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Estimation of ginkgo leaf necrosis induced by Typhoon 0613 with spectral reflectance

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ABSTRACT

Typhoon No. 13 in 2006 (Typhoon 0613) passed through Yamaguchi Prefecture, Japan on Sep. 17, 2006. After being hit by it, many landscape trees, especially ginkgo in Yamaguchi City, showed symptoms of necrosis on the leaf tip and margin, and even the entire leaf. It clearly divided the crowns of some ginkgo trees into the green part and the non-green part. In order to quantitatively study this phenomenon, the normalized difference vegetation index (NDVI) near red edge for ginkgo leaves, measured by a pocket radiometer in the lab, was used to estimate leaf necrosis induced by Typhoon 0613. Based on this research, the optimum wavelength for calculation of the NDVI value of ginkgo leaves damaged by Typhoon 0613 is 679 and 755 nm, which sufficiently corresponds to variance in ginkgo leaf necrosis. By leaf necrosis investigation, the difference in the percentage of necrotic leaves between the windward and leeward sides made the crowns of damaged ginkgo trees show different colors on either side of the crown. An inverse linear relationship between the necrotic area percentage (NAP) and $NDVI_{755nm/679nm}$ was obtained for ginkgo leaves. By analysis of the NDVI using ratio (NDVIr) value of crowns, it was indicated that there were differences in leaf necrosis induced by Typhoon 0613 among sites of different distances away from the coastline and between ginkgo and other tree species. It has potential to be an alternative tool for evaluating the damage status of ginkgo trees hit by typhoons like Typhoon 0613.

Keyword: Ginkgo, Leaf necrosis, Typhoon 0613, NDVI, Spectral reflectance

1. Introduction

Many plants show symptoms of necrosis at the leaf tip and margin when they are affected by extreme environmental conditions such as salt toxicity, water stress, high/low temperature, nutrition deficiency, injured root and trunk, transplanting shock, and disease (Treshow, 1970; Durbin, 1978). Typhoons are one kind of disaster that can cause serious mechanical damage to trees and shrubs, for example, by uprooting, stem breaking, bending and leaning, and so on (Takahashi *et al*., 1981; Yamamoto, 1979; Nobel, 1981; Maki *et al*., 1991). They are also complex calamities that can induce many unfavorable extreme conditions like flooding, gusty winds, and drought as well as salt/sand spray, which cause plants physiological injury (Maki *et al*., 1991; Nobel, 1981). Ginkgo (*Ginkgo biloba L.*) is a showy landscape tree species, which is widely planted in China, Japan, and so on. However, it often shows leaf necrosis (Okinaka *et al.,* 1990) and branch dieback (Shimizu, 2004) after damage by high temperature (Treshow, 1970) or by strong dry typhoon, especially along the coast.

Typhoon 0613 was characterized by low precipitation and high wind speed with maximum gusty wind speed of 42.4 m/s, maximum wind speed of 20 m/s, and precipitation of 26 mm when it hit Yamaguchi City. However, during the hit, as the maximum wind speed reached its peak value, there was almost no rainfall. This rainless or less-rain period persisted more than one month after the hit. Following Typhoon 0613, it is observed that leaf necrotic symptoms appeared on many landscape trees and shrubs in Yamaguchi City, particularly ginkgo. It made the crowns of ginkgo trees obviously different between the windward and leeward sides, which became a problem to be studied in this paper. This kind of damage has also been reported in other papers. Ginkgo trees with symptoms of leaf necrosis extended inland even as far as 100 km from the coastline during the hit by Typhoon 8218 in the area of the Kanto plain, Japan (Okinaka *et al*., 1984). However, the visual scale method was more common in research on ginkgo crowns damaged by typhoons. In this paper, spectral reflectance was used to estimate the damage status in order to find an objective method of estimation and evaluation.

As an important non-destructive approach, the near-infrared spectral analysis method has been widely utilized in the area of agriculture and medicine and the food, fiber, and chemistry industries. In the field of agriculture, it was originally used for the things with lower water content, and its application in fruits, vegetables, and crops with higher water content began in modern times (Iwamoto *et al.,* 1994). However, spectral reflectance measurement has been used to estimate the plant leaf area index (Yamamoto, 1998), chlorophyll concentration (Carter *et al.,* 1994, 2001; Ito *et al*., 2003), nutrient elements (Hinzman *et al*., 1986), water content (Yamamoto *et al.,* 1995; Carter *et al.,* 1993; Ito *et al.,* 2003), and so on. Carter *et al.* (1994) considered that spectral reflectance in narrow wavebands within the 690- to 700-nm range and its ratio to near-infrared reflectance should provide earlier detection of stress-induced chlorosis compared with broad-band systems or narrow bands located at lesser wavelengths. Ito *et al.* (2003) diagnosed the chlorophyll content by the ratio of spectral reflectance at 800 nm and 680 nm. Under water stress, and the change of plant spectral reflectance in the near-infrared range has been reported in some other researches (Holben *et al.,* 1983; Jackson *et al.* 1985; Moran *et al.,* 1989; Yamamoto *et al.,* 1995; Penuelas *et al.*, 1999). Thorhaug *et al.* (2006) stated that browning and necrosis resulted in a clear change in the shape of the reflectance spectra of *Thalassia* blades and suggested that the reflectance spectra at 750 nm might be a suitable stress index. Riedell *et al*. (1995) noted that crop canopy chlorosis and necrosis in small grain fields infested with greenbugs, etc. could be used as a diagnostic tool to detect crop damage from cereal aphid population outbreaks. Yamamoto *et al*. (1996) reported that it was possible to detect the leaf area of soybean damaged by the common cutworm with the normalized difference vegetation index (NDVI) at 750/600 nm. Steddom *et al.* (2005) reached the conclusion that the use of radiometric methods has the potential to increase the precision of assessment of *Cercospora* leaf spot foliar symptoms of sugar beet while eliminating potential bias.

Nevertheless, whether or not it can be used in estimating the damage status of landscape trees hit by strong typhoons like Typhoon 0613 still needs to be researched. What is the optimum wavelength for evaluating the damage status and are there any differences among tree species and trees planted at different sites of different distances from the coastline? In this study, after selecting the optimum spectral reflectance wavelength, leaf necrosis of ginkgo trees induced by Typhoon 0613 was estimated by spectral reflectance analysis combined with the visual scale method. By measuring the necrotic area percentage (NAP) and NDVI of necrotic leaves, the relation between them and the difference in the spectral reflectance of ginkgo leaves among different sites and between ginkgo and other tree species were studied.

2. Materials and Methods

In this research, three experiments were carried out. The first was to study the percentage of differently necrotic leaves in the crowns of ginkgo trees. The second was to study the difference in spectral reflectance between ginkgo and other tree species after being hit by Typhoon 0613. The third was to study the difference in ginkgo leaf necrosis among three sites of different distances from the coastline.

2.1 Measurement of leaf necrotic percentage and spectral reflectance

To study the percentage of necrotic leaves in the crowns of ginkgo trees, six standard branches, three from the leeward side and three from the windward side, from three trees in a shelterbelt were sampled from Yamaguchi University. All the leaves on the branches were visually divided into five necrotic levels according to the necrotic area percentage.

After counting the leaf number, the spectral reflectance for leaves of each level was measured respectively by a radiometer, EKO-MS720, made by EKO Instruments Co. Ltd. Its spectral resolution is 10 nm, its interval of wavelength is 3.3 nm, and the specified wavelength ranges from 350 to 1050 nm. Leaves were measured with a special method in an indoor environment in order to avoid the effect of the gap fraction (Ito *et al.,* 1996) and light condition between the windward and leeward sides of trees in the field measurement, because it is not easy to obtain comparable spectral reflectance data for trees under these conditions. The radiometer was mounted on a tripod 30 cm above the sample leaves. A tray of 20×30×4 cm and vertically measured under a 40-w incandescent lamp was smoothly filled with the sample leaves. A field of view of 25° was selected and the area coverage was 139 cm^2, approximately equal to a circular area with a diameter of 14 cm. Measurements were controlled by a piece of white paper corrected by a standard white board of barium chloride, and three duplications for each level were conducted at different positions on the tray. The spectral reflectance was used to calculate the NDVI by Equation (1):

$$NDVI_{m/n} = \frac{NIR_m - VIB_n}{NIR_m + VIB_n} \qquad (1)$$

where NIR_m is the spectral reflectance in the near-infrared region, VIB_n is the spectral reflectance in the visible region, m = 750, 760, ……, 900, and n = 630, 640,……, 690. According to the wavelength analysis, the optimum wavelength for calculating the NDVI was 755 nm and 679 nm for NIR and VIB. Therefore, all NDVI values and NDVI using ratio (NDVIr) values in the paper were calculated by the spectral reflectance value at these two wavelengths except the NDVI value in the optimum wavelength analysis.

2.2 Measurement of NAP

The leaves were scanned with a Canon D125u2 scanner, and the NAP of each leaf was calculated by the image pixel method. NAP is the proportion of necrotic area to overall leaf area. It was determined by obtaining pixels of the overall leaf and then separating the green part (refer to Fig. 1) from the leaf with the eraser tool of Photoshop. The NAP was calculated by Equation (2), and the NAP value for the level of each leaf was the average NAP value of every leaf on the related scale.

$$NAP = 100 - \left(\frac{Pixels\ for\ green\ area}{Pixels\ for\ overall\ leaf} \times 100\right) \qquad (2)$$

Fig. 1 Overall leaf and green part of a necrotic leaf

2.3 Measurement for comparison between ginkgo and other tree species

The tree species used for comparison with ginkgo include metasequoia *(Metasequoia glyptostroboides Hu et Cheng*), trident maple (*Acer Buergerianum Miq.*), and kaizuka juniper (*Sabina chinensibs L.*), which are widely planted in Yamaguchi City. Leaves were mechanically sampled from shelterbelts of ginkgo, metasequoia, and kaizuka juniper, and from an individual trident maple tree in Yamaguchi University. The spectral reflectance for leaves of every species was measured by the method mentioned in 2.1 with four duplications for each species. The average of the four duplications of spectral reflectance was used to calculate the NDVI value by Equation (1). The NDVIr is an average value between the NDVI value for leaves on the windward side and the NDVI value for leaves on the leeward side. It was calculated as Equation (3).

$$NDVIR = \frac{NDVI\ \ for\ leaves\ \ on\ \ windward + NDVI\ \ for\ leaves\ \ on\ \ leeward}{2} \times 100 \qquad (3)$$

2.4 Measurement for comparison among three sites

To study the difference in leaf necrosis among sites of different distances from the coastline, Site A, Site B, and Site C were selected. Site A is located at Tokusa in Anno Canyon, Site B, at Yamaguchi besides the Fusino River, and Site C, at Ube near Yamaguchi Bay, which are 40.1, 12.6, and 1.7 km away from the coastline, respectively. Sampling and measurement were carried out on Nov. 1 and Nov. 2, 2006 for Site A and Site B and on Nov. 6 and Nov. 8, 2006 for Site C. The distance from the coastline (DC) is the shortest distance from any of the three sites to the coastline measured by an electronic atlas tool named Atlas Z Proffessional5. Meteorological data for these three sites were obtained from the Automated Meteorological Data Acquisition System of Japan.

Six standard branches, three from the windward side and three from the leeward side, were also sampled for each of the three sites, respectively. The method of leaf counting was the same as the abovementioned scale method.

The spectral reflectance for leaves of every site was also measured by the method mentioned in 2.1 with three duplications for each site. The average of the three duplications of spectral reflectance was used to calculate the NDVI value by Equation (1). The NDVIr values were also calculated by Equation (3).

3. Results and discussion

3.1 Selection of the optimal spectra wavelength for the measurement of ginkgo leaves

After summarizing a number of studies concerned with responses to physiological stress, Carter *et al.* (2001) considered the maximum difference in reflectance within a 400- to 850-nm wavelength range between control and stressed states occurring at wavelengths near 700 nm. Spectral reflectance is affected by strong chlorophyll absorption in the range of 670–680 nm and changes with variation in leaf anatomy or water content in response to stresses beyond 730 nm in the near-infrared region (Carter *et al*., 2001). Slaton *et al*. (2001) considered that leaf reflectance in the near-infrared region is primarily affected by leaf structure and the position of the red edge correlated with chlorophyll content, plant phenological stage, as well as plant stresses. Leaf necrosis is characterized by chlorophyll loss and leaf drying as well as leaf structure variation. The optimal wavelength should exist in these regions.

According to the definition of NDVI, many

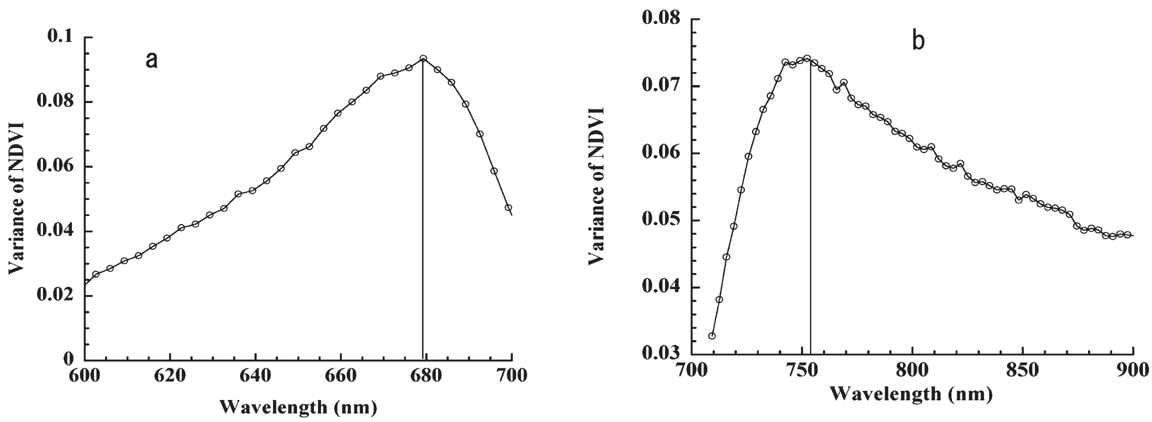

Fig. 2 Variance in NDVI value for ginkgo leaves with different necrotic levels in the visible band (Figure 2-a) and near-inferred band (Figure 2-b). All of the NDVI values in Figure 2-a were calculated by every spectral reflectance value in the visible region and one definite spectral reflectance value from the near-infrared region at a wavelength of 755 nm. All of the NDVI values in Figure 2-b were calculated by every spectral reflectance value from the near-infrared region and one definite spectral reflectance value in the visible region at a wavelength of 679 nm. From this figure, it is evident that the maximum variance in NDVI value is located at a wavelength of 679 nm and 755 nm, and the same values are maintained when they are calculated by different definite spectral reflectance values.

NDVI values can be calculated by measuring spectral reflectance. In this research, the proper wavelength for calculation of NDVI was determined by maximum variance of NDVI for ginkgo leaves of different necrotic levels. Ginkgo leaves for selecting the optimal spectra wavelength were sampled from a ginkgo shelterbelt in Yamaguchi University. After measuring the spectral reflectance in the visible region and near-infrared region, the NDVI values for all of the wavelengths from 600 to 900 nm were calculated. For the visible region, all the NDVI values were calculated by every spectral reflectance value in the visible region and one definite spectral reflectance value from the near-infrared region at a wavelength of 755 nm (refer to Fig. 2-a). For the near-infrared region, all the NDVI values were calculated by every spectral reflectance value from the near-infrared region and one definite spectral reflectance value in the visible region at a wavelength of 679 nm, comparatively (refer to Fig. 2-b). From Figure 2-a and Figure 2-b, it is evident that the maximum variance of NDVI values is at wavelength 755 and 679 nm, respectively, and the same values are maintained when they are calculated by different definite spectral reflectance values.

3.2 Difference in leaf necrosis between the windward and leeward sides of ginkgo trees

It was observed that some landscape trees showed necrosis from the leaf tip and margin to the entire leaf after Typhoon 0613 hit, in which a large variance in necrosis of ginkgo leaves and a significant difference between the windward and leeward sides after Typhoon 0613 hit were observed (refer to Fig. 3). From Figure 3, it can be seen that most leaves leeward of the sampled crowns are non-necrotic leaves, overall green leaves account for 70.9%, and no leaves have become entirely brown. Most leaves windward of the sampled crowns are necrotic leaves and dried leaves, and only 7.83% of them were green overall. This means that it was the difference in the percentage of necrotic leaves between the windward and leeward sides that made the crowns of the damaged ginkgo trees show different colors on either side of the crown.

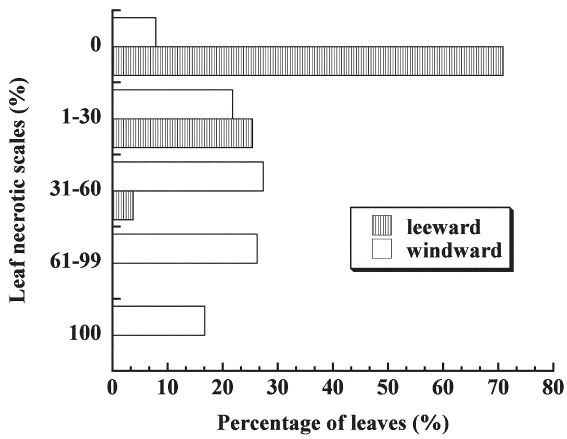

Fig. 3 Percentage of leaves with different necrotic levels for the windward and leeward sides of ginkgo trees sampled from Yamaguchi University. During the investigation, all leaves on the branches were visually counted into five levels, which were 0, 1-30, 31-60, 61-99, and 100%.

Many previous researches on typhoon damage to trees have involved ginkgo (Okinaka *et al.*, 1984, 1990; Shimizu, 2004). However, researches on ginkgo seldom focus on spectral reflectance characteristics. The visual scale method has been more commonly used to observe the damage characteristics of crowns (Okinaka *et al.*, 1984, 1990; Shimizu, 2004; Muhammed *et al.*, 2003), and few of them have been involved in the quantitative study of leaf necrotic area percentage. In this study, the results of spectral reflectance for different necrotic levels of ginkgo leaves showed a great difference, indicating an inverse liner relationship between NAP and $NDVI_{755nm/679nm}$, where R^2=0.985 as shown in Figure 4. It means that the NDVI value decreases as the leaf necrotic area increases. The NDVI values corresponded well with the ginkgo leaf necrotic area. Evidently, it is possible to estimate the necrotic area by measuring the spectral reflectance of leaves.

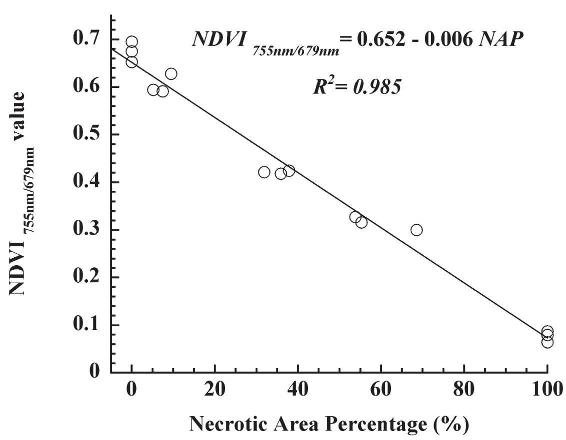

Fig. 4 Relation between the necrotic area percentage (NAP) and $NDVI_{755nm/679nm}$ value.

3.3 Spectral reflectance of necrotic leaves of different tree species

As mentioned above, many plants can show symptoms of leaf necrosis by damage due to extreme environmental conditions (Treshow, 1970). Spectral reflectance may be adopted to evaluate the necrotic status of other tree species besides ginkgo. By spectral reflectance analysis of leaves sampled from the windward and leeward sides of tree crowns after being hit by Typhoon 0613, the kaizuka juniper, an evergreen typhoon damage-resistant tree species (Shimizu, 2004), obviously differed from the other three deciduous tree species. Almost no difference between the windward and leeward sides of the crowns of kaizuka juniper was found in the spectral reflectance curves since there was no necrosis of their leaves. For the other three deciduous tree species, the spectral reflectance curves between the windward and leeward sides can be clearly distinguished because there are more necrotic leaves on the windward side (refer to Fig. 5).

From Table 1, a very clear difference between the evergreen kaizuka juniper and the other three deciduous tree species can be seen from NDVIr. The NDVIr of the crown is 43.9, 47.3, 43.6, and 75.1, respectively, for the sampled trees of ginkgo, metasequoia, trident maple, and kaizuka juniper. The difference among ginkgo, metasequoia, and trident maple was clearly smaller than the difference between the three deciduous trees and the kaizuka juniper. The reason seems to be the necrotic leaves on the windward side of these deciduous trees and the different spectral reflectance sensitivity to them.

Table 1. NDVI and NDVI using ratios (NDVIr) value for necrotic leaves of 4 tree species

	NDVI (755 nm/679 nm)		NDVIr*
	Windward	Leeward	
Ginkgo	0.098	0.781	43.9
Metasequoia	0.166	0.780	47.3
Trident maple	0.167	0.705	43.6
Kaizuka juniper	0.753	0.750	75.1

* NDVIr is the NDVI value using ratios, which is the proportion of NDVI755nm/679nm for the leaves of the windward side to NDVI755nm/679nm for the leaves of the leeward side.

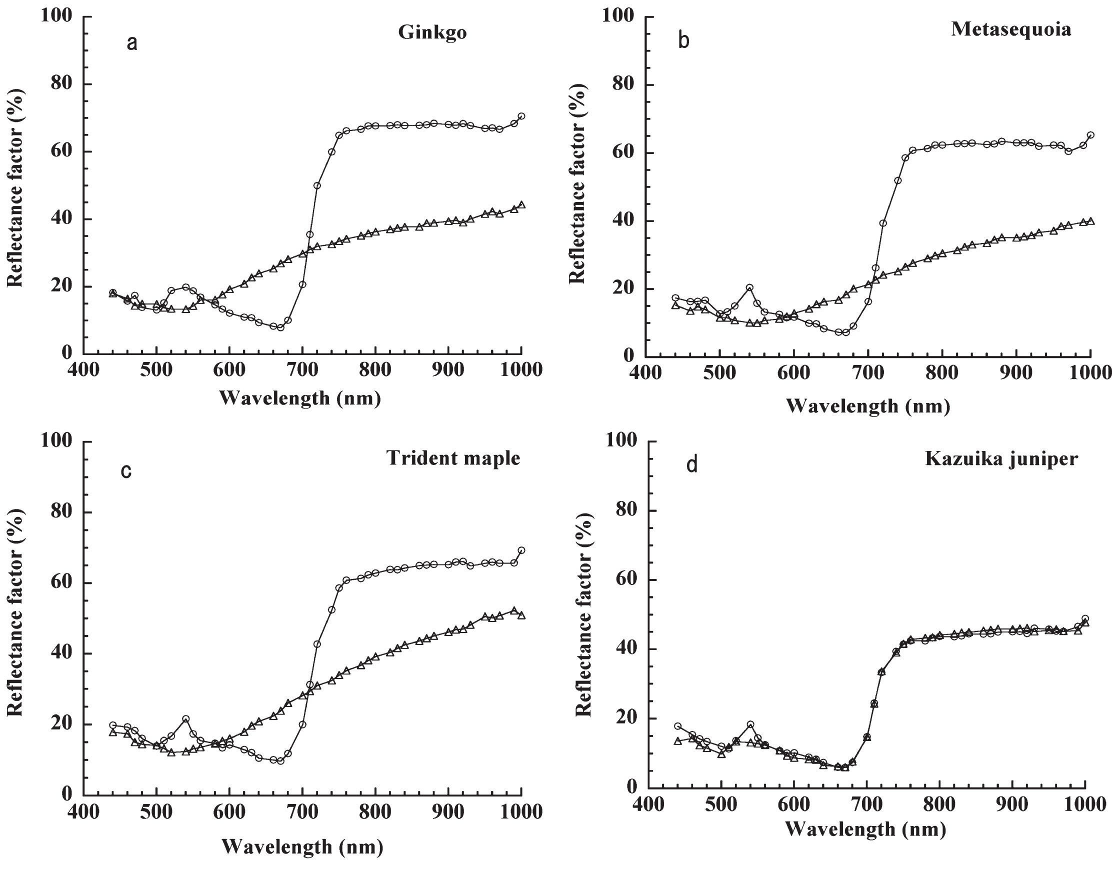

Fig. 5 Spectral reflectance curves for necrotic leaves sampled from the leeward side (○─○) and windward side (Δ─Δ) of four tree species, in which ginkgo (Figure 5-a), metasequoia (Figure 5-b), and kaizuka juniper (Figure 5-d) were sampled from shelterbelts, and trident maple (Figure 5-c) was sampled from an individual tree.

3.4 Difference in leaf necrosis among different sites

According to this study, the spectral reflectance of leaf samples from sites with different DC also varied significantly. Figure 6 shows that almost all leaves sampled from ginkgo trees at Site A, which is more than 40 km from the coastline, were mainly non-necrotic leaves. By contrast, most leaf samples from Site C, less than 2 km from the coastline, were necrotic leaves and dried leaves. The leaf samples from Site B, about 13 km from the coastline, were in the middle position. Therefore, the difference in storm-damaged ginkgo leaves among sites was mainly due to the difference in the percentage of leaves with varying levels of necrosis after Typhoon 0613. The nearer to the coastline, the more leaves there are with serious necrosis after being hit by a typhoon.

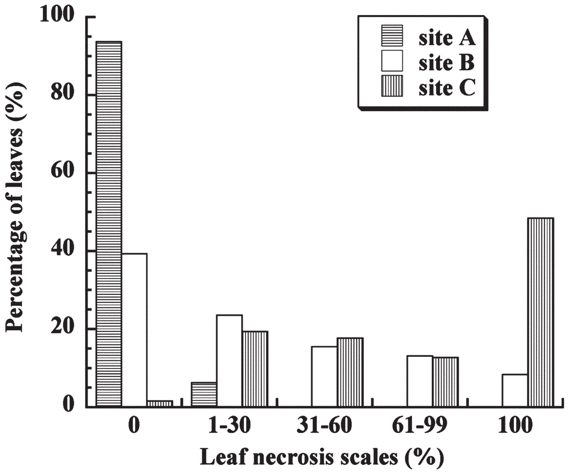

Fig. 6 Percentage of leaves with different necrotic levels for ginkgo trees sampled from three sites (Site A, Site B, and Site C) by the visual scale method. During the investigation, all leaves on the branches were visually counted into five levels, which were 0, 1-30, 31-60, 61-99, and 100%.

Figure 7 shows the spectral reflectance curves of ginkgo leaves sampled from three sites after being hit by Typhoon 0613. It is clear that there was also a big difference in spectral reflectance among the leaves sampled from the windward and leeward sides of ginkgo trees from the three sites. For the samples from Site A, with an NDVI value of 0.679 for both the leeward and the windward side, respectively, the spectral reflectance curves almost overlapped each other so that they could not be distinguished from each other. This means almost no difference in leaf spectral

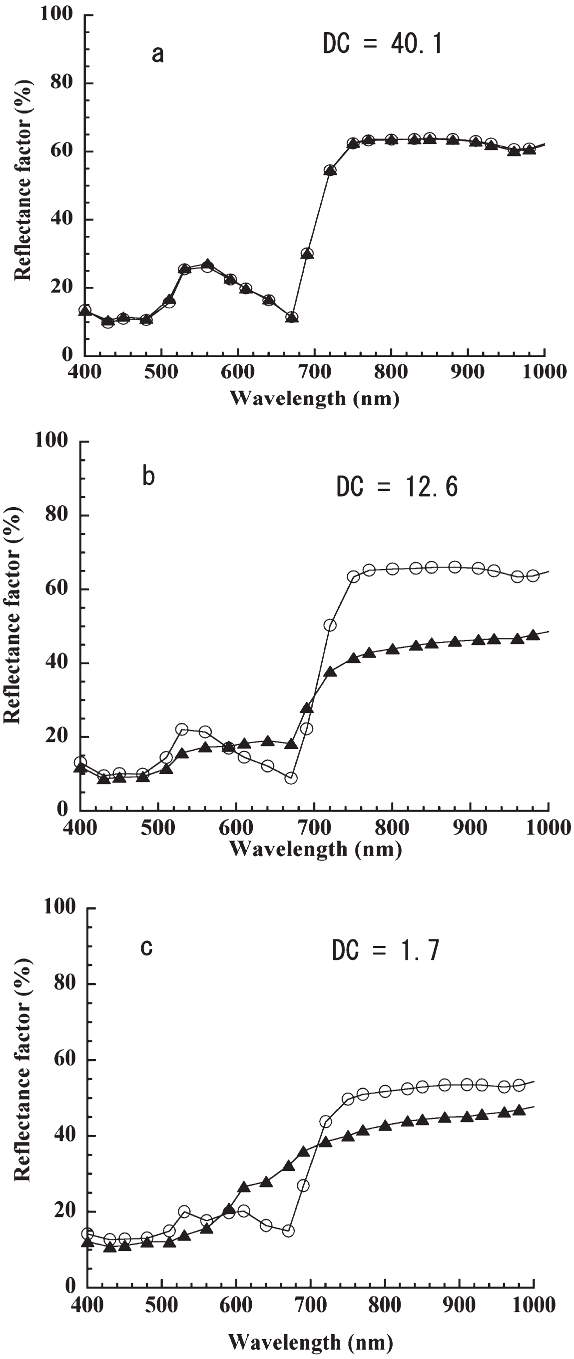

Fig. 7 Spectral reflectance curve for necrotic leaves sampled from the leeward side (○—○) and the windward side (▲—▲) in three sites with different distances from the coastline (DC), in which 7-a, 7-b, and 7-c are respectively the data for Site a, Site b, and Site c. Every line was an average value of three duplications and the NDVI value was calculated by the average spectra reflectance values. Sampling and measurement were carried out on Nov. 1 and Nov. 2, 2006 for Site A and Site B, and on Nov. 6 and Nov. 8, 2006 for Site C.

reflectance between the windward and leeward sides of ginkgo trees at this site. Although the samples from Site B and Site C showed a similar tendency whereby the spectral reflectance curves between the windward and leeward sides of the ginkgo trees were separate from each other, we can clearly find a difference. The spectral reflectance for the leaves of ginkgo trees at Site B, with an NDVI value of 0.749 and 0.373 for the leeward and the windward side, respectively, was significantly higher than that of Site C with an NDVI value of 0.528 and 0.096 for the leeward and windward sides. This implies that Site C contained more necrotic leaves. It is evident that the spectral reflectance characteristics are consistent with the result of the visual scale observation.

Compared to the NDVI value, the NDVIr value corresponded better to the damage status of ginkgo trees, which combined the spectral reflectance of both the windward and leeward sides. Figure 8 shows the NDVIr, DC, maximum wind speed, and precipitation during Typhoon 0613 for the three sites. The NDVIr values were respectively 67.9, 56.1, and 31.2 for Site A, Site B, and Site C. The related maximum wind speeds were respectively 8, 20, and 27 m/s, rainfall, 52, 26, and 14 mm, and distance from coastline, 40.1, 12.6, and 1.7 km. This means that the nearer to the coastline, as the wind speed increased accompanying the decrease in rainfall during Typhoon 0613 for the investigated sites, the smaller the NDVIr values were. In other words, the nearer to the coastline, the greater the leaf necrosis of ginkgo. The result of spectral reflectance was well in accordance with the difference in wind and precipitation. It was also consistent with the result of the visual scale observations of other researchers (Okinaka *et al*., 1984).

4. Conclusion

Based on this research, it is the difference in leaf necrotic status between the windward and leeward sides of ginkgo crowns that causes the variance in discoloration between them. This kind of variation also appears at sites of different distances from the coastline. They can be estimated by measuring the spectral reflectance of ginkgo leaves with different necrotic status by using the pocket radiometer, EKO-MS720.

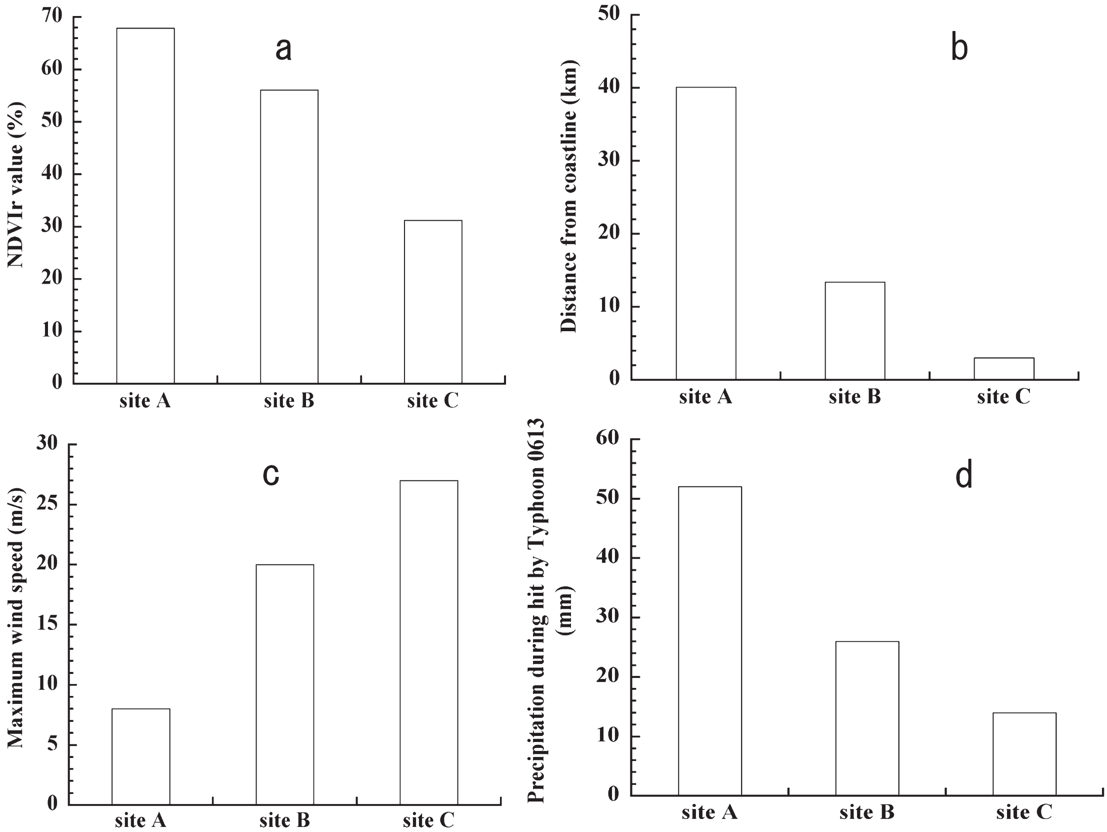

Fig. 8 NDVI using ratios (NDVIr, 8-a) value, distance from the coastline (DC, 8-b), maximum wind speed (8-c), and precipitation (8-d) during the hit by Typhoon 0613 for the sampled leaves from three sites.

The optimum wavelength for the calculation of NDVI for necrotic ginkgo leaves is 679 and 755 nm. The result of measurement of $NDVI_{755nm/679nm}$ is very consistent with the result of direct visual observation, and the close inverse relationship between $NDVI_{755nm/679nm}$ and NAP of ginkgo leaves indicates that it has potential to evaluate the damage status of ginkgo and to be an alternative tool to measure leaf necrosis induced by typhoons like Typhoon 0613, especially by using the NDVIr value.

Comparison between ginkgo and three other tree species indicated that spectral reflectance was more sensitive for the three deciduous tree species with necrotic leaves than for the evergreen kaizuka juniper tree without necrotic leaves. Ginkgo leaf necrosis is a common sight in areas where typhoons frequently occur, especially along the coast, where gingko leaves show smaller NDVIr values.

Salisbury (1805) noted that great leaf injury occurred when rain was not associated with strong wind. The rainless or low-rainfall period during and after Typhoon 0613 reveals that the ginkgo leaf necrosis in Yamaguchi City is just like Salisbury's note.

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