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THE TRANSPIRATION AND MOISTURE ABSORPTION CHARACTERISTICS OF*FICUSMICROCARPA* (L.) AERIAL ROOTS IN THE SOUTH OF CHINA

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Abstract

Ficus microcarpa (L.) has many aerial roots, which grow from the stem and live in the air causing them to absorb moisture from the air. A lot of literature has reported that aerial roots have the function of moisture absorption, and also can prevent water loss. But very little is known about the characteristic of H_2O exchange between aerial roots and the surrounding air. This papermainlyaims to explore the transpiration or moisture absorption of *Ficus microcarpa* (L.) aerial roots. Two experiments were designed and carried out in China *viz.,* H_2O exchange characteristic and vapor absorption experiments. Aerial roots of *Ficus microcarpa* (L.) was used as experimental material. Results showed that the young aerial roots had the function of transpiration when air relative humidity was less than 90%. The rate of transpiration had a negative relationship with the air relative humidity. The aerial roots expressed the function of moisture absorption when air relative humidity reached 100%. The aged aerial roots had weak and transient moisture absorption and transpiration because of the suberification of root epidermal. The research verified that the aerial roots *Ficus microcarpa* (L.) function of moisture absorption or transpiration, but the moisture absorption or transpiration mechanism may need further research.

Key words: H_2O exchange; Transpiration; Moisture absorption; Water potential.

Introduction

Aerial root is a kind of abnormal root, which grows from the stems and branches of the plant, and lives in the air to adapt the hot and wet environment in the process of its long survival (Bellini *et al.*, 2014). Many plants belongs to different plant families have aerial roots, such as Orchidaceae, Morgeniusae, Araceae, Liliaceae, Amaryllidaceae (Huggett, 2010; Deb, & Pongener, 2012; Saifullah *et al.*, 2014). *Ficus microcarpa* (L.) is also a plant with aerial roots, grows in the south of China such as Guangdong, Fujian, Yunnan and Hainan Island where the weather is rainy, hot and humid. Adventitious roots, which grow out from the stem of *Ficus microcarpa* (L.)are called aerial roots, as shown in Fig. 1.

Aerial roots of *Ficus microcarpa* (L.) grow from April to October every year in Chongqing, China. The rate of growth is faster in July and August than the other months. Monthly average air temperature in Chongqing from April to October is between 18 to 28ºC, air relative humidity is between 74-84% (Anon., 2005), which is suitable for the growth of aerial roots of *Ficus microcarpa* (L.).

The function of the organ usually has a relationship with its structure. Many Scholars speculated the function of the aerial roots from their anatomy stucture. Scholars thought that the aerial roots were effective in providing the plant with essential water and nutrients from the atmosphere because of the unusual properties assigned to the velamen. Velamen is the epidermis of aerial roots. It is a specialized water absorption tissue on the surface of the aerial roots, which can absorb gaseous water and nutrition and supply the physiological requirements of the plant. Researchers also thought that only the apical portion (1-2cm) of a growing aerial root, which is usually light green, could absorb water and nutrients provided by the dust in the atmosphere, and other part of the velamen couldn't have the capacity of vapor absorption (Augustus & Lewis, 1957). Many researchers thought that velamen of aerial root was the absorption tissue like the spongy or active carbon,outer cortex cells of aerial root are suberized, only a few channels cells were left to prevent moisture loss (Schleiden & Edwin, 1849; Haberlandt & Montagu, 1914). The velamen consisted of 3 layers of parenchymal cells. Radial vascular bundle was of septemarch. There was no pith in the root. When velamen cells matured, the protoplast disintegrated. There were many small pores and special grain secondary thickening on the cell wall, so that the root could not only be able to absorb moisture in the air, but also water storage (Li *et al.*, 2001).

Also, some researchers had through the experiments explored the water absorption of the aerial roots. Augustus and Lewis (1957) designed experiments to investigate the rate of water absorption and evaporation of excised aerial roots. Studies have shown that the rate of water absorption and evaporation in excised aerial roots were almost the same, but the initial rate of water absorption was slow because the initial presence of air in the velamen cells of the aerial roots.At the same time, Augustus and Lewis (1957) compared the water absorption ability of aerial roots with and without tips for the same kind of plant. Aerial roots which were 18 cm long and with the root tip can absorb water for 8 days, the total capacity of the water absorbing was 10.6 ml. At the same time the aerial roots without root tip can last only 2~3 days, the total quantity of water absorbing was about 2.7 ml. Went (1940) put forward the hypothesis that the aerial roots can capture and fix the water and nutrient on the roots surface, which is the main source of nutrients for the plant. Zotz and Winkler (2013) did the experiment to verify and support that hypothesis. Their research showed that hybrid orchid could absorb water solution within a few seconds, but at the same time, need a few hours by the roots for evaporation. Nutrition absorption follows the dynamics of efficient two-phases, make active migration in external low concentration.

However, few literatures are available on the verification of the moisture absorption and evaporation of aerial roots by the quantity experiment. My previous research (Liu *et al.*, 2011) through the orthogonal experiments revealed that the tender aerial roots of *Ficus microcarpa* (L.) have the function of transpiration, only lignified aerial roots have weak moist absorption rate when the air humidity is higher than 90%. The primary and secondary factors which affect transpiration or moisture absorption is: age > air relative humidity > illumination > temperature. In order to obtain the detail moisture absorption or evaporation function of aerial roots, in this paper, firstly through the single factor experiment to explore the relationship between influence factors and the moisture uptaking or transpiration of *Ficus microcarpa* (L.) aerial roots; secondly, through the experiment to study the moisture uptaking characteristics of tender aerial roots in the air of higher relative humidity.

Materials and Methods

The healthy Aerial Roots of *Ficus microcarpa* (L.) were chosen from the park in the south of China as the experimental material, and made the aerial roots alive when conducting the experiments. Aerial roots are shown in Fig. 2, the appearance of *Ficus microcarpa* (L.) aerial roots is changing periodically. The aerial roots with different outlooks have different structures, as well as different ecological functions. For discussing the various aerial roots conveniently, aerial roots were classified and defined in accordance with the different appearance. The tip part of aerial roots with a white or pale yellow color is younger, we defined the age of younger aerial roots as 1; and when the aerial roots are matured by solar irradiation, dry air and self physiological, the appearance becomes yellow, we defined the age of mature aerial root as 2; when the appearance of aerial roots surface is brown with a cork layer, it was known as aging 3.

Experiment for moisture absorption or transpiration characteristic of aerial roots: The H_2O exchange rate (HER) can be used to represent the moisture absorption or transpiration rate of the aerial roots. LI – 6400XT (American LI - COR company) portable photosynthesis measuring system was used for measuring H_2O exchange rate of aerial roots. When HER is positive, it reveals that aerial root is conducting transpiration; when the HER is negative, it reveals that aerial root is conducting moisture absorption. Temperature control range of the measuring system is environment temperature ± 6ºC and relative humidity control range is 0~ 90%. In the experiment, the open gas circuit was adopted, the standard leaves room (2×3 cm) was connected, and 6400-2B red/blue light source was turned off to test H_2O exchange rate (HER, mmol $H_2O \cdot m^{-2} \cdot s^{-1}$) of aerial roots. Because physiological activity of a single aerial root is weak, to reduce the data fluctuation, the air flow was turned down to 100µmol s^{-1}. Fix the aerial roots into the leaves room. The aerial roots could not completely cover the leaves room. The actual area exposed to the chamber is 3×C cm^2 (C is the cross section circumference of the aerial roots).

Fig. 1. *Ficus microcarpa* (L.) aerial roots.

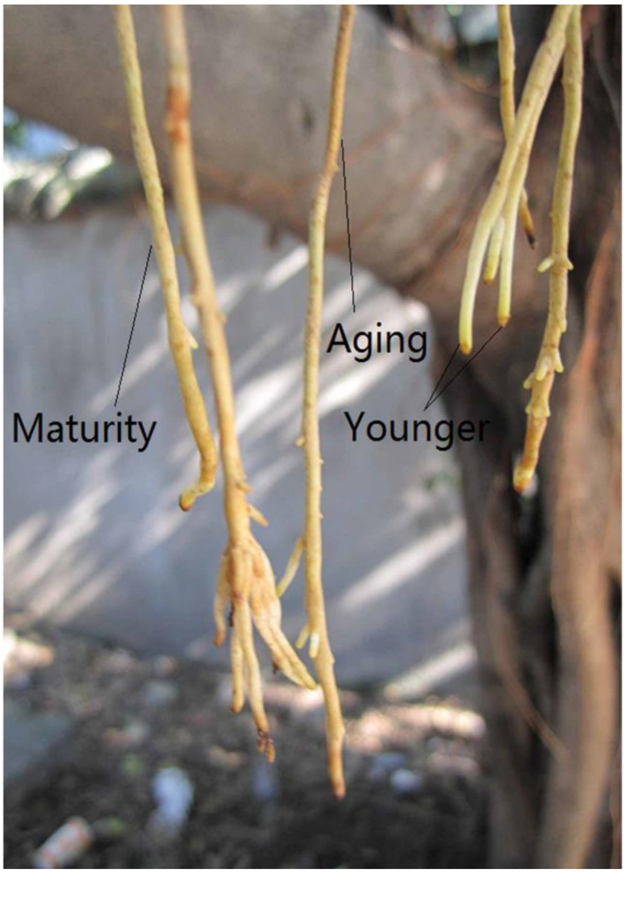

Fig. 2. Experimental material.

Table 1. Factor and level.

Temperature (°C)	28.5					
Relative humidity (°C)	90	80	70	60	50	40
Relative humidity (%)	70					
Temperature (°C)	31		29	27	25	23

Table 2. Experimental plan.

Date and time	Contents
8-17, 12:00pm~8-19, 10:00 pm	Weighing, measure, record data and observe the growth of aerial root
7-29, 9:00am~7-30, 9:00am	

This experiment studied the relationship between surrounding air temperature and air relative humidity with transpiration or moisture absorption of aerial roots. Firstly, we kept air temperature constant, measured HER under different air relative humidity. Secondly, we kept air relative humidity constant, measured HER under different air temperature. The factors and levels are shown in Table 1.

The experiments were conducted in April when there was no wind in the city of Shenzhen in China, respectively selecting three *Ficus microcarpa* (L.), choosing three aerial roots of the age 1 and age 3 from each plant and each measurement was repeated three times.

Experiment for moisture absorption of aerial roots: Aerial roots like the hot and humid environment and can absorb vapor from the air (Schleiden & Edwin, 1849). In the above first experiment, the relative humidity can only reach 90% because of the restriction of the instrument. In order to verify the fact and the quantity of vapor absorption in maximum air relative humidity, the following experiment was designed.

First, we inserted the young and mature parts of aerial roots into a bottle, which was filled with water at the bottom, and made the roots suspended above the water; the mouth of the bottle was sealed, as shown in Fig. 3. We made sure the whole experiment equipment was vertical during the experiment and the air relative humidity inside the bottle could reach to 100%.

Electronic scales were used to weigh, its measuring range is 0 ~ 600 g, precision is 0.01 g. We weighed the total weight of bottle and the inside water before and after the experiment, the weight reduction was the amount of water absorbed by aerial roots. A divided scale was used to measure the length of aerial roots before and after the experiments, its measuring range is 0~30 cm, precision is 0.1 cm.

Temperature and humidity recorders were used to record the temperature and humidity of the inside air. Temperature measuring range of the recorder is – 40°C ~100°C, accuracy is + / - 0.35°C, resolution is 0.01°C; Relative humidity measurement range of the recorder is 0% ~ 99%, accuracy is 3%, resolution is 0.1%.

Experiments were conducted on August 17 and July 29, 2009 in Chongqing city in China, the detailed experimental plan is shown in Table 2.

Results

The influence of air temperature and relative humidity on HER: The experiment results were shown as mean +/- standard deviation (mean+/-SD). The curves are for analyzing the influence of air temperature and relative humidity on HER.

For the aerial root aged 1, when air temperature was consistent and air relative humidity was changing between 40 and 90%, Fig. 4 shows that HER is positive and had the negative liner relationship with the air relative humidity. When air relative humidity is consistent and air temperature is changing between 23~31°C, Fig. 5 shows that HER fluctuate in a narrow range. We can see that the HER is decline firstly and then up and down again with the temperature increasing. These results show that the transpiration rate of tender aerial roots have negative liner relationship with the air relative humidity; and no remarkable relationship with the air temperature. No function of moisture absorption was found also.

For the aerial root aged 3, when air temperature is consistent and air relative humidity is changing between 40 and 92%, Fig. 6 shows that HER also have the negative relationship with the air relative humidity. HER is positive firstly, and when the air relative humidity is lower than 76%, HER change to negative. It revealed that the aging aerial had both the function of transpiration and moisture absorption. It was up to the surrounding air relative humidity. When the air relative humidity was higher than 76%, the aging aerial had the function of moisture absorption. But the function of moisture absorption and transpiration of aged aerial roots could not last for a long time. Fig. 7 shows the change of HER with the time under different air relative humidity. We can see that when air humidity is 90%, aged aerial roots has the function of moisture up taking and the rate of moisture up taking is declined with the time, and is nearly to zero after 20min; when air humidity is 70 and 80%, aged aerial roots has the function of transpiration and the rate of moisture up taking is also declined with the time, and is nearly to zero after a period of time.

Table 3. Experimental data.

Time	The number of aerial roots (number)	Total weight before the experiment (g)	Total weight after the experiment (g)	Weight different before and after experiment (g)	Grow length (cm)
8-17	10	111.63	110.52	1.11g	6.0-15.0
7-29	15	56.39	56.10	0.29g	2.0
	15	52.30	52.02	0.28g	2.0

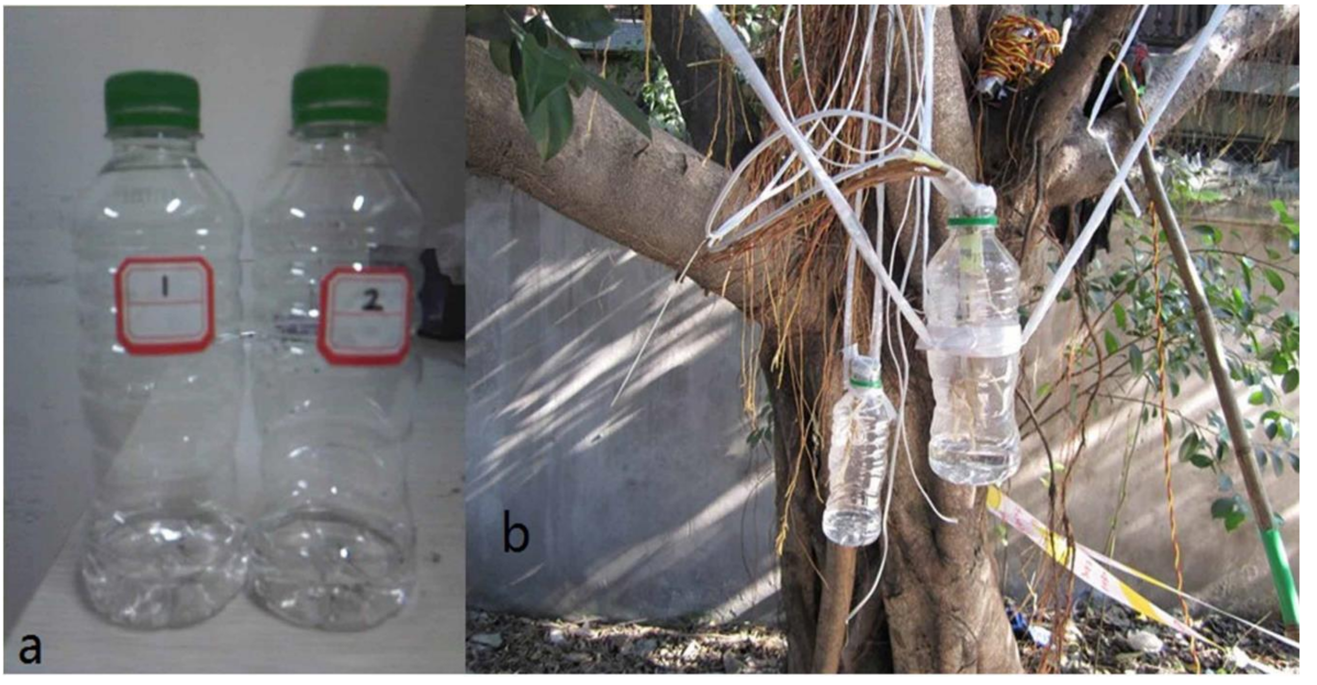

Fig. 3. The device schematic before (a) and in the experiment (b).

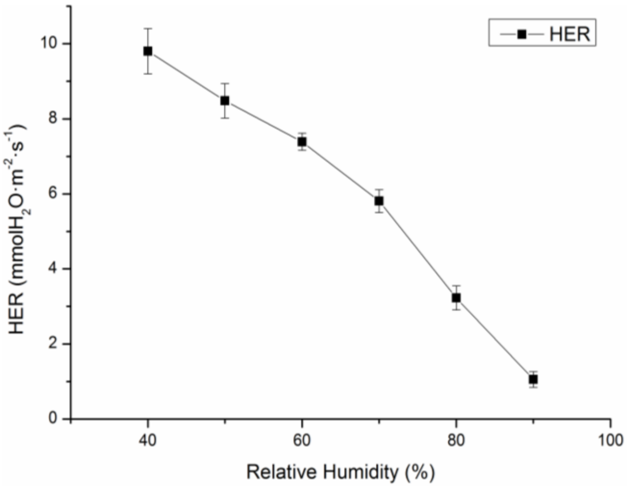

Fig. 4. The curve of HER change with air relative humidity for young aerial roots.

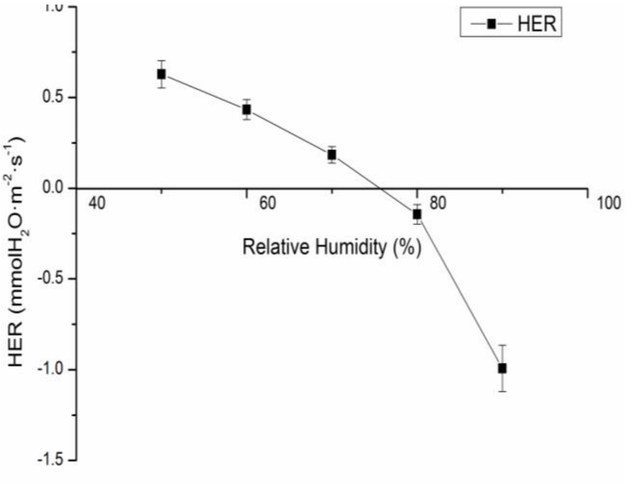

Fig. 6. The curve of HER change with air relative humidity for aged aerial roots.

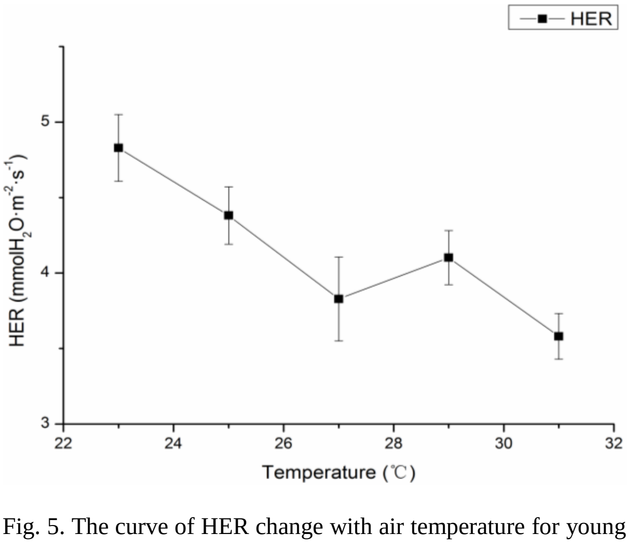

Fig. 5. The curve of HER change with air temperature for young aerial roots.

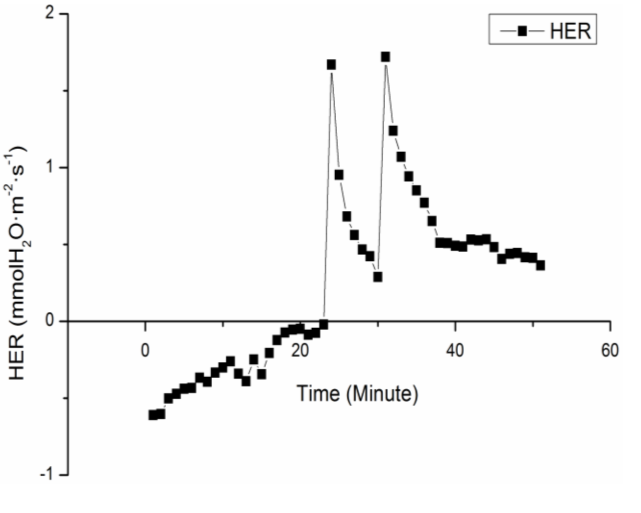

Fig. 7. The curve of HER change with time under different air relative humidity for aged aerial roots.

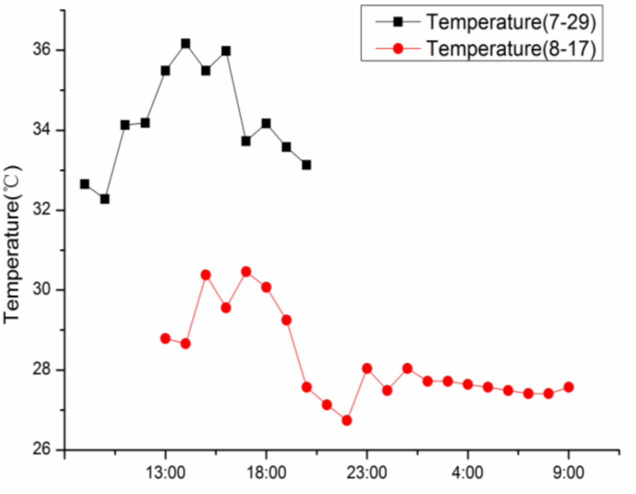

Fig. 8. The ambient temperature and relative humidity of the aerial roots.

The moisture absorption of aerial roots: The air temperature recorded during the experiment was drawn into a curve, as shown in Fig. 8. Relative humidity of the air in the bottle could reach to 100%. Temperature of the air in the bottle was changing with that of the outside air. On August 17, the highest air temperature was about 31°C, the lowest air temperature was about 27°C; On July 29, the highest air temperature was about 37°C, the lowest air temperature is about 32°C.

From the Table 3, it is shown that the total weight of the device is reduced, so water in the bottle decreased, it proves that aerial root have the ability of moisture absorption in the air of 100% relative humidity. If it was supposed that only tender aerial root could absorb the moisture in the air, the quality of moisture absorption was about 0.11g/cm.

After the experiments, the aerial roots were both longer. From the Table 3, it is shown that the aerial roots in the bottles grew 2～15cm overall. The growth rate of aerial roots were 2.4 ~ 6 cm/d in the experiment on August 17, 2008; the growth rate of aerial roots were 2 cm/d in the experiment on July 29, 2010.

In addition, when comparing the morphology of new born aerial roots inside the bottle with them outside the bottle, the new born aerial roots inside the bottle look more white and tender, and many tiny root hairs grow out; and the appearance of new born roots outside the bottle are dark yellow and without root hairs. This shows that high relative humidity can delay the maturing time of the aerial roots, as shown in Fig. 9. Therefore, aerial roots grew well in the air with 100% relative humidity. In order to adapt to high humidity environment, a lot of root hairs with the function of absorption grew from the surface of aerial roots.

Discussion

The previous literatures reported that the aerial roots of plants can absorb the moisture in the air, but most of reports hardly have done experiment to verify their opinion. This paper designed the experiments to explore the characteristic of the moisture absorption of the aerial roots. We find the aerial root has both the function of evaporation and moisture absorption, which is up to the age of the aerial roots and the relative humidity of aerial environment.

In this research, when the relative humidity of air is lower than 90%, the young aerial roots cannot absorb the moisture in the air. As our research shows, the young aerial roots will evaporate in the air. The rate of the evaporation under varying relative humidity is different, and has the negative relationship with the air relative humidity. When the air relative humidity is 40%, evaporation rate is about 10 mmol $H_2O \cdot m^{-2} \cdot s^{-1}$; when the air relative humidity is 90%, evaporation rate is only 1.1 mmol $H_2O \cdot m^{-2} \cdot s^{-1}$. For the mature aerial roots, when the air relative humidity is low, the aerial roots can evaporate the moisture momently; when the air relative humidity is high, the aerial roots can absorb the moisture momently. In the literature [6], it is reported that aerial root of Phalaenopsis hybrids also could loose water after being filled with water and is saturated. And the rate of water loss of aerial roots with thin valeman (*Miltonia spectabilis*) is double that of the aerial roots with thick valeman (*Doriatenopsis malibu*). So the evaporation or moist absorption of aerial roots has the relationship with the structure of the aerial root. Previous research has also pointed out that aerial roots would lignify with their maturity to reduce water loss (Benzing *et al.*, 1983; Tomlinson *et al*., 2014).

When the air relative humidity reaches 100%, the young aerial roots can absorb the moisture in the air. The quality of moisture absorption is about 0.11g/cm during the experimental period. Therefore, the result can prove the fact that aerial root can absorb the moisture in the air. Previous research (Augustus& Lewis, 1957) proved the water imbitition of the excised aerial roots. For about 60 seconds, the aerial roots of 10 species are all saturated with water. This paper also found that aerial roots can grow longer in the saturated air, can give birth to a number of tender root hairs. Webster and Jagels (1977) also reported that aerial roots grow in the moist container can form the root cap and root hair, the morphology of them is similar with the roots that grow in the soil. But growth rate of aerial roots in the experiment is higher than or equal to the record in literature (Patino *et al.*, 1999). The literature recorded that the growth rate of aerial roots of *Araceae* plant in tropical American is about the 2 cm/d in the wet season without being damaged and branching. Aerial root growth rate of *Ficus microcarpa* (L.) are greater than the literature reported that might be caused by different plant species and higher air humidity. This paper also found root growth rate in the second experiment (26~30°C) is lower than in the first experiment (30~ 37°C), it demonstrates that too high of temperature may slow the aerial root growth.

This paper through the experiment was to verify the transpiration and moisture absorption of the aerial root. The transpiration and moisture absorption are both the H_2O exchange between aerial roots and environment. We can try to explain the H_2O exchange, which depends on the water potential difference between aerial roots and environment. If the water potential of air is lower than that of aerial roots, H_2O will release to the air from the aerial roots, so the aerial roots have transpiration; if the water potential of air is higher than aerial roots, H_2O will come into the aerial roots from the moisture air, so the aerial roots have the ability of moisture absorption. And the bigger the water potential difference is, the stronger the transpiration or moisture absorption is. Water potential of moist air increases in proportion with air relative humidity (Lambers, 2003). When aerial roots could conduct transpiration, with air relative humidity increase, water potential difference between aerial roots and air will decrease, so transpiration rate of aerial root will be reduced. When the air humidity is high enough so that the water potential of air is higher than aerial roots. The aerial roots can absorb vapor in the air. When the air temperature is 23 ~ 38ºC, air relative humidity is 100%, air water potential calculated is 0.00 MPa; when air relative humidity decline to 95%, air water potential is reduced to -8 MPa (Zuo, 1996). According to the literature recorded, generally the average water potential of underground roots is -1.5 MPa (Tao, 2006). Assuming that aerial roots have the same water potential range with underground roots, so aerial roots only have moisture absorption ability in moist air, which is nearly saturated.

The surface and inner structure of aerial roots is another side to explain the moisture absorption mechanism of aerial. Scholars in Taiwan have researched the anatomical structure of *Ficus microcarpa* (L.)aerial roots (Xie *et al.,* 2004), the cross section of aged and younger aerial roots were shown in Fig. 10.Their research shows that the structure of aged aerial roots is similar with the stem of the dicotyledonous plants; from the outer to the inner is cork layer, cortex and pericycle. There is xylem and phloem inside of the pericycle and the xylem is exogenous. The research also shows that the structure of younger aerial roots is similar with the roots of the dicotyledonous plant, from outside to inside is the epidermis, cortex, scabbard. There are xylem and phloem inside of the pericycle (Boukhris *et al*., 2013). Part of the cortex cells has chloroplasts. So, it is speculated that the aerial roots have the function of water absorption which is similar to the underground roots; and the aerial roots have the function of transpiration which is similar with leaves. For moisture absorption of aged aerial roots, that is similar to the moisture absorption of porous material, because of the lignification mature aerial roots, the dead cell are full of dry air (Cutter & Li, 1976), then the movement of water depends on vapor partial pressure inside and outside the aerial roots, when the internal vapor partial pressure is less than the water vapor partial pressure of outside air, the aerial roots are hygroscopic, otherwise they could release the moisture.

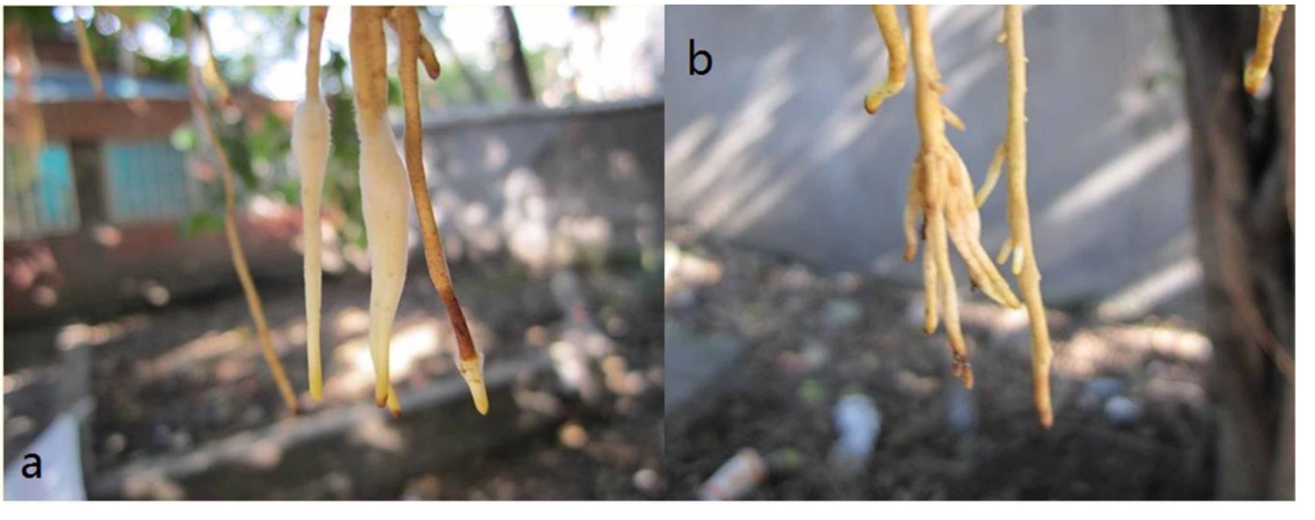

Fig. 9 The growth of aerial root inside (a) and outside (b) the bottle.

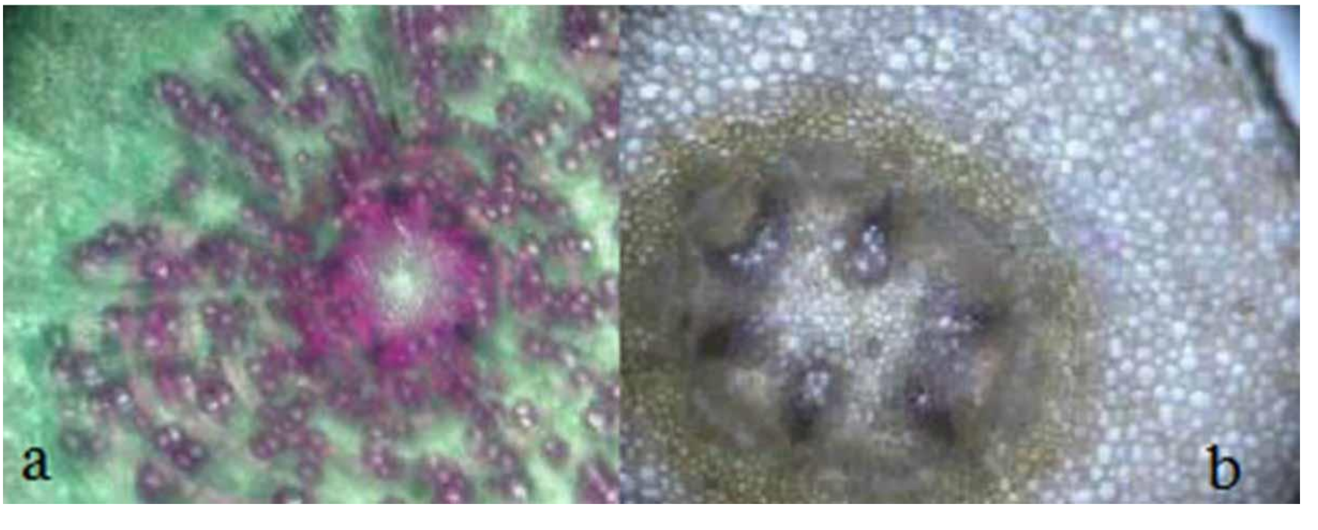

Fig. 10. Cross-section of aged and younger aerial root.

Conclusions

From the above results, we can verify that aerial roots have the function of transpiration and moisture absorption through the experiments. The transpiration has the negative relationship with the air relative humidity, and has no obvious relationship with the air temperature. When the air relative humidity is lower than 90% more or less, the young aerial roots can conduct transpiration; when the air humidity is 100%, the young aerial roots can conduct moisture absorption. For the aged aerial roots, they have weak and short time function of transpiration and moisture absorption. We try to use water potential and the structure of aerial roots to explain the transpiration and moisture absorption characteristics. However, using water potential and the structure of aerial roots to explain the moisture absorption mechanism need further experiments in the future.

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