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Study on water absorption of cactus

Kenya Komine[1]*, Yoshihiro Kubota[2]

[1] Toyo University, Graduate School of Science and Engineering, Saitama, Japan

[2] Toyo University, Department of Mechanical Engineering, Saitama, Japan

* s36A01800050@toyo.jp

Abstract

Water absorption in plants is explained by water potential. Water in plants are transporting with the gradient of water potential. Roots and leaves are important elements in considering water absorption with water potential. However, the cactus has no leaf. In this study, we are focusing how cactus deliver water to the body without leaves. We observed roots, epidermis, and spines using Scanning Electron Microscope (SEM). Also, we observed the path of water absorption by the visualize using the dye solution. The result of observation shows that the cactus has no leaves, but cactus has stoma on its surface. The spines consisted of two types of long spines and short spines. The conduit was connected to spines. The vascular bundle was divided into two when the body is branching. We compared sectional area and conduit area of cactus. The results show that the cactus can grow until the 98.9 times larger than the area of conduit in cross section.

1 Introduction

Everyone knows that the plants are absorbing water from roots. The mechanism of water absorption can be explained with water potential from the plant physiology point of view as shown in Figure 1. L. Taiz and E. Zeiger (2002) explained the water potential is the energy potential balance of osmotic potential, pressure, and gravity etc. The magnitude of energy potential is depending on the parts of plant such as cell, root, conduit, leaf (stoma). So, these parts of plant need to realize the water absorption. Among them, leaves are transpired, changing the gradient of water potential to cause water absorption. Even if there is damage to the leaves, it is possible to deliver water to the tip of the leaf with single vein by K. Sato et al. (2016). The leaves are important organs as shown in above. In the world of nature, the cactus has no leaf, however they can absorb the water from roots. This study is focusing on the understanding the water absorption from the engineering point of view. In this study, we examined the details of *Opuntia microdasys* by Scanning Electron Microscope (SEM). Water absorption by cactus is visualized with dye solution. We investigate the influence of conduit of *Opuntia microdasys* for spreading the water inside the stem.

2 Methods

2.1 Observation by electron microscope

In this experiment, we used *Opuntia microdasys*, which has a flat and fan-shaped appearance and branching stem. We observed three parts of cactus as root, stem, and spines. We observe the root with a length of 1cm from the tip. The outside surface of stem is observed at the area of 1cm x 1cm. Observation of spines is carried out with pulling up from the stem. The collected root, stem and spines were fixed to be observed with SEM.

2.2 Visualize the water flow in cactus

In order to observe the state of water absorption in cactus, we made visualization of water flow in cactus. The equipment used in the experiment shows in Figure2. The stem of cactus was sampled and the root of the stem was immersed in dyeing solution. Bickford, E.D., and Dunn, S (1972) explained that 400nm to 700nm is suitable for causing photosynthetic action. Therefore, in order to promote water absorption, blue LED was irradiated during the experiment. We put it in the darkroom so as not to be affected by light other than the blue LED. The visualization was carried out at each of cross section to understand the direction of water delivering. One of direction is perpendicular to the direction of extension. And we observed how to extend the conduit in the longitudinal direction. The other one is the direction of extension. We observed transverse changes in vascular bundle. We measured the area of colored region with dye and the area cross section of stem by using the image analysis software" ImageJ". We investigate the relationship between the area with colored area and cross section.

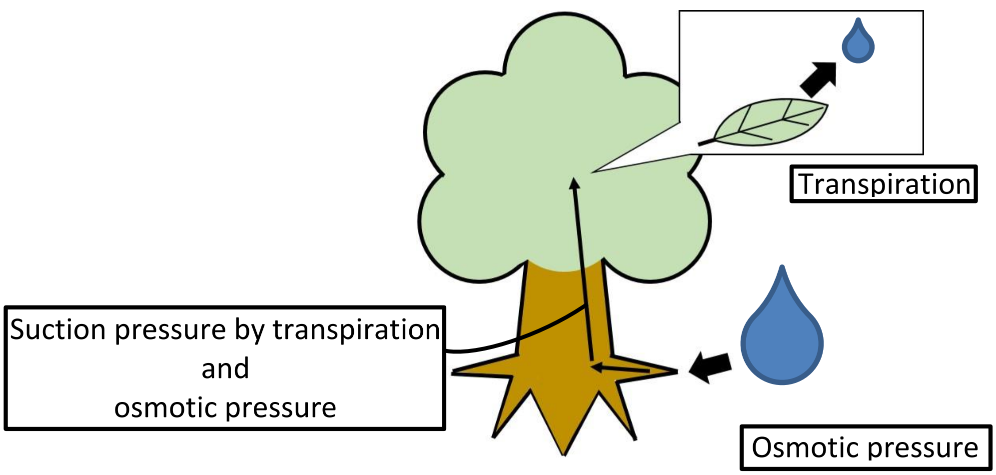


Figure 1: Water absorption model of tree

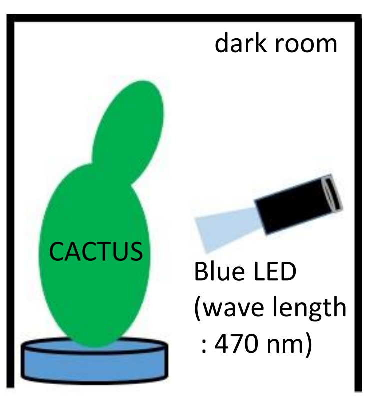


Figure 2: Experimental setup

3 Results

3.1 Surface features of cactus

Figure 3 shows the results of observing root, stem and spines by SEM. Figure 3(a) shows the *Opuntia microdasys*. Figure 3(b) shows the result with SEM of stoma, (c) shows the roots, (d) and (e) show the spines. The results of outside surface show that the stoma is on the surface of *Opuntia microdasys*. And, the surface of the stem has finely divided cells. The *Opuntia microdasys* perform the transpiration from the surface. In the result of root, we confirm the epidermis, endothelium, xylem, and phloem part as the general plants. The spines consist of two types of long spines and short spines. Short spines have a flat shape. Long spines grow straight like a needle. On the side of long spines there has a barb. It can be inferred that this is a function to protect itself from the enemies. The result of enlarged spines as shown in Figure 3(e) shows difference of two types of spines. On the left side in Figure.3(e) shows short spines and the one on the right is long spines. The inside of long spine is observed the hole in a cross section. This shows that the long needle is like a pipe. This suggests that the long spines are related to water absorption. From the observation, we found that the water exit of Opuntia microdasys have two possibilities for transpiration. One is the stoma on the surface of stem. And the other is long spines.

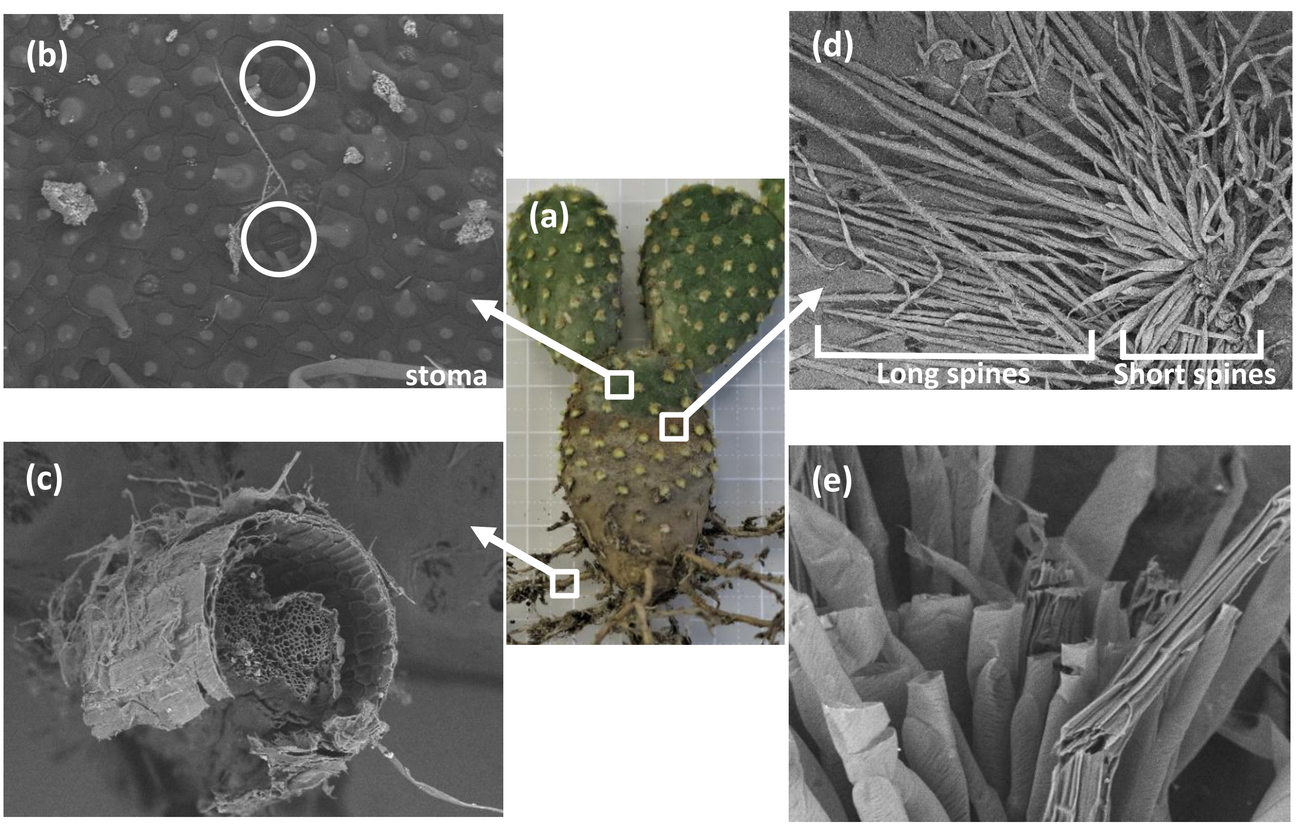


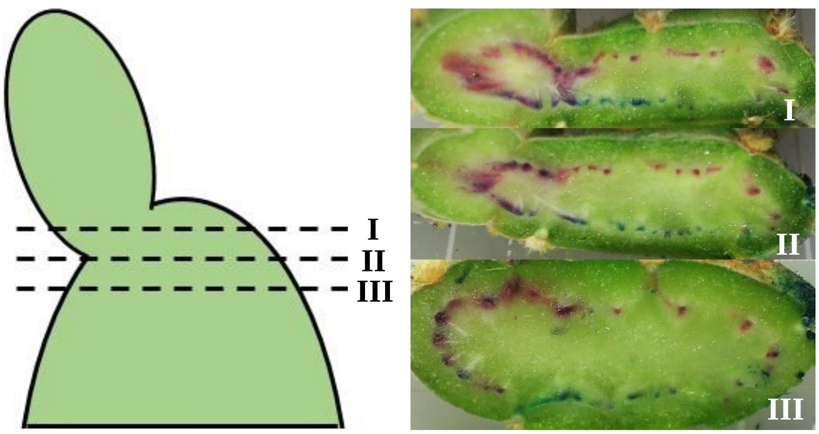
Figure 3: Observation of cactus by scanning electron microscope (SEM).
(a) *Opuntia microdasys*, (b) Epidermis, (c) Root, (d) Spines, (e) Cross section of spines.

3.2 Visualization of the water flow in cactus

Figure 4 shows the results of visualization in cactus by staining. Figure 4 (a) shows the results of cutting cactus vertically. The region of purple color was stained with the dye. There is no conduit in the center of cactus and the conduit extends along the surface of stem. Figure 4(b) shows the result enlarged around the spines. In addition, cactus spines are said to have changed leaves so spines are considered to be related to water absorption by Anderson, Edward F. (2001).

Figure.5 is results of dye visualization at the reconstruction of vascular bundle around the junction of stem of cactus. Figure 5(a) shows the position of observed. The position II means the beginning of junction. Figure 5(b) shows the results of visualization at the several position. The result just before the junction as shown in the position III shows the vascular bundle with elliptical cross section. Figure.5 (a) (b) shows that the vascular bundle is dividing into two as cactus branches. Therefore, the number of conduits decreases with the junction of stem. If the one conduit has the limitation to spread the water inside the stem, the size of stem has to become smaller. The limitation of conduit for spreading of water estimates from the dye visualization.

Figure 4: Dye visualization of path for water absorption
(a) Cross section of cactus, (b) Connection between sap vessel and spines

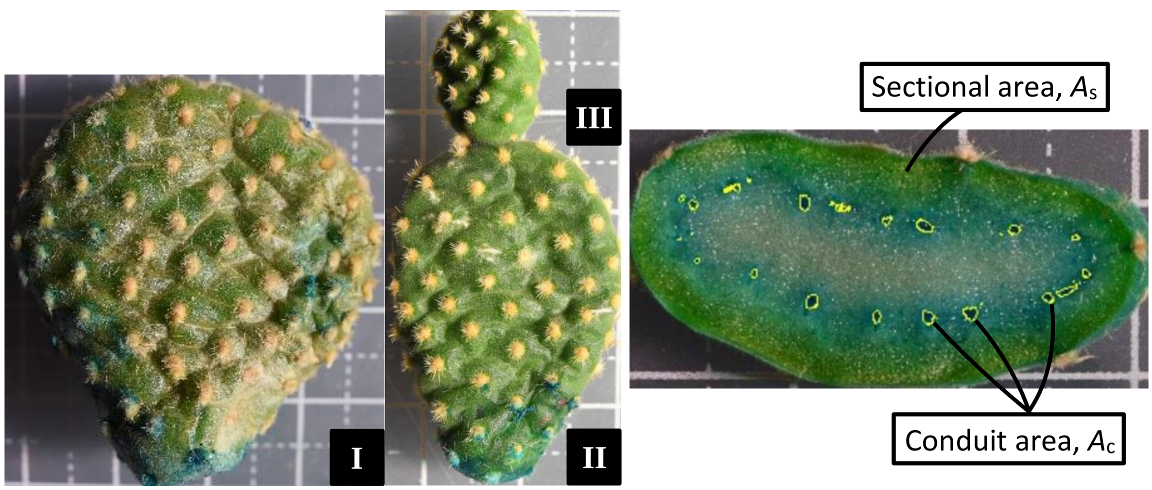


(a) (b)

Figure 5: Dye visualization around the branching of body.
(a) Sketch to show the observed position, (b) results of dye visualization

3.3 Relationship between cross-sectional area and conduit area

Figure 6 shows that the definition of measurement. Three cactuses measured. One is the no junction and the growing sufficiently as shown in I. II and III have the junction. II of cactus is the parent of III. III is the child of II. The height of stem I, II and III are 44mm, 36mm, and 15mm, respectively. These cactuses absorbed the dyed solution. After the absorption, we made the slices of stem. We measured the area of both cross section of stem and conduit. The region of conduit is considered with the intensity of color of dye. Figure 6(b) shows that example of image analysis by using ImageJ. Yellow line shows the edge of conduit. We determined the total area of conduit as A_c. The cross-sectional area at the collected position of stem is defined as A_s. Therefore, A_s / A_c is the area per unit conduit. The larger value shows that the possibility area to supply water by the single conduit. Table 1 shows the average of A_s/A_c, and maximum of A_s/A_c. The result in average value shows that the biggest cactus is minimum. From this comparison, the cactus requires the 28.0 times larger the area of conduit to growth at least. The result of maximum A_s/A_c shows the II of cactus is the biggest as 98.9 times larger than the area of conduit. This means that III of cactus has the possibility to grow about two times larger area of section of stem. Finally, the cactus needs $28.0 < A_s/A_c < 98.9$ for the growing.



(a) (b)

Figure 6: Definition of measurement for conduit area.

Table 1: Relationship between sectional area and conduit area

	Cactus I	Cactus II	Cactus III
Average of A_s/A_c	28.0	58.3	36.0
Maximum of A_s/A_c	81.1	98.9	49.5

4 Conclusion

In this study, we investigated the water absorption of *Opuntia microdasys*. we observed the part on the surface for water absorption by SEM and internal observation by dye flow visualization. Spines is composed of long spines and short spines. There is a thin tube in long spines. The existence of a thin tube in a long spine suggests a remnant of a leaf vein. However, long spines do not have stoma, and stoma is present on the surface of stems. We found that the vascular bundle forms an ellipse along the shape of the stem by dye flow visualization. A part of the vascular bundle grew toward spines. Therefore, it will be related to spines and water absorption. Furthermore, vascular bundle branched when the body is branching. We found to deform the vascular bundle at the bifurcation. Since there is stoma on the surface of cactus, vascular bundle is thought to extend not only to spines but also to stoma. The conduit can supply water in horizontal direction is $28.0 < A_s/A_c < 98.9$. Therefore, the limitation for size of cactus to grow relates the area of conduit.

References

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