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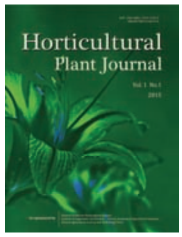

Negative Phototropism of *Chlorophytum comosum* Roots and Their Mechanisms

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Abstract

The aerial roots of *Chlorophytum comosum* were grown hydroponically, allowing us to study the performance and mechanism of negative phototropism. The results of this study were as follows. All the adventitious roots and their branch roots bent away from light with a maximum curvature of approximately 88.5°. Blue-violet light prominently induced negative phototropism while red light had no effect. The root cap was the site of photo perception. Roots with shaded or divested root caps exposed to unilateral light showed no negative phototropism, but resumed their original characteristics when the shade was removed or when new root caps grew. The curvature increased when the light intensity ranged 0–110 μmol · m^{-2} · s^{-1}. The negative phototropism curvature could be promoted by exogenous $CaCl_2$ but was inhibited by exogenous $LaCl_3$; exogenous $CaCl_2$ could reduce the inhibitory effect of $LaCl_3$. Unilateral light induced the horizontal transport of IAA from the irradiated side to the shaded side, resulting in an unequal distribution of IAA in both the sides, leading to negative phototropism. The horizontal transport of IAA was promoted by exogenous Ca^{2+} but inhibited by exogenous La^{3+}.

Keywords: *Chlorophytum comosum*; root; hydroponics; negative phototropism; mechanism

1. Introduction

As early as 1758, French physician and botanist Henri-Louis Duhamel du Monceau inferred in his book on the biology of plants that plant stems and leaves lean toward sunlight (DuHamel, 1758; Kutschera and Briggs, 2012). This remarkable phenomenon was termed *heliotropism* in the 1800s (Whippo and Hangarter, 2006). Later, an increasing amount of experimental proof demonstrated that artificial light sources, such as candles and incandescent lamps, caused a similar response in plants, leading to the introduction of the term phototropism, indicating that photons, the basic units of electromagnetic radiation, were the factors that gave rise to this reaction (Kutschera and Briggs, 2012). Meanwhile, with the introduction of the coleoptile of etiolated grass seedlings as an experimental system to analyze shoot phototropism under laboratory conditions (Darwin, 1880), the positive phototropism of the aerial parts (stems and leaves) received considerable investigation (Briggs, 1963a, 1963b, 2001; Srivastava, 2002;

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Holland et al., 2009; Kutschera and Briggs, 2009; Kutschera and Niklas, 2009; Koller, 2011), but little attention has been paid to underground roots. In the late 1800s and early 1900s, some researchers found that the tap root of white mustard (*Sinapis alba*) seedlings showed a negative phototropic characteristic. (Darwin, 1882; Sachs, 1882; Pfeffer, 1904; Strasburger et al., 1911). Thus, little is known of the negative phototropism of plant roots in regards to their mechanisms (Wang et al., 2002; Kutschera and Briggs, 2012). Recently, it was found that the seminal, secondary, and lateral roots of a variety of plants were negatively phototropic (Okada and Shimura, 1992; Vatha et al., 2000; Briggs et al., 2001; Wang et al., 2002; Mo et al., 2004). Wang et al. (2002) found that negative phototropism was induced by blue light, while red light had no effect. Further investigation revealed that the process of negative phototropism involved polar auxin transport: blue light promoted the transportation of auxins from the irradiated side to the shaded side, resulting in a high concentration of auxin accumulation in the shaded side, even as it inhibited the growth of this side (Wang et al., 2002; Mo et al., 2004).

Chlorophytum comosum is a popular ornamental plant that can absorb a variety of toxic and harmful gases (Wo et al., 2012). It is easy to breed and grow in pots; furthermore, the submergence resistance ability of its roots make it a prospect for hydroponic propagation (Kong et al., 2009). Like rice roots, the hydroponic roots of *C. comosum* exhibit negative phototropism, and their mechanisms were investigated in this study.

2. Materials and methods

2.1. Plant materials and culture conditions

Experiments were conducted in 2012 and 2013 in the Hubei Key Laboratory of Economic Forest Germplasm Improvement and Resources Comprehensive Utilization of Huanggang Normal University, and the Key Laboratory of Crop Genetics and Physiology of Yangzhou University, Jiangsu Province. *Chlorophytum comosum* (Thunb.) Baker seedlings with 2- to 3-mm-long aerial roots were collected from the creeping stem of the same matrix plant, fixed with metallic wire, and inserted into a foam board for suspension culture in a transparent aquarium wrapped in black plastic bags and filled with water. The plants were cultivated in an artificial climate chamber at a temperature of 30 ℃ and a relative humidity of 75%. Seedlings that sent forth new aquatic roots in the direction of gravity were chosen for experiments.

2.2. Treatments and measurement of negative phototropic curvature

Using the methods described by Wang et al. (2002), the bending growth of negative phototropism of *C. comosum* roots were induced by unilateral irradiance of 60 W focus lamps. Light intensity was regulated by changing the distance between the light and *C. comosum* roots. Treatments with monochromatic lights were carried out using filter coatings with different absorption wavelengths. We partially shaded the roots by wrapping foil around different parts of the roots or cutting them to observe the photosensitive site of negative phototropism (Wang et al., 2002). A calcium reagent ($CaCl_2$) and a calcium channel blocker ($LaCl_3$) were added to the water to study the effect of them on the negative phototropism (Chen et al., 2014). The curvature of the negative phototropism was measured by protractor (Wang et al., 2002).

2.3. Determination of IAA content in the irradiated and shaded sides of root tips

Under low temperature and weak light conditions, 4 mm sections of the root tips were cut and split longitudinally into two parts: the irradiated side and the shaded side according to the method described by Mo et al. (2004). Then, 0.5 g samples were obtained from each part to determine the IAA content using the ELISA method.

3. Results

3.1. Negative phototropism of C. comosum roots

The *C. comosum* seedlings used in the study were collected from the creeping stems of the matrix plant; therefore, no seminal roots formed on the seedling plants (Fig. 1).

The root system of the seedlings was composed of adventitious aerial roots, which were green. After a period of water culture, adventitious aerial roots elongated and some branch roots were sent forth from the elongated parts. If planted in the dark, the newly grown parts were white in color (Fig. 1).

The adventitious aquatic roots of *C. comosum* grew downwards with gravity when the roots were cultured in the dark (Fig. 1, A), while a negative phototropism curvature was observed after exposure to unilateral light for 2 h. If the *C. comosum* seedlings were rotated 90° counterclockwise horizontally, the root tips bent away from the unilateral light again, making an angle of 90° on the horizontal plane with the bending section before rotation (Fig. 1, B). At the same time, some branch roots sent forth from the adventitious roots also bent away from the direction of irradiance (Fig. 1, B; Fig. 1, C), and the curvatures were close to the adventitious roots.

As the *C. comosum* roots exhibit gravitropism, the curvature was the vectorial sum of negative phototropism and gravitropism.

3.2. Photosensitive site of negative phototropism of C. comosum roots

The adventitious roots whose tips were shaded or cut did not show negative phototropism (Fig. 2, B), but negative