat). Media examined were perlite (Ambient Minerals Perlite, Benton, AR), peat moss (Premier Sphagnum Peat Moss, Quakertown, PA), a peat moss/perlite mixture (3:1), and a peat moss/sand (Quickrete Play Sand, Quickrete Inc., Atlanta, GA) mixture (2:1). The evening prior to gathering cuttings, media within each flat was prepared, saturated with tap water, and left to drain. Flats were divided into nine groups of five flats each (each group of five flats was considered a block). Cuttings were rooted under intermittent overhead mist. Depending upon greenhouse environmental conditions, mist was active approximately 25 seconds every five minutes, and was regulated by an electronic leaf (Phytotronics Inc., Earth City, MO). In addition, bottom heat (Phytotronics Inc., Earth City, MO) was applied to maintain media temperature of approximately 27 C (80.6 F) (Davies et al. 2018). The greenhouse cooling system was set to maintain greenhouse air temperature > 27 C (81 F), and the natural photoperiod was used. After a period of approximately eight weeks (14 Oct. 2019 (Expt. 1) and 26 Apr. 2020 (Expt. 2)) cuttings were carefully removed from flats, and excess medium rinsed from roots of each cutting. Rooting percentage, root number, and length of longest root were determined. A cutting was considered rooted if the cutting successfully produced one adventitious root (Fox and Montague 2004).

Statistical analysis. Expt. 1 and Expt. 2 each followed a factorial arrangement in a randomized complete block design with 9 blocks. Each block consisted of five flats (45 total flats), and one medium was assigned randomly to four flats within each block. In addition, one flat within each block contained a single row of three containers. Each row was randomly assigned one of the four media treatments (Fig. 3). Therefore, within each block there was a single cutting of each medium x PGR x cultivar treatment, and nine cuttings of each combination within Expt.1, and nine cuttings of each combination within Expt. 2 (252 total cuttings of each cultivar within each experiment). Because rooting of some species is dependent upon time of year (Fox and Montague 2004, King et al. 2011, Swamy et al. 2002), rooting percentage, number of roots for each cutting, and length of each cutting's longest root data from Expt. 1 and Expt. 2 were exposed separately to analysis of variance (ANOVA) suitable for a factorial arrangement in a randomized complete block design (SAS version 9.4, SAS Institute, Cary, NC). However, results from Expt. 1 and Expt. 2 exhibited similar results and trends, and differences between experiments were not detected. Therefore, data from Expt. 1 and Expt. 2 were pooled, and exposed again to ANOVA (Andrenko et al. 2020). If significant differences were found, means were separated by Fisher's least significance difference procedure ($P < 0.05$).

Results and Discussion

Influence of media. Medium influenced lavandin cutting rooting percentage. Of the media examined, the peat moss/sand mixture had the greatest mean rooting percentage (approximately 80%) across cultivar and PGR treatments when compared to cuttings rooted in other media ($P = 0.0001$) (Fig. 4). Mean rooting percentage in the peat moss/sand mixture was 29, 46, and 38% greater when compared to perlite, peat moss, and the peat moss/perlite media, respectively. Number of adventitious roots found on each cutting was also influenced by media ($P = 0.0001$) (Fig. 5). Mean number of roots for each cutting were greatest for cuttings rooted in the peat moss/sand medium (9.3), and least for cuttings grown in the peat moss medium (4.0). Root numbers were similar for cuttings rooted in perlite and the peat moss/perlite media (Fig. 5). For length of the longest root on each lavandin cutting, an interaction occurred between media and cultivar across all PGR treatments ($P = 0.0027$) (Fig. 6). However, regardless of cultivar, mean adventitious root length was greatest for cuttings rooted in the peat moss/sand medium (8.5 cm). In addition, regardless of cultivar, shortest roots were found on cuttings rooted in peat moss (1.3 cm).

When propagating cuttings, the medium must provide an environment which will increase the probability cuttings will form and grow adventitious roots: anchor the cutting, provide water, supply aeration, and reduce amount of light reaching the cutting base (Davies et al. 2018, King et al. 2011, Lemaire 1995). Although physiochemical properties of media used in this study were not directly analyzed, physiochemical properties of this study's media components have been described elsewhere (King et al. 2011,

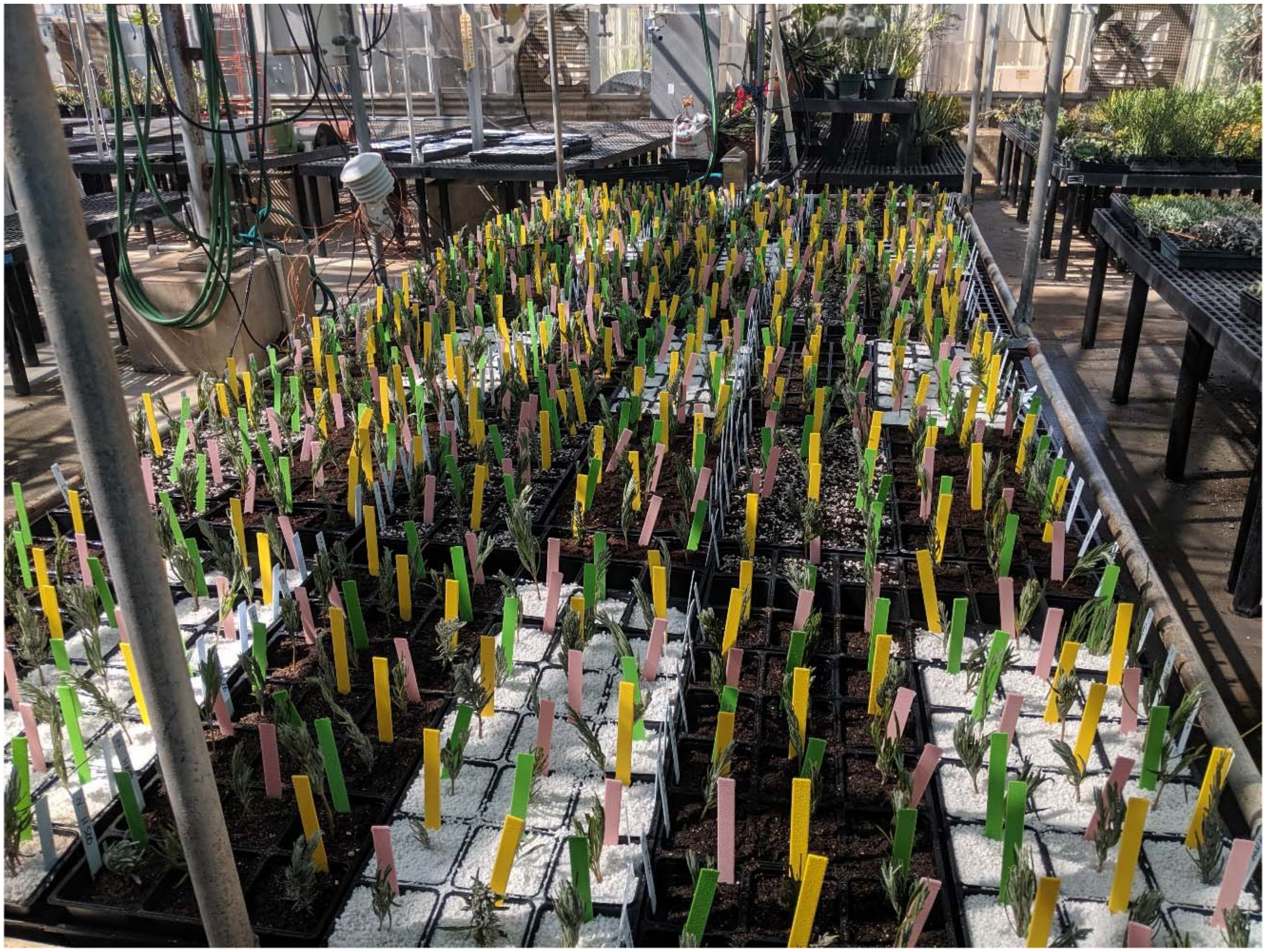

Fig. 3. Mist bench experimental design with three lavandin (*Lavandula x intermedia*) cultivars ('Provence', 'Hidcote Giant', and 'Grosso'), four media (perlite, peat moss, peat moss/perlite, and peat moss/sand), and three different plant growth regulator concentration treatments of indole-3-butyric acid, and naphthaleneacetic acid.

Lemaire 1995, Mazare et al. 2007, Pascual et al. 2018, Zheng et al. 2020). For media used in current experiments, physiochemical properties likely differed between each medium. Compared to other media, the peat moss medium likely was poorly drained, had lower pH, and provided low aeration to cuttings (Davies et al. 2018, King et al. 2011). Excess water within a medium may reduce aeration, and restrict adventitious rooting and root growth (Davies et al. 2018, King et al. 2011). However, uptake of water by a cutting is proportional to the content of water within the medium (King et al. 2011). Therefore, water availability within the medium is critical for rooting cuttings. Our data corresponds with a honeybush (*Cyclopia subternata* Vogel) rooting experiment in which Mabizela et al. (2017) report peat moss to be a poor rooting medium. A number of other studies reveal cuttings of many species do not root well within a peat moss medium (Mazare et al. 2007, Szczepaniak et al. 2016). Perlite medium likely had greater aeration and porosity when compared to peat moss (He and Yi 2014, Lemaire 1995, Mazare et al. 2007, Pascual et al. 2018). However, lack of nutrient availability and excessive aeration of perlite medium has been found to restrict rooting and root growth of cuttings placed within perlite (Daza et al. 2000, Mazare et al. 2007).

Rooting media attributes are a critical factor which affect rooting percentage and root quality characteristics (King et al. 2011, Zheng et al. 2020). Furthermore, successful selection of a propagation substrate is mainly dependent upon biological attributes of the target species (Zheng et al. 2020), and the adaptability of a species to a substrate's physiochemical properties (Lemaire 1995). Similar to our results, mixtures of organic and inorganic media components have been found to provide an excellent rooting medium for many plant species (Pascual et al. 2018, Szczepaniak et al. 2016, Zheng et al. 2020). Our results are similar to rooting experiments of Mazare et al. (2007), who investigated vegetative propagation of white spruce (*Picea glauca* Moench 'Conica') cuttings. Several organic and inorganic substrate treatments were included (sand, peat moss, perlite, 1:1 sand/peat moss, 1:1 sand/perlite, and 1:1 peat moss/perlite). Results indicate rooting percentages were greatest in the peat moss/sand substrate. However, unlike our results, Mazare et al. (2007) reports white spruce cuttings had greater root quality data when rooted in a medium which consisted of a perlite/peat moss mixture. In

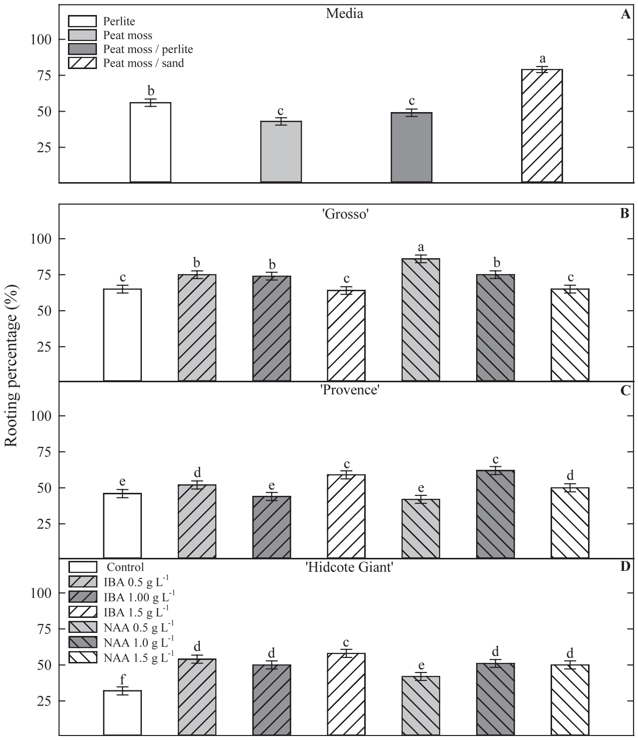

Fig. 4. Influence of media on mean rooting percentage of lavandin (*Lavandula x intermedia*) cuttings across cultivar and plant growth regulator (PGR) (A). Different letters indicate significant media effect ($P = 0.0001$). In addition, influence of interaction ($P = 0.0144$) between lavandin cultivar and PGR on mean adventitious rooting percentage of cuttings across all media treatments (B, C, and D). Different letters indicate significant cultivar x PGR effect. Error bars represent SE of the mean. Data pooled from fall 2019 and spring 2020 experiments.

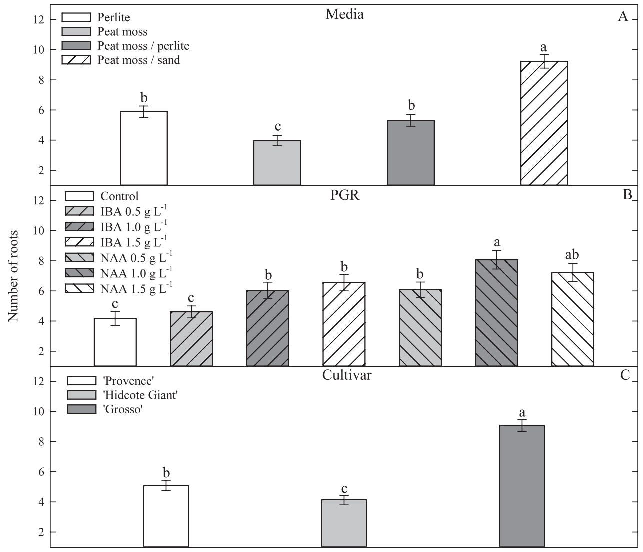

Fig. 5. Influence of media on mean number of adventitious roots produce from lavandin (*Lavandula x intermedia*) cuttings across plant growth regulator (PGR) and cultivar treatments (A). Different letters indicate significant media effect ($P = 0.0001$). In addition, influence of PGR and PGR concentration on mean number of adventitious roots produced from lavandin cuttings across media and cultivar treatments (B). Different letters indicate significant PGR effect ($P = 0.0001$). Also, influence of lavandin cultivar on mean number of adventitious roots produced from each cutting (C). Different letters indicate significant cultivar effect ($P = 0.0001$) across media and PGR treatments. Error bars represent SE of mean. Data pooled from fall 2019 and spring 2020 experiments.

addition, Szczepaniak et al. (2016) found when rooting cuttings of lavender cotton (*Santolina chamaecyparissus* L.), cuttings rooted in a peat moss/sand medium had a greater number of roots when compared to cuttings rooted in either peat moss, or a peat moss/perlite mixture. Comparable to our data, Szczepaniak et al. (2016) report lavender cotton cuttings produced longer roots when placed in a peat moss/sand medium when compared to cuttings placed in peat moss, or a peat moss/perlite medium. Ranjbar and Ahmadi (2017) found miniature rose (*Rosa hybrida* L.) cuttings had a greater number of roots when sand was added to a perlite and tea waste compost medium (1:2:2). Similar data were found with tomato (*Lycopersicon esculentum* Mill.) (He and Yi 2014). It is likely the peat moss medium has a lower pH and greater moisture holding capacity than the sandy, well-drained native soils where lavender is native (Hanamanthagouda et al. 2010, Paton et al. 2004, Upson and Andrews 2004). Medium characteristics of perlite, peat moss, and peat moss/perlite treatments may prohibit cuttings from rooting, and limit root quality characteristics (Davies et al. 2018, Kitir et al. 2018). Our results indicate lavandin rooting was prohibited within perlite, peat moss, and peat moss/perlite media treatments. However, addition of sand to peat moss likely increased medium permeability and aeration (Gislerød 1982, Szczepaniak et al. 2016), and therefore created a favorable environment for rooting these lavandin cultivar cuttings.

When rooting cuttings, a tradeoff between greater rooting percentage (increased medium drainage) and greater root quality (increased medium water holding capacity) has been suggested (King et al. 2011, Zheng et al. 2020). Number of roots produced by a cutting is an indicator of cutting overall health, and a greater number of roots produced by a cutting's root system will increase water and nutrient uptake, which in turn improves cutting survival (Colombi and Walters 2017). However, our results conflict with King et al. (2011), who found greater rooting percentage and greater root quality when baldcypress cuttings were exposed to more aerated and less aerated media, respectively. Our results also disagree with results from previous work with baldcypress (Copes and Randall 1993), and carnation cuttings (Zheng et al. 2020). When rooting cuttings, selecting the proper medium to provide increased rooting and greater root quality appears to be very cultivar and species specific. Therefore, the peat moss/sand medium used in the current study had the greatest positive effect on lavandin rooting percentage and root quality characteristics, and thus appears to be a medium well suited for rooting these lavandin cultivars.

Influence of PGR. Cutting rooting percentage was influenced by PGR. In fact, across all media an interaction occurred between lavandin cultivars and PGR treatments ($P = 0.0144$) (Fig. 4). Of cultivars tested, 'Grosso' cuttings

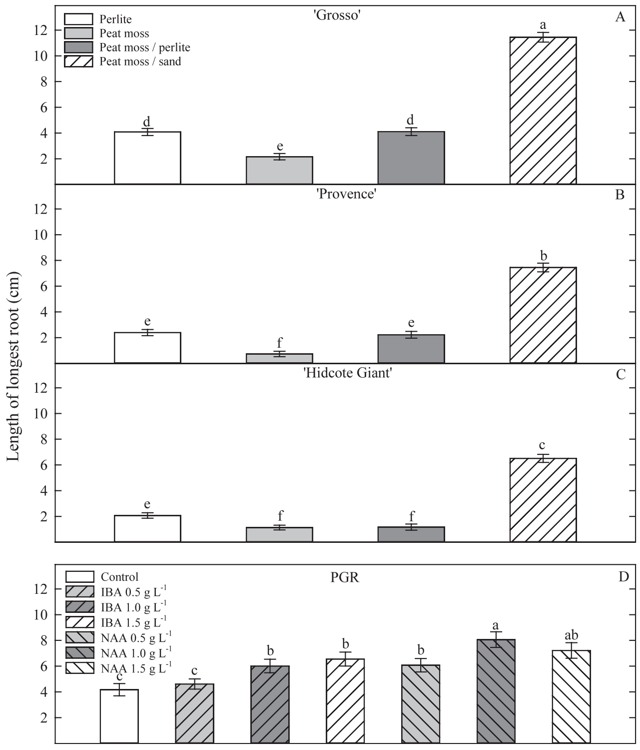

Fig. 6. Influence of interaction (P = 0.0027) between lavandin (*Lavandula x intermedia*) cultivar and media across all plant growth regulator (PGR) treatments on mean cutting adventitious root length (A, B, C). Different letters indicate significant cultivar x media effect. In addition, influence of PGR concentration on adventitious root length of lavandin cuttings (D) across lavandin cultivar and media treatments. Different letters indicate significant PGR effect ($P = 0.0006$). Error bars represent SE of the mean. Data pooled from fall 2019 and spring 2020 experiments.

exposed to 0.5 g·L^{-1} (500 ppm) NAA had the mean greatest rooting percentage, and control 'Hidcote Giant' cuttings had the mean lowest rooting percentage (86 and 32% adventitious rooting, respectively) (Fig. 4). Cultivar rooting percentage also appears to respond differently to PGR concentration. 'Grosso' cuttings tended to have reduced rooting percentage as PGR concentration increased, while rooting percentage for 'Hidcote Giant' and 'Provence' cuttings did not differ, or increased as PGR concentration increased (Fig. 4). Except for cuttings treated with 0.5 g·L^{-1} (500 ppm) IBA, presence of a PGR increased number of roots present when compared to control cuttings (Fig. 5). NAA at concentrations of 1.0 and 1.5 g·L^{-1} (1,000 and 1,500 ppm) produced cuttings with the greatest number of roots. In addition, there was no difference between number of roots produced by cuttings treated with 1.5 g·L^{-1} (1,500 ppm) NAA and the greatest concentrations of IBA (Fig. 5). Trends for the influence of PGR on length of longest root for each cutting (Fig. 6) were similar to data on the effect of PGR on number of roots produced from each cutting (Fig. 5).

Increased rooting percentages of 'Provence' and 'Hidcote Giant' at greater concentrations of PGR are consistent with previous research investigating asexual lavender propagation. Andrade et al. (1999) reports true lavender 'Vera' plantlets had greater rooting percentage when treated with increased concentrations of NAA. Nobre (1996) report similar results when propagating French lavender (*L. stoechas* L.) plantlets. However, findings of Andrade et al. (1999) and Nobre (1996) conflict with rooting response of 'Grosso' cuttings when exposed to greater IBA and NAA concentrations. Similar to our results, Ghosh et al. (2017) indicate star apple (*Grewia asiatica* L.) cuttings had greater rooting percentages at low auxin (IBA and NAA) concentrations, when compared to rooting percentages at greater auxin PGR concentrations. Swamy et al. (2002) report similar results for black locust (*Robinia pseudoacacia* Linn.) and bihul (*Grewia optiva* Drummond) cuttings. Also, lemon balm (*Melissa officinalis* L.) cuttings did not have a greater rooting percentage as IBA and NAA concentrations increased (Sevik and Guney 2013). Lastly, Blythe and Sibley (2009) indicate a comparable response when rooting dwarf Burford holly (*Ilex cornuta* Lindl. & Paxt. 'Burfordii Nana') tip cuttings. Our data confirm lavandin rooting percentage response to increasing auxin PGR concentrations (Fig. 4) may appear to be linear (Andrade et al. 1999, Nobre 1996, Zheng et al. 2020), or curvilinear (Copes and Mandel 2000, Ghosh et al. 2017, Sevik and Guney 2013, Swamy et al. 2002). Therefore, as we describe for lavandin cuttings, rooting percentage response for many species to increased concentrations of an auxin-based PGR is quite variable.

Number of roots for each cutting was also influenced by PGR treatment (Fig. 5). Our results agree with Yusnita et al. (2018), who exposed cuttings of Malay apple (*Syzygium malaccense* L.) to IBA and NAA PGRs. Yusnita et al. (2018) also report when compared to IBA, application of NAA at increased concentrations consistently produced a greater number of roots. In addition, Blythe and Sibley (2012) report a greater number of roots when Heller's Japanese holly (*Ilex crenata* Thunb. 'Helleri') cuttings were exposed to a combination of IBA and NAA treatments. However, Blythe and Sibley (2009) found no difference in number of roots in cuttings of 'Burford Nana' holly cuttings treated with both IBA and NAA when compared to control cuttings.

Greater root length increases overall root surface area, and improves ability of rooted cuttings to uptake water and nutrients (Colombi and Walters 2017). Presence of a PGR tended to increased root length of each lavandin cutting (Fig. 6). Copes and Randall (1993) found similar results with IBA and baldcypress cuttings. Additionally, Blythe and Sibley (2012) indicate total root length of Heller's Japanese holly cuttings were greater with the use of auxin-based PGRs. However, Zheng et al. (2020) report carnation cuttings exposed to greater concentrations of IBA and NAA did not have greater root length. Others report applications of greater IBA and NAA concentrations did not increase cutting root length (Blythe and Sibley 2009, Ghosh et al. 2017, Swamy et al. 2002).

Greater numbers of adventitious root formation on lavandin cuttings when a PGR is applied is likely due to PGR stimulation of cambium activity (Singh et al. 2015), and the ability of auxin-based PGRs to hasten adventitious rooting of cuttings (Blythe et al. 2007). When rooting cuttings, there are a number of options which may improve the production process (Blythe and Sibley 2009, 2012). If required, selection of a PGR and PGR concentration to enhance rooting of cuttings is a critical, yet possibly a costly step (Baldwin and Stanley 1981, Blythe and Sibley 2001). Use of auxin-based PGRs at greater concentrations is known to produce negative, phytotoxic effects on cutting rooting percentage and root quality data (Andrade et al. 1999, Blythe et al. 2007, Blythe and Sibley 2009). Furthermore, our data indicates selection of the correct PGR and PGR concentration for propagation of lavandin by cuttings is essential to provide increased rooting, and greater root quality. In addition, for increased rooting of these lavandin cultivars, our data indicate auxin PGR and PGR concentration is cultivar specific. Therefore, when propagating lavandin tip cuttings, IBA and NAA PGRs used at a number of concentrations appear to have positive effects on cutting rooting percentage and root quality characteristics (Figs. 4, 5, 6).

Influence of cultivar. An interaction occurred between cultivar and PGR for rooting percentage, and cultivar and media for length of longest root found on each cutting (Figs. 4, 6). Therefore, influence of cultivar on cutting rooting percentage, and cutting length of longest root has been partially described and discussed. However, some additional discussion will be provided. Across PGR, mean overall rooting percentage was greatest for 'Grosso' cuttings. Particularly, 'Grosso' cuttings exposed to NAA at 1.5 $g{\cdot}L^{-1}$ (1,500 ppm). In fact, mean rooting percentage for control 'Grosso' cuttings was similar to, or greater than rooting percentage of nearly all other cultivar and PGR treatments (Fig. 4). Across PGR and media, mean number of roots were greatest for 'Grosso' cuttings as well. Across all media and PGR treatments, cuttings of 'Grosso' had 46, and 55% more roots when compared to 'Provence' and 'Hidcote Giant' cuttings, respectively (Fig. 5). For each cultivar, cuttings placed in the peat moss/sand mixture produced longer roots when compared to cuttings of the same cultivar in other media (Fig. 6). Across media treatments, 'Grosso' cuttings in the peat moss/sand medium also had the longest roots (mean of 11.4 cm), while mean longest root length for 'Provence' and 'Hidcote Giant' cuttings in the peat moss/sand medium were 7.5 and 6.5 cm, respectively (Fig. 6).

For these hybrid lavender tip cuttings, rooting percentage, number of roots for each cutting, and length of longest root for each cutting appears to be cultivar specific (Figs. 4, 5, 6). Aljane and Nahdi (2014) investigated effect of five fig (*Ficus carica* L.) cultivars and type of hardwood cutting (age and length of cutting) on rooting percentage, and a number of root quality and cutting parameters (root length, number of roots, etc.). As with our results, they report cultivar differences for rooting percentage, and each measured root quality parameter. Additional research confirms cultivar differences frequently occur when asexually propagating plants through cuttings (Andrade et al. 1999, Copes and Mandel 2000, Epstein et al. 1993, Epstein and Ackerman 1993, Mabizela et al. 2017, McIvor et al. 2014, Noyszewski and Smith 2020), and interactions between genotype and rooting medium have been reported for a number of species (Bajaj 1986). When asexually propagating plants through cuttings, propagators are required to carefully select specific techniques and methods for each genotype (Blythe et al. 2007). Therefore, when propagating lavandin tip cuttings, propagators should balance cultivar choice (genotype) with medium, PGR, and PGR concentration best suited for each particular cultivar.

A complete rooting medium will have a balance between water and air permeability, and water holding capacity. When propagating tip cuttings of 'Grosso', 'Provence', or 'Hidcote Giant' lavandin cultivars, this research demonstrates medium containing peat moss and sand (2:1) is a suitable rooting medium. In addition, depending upon lavandin cultivar, application of IBA or NAA (total immersion method) at 1.0 or 1.5 $g{\cdot}L^{-1}$ (1,000 or 1,500 ppm) will increase cutting rooting percentage, and root quality characteristics. In addition, it appears the combination of optimum propagation media, PGR, PGR concentration, and cultivar produces a synergistic effect, and effectively improves adventitious rooting of lavandin cuttings. Using these procedures, lavandin growers will likely have greater success propagating 'Grosso', 'Provence', and Hidcote Giant' tip cuttings. Although, additional research over a greater number of lavender cultivars, PGR application methods, PGR concentrations, and PGR combinations is required, this work demonstrates methods which should prove beneficial to lavandin propagators and growers who are interested in expanding current operations, and increasing propagation efficiency.

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