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CHARACTERISTICS OF WATER SUPPLYING NETWORK ON LEAF

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Abstract: *The purpose of this study is to analyze the leaf network, understand the characteristics and structure of the network. The leaves remain lush even when insects eat, tear and leave holes. We thought that the structure of the leaf network was responsible for the plant's ability to remain lush despite damage. The veins are used to supply nutrients to the leaf and are the lifeblood of the leaf, but other studies have observed leaf water supply even when only leaf cells are present. Our study will analyze the leaf network, focusing on the network of leaf cells, that could be applied to lifelines. We believe that by applying a network of attack-resistant leaves, it is possible to realize a lifeline that is not affected by natural disasters. This study examines the structure of the leaf network by comparing to the Watts-Strogatz model (WS model), and Barabasi-Albert model (BA model). By comparing the average path lengths and cluster coefficients of each network, the leaf network was found to be a small network. Smaller size may facilitate water supply. The water supplying inside the node needs to realize with the diffusion of water. This diffusion is a phenomenon, so that small substantial network as leaf is suitable for the leaf network.*

Keywords: Leaf Network; Cluster Coefficient; Average Path Length.

INTRODUCTION

The leaves are still green, even though they have been eaten by insects and leave holes in them. If the leaf network is damaged, part of the water supply path will be cut off and the function of the network will be damaged. If the plant does not die, it means that the cells are well supplied with nutrients. One of the functions of leaf veins are used to be a supply nutrient. The main functions of the leaf veins are to provide mechanical support for the leaf in order to maintain a light-sensitive shape and to transport materials (The Botanical Society of Japan, 2016, p.558). It says that the veins of the leaf are the main part in the water metabolism of the plant and play an important role as the lifeline of the leaf. However, water supply of leaves was observed even in only leaf cell condition (Sato *et al*., 2015, p.8). In this study, the annular shape by veins of a leaf is viewed as a single node. Therefore, the purpose of this study is to understand the characteristics of leaf network and the structure of network by focusing on the network of the leaf cell rather than veins.

EXPERIMENTAL METHODS

In our analysis, the node was obtained as the annular shape by veins as same as the result. The image analysis was carried out to understand the structure of water supplying network. The structure of network was visualized with the finding of annular shape by veins as a node. The leaf cell was dissolved to make clear the annular shape. They were soaked in 20% sodium hydroxide solution. After the leaf cell was dissolved, the leaf was scanned into an image. We remove the noise to some extent before analysing by using ImageJ. The dissolved leaf network used in analysis shows in *Figure 1*.

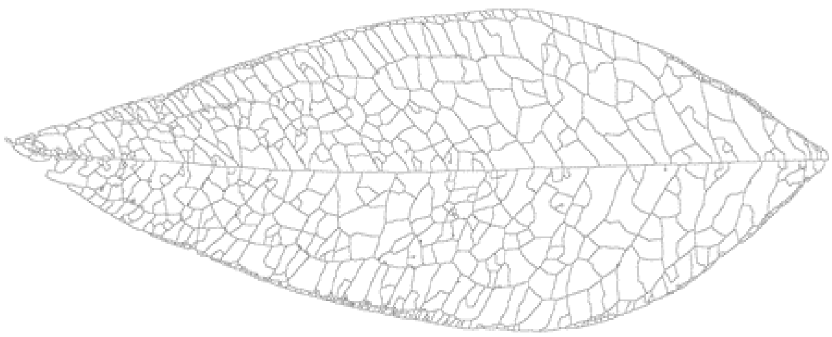

Figure 1 Analysis target.

EXPERIMENTAL RESULTS

We examine the number of nodes, average path length, clustering coefficient, and average degree of network as shown in *Figure 1*. These were investigated with the Python with image analysis. Extract regions from veins in Python and count one region as one node. The node connections were assumed by the adjoining of node. The amounts of nodes in network are 836, the average path length is 12.65, the cluster coefficient is 0.5548, and the average degree is 5.646. The characteristics of leaf network was compared with the Watts-Strogatz model (WS model), and Barabasi-Albert model (BA model). The WS model is a network that combines small-world properties. In this study, we consider a model in which the probability of randomly replacing an edge was changed. The BA model is a scale-free network in which some nodes are connected to many nodes and most nodes are connected to only a few nodes. This means that the BA model has the hub node in the network. We analysed each network. The number of nodes and the average degree were used for the comparison under the same conditions. Two types of attacks were analysed: one in which nodes were eliminated in order of increasing degree, and the other in which nodes were eliminated randomly. We analysed the average path length, cluster coefficients, and order correlations when attacks were continuously applied. The result of the average path length when nodes are eliminated in order of increasing degree is shown in *Figure2*. The probability of the WS model is 0 in this result.

Initially, the WS model has the highest value for the average path length. The smallest value was obtained with BA model. Same results occurred when we erased randomly. The WS model has high small wordless, however this does not have the hub in the network, so that the WS model can keep the connectivity of network until removed node >70%. In contrast, the BA model has the hub in the network, and the hub has the role of connection with the smaller amounts of edges. Thus, if the node was erased, it would be about 30%. Focusing on the leaf network, we find that the average path length changes as the ratio of removed nodes increases, similar to the results of the BA model. These results suggest that leaf network is sparse network than the WS model. Understanding the details of connectivity, we investigated the clustering coefficient.

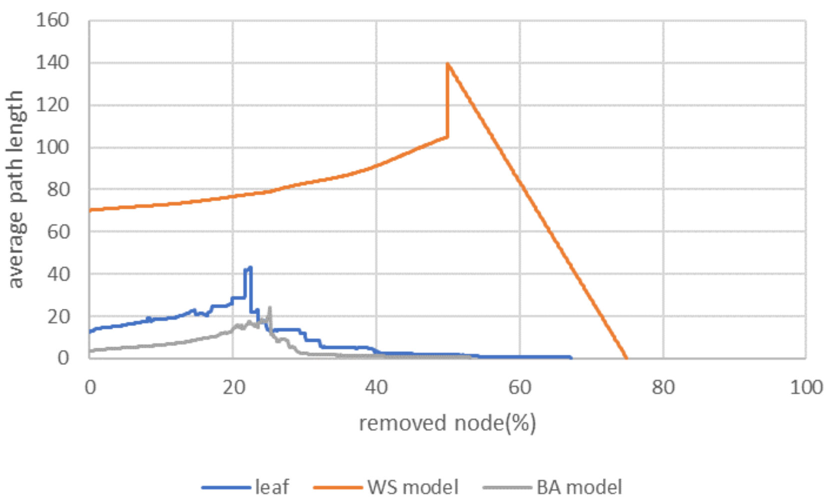

Figure 2 Average path length. Node is removed in order of the high degree.

To understand the details of connectivity, we investigated the clustering coefficient by analyzed the models as shown in *Figure 2*. By eliminating the order of high degrees, the results of clustering coefficient are shown in *Figure 3*. The clustering coefficient of BA model is smaller than the other two networks. This shows that the network of BA model is sparse from the results of the average path length as shown in *Figure 2* and the clustering coefficient. Furthermore, the network of WS model is the substantial with many edges. We can be agreed with these results from the reflection of the function of each network. The network in leaf has the short average path length and the high clustering coefficient. This suggests that the water

supplying network in leaf realizes the substantial network configuring with small amounts of edges. The short path length network has the benefit for the water supplying. The water supplying inside the node needs to realize with the diffusion of water. The diffusion is the slow phenomena, that small substantial network as leaf is suitable for the leaf network.

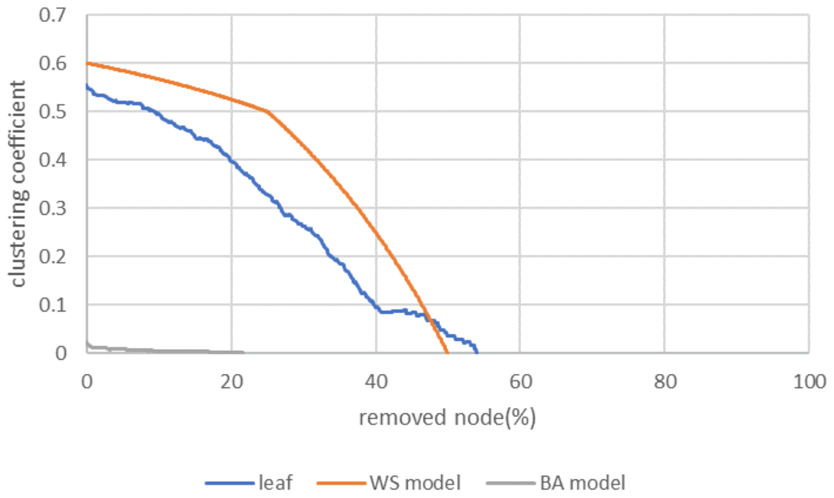

Figure 3 Clustering coefficient. Node is removed in order of the high degree.

CONCLUSION

The network of leaves was discussed. The network structure was analyzed and compared with the Watts-Strogatz model, and Barabasi-Albert model. The number of nodes, average path length, clustering coefficient, and average degree of network were investigated for the comparison. The comparison from these shows that the leaf network is the small substantial network. This has the benefit for the water supplying under the diffusion.

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Yuki Ishizaki. I am a student at Toyo University. The department is the Graduate School of Science and Engineering, Department of Functional Systems. I am a member of Biomechanics Laboratory. The aim of my laboratory is to investigate and apply the characteristic functions of living organisms from an engineering point of view. We are also investigating the functions of living organisms by visualizing fluids and phenomena from an engineering perspective. I focused on the leaf as a function of the organism. The purpose of my research is to analyse the leaf network and to clarify the reason why leaves do not die even if they are eaten by insects.

Yoshihiro KUBOTA

Yoshihiro Kubota is an associate professor of mechanical engineering at Toyo University. His work focuses on the water supplying network from the engineering point of view. This is based on the biomimetics which is the ideology for the development of new products inspired with the function of creatures.