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# Shozo Hiroki : **Unique root elongation habit of *Quercus serrata* subsp. *mongolicoides* in Japan's Tokai District**

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**Abstract**

*Quercus serrata* subsp. *mongolicoides* is one of the key species of the Tokai hilly land element of Tokai District, where the tree is semi-endemic. In this region, its roots elongate obliquely rather than vertically. To examine its root elongation pattern, I obtained acorns from Aichi and Tochigi Prefectures. For comparison, I also obtained *Quercus crispula* acorns from Gifu Prefecture and *Quercus variabilis* acorns from Aichi Prefecture. The acorns were planted, and their root growth was constrained in two dimensions. Seedlings were excavated after 4 months, and the angles of their roots from the vertical were measured. The root angles of *Q. serrata* subsp. *mongolicoides* from Aichi Prefecture averaged 33.2±10.3°, versus 26.3±9.9° for those from Tochigi Prefecture, 4.4±4.0° for *Q. crispula*, and 3.0±2.0° for *Q. variabilis*. The oblique root elongation habit of *Q. serrata* subsp. *mongolicoides* appears to be an adaptation to poor soils or to ridge habitats with poor soil. The origin of the subspecies may be in a region with thin and poor soils in the gravel and sand beds from the Tokai Group sediment.

**Key words** : nutrient-poor soils, *Quercus serrata* subsp. *mongolicoides*, root elongation, Tokai hilly land element.

## Introduction

Many endemic or semi-endemic plants are found in the area of thick gravel and sand beds in Japan's Tokai District, which was given the phytogeographic name "Tokai hilly land element" by Ueda (1989). Most plants of the Tokai hilly land element are inhabitants of wetlands; these include *Magnolia stellata* (Siebold et Zucc.) Maxim. (Ueda 1988), which is a tree species endemic to Tokai District. However, one semi-endemic *Quercus* subspecies grows in dry habitats in this land element. This Japanese deciduous *Quercus* subspecies has recently acquired its scientific name, *Quercus serrata* Murray subsp. *mongolicoides* H.Ohba (Ohba 2006). The tree was previously considered to be *Quercus mongolica* Fisch. ex Ledeb. (Ohwi 1975), although there was some doubt about its correct taxonomic designation. After Ohba's naming of the subspecies, Serizawa (2008) classified the subspecies as a variety of *Quercus crispula* Blume. However, as I will discuss in the discussion, I followed Ohba's nomenclature for this species.

*Quercus serrata* subsp. *mongolicoides* is commonly found on ridges or thin and poor soils of hills in granitic areas and in the Tokai Group sediment in Aichi Prefecture (Hiroki 2001, Matsuse and Hiroki 2009) and in Gifu Prefecture (S. Hiroki, unpublished data), and until recently, its ecology attracted little attention. Hiroki (1982) found that the subspecies was present in poor soils of granitic origin at Obara in Toyota City, Aichi Prefecture. Many *Quercus* species grow in areas with soils derived from granodiorite (a kind of granite), where deep soils often develop, but *Q. serrata* subsp. *mongolicoides* does not grow in these areas. Instead, it grows luxuriantly on poor soils, and particularly on ridges in granitic areas rich in biotite. Hiroki et al. (2001) investigated the soil properties in this granitic area and found that the soil had thin A and B horizons, with depths of less than 3 cm and about 20 cm, respectively, and that the soil had low phosphate and nitrogen contents. In these soils, the root angles of two sympatric species (*Q. serrata* subsp. *mongolicoides* and *Quercus variabilis*) differed dramatically. The angle of the roots from the vertical was about 20° in *Q. serrata* subsp. *mongolicoides*, but only 4.6° in *Q. variabilis* Blume.

Because the methods used to determine the root angle in this early analysis were relatively crude and because the sample size was small, these results could only be considered preliminary. I therefore conducted a more extensive experiment to determine the root angle in these two sympatric species, as well as the roots of *Q. crispula* and a population believed to be *Q. serrata* subsp. *mongolicoides* growing in an area isolated from the Tokai District population (Suda and Hoshino 2008), where the subspecies could be identified by its leaf form and acorn shape.

In this paper, I discuss the unique traits of *Q. serrata* subsp. *mongolicoides* that allow this subspecies to adapt to the poor soils of Tokai District.

## Materials and methods

I collected more than 50 acorns of each species at the following sites: for *Q. serrata* subsp. *mongolicoides*, a site at an elevation about 150 m at Yakusa, in Toyota City, Aichi Prefecture; for *Q. crispula*, a site at an elevation of about 110 m in the Hidarimata Valley, which leads into two valleys on Mt. Hodaka, Gifu Prefecture; and for *Q. variabilis*, a site at an elevation of about 50 m on Higashiyama Hill in Nagoya City, Aichi Prefecture. The collections were made in October 2003 for *Q. variabilis* and *Q. serrata* subsp. *mongolicoides* and in October 2005 for *Q. crispula*. Because *Q. serrata* subsp. *mongolicoides* is also distributed in Tochigi Prefecture, where it is isolated from the population in Tokai District, I also collected acorns of this subspecies at an elevation of about 100 m at Koike, in Tochigi Prefecture. In 2005, it was only suspected by researchers that the two populations were the same species; this has now been confirmed, as I will explain in the Discussion.

The samples were immediately returned to the laboratory of the Graduate School of Information Science at Nagoya University, where the acorns were sown in a planter (60 cm long, 18 cm wide, and 14 cm deep) filled with a 2:1 (v/v) mixture of Akadam volcanic soil and vermiculite and then watered. The germinated acorns were transplanted into planters with the same size and the same soil conditions used to germinate the seeds. The acorns were planted in three rows, with a spacing of 3 to 4 cm between the rows. Acorns of each species were grown in different planters separately. The rows of acorns were surrounded on two sides using parallel vertical partitions of corrugated cardboard so that their roots could only grow in two dimensions.

After raising the seedlings for about 4 months at a room temperature of 24.5±1.0 °C, with watering every 2 or 3 days, the planters were turned on their side and the corrugated cardboard was removed, along with the soil and seedlings. In each population, the angles of the roots from the vertical were measured for a total distance of 10 cm, starting 2 cm below the acorn, and the roots were then photographed.

## Results

Seedlings of *Q. serrata* subsp. *mongolicoides* showed an unusual root elongation habit (Fig. 1a), with the roots growing closer to horizontally than in the other species, at a large angle from the vertical. This was in remarkable contrast with the roots of *Q. crispula* (Fig. 1b) and *Q. variabilis* (Fig. 1c), whose roots grew nearly vertically. The *Q. serrata* subsp. *mongolicoides* roots grew at angles of 33.2±10.3° from the vertical in the Yakusa (Aichi) population and 26.3±9.9° from the vertical in the Koike (Tochigi) population, in contrast with root angles of 4.4±4.0° for *Q. crispula* and 3.0±2.0° for *Q. variabilis* (Table 1).

## Discussion

The results of this study confirm the preliminary results of Hiroki et al. (2001), which showed that the roots of *Q. serrata* subsp. *mongolicoides* elongate at a considerable angle from the vertical, whereas those of *Q. variabilis* do not. I also found that *Q. crispula* showed only a slight deviation from the vertical. The root angles of *Q. serrata* subsp. *mongolicoides* were higher in the present study than in my previous study (Hiroki et al. 2001). The difference in soil conditions between the previous study (granite-derived soils) and the present study (volcanic soils plus vermiculite) may explain the different root angles.

I also found that the roots of *Q. crispula* and


Fig. 1. Root elongation habits of the three oak species. Figures are side views of one of three rows in each species with removing a corrugated paper of one side.
a. *Quercus serrata* subsp. *mongolicoides* from Aichi Prefecture
b. *Q. crispula*
c. *Q. variabilis*

*Q. variabilis* do not elongate obliquely. Thus, it is possible that the oblique root elongation of *Q. serrata* subsp. *mongolicoides* is unique among these species. In this study, I did not examine the root elongation habit of *Q. serrata*, which is the parent species of *Q. serrata* subsp. *mongolicoides*, because I was not familiar with the revised naming by Ohba (2006) at the time of this experiment. It is therefore necessary to examine the root elongation habit of *Q. serrata* in future research. Karizumi (1987) provided a picture of a seedling of *Q. serrata* in a book on tree root systems. Because this picture shows that the seedlings of *Q. serrata* elongated its main root almost directly downward, it is likely that the species does not have an oblique root elongation habit. However, because the sample size is only one photo, it will be necessary to confirm this hypothesis based on many additional samples. I am currently preparing an experiment to determine the root elongation habit of *Q. serrata*.

I have some doubt about Ohba's proposed scientific name of *Q. serrata* subsp. *mongolicoides* for several reasons. First, the petioles of the leaves of *Q. serrata* subsp. *mongolicoides* are more similar to those of *Q. crispula* than to those of *Q. serrata*, as the first two species have short leaf petioles, in contrast with the latter species. Second, all of the involucral scales of the cupule's surface are swollen in *Q. serrata* subsp. *mongolicoides*, which is similar to the partial or total swelling in *Q. crispula* but different from *Q. serrata*, which does not show swelling of the involucral scales. This evidence suggests that the subspecies may be more correctly considered to be a variety of *Q. crispula* (i.e., *Q. crispula* var. *mongolicoides*), as was proposed by Serizawa (2008). However, further examination (perhaps using molecular genetics) will be necessary to clarify this point.

Table 1. Root angles (measured from the vertical) for three *Quercus* species in Japan

| Species | Sampling location | Root angle (mean±SD) | Number of samples |
|---|---|---|---|
| *Quercus serrata* | Yakusa (Aichi Pref.) | 33.2±10.3° | 19 |
| ssp. *mongolicoides* | Koike (Tochigi Pref.) | 26.3± 9.9° | 13 |
| *Q. crispula* | Hodaka Mts. (Gifu Pref.) | 4.0± 4.0° | 23 |
| *Q. variabilis* | Higashiyama Hill (Aichi Pref.) | 3.0± 2.0° | 23 |

I have therefore retained Ohba's *Q. serrata* designation for consistency with the nomenclature used in my previous studies.

The root angles were similar in seedlings from the populations of *Q. serrata* subsp. *mongolicoides* from Tochigi Prefecture (Suda and Hoshino 2008) and from Aichi Prefecture. In combination with the petiole and cupule scale data, this suggests that these isolated populations are the same subspecies and have similar rooting characteristics.

The unique oblique root elongation habit of *Q. serrata* subsp. *mongolicoides* may represent an adaptation to thin, poor soils. The subspecies grows predominantly on poor soils in granitic areas (Hiroki 1982, Hiroki et al. 2001) and on poor soils of the gravel and sand beds of the Tokai Group sediment (Matsuse and Hiroki 2009). Obliquely elongated roots are better able to support a tree on thin soils or on ridges. The relatively new soil materials in granitic areas are generally thin and difficult for tree roots to penetrate, and the ridges rich in gravels of the Tokai Group sediment also make root penetration difficult. Tree species such as *Q. variabilis*, whose roots elongate vertically, may have difficulty becoming established in these soils. I am currently performing a field experiment in a bare field of granitic soils at Obara in Toyota City (Aichi Prefecture). The preliminary results show a tendency toward early mortality of seedlings of *Q. variabilis*, whose roots elongate vertically, whereas seedlings of *Q. serrata* subsp. *mongolicoides* have a higher survival rate.

Though *Q. serrata* subsp. *mongolicoides* grows both in granitic areas and in the gravel and sand sediment area, the subspecies may have evolved in the latter area (i.e., in the Tokai Group sediment), which formed in a large sedimentary basin created by ancient Lake Tokai from the late Miocene to the middle Pleistocene (Makinouchi 2001). The sediments include gravels, sands, and clays. When a layer is rich in gravels and sands, water can easily penetrate, so slopes or ridges that are rich in gravels and sands are extremely dry and the soils are generally poor, particularly when surface soils have been removed by erosion. Such dry, denuded habitats prevent the growth of most tree species other than drought-tolerant or pioneer species such as pines (*Pinus* spp.). It is therefore possible that *Q. serrata* subsp. *mongolicoides* evolved in a niche comprising these severe habitats as a result of natural selection that selected for the oblique root growth habit. Though details of the original habitat of this species are not known, the Tokai Group sediment covers a vast area and has existed for a long time (Makinouchi 2001), suggesting that this would have provided sufficient time for natural selection leading to the fixation of traits such as oblique rooting. It is also possible that *Q. serrata* subsp. *mongolicoides* may have evolved from *Q. mongolica*, which migrated to Japan from continental Asia, or from *Q. crispula*, which descended from higher elevations, during the most recent ice ages, which occurred several times during the Pleistocene. These hypotheses can be tested by means of DNA analysis in future research.

Though *Q. serrata* subsp. *mongolicoides* is widely distributed in granitic areas, this appears to represent secondary expansion of the distribution of the subspecies, because it is generally thought that granite weathers rapidly in Japan and that soil formation is fast, so that thin and poor soils are maintained only temporarily. Thus, granitic areas seem unlikely to be the origin of this subspecies because suitable soils would not persist long enough for speciation to begin. As for the populations of *Q. serrata* subsp. *mongolicoides* in Tochigi Prefecture, their relationship with the Tokai District population is currently unknown, but I suspect that the Tochigi Prefecture population is a relict of the former expansion. For example, I have seen several populations of *Q. serrata* subsp. *mongolicoides* on ridges at elevations of about 400 m in Kamikoike town in Utsunomiya City.

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**広木詔三：東海地方に分布するフモトミズナラ（*Quercus serrata* subsp. *mongolicoides*）の特異な根の伸長特性**

フモトミズナラ（*Quercus serrata* subsp. *mongolicoides*）は準固有種として東海地方に分布する東海丘陵要素の1種であり、その根は斜めに伸長することが知られている。その根の伸長特性を調べるために、愛知県豊田市の八草と、隔離分布する栃木県の小池でそれぞれ50個の堅果を採集し、名古屋大学の情報科学研究科の実験室でプランターに播種し、根の伸長実験を行った。栽培用のプランターに発芽した堅果を3列に並べ、その間を段ボール紙で根が2次元方向に伸びるように設定し、約4ヶ月後にプランターから取り出して根の鉛直方向からの角度を測定した。比較のために、穂高岳のミズナラと名古屋市東山丘陵のアベマキも同様の根の伸長実験を行った。その結果、フモトミズナラの根は鉛直方向から33.2±10.3°（愛知県産）および26.3±9.9°（栃木県産）とかなり斜めに伸長したのに対して、ミズナラとアベマキの根はそれぞれ4.4±4.0°と3.0±2.0°とほぼ鉛直方向に伸長した。このような特異な根の伸長特性は、東海地方のフモトミズナラが東海層群の砂礫層や花崗岩地帯の尾根や痩せ地に生育する上での適応と解釈した。また、その起源が花崗岩地帯ではなく東海層群の砂礫層である可能性について考察を行った。（〒441-8522 豊橋市町畑町1-1　愛知大学国際コミュニケーション学部）

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