**The effect of two biopreparations on rhizogenesis  
in stem cuttings of smoke tree (*Cotinus coggygria* Scop.)**

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**Abstract** Biopreparations stimulate numerous physiological and biochemical processes in plants yet they have little environmental impact. This study evaluated two biopreparations for their effect on rooting of stem cuttings of two cultivars of smoke tree (*Cotinus coggygria*). During rooting, cuttings were sprayed once, twice or three times with aqueous solutions of 0.2% ‘AlgaminoPlant’ or 0.1% ‘Route’. To evaluate their effectiveness relative to the treatments routinely used in the nursery production, some cuttings were treated with a rooting powder Rhizopon AA containing a synthetic auxin IBA (2%) or sprayed with a water solution of IBA (200 mg dm-3). Both biopreparations tested enhanced rhizogenesis in both cultivars. They increased the content of phenolic compounds in the leaves of cuttings and stimulated the activity of catalase, while lowering the content of hydrogen peroxide and the endogenous ethylene production. Given the performance of the two tested preparations it appears that they can be recommended to growers as a replacement for synthetic IBA in nursery production.

**Key words:** *Cotinus coggygria*, rooting, hydrogen peroxide, enzymes, ethylene.

**Introduction**

Production of plant material in the EU is controlled by stringent environmental, economic, juridical and social regulations. In the name of environmental protection, restrictions have been imposed on the use of commonly used rooting powders containing synthetic auxins and fungicides [Ludwig-Muller 2000]. This calls for a search of substitute preparations that are environmentally friendly yet still effective in rhizogenesis and in successful acclimation of plants to different conditions in successive steps of plant production, while maintaining high quality level of the nursery plant material [Wojdyła 2004, Pacholczak et al. 2012].

Biopreparations may constitute such a group of compounds as they contain natural substances with little, if any, predicted environmental effect. They have been viewed as biological substances that stimulate certain physiological or biochemical processes within plants. They are single- or multi-compound preparations containing extracts from plants and/or animals. They affect plant metabolism [Basak, 2008].They are used to generate the highest possible and the best quality yields, especially under environmental conditions unfavorable for plant growth and development [Przybysz et al. 2008].

The potential of biopreparations to enhance rooting of stem cuttings has been evaluated by our team and reported previously [Pacholczak et al. 2010; 2012]. They positively affect quality of plant material and its resistance or tolerance to stresses in every phase of nursery production. These preparations affect some processes in plant cells enhancing plant vitality which in turn appear to lead to more intense growth and vigor, important for potential consumers [Gawrońska et al. 2008, Pacholczak and Szydło 2008]. Biopreparations enable plants to better exploit the growth and development potential of their environment. Their effects are more pronounced under less favorable environmental conditions as they strengthen plants’ natural abilities to cope with stresses [Pacholczak and Szydło 2008].

One of biopreparations – ‘AlgaminoPlant’ (Varichem, Poland) - is a liquid preparation produced on the base of a seaweed extract (18%) from *Sargassum*, *Laminaria*, *Ascophyllum* and *Fuscus*.It containsthree groups of plant hormones: gibberellins, cytokinins and auxins. It is supplemented by potassium salts of amino acids at 10%. The preparation enhances uptake of macro- and microelements and their translocation within plants, increases the respiration rate and root growth, promotes photosynthesis and other metabolic processes [Matysiak et al. 2011]. It positively affects plant resistance to stresses, accelerates flowering and fruit set [Dobrzański et al. 2008]. It also improves the water-holding capacity of the soil and maintains optimal soil pH [Matysiak et al. 2011].

‘Route’ (Dalgety, Poland) is a formulation of zinc ammonium acetate (ZAA) composed of acetic acid, water, ammonium and zinc oxide. Zinc helps plants overcome environmental stresses and enhances their productivity through a better development of root system and a more efficient use of irradiance [Fraser and Percival 2003]. ‘Route’ reinforces (about 18%) cell walls, thus reducing their porosity and indirectly decreasing the mineral nutrient losses from cells [Horne and Leitch 2006]. ZAA action in rhizogenesis is associated with stimulation of endogenous biosynthesis of auxins, which changes the auxin to cytokinin ratio. This in turn results in a more abundant production of auxiliary roots.

Vegetative propagation of smoke tree and its cultivars by conventional methods is slow and problematic [Jacygrad et al. 2012]. Acceleration of this process by biopreparations which enhance the regeneration of the root system in cuttings appears promising. For these reasons, trials were undertaken to evaluate the efficiency of ‘AlgaminoPlant’ and ‘Route’ in propagation of two smoke tree cultivars. An attempt was also made to detect relationships between several biochemical parameters in cuttings, as influenced by treatments, and the subsequent rhizogenesis.

**Materials and methods**

The experiments were carried out in 2011 and 2012 in a commercial nursery of M.M. Kryt in Wola Prażmowska, on two cultivars of smoke tree (*C. coggygria*): ‘Royal Purple’ and ‘Young Lady’. Semi lignified two nodal stem cuttings were prepared from shoots harvested from stock plants free of pathogens and diseases. Cuttings were rooted in styrofoam boxes. They were inserted to the depth of 2 cm into a mixture of peat, perlite and sand (2:1:1), pH 5.0. The mixture was thoroughly wetted and pressed, and covered with a 0.5 cm layer of coarse sand.

Two biopreparations were tested, both in aqueous solutions: ‘AlgaminoPlant’ (0.2%) and ‘Route’ (0.1%). These concentrations, recommended by producers, were verified in preliminary experiments. Cuttings were sprayed with either solution once, twice or three times during the rooting period. The effects of the two preparations were compared to a synthetic auxin (β-indolilobutyric acid, IBA) routinely used in nursery production. IBA was applied either directly to the bases of cuttings in the form of the commercially available rooting powder Rhizopon AA (2% IBA), or by spraying cuttings with aqueous solution of 200 mg dm-3 IBA. Control cuttings were sprayed with distilled water. The experiment began on June 28 and ended on August 29 in 2011, and on June 26 and ended on August 22 in 2012.

Water and the tested solutions were applied with a hand pressure sprayer (volume 1 dm-3) on the start date of the experiment (June 28 2011, June 26 2012), and repeated twice at one week intervals, on July 5 and July 12 in 2011 and July 3 and July 10 in 2012. Rooting took place in plastic tunnels equipped with automatic watering and mist systems as well as with shading devices. During the first two weeks, the cuttings were protected against sun with an opaque foil and a shading cloth. Every two weeks, cuttings were sprayed against *Botrytis* with 0.2% Rovral or Bravo.

The experiment consisted of nine treatments (Tab. 1), each in three replications, each replication containing 20 cuttings. Percentages of rooted cuttings and the degree of rooting were determined 8 weeks after the start of the experiment. The degree of rooting was evaluated on a 5-point scale rating the development of the root ball provided by Pacholczak et al. [2012]. The scores for the degree of rooting represent means of three independent observations by trained personnel. Percent of rooted cuttings was also calculated - only the cuttings with root system within the scale range of 2-5 were regarded as rooted and counted.

For biochemical analyses, leaves from 20 cuttings per treatment were collected three weeks after the beginning of the experiment, from treated and untreated cuttings. They were finely chopped, mixed and 0.5 g samples were used for the measurements of polyphenolic acids, hydrogen peroxide as well as activities of catalase and peroxydase. Triplicate extracts were prepared for each analysis and three measurements were done for each extract producing nine readings for each data point.

For the dry matter content, 1 g samples were dried at 105oC to constant weight [Strzelecka et al. 1982]. Polyphenolic acids were measured according to the colorimetric method with the Arnow’s reagent according to the Polish Norm PN-91/R-87019. The hydrogen peroxide content was measured according to Siedlecka [2010]. The catalase activity was analyzed according to Goth [1991], and the peroxidase activity – by the method of Toczko and Grzelińska [2001]. The endogenous ethylene production was determined with a Hewlett Packard gas chromatograph Model 5890 II.

**Statistical analyses**

To compare the means, percentages of rooted cuttings were transformed according to Bliss [Wójcik and Landański 1989], while the degree of rooting by root transformation: y=x2+(x+1)2, subjected to ANOVA 1 and tested by the Duncan’s test at α=0.05. Results of the biochemical analyses were subjected to the 2-factorial ANOVA and the means were compared by the Duncan’s test at α=0.05.

**RESULTS**

**The degree of rooting and rooting percentages in cuttings of smoke tree ‘Royal Purple’**

In the untreated control less than 20% of cuttings rooted in 2011, and their degree of rooting was below 1.5 (Fig.1). Synthetic auxin IBA more than doubled these values with no significant differences between the rooting powder and sprayed water solution of IBA. Foliar application of ‘AlgaminoPlant’ did not improve rooting relative to the control and neither did spraying with ‘Route’, with the exception of a single application which doubled the percentage of rooting and the degree of rooting relative to the untreated control.

In 2012 rooting was better than in 2011 (Fig. 2). Control cuttings rooted in 60% and their root balls were better developed as expressed by the degree of rooting which attained 2.75. The latter parameter was unaffected by the treatments and ranged between 2.5 and 2.9. Rhizopon AA and the sprayed water solution of IBA significantly increased percentage of rooting relative to control, by 35% and 20%, respectively. A single foliar application of ‘AlgaminoPlant’ improved rooting comparably to the water auxin solution, increasing the percentage of rooted cuttings by 25% as compared to control.

**The degree of rooting and rooting percentages in cuttings of smoke tree ‘Young Lady’**

In 2011, the cuttings of ‘Young Lady’ also rooted poorly – less than 20% in control treatment (Fig. 3) and the effects of treatments were significant. While the commercial powder proved inefficient, sprayed water solution of IBA nearly tripled the percentage of rooted cuttings and doubled the value of rooting degree relative to control treatment. ‘AlgaminoPlant’ sprayed on cuttings once or twice markedly improved the root development and doubled the rooting percentage relative to control. However, the third application did not additionally increase the rooting percentage and appeared to arrest root development. ‘Route’ more than doubled the parameters of rhizogenesis when applied two or three times while the single spraying proved inefficient as compared to untreated cuttings.

Also for ‘Young Lady’ the 2012 was a better year for rooting than was 2011 (Fig. 4). Control cuttings rooted in 46%. Most of the treatments significantly increased this percentage, the triple ‘AlgaminoPlant’ application and the single spray with ‘Route’ being the most effective treatments. Increasing the number of sprayings with ‘Route’ decreased efficiency of this biostimulant. Also a degree of rooting was improved by all but one treatment ( a triple use of ‘Route’) with no significant differences between them.

**Polyphenolic acids**

In both smoke tree cultivars the polyphenolic acids contents were significantly affected by treatments and years (Tab. 2). In ‘Royal Purple’, the average polyphenolic acids content in 2012 was only half of that from 2011 while in ‘Young Lady’. it was lower by one third. Generally, in both years the contents were higher in cuttings treated with biostimulators as compared to control treatments.

In 2011 in ‘Royal Purple’, ‘AlgaminoPlant’ and ‘Route’ increased the polyphenolic acids’ levels relative to untreated cuttings, by 85% and 64%, respectively. In 2012 only ‘Route’ gave such an effect increasing the poliphenolic acids’ content by 23% relative to the control.

In ‘Young Lady’ there was no difference in the contents of polyphenolic acids between the years. In 2011, ‘AlgaminoPlant’ and ‘Route’ raised the levels of polyphenolic acids by 30% and 73%, respectively, as compared to control treatment. In 2012, there was a reduction in polyphenolic acids after the ‘AlgaminoPlant’ application and no effect of ‘Route’ was observed.

**Hydrogen peroxide (H2O2)**

A significant effect of treatments on the hydrogen peroxide content in cuttings of both cultivars was observed, but the effect of the season was statistically significant only in ‘Royal Purple’ (Tab. 3). In ‘Royal Purple’, the average H2O2 content dropped by 50% and 65% after ‘AlgaminoPlant’ and ‘Route’ applications, respectively. This drop was more pronounced in 2012 were the ‘Route’ reduced the H2O2 level by 72% relative to control cuttings.

A similar phenomenon was observed in ‘Young Lady’. In 2011, the H2O2 contents dropped by 41% and 32% after ‘AlgaminoPlant’ and ‘Route’ applications, respectively, relative to control cuttings. In 2012, the effect was smaller for ‘AlgaminoPlant’ while ‘Route’ caused almost a fourfold reduction in the hydrogen peroxide content as compared to control treatment.

**Catalase activity**

The treatments significantly increased the catalase activity in cuttings of both cultivars but the effect of the growing season was statistically significant only in ‘Young Lady’ (Tab. 4). In 2011, ‘AlgaminoPlant’ produced a fourfold increase in enzyme activity in cuttings of ‘Royal Purple’ while in ‘Young Lady’ this treatment produced an over twofold activity increase as compared to control treatments. Slightly lower activity increases were observed after ‘Route’ applications. In 2012, neither of the biopreparations significantly affected catalase activity in neither of the cultivars.

**Peroxidase activity**

Both, treatments and seasons significantly affected peroxidase activity in both cultivars (Tab. 5). The average peroxidase activity was higher in 2012 than in 2011, by nearly 60% and 24% in ‘Royal Purple’ and ‘Young Lady’, respectively. Generally, foliar application of both preparations significantly reduced the enzyme activity. In 2011, the reduction after ‘AlgaminoPlant’ and ‘Route’ application in ‘Royal Purple’ was 20% and 12%, respectively and there was no reduction in 2012. In ‘Young Lady’, it was the other way around: there was no effect in 2011 while in 2012, the preparations reduced the peroxidase activity by 19% and 32% respectively.

**Endogenous ethylene production**

Both the year and the treatment significantly affected the average ethylene production by cuttings of the two cultivars. In 2011, the average production of C2H4 was higher than in 2012, by 29 % and 18 % in ‘Royal Purple’ and ‘Young Lady, respectively.

In both years the auxin treatments either as the rooting powder Rhizopon AA or foliar application of the water IBA solution elevated gas production relative to untreated cuttings. In most cases, the ethylene production was higher after spraying cuttings with the auxin solution as compared to the powder applied to the cuttings’ bases. This increase (over control) ranged between 16-22 % for ‘Royal Purple’ and 141-128 % for ‘Young Lady’, in 2011 and 2012, respectively.

The applications of ‘AlgaminoPlant’ reduced ethylene production in ‘Royal Purple’ in both season, to 60% and 77% of the control after one treatment and to 46% and 53% of the control after three sprayings, in 2011 and 2012, respectively. ‘Route’ also limited C2H4 synthesis in ‘Royal Purple by 23-32% relative to control and approx. 10% in 2011 and 2012, respectively.

There was little effect of ‘AlgaminoPlant’ on the ethylene production in ‘Young Lady’. The preparation reduced the C2H4 production by 17% in 2001 (a single treatment) and by 22% in 2012 (two sprayings). ‘Route’ applications in both years enhanced ethylene synthesis by of 35% to 36%.

**Discussion**

The process of forming a root ball by a stem cutting depends on numerous factors, both internal and external [Spethmann 2001]. Rooting powders containing auxins have been routinely used to enhance rhizogenesis, with the β-indolilobutyric acid (IBA) being the most effective. Pacholczak and Szydło [2008] reported positive effects of Rhizopon AA (containing IBA) on rooting of ninebark cuttings. In this study, in two cultivars of smoke tree, both methods of IBA application (rooting powder Rhizopon AA and sprayed water solution of IBA) stimulated rhizogenesis by increasing the percentage and the degree of rooting.

Biopreparations are relatively new tools created to assist plants in the adjustment to stressful conditions, such as when taking cuttings from stock plants. They also enable plants to make the best use of the rooting conditions provided by nurserymen [Schmidt et al. 2003]. Khan et al. [2009] reported that seaweed extracts promoted growth of roots in *Pinus pinea* seedlings, as measured by their dry mass content. In the tests on maize, biopreparations applied in early stages of plant development produced plants with well developed root systems [Jeannin et al. 1991]. Nedumaran and Peruman [2009] after trials on *Rhizophora mucronata* suggested that the best growth of shoots and roots could be obtained with frequent applications of seaweed extracts in low concentrations. Using a seaweed preparation, Thorsen et al. [2010] enhanced root development in *Plantago lanceolata* but not in *Vigna radiata* where the auxin IAA was effective in promoting rooting. ‘AlgaminoPlant’ tested here on smoke tree has been reported to stimulate rhizogenesis in dogwood (*Cornus alba* ‘Aurea’ and ‘Elegantissima’), but its efficiency depended on a number of treatments [Pacholczak et al. 2012].

Zinc ammonium acetate (ZAA) is an active ingredient of ‘ ‘Route’’ [Cattanach 1992, Pacholczak and Szydło 2008]. As shown in ninebark, its foliar application can improve the percentage and the degree of rooting [Pacholczak and Szydło 2008]. In this study, it enhanced rhizogenesis in smoke tree ‘Young Lady’, similarly to ‘AlgaminoPlant’.

Phenolic compounds affect plant metabolism by improving the respiration efficiency. They also increase auxin contents and the number of auxin receptors [Gawrońska et al. 2008]. Supposedly, they protect auxins against oxidation by inhibiting the IAA oxidase with which they may form the phenol-IAA complexes. These complexes are considered to be co-factors of auxin metabolism and rooting co-factors [Bhattacharya 1988, Fu i in. 2011]. Polyphenolic acids also affect the activity of certain enzymes participating in rhizogenesis and take part in forming lignins covering cell walls [Gorter 1969, Przybysz et al. 2010]. Predictably, an increase in phenolic compounds was observed here after treatments with each of the tested compounds. Similarly, in trials on ninebark, the phenolic compounds increased after the foliar application of biostimulators [Jacygrad and Pacholczak 2010]. On the contrary, phenol levels dropped in herbaceous basil after watering plants with solutions of biopreparations Aminoplant and Goëmar [Rosłon et al. 2011].

Reactive oxygen species (ROS) participate in multiple metabolic processes in cells. Their presence is often related to stress conditions such as drought or wounding, when their synthesis and accumulation take place after normal cell activities are disturbed [Hodges [2001]. They can affect the structure and properties of cell organelles and disturb their functions by oxidizing various compounds which in turn may lead to degradation of membranes, nucleic acids or even cause mutations. Hydrogen peroxide (H2O2) is one of the ROS and it may accumulate in damaged tissues, vessels, stomata and neighboring cells. It appears to be produced by transformation of the superoxide anion in a spontaneous reaction of dismutation or in a reaction catalyzed by the superoxide dismutase [Dietz et al. 2006]. Both, ‘AlgaminoPlant’ and ‘Route’ reduced the hydrogen peroxide contents in cuttings. It appears that both biopreparations mitigated the effects of the oxidative stress thus creating conditions for better root regeneration.

Oxidoreductases are specific enzymes catalyzing redox reactions. They transport electrons and hydrogen atoms between the reductant and the oxidant. Such reactions maintain homeostasis between reduced and oxidized forms of a compound, such as oxygen. When this homeostasis is disturbed, free radicals appear and the oxidative stress occurs. Plant sensitivity to this stress depends on quick removal of free radicals and less so, on the rate of their formation. Enzymes such as peroxidases and catalases are involved in the removal of free radicals [Nowak et al. 2004]. Preparations tested here increased the activities of catalase and polyphenol oxidase while the activity of peroxidase decreased. In tall fescue (*Festuca arundinacea*) treated with a preparation containing an extract from the sea weed *Ascophyllum nodosum,* the activity of superoxide dismutase increased by 30% [Zhang 1997]. This was confirmed by Fike et al. [2001]. On the other hand, Ayad [1998] reported a reduction in the activities of SOD, glutathione reductase and ascorbinian peroxidase in tall fescue treated with the same sea weed extract [Ayad 1998]. According to Zhanng et al. [2006], extracts from algae *Ascophyllum nodosum* increased the SOD activity in *Agrostis stolonifera* infected with a fungus *Sclerotinia homoeocarpa* while reducing the rate of infection. There are no reports on the ZAA effects on the oxidoreductase activity. Here it appears that both ‘AlgaminoPlant’ and ‘Route’ enhance the responses to the oxidative stress by reducing the levels of hydrogen peroxide. In the first phase of this response, the activities of the antioxidative enzymes are enhanced while later that of peroxidase is decreased while catalase remains highly active.

Ethylene is a gaseous plant hormone. First reports on its involvement in rhizogenesis date back to 1930’ties but the mechanism of its action is yet to be discovered [Zimmerman and Hitchcock 1933, Wang and Pan 2006]. Published reports document a positive effect of ethylene on root initiation and development [Pan et al. 2002], a negative one [Nordström and Eliasson 1984] or no effect at all[Harbage and Stimart 1996]. The opinions prevail that the effect may be concentration-dependent [Kawase 1976, Simson 1984], or depends on the physiological state of cuttings, the level of endogenous C2H4 [Liu and Reid 1992, Visser et al. 1996] and its interaction with other hormones, such as a change in tissue sensitivity to auxins stimulated by ethylene [Wang and Pan 2006]. Some woody cuttings, especially conifers, positively respond to treatments with the ethylene-releasing etephon applied prior to the auxin application. Similar effects of stimulation by Ethrel-A (containing ethephon) were observed in etiolated cuttings of *Quercus robur* [Istas and Meneve 1981, Simson 1984]. In this study, the production of endogenous ethylene was reduced after application of ‘AlgaminoPlant’ and ‘Route’.

The results obtained in this work show that several physiological processes in smoke tree cuttings are clearly affected by biostimulators and that the preparations positively affect rhizogenesis. This may help to make a better use of such preparations in the improvement of ornamental plant production in a changing regulatory environment.

**Acknowledgments**

This research was supported by the State Committee for Scientific Research as a part of the Project: “The intensification of propagation of ornamental shrubs by using biostimulants“ (NN 310725140).

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**Table 1.** A list of treatments in the experiment.

|  |  |
| --- | --- |
| **No. of treatment** | **Methods of cuttings treatment** |
| 1 | Control '0' 1 spraying with distilled water (H2O) |
| 2 | Rhizopon AA (2% IBA) powder |
| 3 | 1 spraying with IBA 200 mg ·dm-3 |
| 4 | 1 spraying with ‘AlgaminoPlant’ 0.2% |
| 5 | 2 sprayings with ‘AlgaminoPlant’ 0.2% |
| 6 | 3 sprayings with ‘AlgaminoPlant’ 0.2% |
| 7 | 1 spraying with ‘Route’ 0.1% |
| 8 | 2 sprayings with ‘Route’ 0.1% |
| 9 | 3 sprayings with ‘Route’ 0.1% |

**Table 2.** The effect of biostimulators ‘AlgaminoPlant’ and ‘Route’ on polyphenolic acids content (mg of caffeic   
acid · g d.m.-1) in cuttings of smoke tree (*C. coggygria*)‘Royal Purple’ and ‘Young Lady’.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Cv. | Season | Control | | ‘AlgaminoPlant’ | | ‘Route’ | | **Means**  (for seasons) | |
| ‘Royal Purple’ | *2011* | 13.06 | **c\*** | 24.18 | **e** | 21.48 | **d** | 19.57 | **b** |
| *2012* | 9.10 | **a** | 9.29 | **a** | 11.27 | **b** | 9.89 | **a** |
| **Means**  (for treatments) | 11.08 | **a** | 16.37 | **b** | 16.74 | **b** |  | |
| ‘Young Lady’ | *2011* | 9.08 | **b\*** | 11.85 | **c** | 15.69 | **d** | 12.21 | **b** |
| *2012* | 9.35 | **b** | 8.17 | **a** | 9.30 | **b** | 8.94 | **a** |
| **Means**  (for treatments) | 9.21 | **a** | 10.01 | **a** | 12.49 | **b** |  | |
| \* Means followed by the same letter do not differ significantly at α = 0.05. Statistical evaluation was made for each cultivar separately. | | | | | | | | | |

**Table 3.** The effect of biostimulators ‘AlgaminoPlant’ and ‘Route’ on contents of hydrogen peroxide (H2O2) (µg ·g d.m.-1) in cuttings of smoke tree (*C. coggygria*)‘Royal Purple’ and ‘Young Lady’.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Cv. | Season | Control | | ‘AlgaminoPlant’ | | ‘Route’ | | **Means**  (for seasons) | |
| ‘Royal Purple’ | *2011* | 31.54 | **b\*** | 15.28 | **a** | 16.11 | **a** | 20.98 | **a** |
| *2012* | 75.91 | **c** | 38.92 | **b** | 21.30 | **a** | 45.38 | **b** |
| **Means**  (for treatments) | 53.73 | **b** | 27.10 | **a** | 18.71 | **a** |  | |
| ‘Young Lady’ | *2011* | 90.32 | **d\*** | 53.08 | **b** | 61.33 | **c** | 68.24 | **a** |
| *2012* | 87.73 | **d** | 65.07 | **c** | 22.86 | **a** | 58.55 | **a** |
| **Means**  (for treatments) | 89.02 | **c** | 59.07 | **b** | 42.10 | **a** |  | |
| \* Means followed by the same letter do not differ significantly at α = 0.05. Statistical evaluation was made for each cultivar separately. | | | | | | | | | |

**Table 4.** The effect of biostimulators ‘AlgaminoPlant’ and ‘Route’ on catalase activity (mkat · g d.m.-1) in cuttings of smoke tree (*C. coggygria*)‘Royal Purple’ and ‘Young Lady’.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Cv. | Season | Control | | ‘AlgaminoPlant’ | | ‘Route’ | | **Means**  (for seasons) | |
| ‘Royal Purple’ | *2011* | 439.02 | **a\*** | 2226.78 | **c** | 1679.49 | **bc** | 1448.43 | **a** |
| *2012* | 1004.59 | **ab** | 1653.76 | **bc** | 1089.13 | **ab** | 1249.16 | **a** |
| **Means**  (for treatments) | 721.81 | **a** | 1940.27 | **b** | 1384.31 | **b** |  | |
| ‘Young Lady’ | *2011* | 430.49 | **a\*** | 1126.54 | **c** | 900.35 | **b** | 819.13 | **a** |
| *2012* | 860.29 | **b** | 1092.57 | **b** | 945.21 | **b** | 966.02 | **b** |
| **Means**  (for treatments) | 645.39 | **a** | 1109.56 | **c** | 922.78 | **b** |  | |
| \* Means followed by the same letter do not differ significantly at α = 0.05. Statistical evaluation was made for each cultivar separately. | | | | | | | | | |

**Table 5.** The effect of biostimulators ‘AlgaminoPlant’ and ‘Route’ on peroxidase activity (nkat · g d.m.-1) in cuttings of smoke tree (*C. coggygria*)‘Royal Purple’ and ‘Young Lady’.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Cv. | Season | Control | | ‘AlgaminoPlant’ | | ‘Route’ | | **Means**  (for seasons) | |
| ‘Royal Purple’ | *2011* | 0.836 | **b\*** | 0.672 | **a** | 0.733 | **a** | 0.747 | **a** |
| *2012* | 1.207 | **c** | 1.140 | **c** | 1.187 | **c** | 1.178 | **b** |
| **Means**  (for treatments) | 1.022 | **b** | 0.908 | **a** | 0.957 | **a** |  | |
| ‘Young Lady’ | *2011* | 0.724 | **ab\*** | 0.727 | **ab** | 0.608 | **a** | 0.686 | **a** |
| *2012* | 1.020 | **c** | 0.831 | **b** | 0.694 | **ab** | 0.848 | **b** |
| **Means**  (for treatments) | 0.873 | **b** | 0.778 | **b** | 0.653 | **a** |  | |
| \* Means followed by the same letter do not differ significantly at α = 0.05. Statistical evaluation was made for each cultivar separately. | | | | | | | | | |

**Table 6.** The effect of biostimulators ‘AlgaminoPlant’ and ‘Route’ on endogenous ethylene production (µl · l-1 · kg-1 · h-1) in cuttings of smoke tree (*C. coggygria*)‘Royal Purple’ and ‘Young Lady’.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Treatment | Season | | | | **Means**  (for treatments) | | |
|  | 2011 | | 2012 | |
| *C. coggygria* ‘Royal Purple’ | Control | 152.85 | **i\*** | 102.73 | **f** | 127.81 | **d** | |
| Rhizopon AA | 165.96 | **j** | 120.29 | **gh** | 143.13 | **e** | |
| IBA | 177.55 | **k** | 124.89 | **h** | 151.22 | **e** | |
| ‘AlgaminoPlant’ × 1 | 91.22 | **e** | 78.68 | **d** | 84.95 | **b** | |
| ‘AlgaminoPlant’ × 2 | 71.68 | **cd** | 62.09 | **b** | 66.88 | **a** | |
| ‘AlgaminoPlant’ × 3 | 70.37 | **c** | 54.03 | **a** | 62.20 | **a** | |
| ‘Route’ × 1 | 112.74 | **g** | 93.26 | **e** | 103.00 | **c** | |
| ‘Route’ × 2 | 103.46 | **f** | 93.28 | **e** | 98.37 | **c** | |
| ‘Route’ × 3 | 117.26 | **gh** | 92.63 | **e** | 105.113 | **c** | |
| **Means**  (for seasons) | 118.12 | **b** | 91.36 | **a** |  | |  | |
| *C. coggygria* ‘Young Lady’ | Control | 68.32 | **de\*** | 59.48 | **bcd** | 63.90 | **a** | |
| Rhizopon AA | 99.75 | **ij** | 105.83 | **j** | 102.79 | **c** | |
| IBA | 165.63 | **l** | 135.72 | **k** | 150.67 | **d** | |
| ‘AlgaminoPlant’ × 1 | 56.98 | **bc** | 49.36 | **ab** | 53.17 | **a** | |
| ‘AlgaminoPlant’ × 2 | 65.06 | **cde** | 46.30 | **a** | 55.68 | **a** | |
| ‘AlgaminoPlant’ × 3 | 71.85 | **ef** | 49.47 | **ab** | 60.66 | **a** | |
| ‘Route’ × 1 | 90.29 | **hi** | 67.34 | **cde** | 78.82 | **b** | |
| ‘Route’ × 2 | 92.59 | **hi** | 78.62 | **fg** | 85.61 | **b** | |
| ‘Route’ × 3 | 91.22 | **hi** | 86.90 | **gh** | 89.06 | **b** | |
| **Means**  (for seasons) | 89.08 | **b** | 75.45 | **a** |  | |  | |
| **\*** Means followed by the same letter do not differ significantly at α = 0.05. Statistical evaluation was made for each cultivar separately. | | | | | | | | |