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韓國의 木本植物의 外生菌根에 関한 調査*1

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Survey of Ectomycorrhizae in the Selected Woody Species in Korea*1

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Occurrence of ectomycorrhizae in the selected woody plants growing in Korea was surveyed and compared with that reported in the literature. Ectomycorrhizae were common features in Pinaceae, Salicaceae, Betulaceae, Fagaceae, Ulmaceae, and Tiliaceae, which agreed with literature. We were unable to find ectomycorrhizae in Cupressaceae, *Juglans*, Rosaceae, and *Acer* which were reported to have facultative ectomycorrhizae. Other species observed did not have ectomycorrhizae.

韓國에서 自生하는 木本植物에 共生하는 外生菌根의 分布狀態를 樹種別로 調査하였다. 外生菌根은 소나무科, 버드나무科, 자작나무科, 참나무科, 느릅나무科, 피나무科의 樹種에서 모두 発見되었으며, 偶発的으로 菌根을 形成한다고 外國文献에 発表되어 있는 측백나무科, 가래나무属, 장미科, 단풍나무属의 樹種에서는 外生菌根을 発見할 수가 없었다.

INTRODUCTION

Even though mycorrhizal research has been very active in many parts of the world and has progressed with remarkable success in U.S.A., no single paper has published in Korea about mycorrhizae. Mycorrhizae is literally fungus-root, a form of symbiosis between host plant roots and soil fungi. The host plants provide foods for the fungi, while fungi help the host roots absorb mineral nutrients, such as phosphorus and nitrogen (Meyer, 1974). Therefore, the mycorrhizae are beneficial to the host plants and are believed to be essential to many forest trees, because without formation of mycorrhizae many forest trees, especially Pinaceae family, grow poor or cannot survive at all (Marks and Kozlowski, 1973). In addition, formation of mycorrhizae is stimulated in the soil of low fertility (Lee et al., 1981) and has been known to increase survival rate of outplanted trees in eroded sites and coal mine spoils (Marx, 1977).

According to Trappe (1977), about 95% of the world's present species of vascular plants belong to families that are characteristically mycorrhizal, or about 90% of seed plants may form mycorrhizae with various fungi, suggesting ubiquitous nature of mycorrhizae in higher plants.

Mycorrhizae are commonly classified into three types, according to the patterns of fungal penetration into the host roots; ectomycorrhizae (fungal hyphae form fungal sheath on the root surface and form Hartig net in the cortex by growth of hyphae in the intercellular spaces), endomycorrhizae (fungal hyphae proliferate within the individual cortical cells without forming fungal sheath on the root surface), and ectendomycorrhizae (feature characteristics of both ecto-and endomycor-

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rhizae). Ectomycorrhizae are found mostly in woody plants and in all members of Pinaceae, Salicaceae, Betulaceae, and Fagaceae and in some members of Cupressaceae, Juglandaceae, Rosaceae, Ulmaceae, Aceraceae, and Tiliaceae (Meyer, 1973). Endomycorrhizae are common features in *Platanus*, *Ulmus*, *Juglans*, *Fraxinus*, *Liriodendron*, and *Liquidamber* in woody plants and in most agronomic plants Kormanik *et al.*, 1977). Both ectomycorrhizae and endomycorrhizae are found in the same trees of Cupressaceae, Salicaceae, Juglandaceae, Tiliaceae, Myrtaceae, Rosaceae, *Quercus*, *Alnus*, *Ulmus*, and *Arbutus* (Gerdemann, 1975; Meyer, 1973; Marx, 1977).

This paper presents occurrence of ectomycorrhizae in woody plants found in Korea and describes general external morphology of host roots and fungal symbiont.

MATERIALS AND METHODS

The study area was a part of experimental forests in Kwangneung, Kyunggi Province, where Central Branch Station of Forest Research Institute was located, and has been maintained as an arboretum for indigenous and exotic species. In september of 1980, root samples were collected from the top 10 to 15 cm soil and gently washed with water. The color of the mycorrhizae and attached roots was recorded in the field and the roots were stored in a bottle with fixative (standard FAA solution) until microscopic examination. The roots were observed under a dissecting microscope for external structure and under a light microscope for internal morphology after hand sectioning. Mycorrhizal tips were differentiated from non-mycorrhizal tips by criteria described by Wilcox (1968).

a total of 60 genera, 100 species were examined in this study.

RESULTS AND DISCUSSION

In most cases, external structures of ectomycorrhizae were so conspicuous that even with unaided eyes one could easily distinguish mycorrhizal roots from non-mycorrhizal ones (Fig. 1). Ectomycorrhizal roots lacked root hairs (Fig. 1) and were commonly associated with white massive fungal mycelium around the roots (Fig. 2). The diameter of the infected roots were larger than uninfected ones which had smooth surface with root hairs. Fungal hyphae formed either thin or thick weft around the root surface (called fungal sheath or mantle, Fig. 3) and also penetrated into the cortex (between cortical cells without entering individual cells of the cortex) forming "Hartig net" in the middle lamellae (Fig. 4). The fungal sheath and Hartig net were most prominent features of Pinaceae, Betulaceae, Salicaceae, Fagaceae, and Tiliaceae. Unforked, bifurcate (Fig. 1), repeated bifurcate, pinnate, coralloid (Fig. 5a) and tuberculate (Fig. 5b) mycorrhizal tips were observed in this study. Tuberculate mycorrhizae were found only in *Pinus koraiensis*. The color of mycorrhizae varied widely from milky white, orange, light brown to dark brown, purple and black.

Table 1 summarizes the structures of ectomycorrhizae in 100 species observed. The ectomycorrhizae were common features in Pinaceae, Salicaceae, Betulaceae, Fagaceae, Ulmaceae, and Tiliaceae, which well agreed with literature (Table 2). We did not pay attention to the endomycorrhizae which might be found in many of these species. We were unable to find ectomycorrhizae in the following families and genera which were reported to have ectomycorrhizae: Cupressaceae, Rosaceae, *Juglans*, and *Acer*. These species appeared to have facultative ectomycorrhizae. Meyer (1973) described that *Cupressus*, *Juniperus*, *Salix*, *Betula*, *Corylus*, *Alnus*, *Ulmus*, *Pyrus*, *Acer*, and *Eucalyptus* were facultative ectomycorrhizal genera which were capable of thriving in the absence of true ectomycorhizal fungi, while obligate ectomycorrhizal trees were members of the floowing genera, *Abies*, *Larix*, *Picea*, *Pinus*, *Carpinus*, *Fagus*, and *Quercus*. Some genera which have been reported non-mycorrhizal in the literature were found free of ectomycorrhizae and were mostly common in deciduous species (last part of Table 1).

It is encouraging to know that formation of ectomycorrhizae has been successful in Korea. We have introduced several exotic pines in this country and have not faced any problems with mycorrhizal formation, compared with Australia and Puerto Rico where failure of original introduction of *Pinus radiata* and *P. caribaea*, respectively, resulted from lack of mycorrhizal fungi (Vozzo and Hacskaylo, 1971).

Recently, scientists in U.S.A. were successful in isolation and mass culture of "super-strains" of mycorrhizal fungi which survive remarkably well in poor sites and eroded coal mine spoils (Marx, 1977). In addition, seedling inoculated with these fungi grew faster than uninoculated control. Their results suggested that in near future we can manipulate natural symbiosis between seedlings in the nursery and fungal symbionts to increase survival and growth rate of out-planted trees and finally increase general forest productivity.

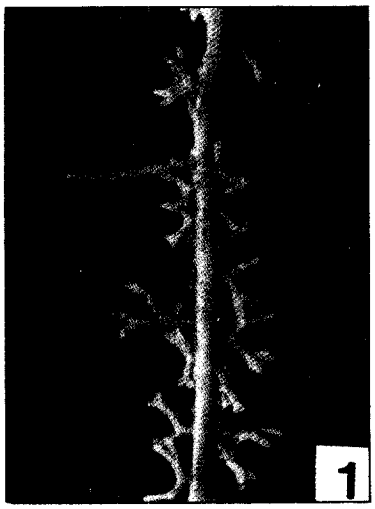
Fig. 1. Bifurcate mycorrhizae in an one-year-old *Pinus rigida X taeda* seedling.

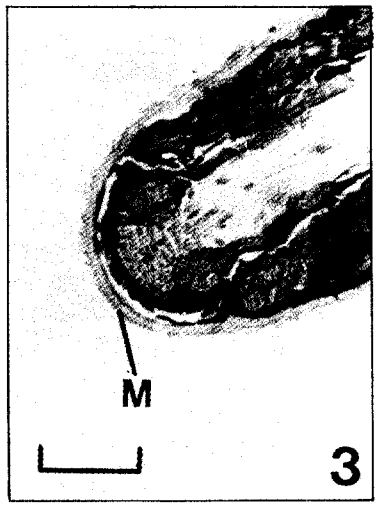
Fig. 2. White conspicuous mycelium on the root surface of *P. taeda*.

Fig. 3. A root tip of *P. taeda* with prominent fungal mantle (M) on the root surface. The meristematic region does not have root cap tissue. The bar is 100 μ.

Fig. 4. A cross section of *P. koraiensis* root with well developed Hartig net (H) in the cortex and fungal mantle (M) on the root surface. Epidermis (E) contains tanniniferous substance. The bar is 30 μ.

Fig. 5. Coralloid (a) and tuberculate (b) mycorrhizae in *P. koraiensis*.





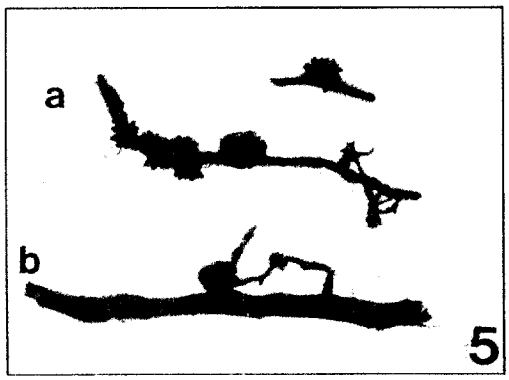


Table 1. Occurrence and morphology of ectomycorrhizae in the selected woody species found in Korea. A total of 31 families, 60 genera, 100 species were observed in this study.

Species	Ecto.	Description
Ginkgoaceae		
Ginkgo biloba	−	have conspicuous short lateral roots with many white root hairs; no ecto.
Taxaceae		
Taxus cuspidata	−	light brown; long, bead-form lateral roots, ramiform roots with many root hairs; no ecto.
Cephalotaxus Koreana	−	yellow to light brown; thick, long, pointed roots, difficult to distinguish between main and lateral roots; no ecto.
Pinaceae		
Pinus koraiensis	+	mycorrhizae in all pines except in *P. koraiensis*
Pinus thunbergii	+	
Pinus densiflora	+	unforked, bifurcate, repeated bifurcate, coralloid, tuberculate;
Pinus rigida	+	glabrous, wooly, cottony tip; white to light brown; black tip
Pinus taeda	+	
Pinus strobus	+	
Pinus banksiana	+	
Pinus sylvestris	+	
Larix leptolepis	+	pinnate, unforked; wooly tip; white to light brown thread-like rhizomorph; black tip mycorrhizae.
Picea abies	+	pinnate; glabrous, cottony, wooly tip; white, light brown, orange,
Picea koraiensis	−	reddish brown; black tip mycorrhizae.
Abies holophylla	+	some unforked, mostly pinnate; reddish brown with white
Abies nephrolepis	+	mycelium.
Abies koreana	−	
Taxodiaceae		
Cryptomeria japonica	−	white; pointed long lateral roots; no ecto.
Metasequoia glyptostroboides	−	white, conical short roots; no ecto.
Cupressaceae		
Thuja occidentalis	−	light brown, pointed lateral roots; no ecto.
Chamaecyparis pisifera	−	light brown, fine, long, pointed roots; difficult to distinguish
Chamaecyparis obtusa	−	between main and lateral roots; no ecto.
Juniperus chinensis	−	reddish brown, pointed, short or long lateral roots; no ecto.
Juniperus chinesis var. *sargentii*	−	
Juniperus rigida	−	
Salicaceae		unforked long zigzag lateral roots, ramiform, white wooly;
Populus euramericana	+	black mycorrhizae.
Populus tomentiglandulosa	+	unforked, pinnate; long or short zigzag,white or brown cottony
Salix graciliglans	+	tips.

Species	Ecto.	Description
Juglandaceae		
Juglans mandshurica	−	light brown, conical short lateral roots; no ecto.
Juglans sinensis	−	
Betulaceae		
Alnus japonica	+	unforked, pinnate, white to light brown, conspicuous lateral roots.
Alnus hirsuta var. *sibirica*	+	
Betula platyphylla	+	unforked, pinnate; white wooly or cottony tips and black tips;
Betula platyphylla var. *japonica*	+	
Betula verrucosa	+	
Carpinus laxiflora	+	unforked, light brown; swelling cottony tips at the end of fine lateral roots and black tips.
Carpinus cordata	+	
Fagaceae		
Quercus aliena	+	unforked, pinnate, ramiform; white, orange, light brown; glabrous, wooly tips with branching rhizomorphs and black tips.
Quercus acutissima	+	
Quercus grosseserrata	+	
Quercus mongolica	+	
Quercus rubra	+	
Quercus serrata	+	
Quercus variabilis	+	
Castanea crenata	+	unforked, pinnate; white cottony; zigzag, short or long conspicuous lateral roots.
Ulmaceae		
Celtis jessoensis	+	unforked: light brown; short stumpy cottony glabrous tips
Ulmus davidiana	−	pinnate; light brown; conspicuous short lateral roots.
Ulmus pumila	−	
Zelkova serrata	−	brown; conical, bead-form, conspicuous short lateral roots; no ecto.
Berberidaceae		
Berberis koreana	−	yellow, fine long roots; difficult to distinguish between main and lateral roots; no ecto.
Cerciphyllaceae		
Cercidiphyllum japonicum	−	light brown, pointed long roots; difficult to distinguish between main and lateral roots; no ecto.
Magnoliaceae		
Magnolia sieboldii	−	milky white to light brown; long or short pointed lateral roots; no ecto.
Liriodendron tulipifera	−	light brown, a few short lateral roots; mostly difficult to distinguish between main and lateral roots; no ecto.
Leguminosae		
Amorpha fruticosa	−	light brown; conspicuous pointed fine short lateral roots with nodules; no ecto.
Lespedeza maximowiczii	−	light brown; conspicuous pointed fine long or short lateral roots with nodules; no ecto.
Lespedeza cyrtobotrya	−	

Species	Ecto.	Description
Maackia amurensis	−	light brown, pointed short or long lateral roots; no ecto.
Robinia pseudoacacia	−	light brown, pointed short or long lateral roots with nodules; no ecto.
Platanaceae		
Platanus occidentalis	−	white; pointed short or long lateral roots; no ecto.
Rosaceae		
Crataegus pinnatifida	−	light brown; conspicuous conical short lateral roots; no ecto.
Malus baccata	−	light brown; conical lateral roots; no ecto.
Prunus americana var. *ansu*	−	light brown; difficult to distinguish between main and lateral roots; no ecto.
Prunus padus	−	light brown; fine long pointed lateral roots; no ecto.
Pyrus pyrifolia	−	light brown; conspicuous pointed short lateral roots; no ecto.
Sorbaria sorbifolia var. *stellipila*	−	light brown; conical short lateral roots; no ecto.
Spiraea salicifolia	−	light brown to yellow; pointed fine long lateral roots; no ecto.
Spiraea prunifolia var. *simpliciflora*	−	light brown; difficult to distinguish between main and lateral roots; no ecto.
Spiraea pubescens	−	light brown; conspicuous short or long lateral roots; no ecto.
Stephanandra incisa	−	light brown; difficult to distinguish between main and lateral roots; no ecto.
Saxifragaceae		
Philadephus schrenckii	−	white; difficult to distinguis between main and lateral roots; no ecto.
Euphorbiaceae		
Securinega suffruticosa	−	white to light brown; pointed fine long lateral roots; no ecto.
Rutaceae		
Phellodendron amurense	−	yellow; difficult to distinguish between main and lateral roots; no ecto.
Evoida daniellii	−	white; pointed long or short lateral roots; no ecto.
Zanthoxylum schnifolium	−	white; fine long or short pointed lateral roots; no ecto.
Anacardiaceae		
Rhus chinensis	−	white; difficult to distinguish between main and lateral roots; no ecto.
Aceraceae		
Acer saccharum	−	white to light brown; conical or bead-form short lateral roots; no ecto.
Acer palmatum	−	
Acer saccharinum	−	
Acer ginnala	−	
Acer mono	−	
Acer triflorum	−	

Species	Ecto.	Description
Staphyleaceae		
Staphylea bumalda	-	white to light brown; difficult to distinguish main and lateral roots; no ecto.
Tiliaceae		
Tilia amurensis	+	unforked; white cottony; thick short tips at the end of fine long lateral roots.
Tilia megaphylla	+	unforked; white to light brown cottony tips; conspicuous short lateral roots.
Elaeagnaceae		
Elaeagnus umbellata	-	light brown; fine long pointed lateral roots; no ecto.
Araliaceae		
Acanthopanax sessiliflorus	-	white; long or short pointed lateral roots; no ecto.
Cornaceae		
Cornus controversa	-	white; a few short lateral roots only; difficult to distinguish between main and lateral root; no ecto.
Cornus officinalis	-	
Cornus kousa	-	
Styracaceae		
Styrax japonica	-	white; long or short pointed lateral roots; no ecto.
Oleaceae		
Fraxinus mandshurica	-	white to light brown; long pointed lateral roots with many root hairs; no ecto.
Fraxinus rhynchophylla	-	
Ligustrum obtsifolium	-	white to light brown; pointed fine long lateral roots; no ecto.
Forsythia koreana	-	white to light brown; difficult to distinguish between main and lateral roots; no ecto.
Syringa dilatata	-	light brown; difficult to distinguish between main and lateral roots; no ecto.
Scrophulariaceae		
Paulownia coreana	-	yellow with red spots; a few short lateral roots only; difficult to distinguish between main and lateral roots; no ecto.
Paulownia tomentosa	-	
Bignoniaceae		
Catalpa bignonioides	-	light brown with red spots; a few long lateral roots only; no ecto.
Caprifoliaceae		
Viburnum koreanum	-	brown, difficult to distinguish between main and lateral roots; no ecto.
Weigela subsessilis	-	white, difficult to distinguish between main and lateral roots; no ecto.

Abbreviations;

-: Ectomycorrhizae absent.

+: Ectomycorrhizae present.

Table 2. Distribution of ectomycorrhizae in the woody plants of economic importance

Family	Genus
Pinaceae	*Abies, Cedrus, Larix, Picea, Pinus, Pseudotsuga, Tsuga*
Cupressaceae	*Cupressus, Juniperus, Chamaecyparis*
Juglandaceae	*Carya, Juglans*
Salicaceae	*Populus, Salix*
Betulaceae	*Alnus, Betula, Carpinus, Corylus, Ostrya*
Fagaceae	*Castanea, Castanopsis, Fagus, Lithocarpus, Quercus*
Ulmaceae	*Ulmus*
Rosaceae	*Crataegus, Malus, Pyrus, Sorbus*
Aceraceae	*Acer*
Tiliaceae	*Tilia*
Myrtaceae	*Eucalyptus*
Ericaceae	*Arbutus*

* *adopted from Meyer (1973) and Gerdemann (1975)*

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