

**Zeitschrift:** Mycologia Helvetica  
**Herausgeber:** Swiss Mycological Society  
**Band:** 6 (1994)  
**Heft:** 1

**Artikel:** Ubiquinones as generic criteria in Eumycota  
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**DOI:** <https://doi.org/10.5169/seals-1036329>

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## Ubiquinones as generic criteria in Eumycota

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Ubiquinone (= coenzyme Q) is an enzyme of the respiratory chain. It is nearly ubiquistically distributed in Procaryota and in Eumycota. In fungi, it occurs in 9 alternative types, distinguished by the configuration of the isoprenoid side chain: there may be 5 to 10 isoprene units, and one or two terminal units may be hydrogenated or not. The resulting types are called

ubiquinone Q-5, Q-6, Q-7, Q-8, Q-9, Q-10 and

ubiquinone Q-9(H<sub>2</sub>), Q-10(H<sub>2</sub>), Q-10(H<sub>4</sub>).

In Q-10(H<sub>2</sub>) two isomeres are possible, but they are indistinguishable in current analyses. The analysis of ubiquinone type is possible either by paper chromatography or by HPLC.

Several ubiquinone types may be demonstrated in the same organism. In such cases nearly always one of them (the "major ubiquinone") is prevalent by far. In rare cases two major ubiquinones are present in relations 1:1 or 2:1. Only the major ubiquinones seem to be of taxonomic relevance, while the "minor ubiquinones" can be understood as intermediates of current biosynthesis.

In recent years, the analysis of ubiquinone types has been shown to be of great taxonomic interest, beginning with a series of papers on yeast taxonomy (Yamada & Kondo 1971 ff.). It could be demonstrated that

- different strains of the same species have the same ubiquinone type, even if analyzed by different students and on different continents;
- anamorphic and teleomorphic states of the same species have the same ubiquinone type;
- closely related species have the same ubiquinone type;
- ubiquinones may be extracted from mycelial and yeast cultures, from fresh fruitbodies, and from exsiccata.

The most generally distributed type of ubiquinone is Q-9, which occurs in all investigated classes of fungi *sensu lato* (fig. 1); in several classes or subclasses of fungi it is the only type demonstrated as yet. The "shorter" ubiquinones Q-5, Q-6, Q-7, and Q-8 have been found only in yeasts and yeast-like (dimorphic) fungi. The hydrogenated types have been found only in Ascomycetes and in a few cases in Ustomycetes.

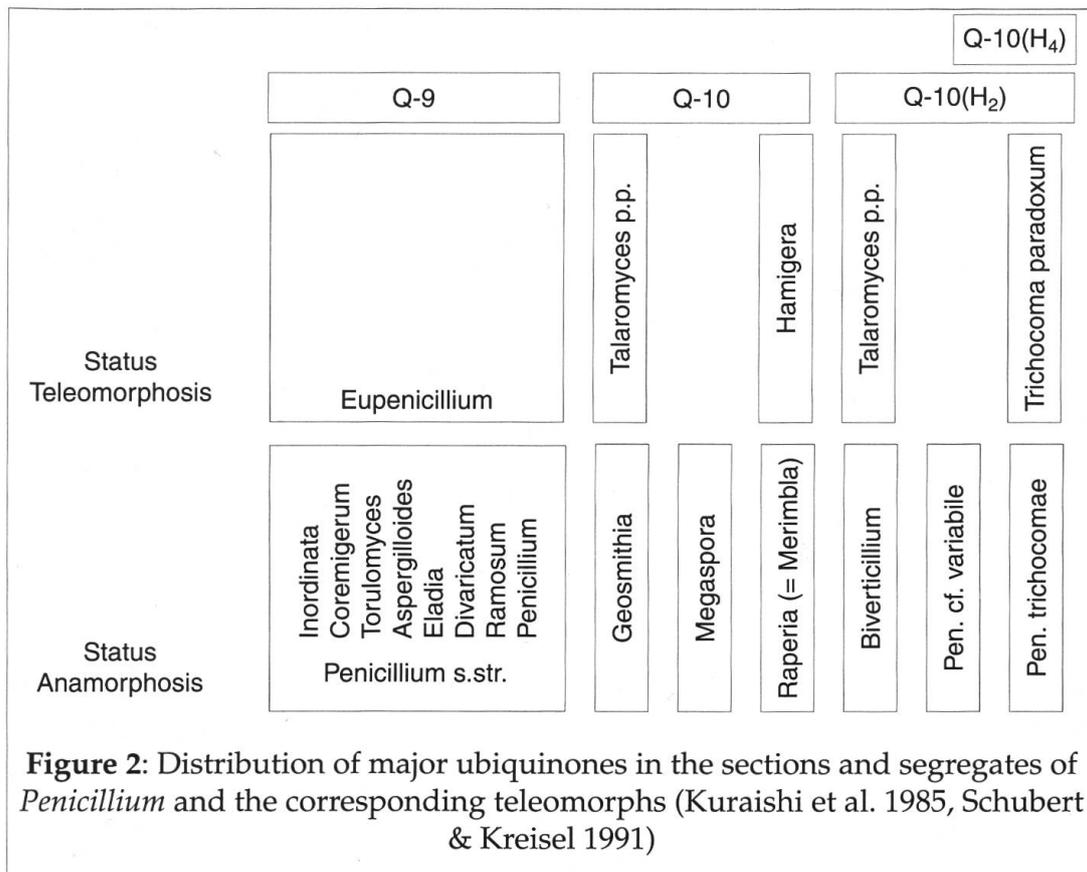
Ubiquinones in Fungi									
Acrasiomycetes									9
Oomycetes									9
Zygomycetes									9
Endomycetes	5	6	7	8	9	10			
Ascomycetes				8	9	10	10(H <sub>2</sub> )	10(H <sub>4</sub> )	
Teliomycetes									9
Ustomycetes				8	9	10	10(H <sub>2</sub> )		
Basidiomycetes									
— Heterobasidiomycetidae			8	9	10				
— Hymenomycetidae									9
— Gasteromycetidae									9

**Figure 1:** Distribution of major ubiquinones in the classes of Fungi

In many cases ubiquinone types may serve as generic criteria. During the past 20 years nearly all cultivated species of yeasts and many yeast-like fungi have been analyzed - mainly by Japanese researchers -, and this has led to a splitting of teleomorphic and anamorphic genera (table 1). With exception of the large artificial genus *Candida* and the so-called "black yeasts", the yeast genera in their actually accepted concepts are "ubiquinone-clean", as demonstrated in the proposed system of Von Arx & Van der Walt (1987); cf. Kreisel (1991) and tables 2 and 3.

In filamentous fungi - that is the great majority of fungi - the distribution of ubiquinones is often more complicated, particularly in many groups of Ascomycetes and related anamorphs. Their systematic analysis began only rather recently with a paper by Kuraishi et al. (1985). These authors demonstrated that several major genera of anamorphs are heterogeneous with regard to ubiquinone type, e.g. *Aspergillus*, *Paecilomyces*, and *Penicillium*. The same was found in *Sporothrix* by Suzuki & Nakase (1985) and in *Trichosporon* (Hara et al. 1989).

In *Sporothrix*, several researchers demonstrated that ubiquinone types could be correlated with cell wall carbohydrate patterns, with shape of septal pores and (if present) with the teleomorphs. That way it became evident that *Sporothrix* is a very heterogeneous anamorphic genus which includes anamorphs of *Endomycetes*, *Ascomycetes*, and *Basidiomycetes* (table 4; De Hoog et al. 1985, Wejman & De Hoog 1985, Smith & Batenburg-Van Der Vegte 1986, Suzuki & Nakase 1986, Traquair et al. 1989). The type species, *S. schenckii*, is ascomycetous and belongs to the teleomorphic genus *Ophiostoma* (De Hoog 1974).



A larger number of *Penicillium* species have been analyzed by Kreisel & Schubert (1990) and Schubert & Kreisel (1991 and unpublished data). *Penicillium* has two rather different teleomorphs, namely *Eupenicillium* and *Talaromyces*. We have demonstrated that all investigated species of *Eupenicillium* and of related *Penicillium* anamorphs have Q-9, while *Talaromyces* and related *Penicillium* anamorphs - corresponding to *Penicillium* sect. *Biverticillium* in the system of Stolk & Samson 1985 - have Q-10(H<sub>2</sub>), a differentiation which is clearly supported by the deviating shape of phialides and morphology of conidiophores (see also Pitt 1979a).

*Penicillium* sect. *Geosmithia*, already segregated by Pitt(1979b) as a genus for its own, based on the shape of phialides and of conidia, has ubiquinone Q-10 supporting its generic independence. The same holds for the small segregated genus *Raperia* with its teleomorph *Hamigera*, which equally is characterized by ubiquinone Q-10 (fig. 2).

*Aspergillus* is an anamorphic genus, actually articulated in 18 sections (Gams et al. 1985), and correlated with no less than 10 genera of teleomorphs.

GENERIC CONCEPTS IN MYCOLOGY  
A Herbette Symposium in Lausanne, 1991

Table 1: YEAST GENERA segregated by means of ubiquinone types			
1984	<i>Fellomyces</i> Yamada & Banno	Q-10	heterob.
	<i>Sterigmatomyces</i> Fell 1966	Q-9	heterob.
1985	<i>Waltomyces</i> Yamada & Nakase	Q-10	ascogen.
	<i>Lipomyces</i> Lodder & Kreger-van Rij 1952	Q-9	ascogen.
1986	<i>Holleya</i> Yamada	Q-9	ascogen.
	<i>Nematospora</i> Peglion 1897	Q-5, Q-6	ascogen.
1986	<i>Bensingtonia</i> Ingold	Q-9	(heterob.)
	<i>Sporobolomyces</i> Kluyver & van Niel 1924	Q-10	(heterob.)
	<i>Bullera</i> Derx 1930	Q-10	(heterob.)
1987	<i>Hasegawaea</i> Yamada & Banno	none	ascogen.
	<i>Schizosaccharomyces</i> Lindnere 1893	Q-10	ascogen.
	<i>Octosporomyces</i> Kudrjawzew 1960	Q-9	ascogen.
1987	<i>Saitoella</i> Goto & al.	Q-10	(ascogen.)
	<i>Rhodotorula</i> Harrison 1927	Q-9	(heterob.)
1987	<i>Mrakia</i> Yamada & Komagata	Q-8	heterob.
	<i>Leucosporidium</i> Fell & al. 1970	Q-9	heterob.
1988	<i>Erythrobasidium</i> Hamamoto & al.	Q-10(H2)	heterob.
	<i>Rhodospiridium</i> Banno 1967	Q-9	heterob.

Table 2: Ubiquinones of the Sporobolomycetaceae			
<i>Bensingtonia</i> Ingold 1986	Anam. = <i>B. ciliata</i>	Q-9	
<i>Bullera</i> Derx 1930	Anam. = <i>B. alba</i>	Q-10	
<i>Sporobolomyces</i> Kluyver & van Niel 1924	Anam. = <i>S. roseus</i>	Q-10	
<i>Sporobolomyces</i> p.p.	Anam. = <i>S. elongatus</i>	Q-10(H2)	
<i>Sporidiobolus</i> Nyland 1949	Telem. = <i>S. johnsonii</i>	Q-10	
Ref.: Nakase & Suzuki 1986, Nakase & Boekhout 1988			

Table 3: Ubiquinones of the Filobasidiaceae			
<i>Filobasidiella neoformans</i> Kwon-Chung (type)		Q-10	
<i>Filobasidium capsuligerum</i> (Fell. & al.) Rodr. de Miranda		Q-10	
<i>Filobasidium floriforme</i> Olive		Q-10	
<i>Filobasidium uniguttulatum</i> Kwon-Chung		Q-9	
<i>Cystofilobasidium bisporidiis</i> (Fell. & al. ) Oberw.		Q-8	
<i>Cystofilobasidium capitatum</i> Oberw. & Bandoni		Q-8	
<i>Cystofilobasidium infirmominiatum</i> (Fell & al. ) Hamamoto & al.		Q-8	

Ubiquinones Q-9, Q-10 and Q-10(H<sub>2</sub>) are the major ubiquinones found in *Aspergillus*. Kuraishi et al. (1990) investigated the distribution of ubiquinone types in the infrageneric units as established in the systems of Raper & Fennell (1965) and Gams et al. (1985). In both *Aspergillus* systems, not all of the

Table 4: *Sporothrix*

<i>Sporothrix</i>	sectio	group	carbohydrate pattern	septal pores	ubiquinone	teleomorph tax. position
<i>catenata</i> <i>foliorum</i> <i>fungorum</i> <i>guttuliformis</i>	Farinosa	A	Glu Man Gal	micropores simple or multiple	Q-9	<i>Stephano- ascus</i> (Endomyc.)
<i>ghanensis</i> <i>insectorum</i> <i>rarii</i> <i>sclerotialis</i>	Farinosa	A	Glu Man Gal	simple with Woronin body	Q-10(H2)	unknown (Ascomyc.)
<i>curviconis</i> <i>inflata</i> <i>schenkii</i> TYPE	Sporothrix	B	Glu Man Gal Rha	simple with Woronin body	Q-10(H2)	<i>Ophiostoma</i> (Ascomyc.)
<i>luteoalba</i> <i>cyanescens</i>	Luteoalba	C	Glu Man Gal Xyl	dolipores	Q-10	unknown (Dacrymyc.)
Ref.:	1	2	2	3	4	various

1: Kreger van Rij 1984  
2: Weijman & De Hoog 1985  
3: Smith & Batenburg 1986  
4: Suzuki & Nakase 1986

Table 5: *Aspergillus* - anamorphic species

Q-9	Q-10	Q-10(H2)
Metulae absent (uniseriate):		
1 <i>Aspergillus</i>	3 <i>Fumigati</i>	
5 <i>Restricti</i>	3 <i>Clavati</i>	
3 <i>Cervini</i>		(1 <i>Cervini</i> )
1 <i>Ornati</i>	(1 <i>Ornati</i> )	(3 <i>Ornati</i> )
← (1 <i>Clavati</i> ) →		
Metulae present or absent (uni- /biseriate):		
21 <i>Nigri</i>	(2 <i>Flavi</i> )	8 <i>Flavi</i>
1 <i>Cremeri</i>		1 <i>Candidi</i>
2 <i>Wentii</i>		(3 <i>Wentii</i> )
(1 <i>Circumdati</i> )	(2 <i>Circumdati</i> )	14 <i>Circumdati</i>
(1 <i>Sparsi</i> )		4 <i>Sparsi</i>
Metulae present (biseriate):		
		1 <i>Nidulantes</i>
		9 <i>Versicolores</i>
		3 <i>Usti</i>
		3 <i>Terrei</i>
		3 <i>Flavipedes</i>
Reference: Kuraishi et al. 1990		
() = type excluded		
numbers = taxa investigated		

Q-9	Q-10	Q-10(H <sub>2</sub> )
Metulae absent (uniseriate):		
13 <i>Eurotium</i> Link:Fr. ( <i>Aspergillus</i> )	9 <i>Neosartorya</i> Malloch & Cain ( <i>Fumigati</i> )	
1 <i>Edyullia</i> Subram. ( <i>Aspergillus</i> )	2 <i>Hemicarpenales</i> Sarbhoy & E. ( <i>Ornati</i> )	
2 <i>Sclerocestia</i> Subram. ( <i>Ornati</i> )	1 <i>Warcupiella</i> Subram. ( <i>Ornati</i> )	
Metulae present or absent (uni- /biseriate):		
4 <i>Chaetosartorya</i> Subram. ( <i>Cremeri</i> )	1 <i>Petromyces</i> Malloch & Cain ( <i>Circumdati</i> )	
Metulae present (biseriate):		2 <i>Fennellia</i> Wiley & Si. ( <i>Flavipedes</i> )
	←—————	24 <i>Emericiella</i> Berk. & Br. ( <i>Nidulantes</i> )
Reference: Kuraishi & al. 1990		numbers = taxa investigated

accepted sections are "ubiquinone-clean": in the system of Gams et al. four of the 18 sections appear to be heterogeneous, namely *Sparsi*, *Circumdati*, *Wentii* and *Ornati*, because 14 of the anamorphic taxa seem to be placed in a "wrong" section (table 5), but the 10 teleomorphs are "clean" (table 6). Moreover, it reveals that all sections and teleomorphs with constant metulae (i.e. the strictly biseriates) do have Q-10(H<sub>2</sub>), although many *Nidulantes* resp. *Emericella* additionally have Q-10.

A serious problem still exists in *Trichosporon*, where even in the type species (*T. beigeli* = *T. cutaneum*) three different ubiquinones have been found in different strains (Yamada et al. 1982, Hara et al. 1989):

Q-10 in 14 strains, including the type strain, Q-9 in 29 strains, Q-8 in 1 strain, while 7 other investigated *Trichosporon* strains all have Q-9. On the other hand, there are large groups of fungi which seem to be quite uniform with regard to ubiquinone type. In Ascomycetes, e. g. all investigated taxa of Hypocreales, Clavicipitales, and Dothideales s. l. (i. e. the bitunicate Ascomycetes) and all their related anamorphs have ubiquinone Q-10(H<sub>2</sub>) (Kuraishi et al. 1985). In Teliomycetes (Pucciniales) all investigated taxa have Q-9 (Sugiyama et al. 1988), and in Basidiomycetes all investigated Homobasidiomycetes (Hymenomycetidae and Gasteromycetidae) have Q-9 (Kuraishi et al. 1985, and our own results). That seems to be not promising for

further attempts of ubiquinone chemotaxonomy in larger fungi. But facing the huge number of species still to be analyzed, surprising results cannot be excluded, and in some future ubiquinone analysis may also become interesting in the taxonomy of macromycetes.

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