The Emission of Isoprene From Oak Leaves

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The oaks of the world are a complex group. Determining which oak species throughout the world release isoprene to the atmosphere is also complex. Isoprene is produced in oak leaves only when the leaves are in sunshine, and is not produced in the dark. All of the oaks of North America release large quantities of isoprene to the atmosphere, and as much as 2 to 10 percent of the carbon fixed during photosynthesis is lost this way.

Isoprene is a C_5H_8 hydrocarbon that has two unsaturated bonds, allowing it to react very quickly in the atmosphere. It is the most reactive hydrocarbon released into the air in large quantities. Essentially, all of the isoprene emitted into the atmosphere comes from plant foliage during the daylight hours. Isoprene participates strongly in smog-type chemical reactions and one of the byproducts of these reactions in urban areas is the formation

Table 1. The Status of Isoprene Emissions for Oaks from China and Japan.

Species	Isoprene Emission
Quercus acuta	NO
Q. acutissima	NO
Q. aliena	YES
Q. aliena Var. *Acutaserrata*	YES
Q. acutadentata	YES
Q. bambusaefoila	NO
Q. chenii	NO
Q. dentata	YES
Q. elmerii	NO
Q. gilva	NO
Q. glandulifera	YES
Q. glauca	NO
Q. leucotrichophora	NO
Q. liaotungensis	YES
Q. mongolica	YES
Q. myrsinaefolia	NO
Q. phillyraeoides	NO
Q. stenophylla	NO
Q. variabilis	NO/YES

Table 2. The Status of Isoprene Emissions for Oaks from Europe and the Middle East

Species	Isoprene Emission
Quercus Brantii	NO
Q. boisseiri	YES
Q. caliprinos	NO
Q. canariensis	YES
Q. castaneifolia	NO
Q. cerris	NO
Q. coccifera	NO
Q. faginea	YES
Q. haas	YES
Q. iberica	YES
Q. ilex	NO
Q. ithaburensis	NO
Q. libani	NO
Q. macrolepis	NO
Q. petraea	YES
Q. pontica	YES
Q. pubescens	YES
Q. robur	YES
Q. xturnerii	YES
Q. suber	NO
Q. trojana	NO
Q. vallonea	NO
Q. xhispanica	NO

of excess ozone, on a scale comparable to that produced from auto exhaust. Along the eastern seaboard and Appalachian highlands, where the oaks have replaced the American chestnut tree, the oaks contribute especially large amounts of this very reactive hydrocarbon to the air corridors of the local urban areas. Current photochemical models suggest that these summertime emissions from the forests interfere with the achievement of the Environmental Protection Agency (EPA) mandated ozone standard in and between the urban airsheds in Pennsylvania, New Jersey, New York, Connecticut, Rhode Island and Massachusetts.

But not all of the oaks of the world release isoprene to the atmosphere. The oaks of China and Southeast Asia that belong to the *Cyclobalanopsis* section in the genus *Quercus* do not produce isoprene (Table 1). However the white oaks in these regions do produce isoprene at rates similar to those produced by the *Lepidobalanus* and *Erythrobalanus* oaks in North America. Throughout northern Europe the high production of isoprene from the white oaks occurs as well. However, in the Mediterranean area many deciduous and live oak species do not produce isoprene (Table 2). This is highly unusual since, in the Mediterranean regions of the world, the occurrence of isoprene-emitting plants is very high. The deciduous species around the Mediterranean that do release isoprene seem to be more closely related to the common white oak of Europe, *Q. robur*. The dominant deciduous species that release very little to no isoprene are *Q. castaneifolia*, *Q. cerris*, *Q. trojana* and sometimes *Q. petraea*. None of the evergreen oaks (*Q. calliprinos*, *Q. coccifera*, *Q. ilex*, *Q. ithaburensis* and *Q. suber*) produce isoprene. A very interesting twist is that both *Q. ilex* and *Q. suber* have monoterpene ($C_{10}H_{16}$) emissions instead (Table 3), similar to those from pine trees, but at much higher rates and only when the foliage is in sunshine. This is also observed in the deciduous foliage of *Q. cerris*.

The hybrid oak *Q. xturneri* - a cross between *Q. ilex* and *Q. robur* - produces moderate amounts of both isoprene (inherited from *Q. robur*) and monoterpene (inherited from *Q. ilex*). In the case of the hybrid *Q. xhispanica*, a cross between *Q. suber* and *Q. cerr*is, no isoprene is produced. This active physiological emission of oaks is very different from the more passive thermal emission of monoterpenes from pines.

In my surveys exploring for plants that produce isoprene, a fascinating array of physiological and taxonomic relationships has been observed. Currently we have identified with gas chromatography and mass spectrometry measurements more than 280 compounds emitted from the intact foliage of several dozen tree species. Surprisingly, biogenic sources of monoterpene hydrocarbons have been observed

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being released in other tree species not known for having terpenoid oils in their leaves. These emissions occur under physiological conditions similar to the light-dark regimen required for the on-off production of isoprene, and in a variety of important forest broadleaf genera including *Acer, Betula,* and *Lithocarpus*, in addition to *Quercus*. How these studies relate to the oaks and their close relatives is very interesting. For example, the volatile organic compounds in the foliage emissions from *Q. robur* are 97 percent isoprene, with almost no monoterpenes. However, the foliage actively emits higher molecular weight sesquiterpene ($C_{15}H_{24}$) compounds like beta bourbonene, which are normally beyond the range of routine measurement of the volatile emissions. But it is these higher molecular weight hydrocarbons and their oxygenated products that most probably have a role in the communication between plants through their volatilized emissions. To my knowledge isoprene does not function in this role, but rather is believed to protect the photosynthetic apparatus in the leaf from short- term high temperatures. Clearly, oaks continue to be the most interesting of trees.

Table 3. The Status of Monoterpene Emissionsof Oak Species that do not release Isoprene.

Section Cerris	**Isoprene Emssion**	**Monoterpene Emission**
Q. acutissima	NO	SOME
Q. castaneifolia	NO	NO
Q. cerris	NO	YES
Q. macrolepis (*Q. aegilops*)	NO	NO
Q. ithaburensis	NO	YES
Q. trojana (*Q. macedonica*)	NO	NO
Q. variabilis	NO/YES	NO/YES
Section Suber		
Q. calliprinos	NO	?
Q. coccifera	NO	YES
Q. suber	NO	YES
Q. Xhispanica (*Q. cerris X suber*)	NO	YES
Section Ilex		
Q. chrysolepis	YES	NO
Q. ilex	NO	YES
Q. phillyraeoides	NO	YES
Q. virginiana	YES	YES/NO