THERMOPHILIC FUNGI: BIODIVERSITY and TAXONOMIC STATUS.

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RÉSUMÉ : Une évaluation critique du statut nomenclatural et, dans certains cas, également du statut taxonomique, a été entreprise pour les champignons thermophiles décrits à ce jour. La distinction entre éléments thermophiles et thermotolérants se base sur les définitions élaborées par Cooney & Emerson. Au total près de quarante espèces et variétés s'avèrent aptes à réaliser un développement optimal à des températures élevées. Des recherches taxonomiques complémentaires sont toutefois nécessaires pour résoudre les problèmes résiduels : la résultante serait une légère réduction de l'effectif du groupe.

Une croissance optimale à des niveaux thermiques situés au-delà du seuil maximal des espèces mésophiles individualise quelques Mucorales, Eurotiales et Sphaériales, un nombre limité d'Hyphomycètes et un seul Agonomycète. Aucun Coelomycète ni aucun Basidiomycète n'exprime cette particularité écologique. Les Mucorales recensées sont des éléments du genre *Rhizomucor* et de l'ent. générique non valide *Thermomucor*. *Rhizomucor pusillus* (espèce-type) et *Rh. miehei* sont des taxons valides ; *Rh. pusillus* se révèle un synonyme intérieur de l'espèce-type. La validité taxonomique des *Rhizomucor tauricus* et *Rh. naumalensis* reste à confirmer.

Parmi les vingt ascomycètes répertoriés, *Canariomyces thermophila* et *Chaetomium mesopotamicum* sont des taxons bien définis. Ceci n'est pas le cas des *Chaetomium britannicum* et *Ch. virginicum*, à statut taxonomique encore imprécis ; il en est de même pour leurs liens respectifs avec *Chaetomium thermophilum* et ses deux variétés. *Dactylomyces thermophilus* est retenu comme seul élément du genre *Dactylomyces*, celui-ci n'en est plus considéré comme congénérique de *Thermoascus*, pour ce dernier, seule l'espèce-type et une variété sont admises. Le nouveau genre *Coonemeria* est proposé pour rassembler les autres espèces des deux entités précédentes. *C. crustacea* (= *Dactylomyces crustaceus*) est sélectionné comme espèce type ; *C. aegyptiaca* (= *Thermoascus aegyptiacus*) et *C. verrucosa* (= *Th. crustaceus* var. *verrucosus* et = *Th. taitungiacus*) y sont également rattachés. Ces trois genres ont comme particularité commune, les caractères de leurs téléomorphes. Cependant, *Dactylomyces* révèle une forme imparfaite du genre *Polypaecilum*. *Coonemeria* des structures conidiogènes de type *Paecilomyces* alors que les *Thermoascus* ne produisent d'anamorphes à conidies en chaînes.

Corynascus heterothallicus et *C. thermophilus* sont des ascomycètes à périthèces clos ayant chacun une forme imparfaite distincte, respectivement *Myceliophthora thermophila* et *M. fergusii* en raison du caractère hétérothallique des téléomorphes. Les anamorphes peuvent être isolés séparément lors des recherches portant, par exemple, sur des matériaux subissant un processus d'auto-échauffement. *Metamicrocarpus aureus* développe une forme conidienne arthrosporée dont est dépourvu *M. thermophilus* (= *Thielavia minuta* var. *thermophila*). Les trois *Talaromyces* thermophiles sont associés à des anamorphes de type *Paecilomyces* (*T. thermophilus* et *T. vinaceus*) ou *Penicillium*

I. chartarum et *I. thermophilus*. Le genre *Thielavia* revele egalement trois thermophiles. *Th. terrestris*, espece type, est un ascomycete cosmopolite dont la forme imparfaite *Acremonium alabamense* se rencontre souvent en l'absence du teleomorphe. *Th. australiensis*, pour lequel peu d'informations sont disponibles et le recent *Th. pongungia* dont certains caracteres suggerent son appartenance au genre *Chaetomidium*.

Le groupe des hyphomycetes rassemble treize especes. Cependant, *Acremonium alabamense* et deux *Mycelia sterila* sont des anamorphes d'ascomycetes plus ou moins heterothalliques, qui peuvent par consequent se developper sans les formes parfaites correspondantes. *Mycelophthora indica* se revele un synonyme de *M. thermophila*. Les taxons macedines restants sont *Acremonium thermophilum*, seul autre element thermophile du genre, *Myceliophthora hinnulea* a forme parfaite encore inconnue et *Malbranchea cinnamomea*, unique thermophile du genre *Malbranchea* dont les mesophiles sont associes a des formes parfaites connues. *Thermoidiomatospora tibungera* s'individualise par ses colonies mycelliennes pourvues de boucles et la presence d'une forme conidienne de type aleuriosporee.

Les hyphomycetes dematies relevent des genres *Humicola*, *Scytalidium* et *Thermoascus*. Ce dernier se revele etre une entite generique assez homogene et son espece type represente le premier thermophile avere. *Humicola grisea* var. *thermoidea* et *H. lanuginosa* var. *cavernicola* sont proposes comme synonymes additionnels a l'espece type. Le genre comporte egalement *Thermoascus thermophilus*, *Th. stellatus* et le mesophile *Th. verrucosus*.

Le statut taxonomique de *Humicola hyalothermophila* se doit d'etre reconsiderer, en meme temps que les *Humicola grisea* var. *thermoidea* et *H. insolens*, recemment places en synonymies avec *Scytalidium thermophilum*, base sur *Torula thermophila*. Ces deux *Humicola* sont retenus dans immediat dans le complexe *Scytalidium thermophilum*, dans l'attente d'une redefinition des statuts taxonomiques respectifs. *Scytalidium thermophilum* s'ecarte du concept generique de *Scytalidium* fonde sur l'espece type *S. lignicola*, ce qui n'est pas le cas pour *S. indonesicum*. *Scytalidium allahabadium* s'est avere correspondre au *S. thermophilum* synonyme. *Humicola nigrescens* var. *thermoidea* est un synonyme ulterieur de *H. grisea* var. *thermoidea* alors que *H. fuscoatra* var. *nigra* est identique au *H. insolens*.

Deux taxons revelent un statut incertain. *Mucor thermo-hyalosporus* (*Rhizomucor pusillus*?) et *Stibella thermophila* en quete d'un genre plus approprie. D'autre part, divers taxons se sont vu attribuer des epithetes specifiques pouvant conduire a confusion au regard des aptitudes thermophiles respectives. Les cas les plus simples concernent des champignons denommes *thermophilum* ou de ses variantes et qui sont loin de representer des thermophiles sur la base des definitions etablies. Exemples, l'ascomycete *Achaetomium thermophilum* (un synonyme ulterieur de *A. macrosporum*, une espece thermotolerante), les hyphomycetes *Cladosporium thermophilum*, *Gliomastix thermophila* et *Zalerion thermophilum* (le statut taxonomique des deux derniers reste a considerer), l'oomycete *Lagenidium thermophilum*, le zygomycete *Mucor thermophilus* et enfin la levure *Endoblastomyces thermophilus* a statut taxonomique non valide. *Mesaconiphulla thermophila* est un basidiomycete simplement observe dans une localite chaude et humide, des cas similaires ont ete egalement recenses.

Le binome *Sporotrichum cellulophilum* est un exemple d'une source differente de confusion. Ce taxon ne possede de statut taxonomique d'aucune sorte. Il est cependant frequemment signale comme thermophile dans la literature portant sur les etudes enzymiques des champignons. Ces binomes fantomes sont relativement frequents dans ce type de publications. Cette pratique prejudiciable devrait être définitivement abandonée.

ABSTRACT. A critical reappraisal of nomenclatural status and in some cases also of taxonomic ones was undertaken for known thermophilic fungi. Distinction between thermophilic and thermotolerants follows definitions elaborated by Cooney & Emerson. Altogether less than forty species and varieties are able to achieve best development at high temperatures. Further taxonomic work is however needed to solve residual problems. The outcome will be a slight reduction of the group.

Optimum growth at temperatures above the maximum threshold of mesophiles characterise few Mucorales, Eurotiales and Sphaeriales, a limited number of Hyphomycetes plus one Agonomy-

cete species. No Coelomycete and no Basidiomycete develop such ecological feature. Recorded Mucora ceae are species of *Rhizomucor* and the invalid monospecific genus *Thermomucor*. *Rhizomucor* (type species) and *Rh. miehei* are valid taxa. *Rh. pakistanicus* proved to be a later name for the former. The validity of *Rhizomucor tauricus* and *Rh. hiemalis* awaits confirmation.

Among the twenty ascomycetes, *Chaetomium thermophila* and *Chaetomium megasporum* are well defined taxa. But the status of *Chaetomium brasiliense* and *Ch. virgatisporum* is still unclear. Also relations with *Ch. thermophilum* and its two varieties awaits clarification. *Dactylomyces thermophilus* is retained as the sole species of the genus, no longer regarded as congeneric with *Thermoascus*, for the latter only the type and one variety are accepted. A new genus *Corynascella* is proposed to accomodate remaining taxa of both genera. *Corynascella crustacea* (= *Dactylomyces crustaceus*) is selected as type species. *C. aegyptiaca* (= *Thermoascus aegyptiacus*) and *C. verrucosa* (= *Th. crustaceus* var. *verrucosus* and *Th. taitungiacus*) are two other members of this genus. These three genera have in common the characters of their teleomorphs. But *Dactylomyces* has a *Polycatenothamnus* type anamorph. *Corynascella* develop conidiogenous structures of the *Paecilomyces* type while *Thermoascus* has no anamorph producing chains of conidia.

Corynascella crustacea and *C. thermophila* are elsewhere ascomycetes having a well defined anamorphic state, namely *Myceliophthora thermophila* and *M. fergusii* as the teleomorphs are heterothallic; the anamorphs could be observed alone in studies involving, for instance, cell related materials. *Myceliophthora* has a well defined arthroconidial state not developed by *M. thermophila*. *Thielavia minuta* var. *thermophila*. The three thermophilic *Talaromyces* have conidial states belonging either to *Paecilomyces* (*T. byssochlamydoides*) or to *Penicillium* (*T. emersonii* and *T. thermophilus*). *Thielavia* (also three species) is represented by the widely distributed *Th. terrestris* whose anamorph *Acremonium dichromosporum* could equally be isolated separately. The undocumented *Th. australiensis* and the recent *Th. peruviana* with features favouring its relocation in *Chaetomidium*.

Recorded hyphomycetes comprise thirteen taxa. But *Acremonium alabamense* and two *Myceliophthora* are anamorphs of almost heterothallic ascomycetes; these could thus develop at high temperatures without producing respective ascocarps. *Myceliophthora lamellicola* is considered a synonym of *M. thermophila*. Other nonfoedinaceous taxa are *Acremonium thermophilum*, the second thermophilic of the genus, *Myceliophthora mamillata* perfect state is yet unknown and *Malbranchea cinnamomea* sole thermophile of a genus whose mesophilic components are associated with perfect states. *Dichotomomyces cejpii* (= *Sporotrichum fibuligera*) is unique by its hyphae dissolving septal clamp connections and the formation of an aleuriosporic state.

Dematiaceous thermophiles are members of *Humicola*, *Scytalidium* and *Thermomyces*. The latter is regarded as a homogeneous genus with the type species *Thermomyces lanuginosus* being the first established thermophile. *Humicola grisea* var. *thermoidea* and *H. lanuginosa* var. *cellulolytica* are oldest nomenclature names for the type species. Other known members are *Thermomyces dupontii*, *Th. stellatus* and the mesophilic *Th. verrucosus*.

The taxonomic status of *Humicola hyalothermophila* awaits to be reconsidered together with *Humicola grisea* var. *thermoidea* and *H. insolens*, recently placed in synonymy with *Scytalidium thermophilum*, based on *Torula thermophila*; both *Humicola* are placed here for the moment as synonyms of the complex *S. thermophilum* pending reassessment. *Scytalidium thermophilum* deviates from the current concept of *Scytalidium*, based on *S. lignicola*, but such is not the case for *S. dimidiatum*. *Scytalidium allahabadense* proved to match *S. thermophilum sensu lato*. *Humicola nigrescens* var. *thermonigrata* duplicates the description of *Humicola grisea* var. *thermoidea* while *H. fuscoatra* var. *nigra* is identical to *H. insolens*.

Two taxa have an uncertain position. *Mucor thermohyalospora* (*Rhizomucor pusillus*) and *Stilbella thermophila* requiring a more appropriate genus. Also several taxa disclose confusing specific epithets with regard to thermophilic abilities. Simple cases refer to fungi with epithets as *thermophilum* or variants of, and that are not thermophilic based on accepted definitions. Examples: the ascomycete *Achaetomium thermophilum* (a later synonym of *Emericella rugulosa*, a thermotolerant); the hyphomycetes *Calcarisporiella thermophila*, *Gilmaniella thermophila* and *Zalerion thermophilum* (the latter two have yet unsettled status); the oomycete *Lagenidium thermophilum*, the zygomycete *Mucor*

thermophilus and finally the invalid yeast *Endoblastomyces thermophilus*. *Melanophalla thermophila* is a basidiomycete simply observed in a warm humid locality; similar cases could also be traced.

The binomial *Sporotrichum echinophilum* is an example of a different confusing situation. The taxon has no taxonomic status of any type although being infrequently reported as a thermophile in literature related to fungal enzymic studies. Such ghost binomials are not uncommon in these publications. This practice being a source of serious confusion should be definitely prohibited.

INTRODUCTION

Temperature is one of the extremely important environmental variables that play a decisive role in the survival, growth, distribution and diversity of microorganisms on the surface of the earth. The response of fungi to temperature varies between the two extremes of obligatorily thermophilic through thermotolerance to psychrophilic species. However, by far the majority of known fungi are mesophiles developing in culture between 5 and 37° C, the psychrophiles extend below that range of temperatures (Dix & Webster, 1995).

Thermophily has been defined variously with reference to different groups of microorganisms and sometimes also within the same group. The response of fungi to high temperatures has been the subject of classificatory schemes successively proposed by Apinis (1963), Cooney & Emerson (1964), Cravenet *al.* (1964), Evans (1971) and Crisan (1973). These schemes are either based on values of minimum and maximum growth temperatures alone or, in addition, integrate the criteria of optimum development.

The commonly accepted definitions of thermophilic and thermotolerant fungi are those of Cooney & Emerson (1964). Thermophilic fungi are those that have a growth temperature maximum at 50° C or above and a temperature minimum of 20° C or higher. Thermotolerant species are those that have a growth temperature maximum of about 50° C and a temperature minimum well below 20° C. This simple segregative scheme is sometimes difficult to apply since the response of thermophilic taxa at the minimum temperature threshold tends to vary among respective strains.

Serious consideration of fungi able to develop only at high temperatures dates back to 1899 when P. Tsiklinsky first reported on a thermophilic hyphomycete incidently encountered on a potato inoculated with garden soil. The fungus was then grown on bread kept at 52-53° C and its thermophilic nature assessed. Tsiklinsky named this hyphomycete *Thermomyces lanuginosus*. Rapidly, however, this thermophile was successively relocated in other genera as *Acremoniella*, *Humicola*, *Monotospora* and *Sepedonium* before its definite reinstallment in *Thermomyces*. Similar changes also characterize thermophilic moulds described in the early decades of the nineties. The outcome of such changes is the chaotic nomenclatural state of few members of this group in published literature. Absence of homogeneity in binomial citations develop cases of taxonomic confusion coupled with divergence in species concept (Cooney & Emerson, 1964). The final result is a partial or total incomplete identification of encountered taxa or names reported being shadowed.

Although Lindt description of *Rhizomucor pusillus* (as *Mucor pusillus*) dates back to 1886, there is a general agreement that Tsiklinsky (1899) is the first to drew attention to thermophilism among fungi. Very rapidly, Miehe's (1905) serious investigation of self heating hay produced the first extensive report on thermophily in fungi. This author isolated and studied a range of thermophiles including *Thermoidea aurantiaca* and *Malbranchea cinnamomea* (Miehe, 1907). Griffon & Maublanc (1911) then introduced the first thermophilic *Penicillium*, *P. dupontii*, now *Talaromyces thermophilus*. It is only several decades later that La Touche (1950) reported on the new *Chaetomium thermophile*. Such discovery generated much interest to this group of fungi, substantiated by the cellulolytic nature of the new ascomycete.

Several pioneer publications then followed on thermophilic fungi inhabiting soils of temperate regions (Apinis, 1963, Eggins and Malik, 1969), tropical areas (Hedger 1974, Gochenaur, 1975) and on soils of arid regions (see review in Mouchacca, 1995) Thermophilic fungi of habitats rich in organic materials were also extensively surveyed and data from relevant publications critically reviewed by Tansey & Brock (1978) Reports on less widespread habitats and habitats deserving future investigations were also considered by Tansey & Brock (1978).

The first modern comprehensive account on the taxonomy, biology and economic importance of thermophilic fungi was published by Cooney & Emerson (1964) Eleven thermophiles were reported Since then the number of taxa developing at high temperatures is expanding rapidly In 1973, Crisan provided a list of 55 names of thermophilous fungi, i e thermophilic and thermotolerant ones, however, only half are thermophiles in the sense of Cooney & Emerson Crisan reviewed in addition current concepts about thermophilism in microorganisms, he then underlined that our knowledge about the physiological ability of fungi to grow at elevated temperatures was much limited Later Simson & Tansey (1977) prepared a guide to species able to grow and sporulate at 45 C, this list concerns eight mucorales, around twenty taxa each of ascomycetes and hyphomycetes and two basidiomycetes. The subsequent list prepared by Tansey and Brock (1978) reports 67 species or varieties growing at 50° C or above, a good proportion of these taxa was however not specified at the species level A Russian compilation of descriptions and published illustrations of thermophilic fungi was prepared by Bilai & Zakharchenko (1987), 38 species were considered but few are not strict thermophiles. Finally, according to Abdullah & Al Bader (1990), around 70 species detected in various substrates are now reported to be thermophilic or thermotolerant

Cooney & Emerson (1964) monograph introduced new thermophilic taxa However, some taxonomic decisions they adopted rapidly proved to be misleading and their descriptions of novel taxa supported not critical analysis. These limitations triggered subsequent studies Several interesting notes thus appeared in the sixties clarifying pending problems while expanding the group. Apinis & Chester (1964) described *Dactylomyces crustaceus* Pugh *et al* (1964) reintroduced *Thermomyces* Stolk (1965) assessed the taxonomic status of *Penicillium duponti* and *Thermoascus aurantiacus* Again Apinis (1967) clarified generic concepts of *Dactylomyces* and *Thermoascus* However, inspite of the above and later contributions, not all standing problems received attention Recently, Straatsma and Samson (1993) focused on both *Humicola* proposed by Cooney & Emerson (1964).

The material of this contribution was collected while preparing a lecture for the Microbial Diversity and Ecosystem Function workshop held at Egham, UK, in 1993 The lecture focused on thermophilic fungi of desert soils, an example of a neglected extreme environment (Mouchacca, 1995) A second lecture on the subject was later presented at IMC V, this was entitled "Thermophilic and thermotolerant fungi in the Middle East Biodiversity and Taxonomic Reappraisal" (Mouchacca, 1994), however, the corresponding note suffered some publication delay In the sametime, the first draft of the present paper was due to be part of a book in the pipeline somewhere in the Indian subcontinent Decision was then taken to update and publish the applied last version

The present document aims to provide a sound reappraisal of the nomenclatural and in some cases of the taxonomic status of known thermophiles. First to overcome a major difficulty encountered while interpreting published data on this ecological group Second to enhance future taxonomic work on its components and, finally, to stress the attention on taxa other than those commonly studied for eventual industrial applications

THERMOPHILIC MUCORALES

— *Rhizomucor pusillus* (Lindt) Schipper — Studies in Mycology 17: 54. 1978.

basionym: *Mucor pusillus* Lindt — Archiv für experimentelle Pathologie und Pharmakologie 21: 272. 1886.
= (?) *Mucor septatus* Bezold in Siebenmann — Die Schimmelmykosen den menschlichen Ohres: 97. 1889.
= *Rhizomucor septatus* (Bezold) Lucet & Cost. — Archives de Parasitologie 4: 362. 1901.
= *Mucor* (sect. *Rhizomucor*) *parasiticus* Lucet & Cost. — Comptes rendus hebdomadaires des Séances de l'Académie des Sciences, Paris 129: 1033. 1899.
= *Rhizopus parasiticus* (Lucet & Cost.) Lendner — Matériaux pour la Flore Cryptogamique Suisse 3: 115. 1908.
= (?) *Mucor muriperda* Sacc. & Sinigaglia in Sacc. — Sydow, Annales Mycologici, Ser. II, 11: 321. 1913.
= *Tieghemella muriperda* (Sacc. & Sinigaglia) Naumov — Opredelitel' Mukorovykh (Mucorales): 84. 1935.
= *Mucor buntingii* Lendner — Bulletin de la Société botanique de Genève 21: 260. 1930.
= *Mucor hagemii* Naumov — Opredelitel' Mukorovykh (Mucorales): 55. 1935 (*nom. inval.*, Art. 36.1).
= *Rhizomucor pakistanicus* Qureshi & Mirza — In Mirza, Khan Begum & Shagufta "Mucorales of Pakistan (Faisalabad)": 100. 1979 (*nom. inval.*, Art. 37.1); Qureshi & Mirza — Biologia, Lahore 29: 343. 1983, a superfluous publication.

Descriptions: Cooney & Emerson (1964); Schipper (1978); Domsch *et al.* (1980).

This is the type species of *Rhizomucor* (Lucet & Cost.) Wehmer: Vuill. The genus was reintroduced by Schipper (1978) to seggregate three hitherto known thermophilic species of *Mucor* distinguished by the presence of rhizoids at the base of their sporangiophores.

The early history of *Rhizomucor pusillus* (as *Mucor pusillus*) and its long confusion with the *Mucor* species studied by Miehe (Miehe, 1907; now *Rhizomucor miehei*) was reviewed by Cooney & Emerson (1964). The former had indeed often been misidentifed with the equally thermophilic, thinly growing and equally common *Rhizomucor miehei*. This zygomycete is however regularly homothallic while in *Rhizomucor pusillus* homothallic isolates have only exceptionally been found. An excellent account of the morphology, physiological characteristics and distribution is provided by Domsch *et al.* (1980).

Rhizomucor pakistanicus was isolated from several sources in Pakistan: groundnut seeds and lizard droppings collected at the city of Faisalabad, from a potato field at Sialkot and from soil at Rawalpindi (Mirza *et al.*, 1979). It was then correctly assigned to *Rhizomucor* (indicated as *Rhizomucor* Lucet & Cost.) on account of the presence of rhizoids. However no comparison was undertaken with the indicated type species, *Rhizomucor parasiticus* Lucet & Cost. Further, in the second superfluous publication made by the same authors (simply a duplicate of the former), taxonomic decisions concerning this genus introduced by Schipper (1979) were overlooked. For *Rhizomucor pakistanicus*, a number of morphological features forwarded in its description leads to consider the fungus as a synonym of *Rh. pusillus*.

The current concept of *Rhizomucor* was however recently expanded to make provision for mesophilic isolates also producing rhizoids from the base of their sporangiophores. *Rhizomucor variabilis* Zheng & G.-q Chen var. *variabilis* was obtained from a cutaneous mucormycosis of a human hand in China (Zheng & Chen, 1991). *Rhizomucor variabilis* var. *regularior* Zheng & G.-q. Chen represent another agent of cutaneous human disease (Zheng & Chen, 1993). Optimum, maximum and minimum growth temperatures of the two varieties are the same, i. e. 24-30° C, 37° C and 9° C respectively. The additional mesophilic *Rhizomucor endophyticus* Zheng & H. Jiang (1995) was isolated from wheat collected in China; its optimum, maximum and minimum growth temperatures are even lower, being 18-28° C, 36° C and 5° C respectively.

— *Rhizomucor miehei* (Cooney & Emerson) Schipper — Studies in Mycology 17: 58. 1978.

basionym: *Mucor miehei* Cooney & Emerson — Thermophilic Fungi: 26. 1964.

Descriptions: Cooney & Emerson (1964); Schipper (1978).

As stressed before, isolates of this zygomycete regularly produces zygospores in cultures. This finding led Cooney & Emerson (1964) to propose a specific rank for this taxon previously considered as identical to the almost morphologically similar type species. Schipper (1978) stressed however that the general morphology could also be used to distinguish both taxa. *Rhizomucor miehei* exhibits a looser sympodial branching pattern with relatively longer side branches while *Rh. pusillus* produces small bunches of short subterminal branches on the main sporangiophores. In addition the sporangia and columellae of the latter are usually larger.

Rhizomucor miehei displays a wide geographic distribution (Domsch *et al.*, 1980). Factors affecting development of zygospores were investigated by Lasure & Ingle (1976) and those regulating germination of sporangiospores by Deploey (1992).

— *Rhizomucor nainitalensis* Joshi — Sydowia 35: 100. 1982.

This still Indian based homothallic zygomycete was isolated form a heavily decomposed oak log in the forest of Pungote, Nainital. It differs from *Rhizomucor miehei*, *Rh. pusillus* and *Rh. tauricus* mainly by sporangiospores of varying shapes and sizes: subglobose, ellipsoidal, oblong, reniform, dump-bell shaped, etc.. , 3-6 µm or more wide. Variation in sporangiospore shape might however be an artefact.

According to Joshi (1982), growth is very rapid at 48° C filling half of a Petri dish in 2 d. At 38° C, "the growth of the mycelium takes place after three days but about one week is required to colonize the culture medium in a petri dish at 25° C". *Rhizomucor nainitalensis* appears very close to *Rh. miehei*.

— *Rhizomucor tauricus* (Milko & Schkurenko) Schipper — Studies in Mycology 17: 62. 1978.

basionym: *Mucor tauricus* Milko & Schkurenko — Novosti sistematiki nizshikh rastenii 7: 139. 1970.

Description: Schippers (1978).

The fungus is apparently still known only from the original strain isolated from forest soil in the Ukraine. It was maintained as a separate species by Schipper (1978)

pending further informations. *Rhizomucor tauricus* is distinguished from other thermophilic *Rhizomucor* mainly by definitely more swollen sporangiophores. Growth and sporulation occurs between 24-55° C, development is extremely slow at 21° C and nil at 57° C.

***Thermomucor indicae-seudaticae* Subrahmanyam, Mehrotra & Thirumalachar (as "Subrahamanyam,...") — Georgia Journal of Botany 35: 2. 1977. (*nom. inval.*, Art. 37.1).**

Descriptions: Subrahmanyam, Mehrotra & Thirumalachar (1977), Schipper (1979).

This is the type species of *Thermomucor* Subrahmanyam *et al.* (1977) which is apparently still monospecific. It was established mainly on account of formation by the type species of smooth zygospores and presence of rhizoids. Zygospores are definitely rough-walled in members of *Absidia* van Tieghem, *Mucor* Mich. Fr., *Rhizopus* Ehrenb. Corda and *Rhizomucor*.

The described strain was isolated from municipal compost at Pimpri, Poona, India. Prior to its description, this zygomycete was reported as *Rhizopus* sp. and as such isolated from various habitats in Europe, India, Ghana and Nigeria (Schipper, 1979).

THERMOPHILIC ASCOMYCETES

***Canariomyces thermophila* Guarro & Samson in von Arx, Figueras & Guarro — Beihefte zur Nova Hedwigia 94: 34. 1988.**

Canariomyces von Arx (von Arx, 1984) was established for a mesophilic cleistothecial ascomycete, *C. notabilis* von Arx, having ascoma wall made up of angular dark cells, irregularly disposed asci, aseptate ascospores dextrinoid when young and provided with a single germ pore, an anamorph having conidia of the form genus *Chrysonilia* von Arx (catenate aseptate or septate hyaline conidia) and of *Trichosporiella* Kamyschko (simple lateral conidia) is produced.

Canariomyces thermophila was isolated from Cameroon, Africa, apparently from soil. The original protologue is based on colonies developing at 45° C but no data about minimum and maximum growth temperatures are provided. Ascospores are greenish brown when mature with a subapical germ pore, 14.0-18.0 × 7.5-10.0 µm. However no anamorph developed in cultures of the single available strain.

***Chaetomium britannicum* Ames — A Monograph of the Chaetomiaceae: 16. 1963.**

Descriptions: Ames (1963); von Arx *et al.* (1986).

This *Chaetomium* was described as having ovoid to vase-shaped ascomata. Terminal and lateral hairs are very slender, greyish, straight to undulate. Asci club shaped, 8-spored. Ascospores brown, large, 19-24 × 11-14 µm, irregularly oval, rounded on the ends. In the protologue, it is simply indicated that "perithecia develop when incubated at approximately 47° C. A thermophile" (Ames, 1963). The specific epithet refers to the type locality: southern part of England.

The original material developed on mushroom compost and apparently no living culture was realised. von Arx *et al.* (1986) regard this *Chaetomium* as a doubtful species, only ascospores could be observed in the type specimen at BPI. Millner (1977) attempted but without success to obtain a culture from the dried type material, as no living strain, authentic or representative, was available to him, no growth temperature relationships could thus be established.

Gochenaur (1975) reported having isolated this *Chaetomium* from soil in the Bahamas but Millner *et al.* (1977) stressed the absence of a corresponding culture or herbarium specimen. Further and based on informations communicated by Gochenaur, the micromorphology of the fungus she examined was probably not *Chaetomium britannicum*. Spores of Gochenaur's taxon measured 13 (-18) × 7 (-10) µm and had subapical germ pores while spores from Ames material measure 19.0-24.8 × 11-14 µm and have single apical germ pores (Millner *et al.*, 1977). *Chaetomium britannicum* remains undocumented in the sense of Cooney and Emerson. Also no additional record either from the type locality (Cannon *et al.*, 1985) or elsewhere has apparently been published.

Chaetomium mesopotamicum Abdullah & Zora — Cryptogamic Botany 3: 387. 1993.

The original locality is a date palm plantation in Basrah, Iraq. This recently described species has a growth temperature range from 30-52° C. It differs from *Chaetomium thermophilum* LaTouche and *Ch. virginicum* Ames by its clavate asci and long highly branched terminal hairs. Ascospores are globose to ovoid, olive to brown, 5.5-7.8 × 5.2-6.3 µm, provided with one apical germ pore.

Chaetomium thermophilum LaTouche as "*thermophile*" Transactions of the British mycological Society 33: 94. 1950; Cooney & Emerson — Thermophilic Fungi: 62. 1964.

– ? *Chaetomium virginicum* Ames. A Monograph of the Chaetomiaceae: 43. 1963, *fide* von Arx *et al.*, 1986.

Descriptions. LaTouche (1950), Ames (1963), Cooney & Emerson (1964), von Arx *et al.* (1986).

This is the first known thermophilic *Chaetomium*. The species is also distinguished by its long, tapering terminal hairs at times dichotomously branched at wide angles. Ascospores are dark brown, globose to subglobose, 7.9 × 5-7 µm, prominently umbonate at one end.

Cooney & Emerson (1964) observed this *Chaetomium* to produce in culture two dissimilar growth patterns, as a result they proposed two new varieties *coprophile* and *dissitum*.

Chaetomium thermophilum LaTouche var. *coprophile* Cooney & Emerson — Thermophilic Fungi: 69. 1964.

The variety is mainly distinguished by the presence of dichotomously branched hairs, which more or less completely covers the entire perithecium.

***Chaetomium thermophilum* LaTouche var. *dissitum* Cooney & Emerson — Thermophilic Fungi: 68. 1964.**

Differs from the species mainly in the diffuse manner in which perithecia are produced in culture.

***Chaetomium virginicum* Ames — A Monograph of the Chaetomiaceae: 43. 1963.**

The fungus was originally isolated from leaf litter collected under very old trees at White Marsh, North of Old Point Comfort, Virginia (USA). Perithecia are described as globose, up to 240 µm wide. Terminal and lateral hairs cover the entire perithecium, indistinguishable, irregularly branched, minutely granular, 2-4 µm wide. Asci cylindrical, 8 spored, 70 × 10 µm. Ascospores yellow brown to pale brown, almond shaped, 8-11.5 µm. A thermophile (Ames, 1963).

Cooney & Emerson (1964) consider this species to approximate *Chaetomium thermophilum* while being identical to its variety *coprophile*, ascomata of the latter are also entirely covered by dichotomously branched perithecial hairs. On the basis of morphological characters and growth-temperature responses, Millner (1977) provided evidences that *Chaetomium virginicum* (culture TA-7 obtained from L. M. Ames collection at BPI) is identical to *Ch. thermophilum* var. *coprophile*. This proposal was later substantiated by Millner *et al.* (1977), among the large number of Chaetomia studied by these authors, ascospores with papillate germ pores were found only in *Chaetomium thermophilum*, its two varieties and *Ch. viginicum*.

Chaetomium virginicum is also regarded as a probable synonym of *Ch. thermophilum* by von Arx *et al.* (1986).

— *Coonemeria* Mouchacca *gen. nov.*

Thermophila. Coloniae lanatae aurantiae-rubrae quando ascoma matura sunt. Initium ascomatis est convoluta hypha. Ascoma non-ostiolata, sphaerica, solitaria vel confluenta; ascomata confluentes in crusta disposita. Ascomatis paries crassus, e cellulis pseudoparenchymaticis compositus, ascomatis textura angulosa. Ascus ex hamo singulato orundus, ovoideus vel piriformis, octosporus, demde evanescens. Ascospora unicellularia, ellipsoidea vel ovoidea, flavescens vel pallida aurantio-brunnea, cum pariete crassa laeve vel verrucosa. Structura conidiogena semper praesens, similis Paecilomyces Bainier *forma genericum*.

Species typica: *Coonemeria crustacea* (Apinis & Chesters) Mouchacca.

Thermophilic. Colonies lanose, reddish orange due to mature ascomata. Ascomatal initials a coiled hyphae. Ascomata non-ostiolate, spherical, solitary to confluent, forming a crusty layer, ascomatal wall thick, made up of pseudparenchymatous cells, *textura angularis*. Asci arise singly from croziers, ovoid to pyriform, 8-spored, evanescent. Ascospores unicellular, ellipsoid to ovoid, yellowish to pale reddish-brown, thick-walled, smooth to verrucose. Conidiogenous structures always present, belong to form genus *Paecilomyces* Bainier.

Type species: *Coonemeria crustacea* (Apinis & Chesters) Mouchacca.

Etymology: genus name coined from the first four respective letters of Cooney & Emerson's names, authors of the first comprehensive (although somewhat confusing) monograph on thermophilic fungi.

Coonemeria is proposed to accomodate thermophilic cleistothecial ascomycetes having coiled ascogonial initials, pseudparenchymatous walls of *textura angularis* type and a distinctive *Paecilomyces* anamorph. Asexual reproductive structures generally represent comparatively reduced forms of well elaborated *Paecilomyces* conidial structures developed in several taxa of this form genus (Samson, 1974).

The three species accepted in *Coonemeria* were formerly assigned to *Thermoascus* Miehe (Miehe, 1907) and *Dactylomyces* Sopp (Sopp, 1912). These genera have morphologically similar perfect states. *Thermoascus* is distinguished by the absence of any accessory state producing chains of conidia while this state belong to *Polypaecilum* G. Smith in the case of *Dactylomyces* (Apinis, 1967). The proposal of *Coonemeria* definitely clarifies the status of ascomycetes formerly placed in one or the other of these entities.

Anamorphs of the *Paecilomyces* type are also associated with *Talaromyces* Benjamin and *Byssochlamys* Westling (Stolk & Samson, 1972). The former is distinguished by soft white to yellow ascomata having walls composed of loose hyphae and the production of asci in chains. Most *Talaromyces* however are associated with Penicillia while only two have a *Paecilomyces* state, the latter were placed by Stolk & Samson (1972) in *Talaromyces* section *Emersonii* the thermotolerant *T. leycettanus* Evans & Stolk and the thermophilic *T. byssochlamydoides* Stolk & Samson, here considered. The two other taxa of the section have Penicillia: the thermophilic *T. emersonii* (treated in this note) and the thermotolerant *T. bacillosporus* Benjamin.

On the other hand, all *Byssochlamys* have a conidial *Paecilomyces* state. This teleomorphic genus is characterized by initials consisting of swollen antheridia and coiled ascogonia producing almost naked ascomata in which globose asci are formed from croziers (Stolk & Samson, 1972).

Coonemeria crustacea (Apinis & Chesters) *comb. nov.*

basionym *Dactylomyces crustaceus* Apinis & Chesters — Transactions of the British mycological Society 47: 428. 1964

Thermoascus crustaceus (Apinis & Chesters) Stolk — Antonie van Leeuwenhoek 31: 272. 1965

anamorph *Paecilomyces crustaceus* Apinis & Chesters — Transactions of the British mycological Society 47: 428. 1964

Misapplied names *Thermoascus aurantiacus* Miehe — Die Selbsterhitzung des Heues. 70. 1907; *sensu* Cooney & Emerson — Thermophilic Fungi: 39. 1964

– *Dactylomyces thermophilus* Sopp — Skrifter udgivne af videnskabs selskabet i Christiania. Mathematisk naturvidenskabelig klasse 11: 35. 1912, *sensu* Cooney & Emerson — Thermophilic Fungi: 39. 1964

– *Penicillium thermophilus* (Sopp) Biourge — La Cellule 33: 106. 1923, *sensu* Cooney & Emerson — Thermophilic Fungi: 39. 1964

– *Penicillium thermophilum* (Sopp) Sacc., *fide* Trotter 1931 — *Sylloge Fungarum* 25 (Suppl. 10): 671.1931, *sensu* Cooney & Emerson — Thermophilic Fungi: 39. 1964

Descriptions: as *Dactylomyces crustaceus* by Apinis & Chesters (1964) and Apinis (1967), as *Thermoascus aurantiacus* by Cooney & Emerson (1964), as *Thermoascus crustaceus* by Stolk (1965), Awao & Otsuka (1974) and Chen & Chen (1996).

In 1964, Apinis & Chesters reported on an ascomycete isolated at 38° C from grass debris collected in a salt marsh on the Lincolnshire coast. *Dactylomyces* Sopp was then thought to be the correct genus. The fungus also proved to compare with the CBS strain 374.62 (= QM 6798 = NRRL 1563) deposited by Raper & Fennell as *Dactylomyces thermophilus*, the genus type species. At that time, Sopp's fungus was only known from the original description and illustrations (Sopp, 1912).

Apinis & Chesters (1964) compared these two *Dactylomyces* strains with the protologue of the type species and noted several discrepancies. Both isolates were found to deviate by the absence of dactyloid conidiophores bearing small conidia and the presence of relatively small asperulate ascospores. For *Dactylomyces thermophilus*, Sopp had reported ascospores as oval, smooth, 10-12 × 6-7 µm. Ascospores of the living strains were reddish brown, globose to oval, rough and smaller, 7-9 × 5-7 µm. Further, their respective anamorphs were found to perfectly fit in *Paecilomyces* with conidia being hyaline, cylindrical to oval, smooth, 3-8 × 2-4 µm. Based on these deviations, Apinis & Chesters proposed the new *Dactylomyces crustaceus* and selected as type material their strain BDUN 378 (= IMI 102470).

Also in 1964, Cooney & Emerson published their monograph on thermophilic fungi. They provided a latin diagnosis for the type species of *Thermoascus*, *Th. aurantiacus* based on their strain M 206516. They also regarded *Dactylomyces* as congeneric with the previously described *Thermoascus* and thus listed known synonyms of both states of *D. thermophilus* under *Thermoascus aurantiacus* (see also under *Dactylomyces thermophilus*). Before this monograph, the anamorph of *Dactylomyces thermophilus* was regarded as approximating a *Penicillium* (Biourge, 1923).

A year later, Stolk (1965) re-examined strain CBS 374.62 and concurred with Apinis & Chesters (1964) about its similarity with their *Dactylomyces crustaceus*. Stolk admitted however Cooney & Emerson's (1964) disposition for *Dactylomyces* and accordingly proposed the new combination *Thermoascus crustaceus* (Apinis & Chesters) Stolk. Stolk finally compared the above strain with four other CBS cultures labelled *Thermoascus aurantiacus*: CBS 256.34, 257.34, 415.62 & 398.64. No conidial state matching the anamorph Cooney & Emerson (1964) depicted for this ascomycete developed in any of these cultures. Stolk then concluded "Cooney & Emerson's strain M206516 of *Thermoascus aurantiacus* is most likely identical with CBS 374.62", a suggestion being subtantiated by the fact that the relevant iconography is suggestive of *Paecilomyces*.

Finally, in 1967, Apinis re-examined strain M 206516. It proved conspecific with *Dactylomyces crustaceus*. Thus he, first, confirmed Stolk's suggestion about this strain and, second, the description provided by Cooney & Emerson (1964) for *Thermoascus aurantiacus* applies in fact to the former. In addition, the study of fresh isolates matching the protologue of *Dactylomyces thermophilus*, lead Apinis (1967) to conclude *Dactylomyces* should be maintained distinct from *Thermoascus*, a decision largely accepted subsequently (Cannon *et al.*, 1985; Eriksson & Hawksworth, 1993). As underlined before, the development of a distinctive *Paecilomyces* anamorph favours the placement of *Dactylomyces crustaceus* in *Coonemeria*.

On common laboratory agar media, the minimum growth temperature lies between 20-25° C with the maximum being below 60° C. Optimum growth is around 40° C with a standard Petri dish being covered in 4 d, mature colonies are colored orange with orange brown reverse.

Initials a simple ascogonial coil. Cleistothecia scattered or confluent and then forming a crusty layer, spherical, 300-700 µm diam., orange to reddish-brown. Ascomatal wall made of few layers of brown pseudparenchyma cells with slightly thickened walls.

Asci are produced singly from croziers, irregularly disposed in the ascomatal cavity, 8-spored, subglobose to pyriform, 15-20 × 13-16 µm, evanescent. Ascospores oval, pale brown to red-brown, 6.0-8.0 × 5.0-6.5 µm, wall 0.5 µm thick, provided with fine echinulations.

Asexual reproductive structures develop within 2 d at 40° C, they are evanescent and not affecting overall colony characters. Conidiophores coarse, septate, pale yellow, smooth, up to 900 µm long, tapering to 4-5 µm wide apical parts. Upper parts of the conidiophores bears irregularly arranged branches, 6-35 × 4-5 µm, these are usually rebranched and end with phialides, phialides occur either singly as side branches, or in irregular verticils of 2-3, phialides cylindric, 12-30 × 5.7 µm, gradually tapering to a long conidium-bearing tube, slightly bent away, 12 × 3 µm. Conidia produced in conspicuous long diverging chains, smooth, yellow to pale brown, cylindrical when young, ellipsoid when mature, 6-10 × 3.6 µm, responsible for the slight ochraceous color of young colonies.

Coonemeria crustacea is distinguished from the two other members of the genus mainly by oval finely echinulated ascospores. It displays a wide geographic distribution being isolated from soil in several localities and from various self-heating material (Cooney & Emerson, 1964; Cannon *et al.*, 1985; Chen & Chen, 1996).

Coonemeria aegyptiaca (Ueda & Udagawa) *comb. nov.*

basionym *Thermoascus aegyptiacus* Ueda & Udagawa Transactions of the Mycological Society of Japan 24: 135. 1983.
anamorph *Paecilomyces aegyptiaca* Ueda & Udagawa Transactions of the Mycological Society of Japan 24: 135. 1983

The fungus was originally isolated from a sample of marine sludge collected along the Suez Canal banks at Port-Said City, Egypt. It develops between 25 to 55° C with the optimum being at 40° C. At this temperature, colonies fill the plate within 4 d with a thin almost submerged basal mycelium producing numerous superficial ascocarps, often forming a crusty mass, vinaceous to reddish brown, conidia fairly abundant, grayish yellow and not affecting colony color.

Cleistothecia superficial, subglobose, orange-brown, 250-550 µm wide, initials a simple coiled hyphae. Peridium 25-40 µm thick, pseudoparenchymateous, rather coriaceous, *textura angularis* type. Asci borne singly on croziers, scattered in the ascomatal cavity, 8-spored, ovate, 14-18 × 11-15 µm, evanescent. Ascospores 1-celled, ellipsoid to ovoid, yellowish to pale reddish orange, 6.0-8.5 × 4.0-5.5 µm, thick-walled and nearly smooth (slightly verruculose under SEM).

Conidiophores erect arising more commonly from aerial trailing hypae, hyaline, smooth-walled, 50-300 × 5-7 µm, apical parts irregularly branched and bearing terminal verticils of 2-4 phialides usually without any metulae, phialides solitary or irregularly verticillate, cylindric, 12-30 × 3-6 µm. Conidia formed in long divergent or tangled chains, continuous, hyaline but fulvous in mass, cylindrical to elliptical, 4.5-11 × 3.4 µm, conida sometimes ovoid to subglobose, 3.5-10 diam.

Coonemeria aegyptiaca is mainly distinguished by its ellipsoidal almost smooth ascospores. Ueda & Udagawa (1983) indicate the fungus produces two morphological kinds of asexual stretures: the typical *Paecilomyces*-type with cylindrical to doliform conidia are produced at 37-40, at higher temperatures, conidia are subglobose to ovoid, borne in shorter chains on phialides having a swollen and thick-walled apex.

Coonemeria aegyptiaca was recently reported by Abdullah & Al-Bader (1990) to inhabit soil in Iraq

Coonemeria verrucosa (Yaguchi, Someya et Udagawa) comb. nov.

basionym *Thermoascus crustaceus* (Apinis & Chesters) Stolk var *verrucosus* Yaguch., Someya et Udagawa Mycoscience 36: 161. 1995.

Thermoascus taitungiacus Chen K Y & Chen Z-C Mycotaxon 50 226 1996

anamorph. *Paecilomyces taitungiacus* Chen K-Y & Chen Z C Mycotaxon 50. 226 1996

= *Paecilomyces crustaceus* Apinis & Chesters *pro parte fide* Yaguchi, Someya et Udagawa Mycoscience 36: 161. 1995.

Descriptions: Yaguchi *et al* (1995); Chen & Chen (1996).

Colonia in agaro malto addito dispositae post 7 dies et temperatura 40° C cum 9.0 cm diametro lanatae. Ascomates superficiales intermixta cum pauco conidiogenis structuris. Mycelium ex hyphis hyalinis, septatis, ramosis, laevibus, 2-8 µm crassis.

Ascoma non-ostiolatum solitarium ad confluens demde crustaceum sphaericum aurantiocanqua cum 300-600 µm diametro. Peridium crassum pseudparenchymatum textura angulare. Asci dispersi in ascomatis cavitate subglobosi vel piriformes, 12-16 × 11-14 µm octospori evanescentes. Ascosporae unicellulares ellipsoideae rare subglobosae hyalinae ad pallidae aurantiacae, 6-8 × 5-6 µm, cum crasso verrucoso pariete.

Conidiophorum septum, laeve hyalinum ad brunneum 100-300 × 6-10 µm. Apicis regio irregulariter ramosa, terminales rami cum solitariis phialidibus vel verticillatis per 2-4. Phialis cylindrica 16-30 × 4-6 µm. Conidia disposita in catenis non coalescentibus, conidia cylindrica, flavida laeva, 4-10 × 2-4 µm, conidia elliptica aliquando 5-8 × 4-6 µm.

Holotypus PF 1160 cultura exsiccata ex soli isolata a I. Yaguchi, Guanghou in Sina, 4 XI 1993. In herbario Musei et Instituti Historiae Naturalis Chiba CBM deposita.

On common laboratory agar medium, colonies filling the plate in 7 d at 40° C, lanate with superficial ascomata intermixed with sparse conidiophores and conidia, rosy buff to orange, reverse reddish-brown, conidiogenesis inconspicuous not affecting colony appearance. Optimal growth between 30 and 40° C, the minimum lies between 20 and 25° C and the maximum somewhat above 55° C.

Ascomatal initials a coiled hyphae. Cleistothecia solitary or confluent and then forming a crusty layer, orange, spherical, 300-600 µm diam., peridium pseudoparenchymatous of *textura angularis* type, outer layer consisting of thick-walled yellow brown angular cells, 4-8 × 2-6 µm, inner layer of hyaline, angular or rounded cells, 10-20 µm wide. Asci irregularly disposed, 8-spored, globose to pyriform, 12-16 × 11-14 µm, evanescent. Ascospores unicellular, hyaline to pale-orange, ellipsoidal, rarely subglobose, 6-8 × 5-6 µm, thick-walled, verrucose.

Conidiophores arise from the basal mycelium or from aerial hyphae, stipes hyaline to brownish, septate, smooth, 100-300 × 6-10 µm, apical parts not uniformly branched giving rise to irregular verticils of terminal and subterminal secondary branches, these bear phialides either singly or in verticils of 2-4, cylindrical to slightly swollen, 16-30 × 4-6 µm. Conidia produced in long disordered chains, unicellular, cylindrical, truncate at both ends, yellowish, smooth, 4-10 × 2-4 µm, few wider elliptical conidia sometimes produced, 5-8 × 4-6 µm.

Holotype PF 1160, a dried culture of a soil isolate from Guanghou, China, 4. XI 1993, deposited at the Natural History Museum and Institute, Chiba, Japan (CBM) and at T Yaguchi collection (described as *Thermoascus crustaceus* var *verrucosus*)

While describing *Thermoascus taitungiacus*, Chen & Chen (1996) were probably unaware of the verrucose variety of *Th crustaceus* established a year before by the Japanese mycologists Yaguschi *et al* (1995) Authentic material of both taxa have in common a soil origin and not widely separated original locations. Indeed the former derives from a weed soil located at Taitung in Taiwan, while the latter was isolated form a soil sample taken from the Chinese locality of Guanghou

Ascospores of the Taiwanese fungus were described as being yellowish green (although overall colony color tends to orange tones), oval to elliptical, rarely subglobose, 6 3-7 5 × 4 5-5 6 µm, thick-walled and predominantly echinulate when viewed under light microscope but irregularly verrucose under SEM A comparison of given SEM pictures for both taxa clearly stress ascospore ornamentation is similar being represented by large well individualised warts of heterogeneous shape.

Coonemeria verrucosa is mainly distinguished by its definitely verrucose ellipsoidal ascospores. These are smooth in *C aegyptiaca* and finely echinulated in *C crustacea* The ascomycete might have been previously mislead with *Coonemeria crustacea* Nevertheless further comparative studies are required to ascertain differences in growth temperatures relations and other minor morphological characters.

Corynascus heterothallicus (van Klopotek) von Arx — Sydowia 34: 25. 1981(1982).

basionym *Thielavia heterothallica* van Klopotek Archives of Microbiology 107 223-224. 1976.
anamorph *Myceliophthora thermophila* (Apinis) van Oorschot Persoonia 9 403 1977
basionym *Sporotrichum thermophilum* Apinis as '*thermophile*' Nova Hedwigia 5 74 1963
Chrysosporium thermophilum (Apinis) van Klopotek Archives of Microbiology 98 366. 1974

Descriptions von Arx (1981(1982)), van Klopotek (1976), Domsch *et al* (1980, as *Thielavia heterothallica*).

Apinis (1963) isolated several strains of a new thermophilic "*Sporotrichum*" anamorph from soil and plant debris in Nottingham, UK, he was not aware of the heterothallic nature of the corresponding teleomorph Few years later, von Arx (1971) provided a modern definition of *Sporotrichum* Link based on a freshly isolated strain matching the type species *S aureum* Link S. F Gray This form genus was then restricted to hyphomycetes having basidiomycetous affinities as evidenced by the regular presence of clamp connections at the cross walls and production of simple types of aleuriospores. On account of this new definition, van Klopotek (1974) transferred Apinis fungus to *Chrysosporium* Corda

Myceliophthora Costantin was reintroduced by van Oorschot (1977) as suggested earlier by von Arx (1973) in his treatment of *Sporotrichum* and related genera This disposition aimed to accomodate the type species *Myceliophthora lutea* Costantin and the *Chrysosporium* - *Sporotrichum*) anamorphs of two hitherto described ascomycetes, *M lutea* has not yet developed a corresponding teleomorph The fungus described by

Apinis is now widely accepted as belonging to *Myceliophthora*. It differs from known species by its dark colored colonies and smaller mostly obovate conidia, 4.5-11.0 × 3.0-4.5 µm; conidia are hyaline, smooth and thick-walled.

The teleomorph was later discovered by van Klopotek (1976) after mating appropriate strains. Developed cleistothecia produced ascospores ellipsoidal, dark brown, 7.5-11.0 × 5.0-7.0 µm, provided with one distinctive germ pore. The teleomorph was described as *Thielavia heterothallica*. Few years later, it was relocated in *Corynascus* von Arx which groups ascomycetes having anamorphs of the *Myceliophthora* type (von Arx *et al.*, 1986).

An excellent account of the cultural and physiological characteristics and the distribution of this fungus is provided by Domsch *et al.* (1980).

Corynascus thermophilus (Fergus & Sinden) van Klopotek — Archives of Microbiology 98: 366. 1974.

basionym *Thielavia thermophila* Fergus & Sinden. Canadian Journal of Botany 47: 1635. 1969.
= *Chaetomidium thermophilum* (Fergus & Sinden) B. Lodha. In Taxonomy of Fungi. Proceedings of the International Symposium Madras 1973. Part I: 248. 1978.
anamorph *Myceliophthora fergusii* (van Klopotek) van Oorschot. Persoonia 9: 406. 1977.
basionym *Chrysosporium fergusii* van Klopotek. Archives of Microbiology 98: 366. 1974.

Descriptions. Fergus and Sinden (1969), Hedger and Hudson (1970), van Klopotek (1974), von Arx (1975).

Mating of several pure strains of another thermophilic "*Sporotrichum*" species isolated from mushroom compost in Pennsylvania (USA) developed black ascocarps of a new heterothallic cleistothecial ascomycete. This was described as *Thielavia thermophila* by Fergus & Sinden (1969). No provision was however then made for the corresponding anamorph. This was simply regarded as deviating from *Sporotrichum thermophilum* Apinis by some cultural characteristics. Both hyphomycetes were later compared by Hedger & Hudson (1970) following isolates obtained in Britain. Distinctive growth and morphological features were also simply underlined by Hedger and Hudson.

In 1974, van Klopotek ascribed the anamorph of *Thielavia thermophila* to *Chrysosporium* Corda while dedicating the hyphomycete to Fergus; she also transferred the teleomorph to the recently established *Corynascus* von Arx. *Chrysosporium fergusii* was later on relocated in *Myceliophthora* by van Oorschot (1977) together with the anamorph of a second *Corynascus* species. However it is unfortunate the specific epithet *thermophila* was not selected for the anamorph of *Corynascus thermophilus*. Such would have prevented any form of confusion with the anamorph of *Corynascus heterothallicus* (van Klopotek) von Arx named *Myceliophthora thermophila* (Apinis) van Oorschot.

Corynascus thermophilus being a heterothallic ascomycete is usually only represented by its aleuriospores in isolation studies. These are ellipsoidal or obovate, nearly hyaline and measure 7-12 × 5-8 µm. Mating of appropriate strains would produce cleistothecia black, globose, usually smooth, up to 300 µm diam. Asci are irregularly disposed, each having four ascospores being ellipsoidal, dark brown, 22-32 × 17-22 µm, provided with two prominent germ pores.

Corynascus novoguinensis (Udagawa & Horie) von Arx also produces a *Myceliophthora* anamorph but yet unnamed. However this fungus has its maximum growth temperature at 40° C as compared to 55° C for *Myceliophthora fergusii* (van Oorschot, 1980).

***Dactylomyces thermophilus* Sopp — Skrifter udgivne af videnskabsselskabet i Christiania. Mathematisk-naturvidenskabelig klasse 11: 35. 1912.**

= *Thermoascus thermophilus* (Sopp) von Arx — The Genera of Fungi Sporulating in Pure Culture: 84. 1970

anamorph: *Polypaecilum* sp.; *fide* Apinis, 1967.

Misapplied names: *Thermoascus aurantiacus* Miehe 1907, *sensu* Cooney & Emerson Thermophilic Fungi. 39. 1964.

Penicillium thermophilus (Sopp) Biourge 1923, *sensu* Cooney & Emerson — Thermophilic Fungi. 39. 1964.

= *P. thermophilum* (Sopp) Sacc., *fide* Trotter 1931 — *Sylloge Fungorum* 25 (Suppl. 10) 671.1931; *sensu* Cooney & Emerson — Thermophilic Fungi: 39. 1964.

Description: Apinis (1967).

This is the type species of *Dactylomyces* Sopp (Sopp, 1912). The original material developed in Norway on the wooden casing of a bath thermometer. In the protologue, Sopp suggested the new genus might be identical with *Thermoascus* Miehe, despite his awareness of marked differences between respective type species, for example, the presence of a penicilloid anamorph in his fungus and the absence of a distinctive conidial state in the type species *Thermoascus aurantiacus*. Absence of authentic material for effective comparison made a considerable impact on subsequent interpretations of both genera. Such resulted in much confusion in the identity of respective type species.

The presence of a penicilloid anamorph in the description of *Dactylomyces thermophilus* lead Biourge (1923) to list this name among the hitherto known Penicillia. However Biourge did not include the corresponding *Penicillium thermophilus* in his group of accepted species. Trotter (1931) published a short description of *Penicillium thermophilum* (Sopp) Sacc. Later and for their treatment of Penicillia, Raper & Thom (1949: 20) examined a culture obtained by Prof. Ralph Emerson from retting guayule at Salinas, California, believed to represent Sopp's fungus. In addition to developed ascospores, conidial structures were found by Raper & Thom to be very large and coarse, evanescent, somewhat penicillate and thus not characteristic of their concept of *Penicillium* Link. These authors then regarded *Thermoascus* as a possible synonym of Sopp's genus.

Few years after the publication of Raper & Thom's Manual of the Penicillia (1949), Raper & Fennell deposited at the CBS the strain NRRL 1563 as *Dactylomyces thermophilus* Sopp (List of Cultures, Supplement 1: 1962), this number originally referred to a strain of *Cephalothora tropica* but from about 1950, it was discovered that it has been replaced by a strain of this ascomycete.

In 1964, Cooney & Emerson provided a latin diagnosis for *Thermoascus aurantiacus* based on their strain M 206516. This isolate was made from retting guayule in June 1945, at Salinas, California, but their is no clear indication whether it is the same strain earlier examined by Raper & Thom (1949). For this ascomycete, Cooney & Emerson depicted a distinctive conidial stage. Their illustration approximate figures produced by

Sopp (1912) for his *Dactylomyces thermophilus* and which are rather reminiscent of *Paecilomyces* Bain. Cooney & Emerson also admitted Sopp's suggestion his fungus being identical to *Thermoascus aurantiacus*. They substantiated their conclusion by the assumption that isolates of the latter examined by Miehe (1907) might represent "some naturally occurring strains of *Thermoascus* (*Dactylomyces*) incapable of producing conidia". As *Thermoascus* predates *Dactylomyces*, the former was thus retained. Earlier synonyms of the type species of the latter were then disposed under *Thermoascus aurantiacus*. At the date of publication of Cooney & Emerson's book on thermophilic fungi, *Dactylomyces* was still a monospecific genus.

In 1964 however, Apinis & Chesters (1964) added a second species to *Dactylomyces*, *D. crustaceus*, developing a conspicuous *Paecilomyces* anamorph designated *P. crustaceus*. For this work, they re-examined Raper & Fennell's *Dactylomyces thermophilus* strain (NRRL 1563, = CBS 374.62), this proved to match the fungus they were proposing. One year later, Stolk (1965) also studied this isolate, she concurred with Apinis & Chester's decision. Stolk then suggested Cooney & Emerson's neotype of *Thermoascus aurantiacus* (M 206516) is most likely identical with *Dactylomyces crustaceus*.

Stolk (1965) also examined all cultures maintained at the CBS as *Thermoascus aurantiacus*: CBS 256.34, CBS 257.34, CBS 415.62 and CBS 398.64. These strains were characterized by the presence of ascospores being elliptical and finely echinulated, 5.0-7.0 × 3.5-5.0 µm, and the general absence of an associated anamorph producing chains of conidia. Miehe (1907) had already stressed the absence of any conidial state producing spore chains in his type species and such was confirmed few years later by Noack (1912). Stolk then stresssed these features should distinguish Miehe's fungus from *Dactylomyces crustaceus* Apinis & Chesters (having a *Paecilomyces* anamorph) and also from the yet unclear *D. thermophilus* Sopp. Unfortunately Stolk (1965) tranferred *Dactylomyces crustaceus* to *Thermoascus*.

In 1967, Apinis re-examined *Thermoascus aurantiacus* neotype strain M 206516. He found it to rather correspond to *Dactylomyces crustaceus* Apinis & Chesters having a well defined *Paecilomyces* anamorph. This observation enabled Apinis to definitely refute the similarity of these two teleomorphic genera as stated by Cooney & Emerson (1964). At that time, Apinis was already familiar with the ascomycete described by Miehe, from pasture soils, he had isolated (Apinis, 1963) several strains matching the original description.

Based on several fresh isolates originating from Sweden and England, Apinis (1967) then provided an updated description of *Dactylomyces* type species, *D. thermophilus*. The fungus has hyaline, unicellular ascospores, more or less oval and smooth, 5.5-8.0 × 3.5-6.0 µm. Conidia are also produced, these are continuous, cylindrical to ovoid, subhyaline, smooth, 3.0-11.0 × 2.5-5.5 µm. Such ascospores and conidial dimensions are somewhat smaller than those reported by Sopp (1912), however there is a general agreement that measurements given by this author are unreliable. Apinis (1967) selected as neotype strain BDUN 394 (= IMI 123298) obtained by T. Nilsson in Sweden. No provision was established for the anamorph. He simply indicated chains of conidia are produced by branched annellophores as in the recently described form genus *Polypaecilum* G. Smith (Smith, 1961). Apinis proposed two new subgenera to consider distinctiveness in anamorphs of both *Dactylomyces*. Subgenus *Dactylomyces* based on the type and subgenus *Paecilomycopsis* based on *D. crustaceus*. These subgeneric divisions were rapidly regarded as superfluous.

Inspite of clarifications introduced by Apinis (1967), von Arx (1970) listed *Dactylomyces* as congeneric with *Thermoascus*, a taxonomic disposition he maintained for

several years (von Arx, 1987), apparently he was following Stolk (1965) who did transfer *Dactylomyces crustaceus* to *Thermoascus*. However this generic synonymy did not gain general acceptance (Malloch & Cain, 1972, Cannon *et al.*, 1985, Eriksson & Hawksworth, 1993). *Dactylomyces* Sopp is actually considered a valid distinctive generic entity.

Melanocarpus albomyces (Cooney & Emerson) von Arx — Studies in Mycology 8: 17. 1975.

basionym *Myriococcum albomyces* Cooney & Emerson — Thermophilic Fungi: 60. 1964.
Thielavia albomyces (Cooney & Emerson) Malloch & Cain — Canadian Journal of Botany 50: 65. 1972.

Descriptions: Cooney & Emerson (1964), von Arx (1975), von Arx *et al.* (1988), Guarro *et al.* (1996).

Cooney & Emerson ascribed this fungus to the sterile form-genus *Myriococcum* Fr. based on Corda's interpretation of its type species, *M. praecox* (Corda, 1842). They based their decision on the account both fungi have in common "the dark, shiny astomous fruiting bodies, associated with a white, mucedineous subiculum". Such an addition was made inspite of their awareness no asci were ever reported in *Myriococcum praecox* and also that what was considered as "spores" by Corda was apparently only the inner cells of immature ascocarps.

The genus *Melanocarpus* von Arx (von Arx, 1975) was later proposed to accommodate this widespread ascomycete known to produce in culture a characteristic arthroconidial state. This anamorph is not developed by taxa of the two related genera *Thielavia* Zopf and *Chaetomidium* (Fuckel) Zopf. Smooth ascomata and obovate-oblate darker ascospores provided with a prominent germ pore (13-16 × 11-14 × 9-11 µm) were also then considered additional distinguishing features. Further, the presence of a pseudoparenchymatous wall in *Melanocarpus albomyces* precludes any confusion with the hitherto known species of *Thielavia* (von Arx, 1975).

The original concept of *Melanocarpus* was however subsequently partly expanded by von Arx *et al.* (1988) to allow provision for the mesophilous *M. oblatus* Guarro & van der Aa described in the meantime, arthroconida are produced by this species. This tendancy was also recently substantiated by Guarro *et al.* (1996) with their description of the mesophilic *Melanocarpus coprophilus* Guarro & Valldos., and the transfer of *Thielavia minuta* var. *thermophila* Abdullah & Al-Bader. However both latter taxa are not known to have an associated arthroconidial state or any other state, a feature that should have favoured their inclusion rather in *Chaetomidium*.

Melanocarpus thermophilus (Abdullah & Al-Bader) Guarro, Abdullah & Al-Bader — Mycological Research 100: 75. 1996.

basionym *Thielavia minuta* (Cain) Malloch & Cain var. *thermophila* Abdullah & Al-Bader — Basrah Journal of Agricultural Science 5: 116. 1992.

Descriptions: Abdullah & Al-Bader (1992); Guarro *et al.* (1996).

Living strains of the thermophilic variety of *Thielavia minuta* (Cain) Malloch & Cain (a mesophile) originate from a forest soil in the north of Iraq. Re-examination of authentic material led Guarro *et al.* (1996) to relocate the fungus in *Melanocarpus* von Arx

as *M. thermophilus*. However this ascomycete produces not the arthroconidial anamorph characteristic of the type species. Asci are 8-spored with ascospores being ovoid, dark brown, 7.5-9.0 × 6.0-7.5 µm, each provided with a single germ pore.

Talaromyces byssochlamydioides Stolk & Samson — Studies in Mycology 2: 45. 1972.

anamorph *Paecilomyces byssochlamydoides* Stolk & Samson — Studies in Mycology 2 45. 1972

Descriptions. Stolk & Samson (1972); Awao & Otsuka (1974).

This species of *Talaromyces* Benjamin is definitely less reported than its close relative *T. emersonii* Stolk. It is mainly distinguished by its conspicuous *Paecilomyces* anamorph as compared to the *Penicillium* state of the latter. Ascomata always develops in culture concomitantly with the anamorph and such prevents its confusion with the similar imperfect taxon *Paecilomyces variotii* Bainier. Ascospores are globose to subglobose, 3.7-4.5 × 3.5-4.0 µm, thick-walled smooth or nearly so, often partially covered by material which may represent the remnants of a gelatinous covering.

Dactylomyces crustaceus Apinis & Chesters also has a *Paecilomyces* state but its conidia are ellipsoidal as compared to the cylindrical conidia of *Talaromyces byssochlamydioides*. The latter was apparently only reported from soil in Japan (Awao & Otsuka, 1974) and Egypt (Mouchacca, 1995).

Talaromyces emersonii Stolk — Antonie van Leeuwenhoek 31: 262. 1965; Stolk & Samson — Studies in Mycology 2: 48. 1972.

– *Byssochlamys* sp. *fide* Cooney & Emerson — Thermophilic Fungi 155. 1964
anamorph *Penicillium emersonii* Stolk — Antonie van Leeuwenhoek 31: 262. 1965
Geosmithia emersonii (Stolk) Pitt — Canadian Journal of Botany 57: 2027. 1979
Misapplied names: *Talaromyces duponti* (Griffon & Maublanc) Apinis, *sensu* Apinis Nova Hedwigia 5: 72. 1963; as *comb. nov.* (*nom. inval.*, Art. 36.1).
- *Penicillium duponti* Griffon & Maublanc 1911, *sensu* Apinis — Nova Hedwigia 5: 72. 1963

Descriptions. Stolk (1965), Stolk & Samson (1972), Domsch *et al.* (1980).

Talaromyces emersonii was described inclusive of its distinctive anamorph developing Penicillia of the *Asymmetrica* type. The selected representative strain was obtained by Mrs. A. J. van der Plaats-Niterink from Italian compost but other isolates were also then available at the CBS. Dedicated to R. Emerson for his contribution to our knowledge of thermophilic fungi.

Apinis (1963) based his taxonomic decision on strain BDUN 272 (= CBS 397.64) isolated from soil near Nottingham (UK). Stolk (1965) re-examined this isolate which proved to represent *Talaromyces emersonii* rather than the teleomorph of *Penicillium duponti* as concluded by Apinis. The same observation also applies to strain CBS 394.64 labelled *Byssochlamys* sp. by Cooney & Emerson (Stolk, 1965).

The anamorphic genus *Geosmithia* Pitt (Pitt, 1979) was erected to accomodate Penicillia formerly placed in the *Penicillium pallidum* series. These are mainly distinguished by the formation of cylindrical conidia borne from cylindroidal, rough walled

phialides and not colored green en masse. Stolk & Samson (1985) emitted doubts as to the necessity of such a generic distinction based on slight morphological differences. In *Penicillium* such differences are instead appropriately used to delimit generic sections. The anamorph of *Talaromyces emersonii* is thus better referred to as a *Penicillium*.

Talaromyces emersonii was subsequently reported from various habitats (Domsch *et al.*, 1980). It produces globose, reddish to orange brown ascomata, up to 300 µm diam., ascospores are thick-walled, smooth, subglobose to ovoidal, 3.5-4.0 × 2.7-3.5 µm, ascospores may be covered by material representing remnants of a gelatinous coating.

Talaromyces thermophilus Stolk — Antonie van Leeuwenhoek 31: 268. 1965; Stolk & Samson — Studies in Mycology 2: 55. 1972.

Penicillium dupontii Griffon & Maublanc emend. Emerson in Raper & Thom, A Manual of the Penicillia. 573-577. 1949.

– *Talaromyces dupontii* (Griffon & Maublanc) Emerson, incidently mentioned by Fergus, Mycologia 56: 277. 1964 (*nom. inval.*, Arts. 36.1 & 37.1)

anamorph *Penicillium dupontii* Griffon & Maublanc, Bulletin trimestriel de la Societe mycologique de France 27: 73. 1911

– ? *Catromyces sphagnicola* Mal'chevskaya, Trudy Pushkin nauchno-issled. Lab. Rasv. Sel'skokhoz. Zhivot. Inst. 13: 23. 1939.

Misapplied names: *Talaromyces dupontii* (Griffon & Maublanc) Apinis, *sensu* Apinis, Nova Hedwigia 5: 72. 1963, as *comb. nov.* (*nom. invalid.*, Art. 36.1).

Talaromyces Penicillium dupontii (Griffon & Maublanc) emend. Emerson in Raper & Thom, 573. 1949, l. c. Cooney & Emerson, Thermophilic Fungi 28. 1964 (*nom. inval.*, Art. 36.1).

Descriptions: Stolk (1965); Stolk & Samson (1972); Pitt (1979).

The original publication of Griffon & Maublanc (1911) dealt only with the *Penicillium* anamorph. No corresponding teleomorph was reported from cultures of the two strains then available for study. These were obtained in France from manure and damp hay by Mr. Dupont, Chief-Chemist at the Ecole Nationale d'Agriculture de Grignon, and to whom the fungus was dedicated. Unfortunately, the two original isolates are definitely lost.

The fungus was later on and in 1945 isolated by Emerson from retting guayule shrub at Salinas, California, for the first time the perfect state developed in culture. Emerson then prepared an emended description of both states of *Penicillium dupontii* based upon his strain No. 26 (= NRRL 2155) to be incorporated by Raper & Thom in their first Manual of the Penicillia (1949: 573).

In 1963, some confusion about this taxon was introduced by Apinis. Under the binomial *Talaromyces dupontii* (Griffon & Maublanc) Apinis, he provided a description of a teleomorphic fungus thought to "correspond in general to the original strain described from France". As representative material, Apinis selected his strain BDUN 272 originating from a water-logged pasture in Nottingham. The above binomial was however not validly published as no latin diagnosis provided and no new type material specified.

Further confusion but of the nomenclatural type was also simultaneously introduced by Fergus (1964) following his study of an isolate from compost in Pennsylvania (USA). His observations were published under the name *Talaromyces dupontii* (Griffon & Maublanc) Emerson, a combination not proposed as such by Emerson himself.

Unfortunately, this designation was subsequently reproduced in several studies of thermophilic fungi.

Two years later Stolk (1965) re-examined Apinis strain BDUN 272. She found it to largely deviate from Emerson's isolate No. 26 (= NRRL 2155, = CBS 236.58). Moreover, the former proved to perfectly match her newly described *Talaromyces emersonii* Stolk. To eliminate the state of confusion prevailing around the name *Talaromyces duponti*, Stolk then proposed the new name *Talaromyces thermophilus* for this teleomorph and provided a latin diagnosis. Emerson strain was then selected as holotype (Stolk, 1965; Pitt, 1979). However, the original accession number of this holotype was erroneously cited by Cooney & Emerson (1964: 28) under the diagnosis provided for this fungus is indicated specimen M 206516 (our culture No. 26). In fact strain M 206516 was selected by Cooney & Emerson as representing their interpretation of *Thermoascus aurantiacus* Miehe (1964: 50) and this corresponds to their annotation: our culture No. 2.

Pitt (1979) stressed the reasons why the corresponding perfect state should be maintained in *Talaromyces* and to continue considering its simple reduced anamorph as a *Penicillium*. *Talaromyces thermophilus* is the only thermophile with a *Penicillium* anamorphic state producing green conidia. This character should prevent any misidentification since ascocarps do not always readily develop in cultures of freshly isolated strains. The fungus grows fairly rapidly and optimally at 45-50° C, no growth develops at 25° C and 60° C respectively. Ascospores are ellipsoidal, 3.5-4.5 × 2.2-3.5 µm, ornamented by 2-6 somewhat jagged, irregular, usually longitudinal ridges.

Thermoascus aurantiacus Miehe — Die Selbsterhitzung des Heues: 70. 1907.

– ? *Thermoascus ivatschenkoi* Mal'chevskaya. Trudy Pushkin. Nauchno issled. Lab. Razv. sel'khoz. Zhivot. 13: 26. 1939, *fide* Cooney & Emerson. Thermophilic Fungi: 39. 1964.

Misapplied names: *Thermoascus aurantiacus* Miehe 1907, *sensu* Cooney & Emerson. Thermophilic Fungi: 39. 1964.

Dactylomyces thermophilus Sopp 1912, *sensu* Cooney & Emerson. Thermophilic Fungi: 39. 1964.

Penicillium thermophilus (Sopp) Bourge 1923, *sensu* Cooney & Emerson. Thermophilic Fungi: 39. 1964.

Penicillium thermophilum (Sopp) Sacc., *fide* Trotter 1931; *sensu* Cooney & Emerson. Thermophilic Fungi: 39. 1964.

Descriptions: Stolk (1965), Apinis (1967), Awao & Otsuka (1973), Domsch *et al.* (1980), Chen & Chen (1996).

The type species of *Thermoascus* Miehe (Miehe, 1907), *T. aurantiacus*, was isolated from self-heating hay and carefully described by the author. Few years later, Sopp (1912) reported a second thermophilic ascomycete having a well developed conidial state and for which he proposed the new genus *Dactylomyces*. Sopp then considered *Thermoascus aurantiacus* as approximating his *Dactylomyces thermophilus* n. sp. *ad interim*. This suggestion coupled with the lack of any authentic material for either ascomycetes resulted in much confusion about the exact nature of Miehe's fungus.

In 1963, Apinis isolated from soil near Nottingham several strains he referred to *Thermoascus aurantiacus*. These isolates exhibited no morphological deviations from the original description. They also proved to match a strain maintained at the CBS under this

binomial and isolated by Noack (1912). Apinis noted the structure of the cleistothecium be related to certain species of the *Gymnoascaceae* with the presence of large clavate conidia reminescent of "clasterospores" of some *Trichophyton* species.

In 1964, Cooney & Emerson provided a detailed description and a latin diagnosis of *Thermoascus aurantiacus* based on their "strain M 206516 (our culture No 2)" thought to match Miehe's fungus. This was also then regarded as an earlier name of *Dactylomyces thermophilus*. In the established description, a distinctive conidial state is depicted. This anamorph approximate figures produced by Sopp (1912) and which were later regarded (Stolk, 1965) as rather reminiscent of *Paecilomyces* Bain. (see also comments under *Dactylomyces thermophilus*).

However, in the same year, Apinis & Chesters (1964) introduced *Dactylomyces crustaceus* (anamorph *Paecilomyces crustaceus*) and reported to it the CBS strain 374.62 (= NRRL 1563) labelled *Dactylomyces thermophilus* by Raper & Fennell. In 1965, Stolk re-examined this strain and concurred with Apinis & Chester's decision. She then suggested Cooney & Emerson's neotype of *Thermoascus aurantiacus* (M 206516) is most likely identical with *Dactylomyces crustaceus*.

Stolk (1965) then examined all cultures maintained at the CBS as *Thermoascus aurantiacus*: CBS 256.34, CBS 257.34, CBS 415.62 and CBS 398.64. These isolates produced elliptical finely echinulated ascospores, measuring 5.0-7.0 × 3.5-5.0 µm. No associated anamorph producing chains of conidia was developed by any. The absence of an anamorph producing spore chains was already stressed by Miehe (1907) and such was confirmed few years later by Noack (1912). Stolk then underlined these features support the distinctiveness of *Thermoascus aurantiacus* from *Dactylomyces thermophilus* (having a yet undefined anamorph) and also from the well described *Dactylomyces crustaceus* and its *Paecilomyces* anamorph. Unfortunately Stolk then tranferred the latter to *Thermoascus*.

In 1967, Apinis published a comparative study of *Thermoascus* and *Dactylomyces* based on freshly isolated strains. He re-examined Cooney & Emerson strain M 206516 and confirmed Stolk (1965) suggestion about its similarity with *Dactylomyces crustaceus*. This lead to a definite rejection of Cooney & Emerson's taxonomic considerations about *Thermoascus* type species and to its identity with *Dactylomyces thermophilus*. Second, the morphology of Apinis fresh isolates of *Thermoascus aurantiacus* was in line with Stolk (1965) observations.

Apinis also noted the presence in the aerial mycelium of "conidia of *Aphanoascus* or *Microsporum* type developing terminally on long or short hyphal branches singly and being clavate or somewhat spindle-shaped, smooth, 0-3 septate, 12-35 × 5-10 µm". Miehe (1907) did mention such aleuriospores in the type species. Strain BDU N 343 (= IMI 91787) isolated from alluvial grassland soil was designated neotype for *Thermoascus aurantiacus*.

Recent reports confirms *Thermoascus aurantiacus* have a wide distribution (Domsch *et al*., 1980, Chen & Chen, 1996). This ascomycete proved to be a strong thermophile with growth starting at 30° C and up to 62° C, growth optimum around 45° C with formed colonies being bright orange to orange brown. Ascospores are definitely elliptical and slightly roughened. Presence of terminal aleuriospores apparently depends on examined strains.

Thermoascus was placed in the family *Onygenaceae* (order Onygenales) by Benny & Kimbrough (1980); they placed *Dactylomyces* in the *Trichocomaceae* (order Eurotiales). It was maintained in this family by von Arx (1987) but with *Dactylomyces* being a synonym. *Thermoascus* was however excluded by Currah (1985) from the *Onygenaceae*

because "there is no evidence of keratinolytic abilities nor does it have strictly rhexolytically dehiscing conidia". Currah mentions not *Dactylomyces*

Thermoascus isatschenkoi is regarded as a doubtful species of which no satisfactory description exists and no material is available for comparison (Cooney & Emerson, 1964, Apinis, 1967).

Thermoascus aurantiacus Miehe var. *levisporus* Upadhyay, Farmelo, Goetz & Melan — Mycopathologia 87: 73. 1984.

The original isolate was obtained from a top layer soil at La Ceiba Republic of Honduras Minimum and maximum growth temperatures are 31 and 61 C respectively with the optimum being at 49 50° C The variety differs mainly by ellipsoidal smooth rather than "echinulate ascospores", 3 7-7 1 × 2 2-5 5 µm (5 0-7 0 × 3 5-5 0 µm for the species) Conidial anamorph of the aleuriospore type matching those of the species were infrequent, borne terminally, clavate, thick walled, smooth, 15-25 × 7-17 µm All other characters duplicate the species Production of protease enzymes was also assessed (Matey *et al*., 1984).

Thielavia australiensis Tansey & Jack — Canadian Journal of Botany 53: 82. 1975.

Descriptions Tansey & Jack (1975), von Arx (1975), von Arx *et al* (1988)

The protologue was based on strains isolated from nesting material of an incubator bird the mallee fowl *Leipoa ocellata* Gould in New South Wales, Australia Optimum growth recorded at 35-40° C maximum at 50° C, minimum not defined

This *Thielavia* is distinguished by small pyriform brown ascospores, 6-8 × 5-6 µm, having a germ pore at the attenuated end Simple aleurioconidia are produced in culture according to the protologue, these are continuous, lateral, sessile, colorless, ovoid, 5-8 × 3-5 µm The fungus has apparently not been reported after its description (von Arx *et al*., 1988).

Thielavia pingtungia Chen K-Y. & Chen Z-C. — Mycotaxon 60: 242. 1996.

The fungus was isolated from a sugar-cane field in Taiwan The specific epithet refers to the original locality Pingtung No growth developed between 25 and 30° C with the optimum being around 40° C and the maximum fairly above 50° C

The species is characterized by dark globose cleistothecia covered with brown thick-walled hairy appendages, ascomatal hairs of the *Chaetomium* type, 2 5-4 0 µm wide and up to 350 µm long, ascomatal wall pseudoparenchymatous. Asci cylindric, 40-52 × 7-9 µm, stipitate, fasciculate, 8 spored Ascospores usually uniseriate, globose to subglobose dark brown smooth, thick walled, 8 5-10 0 × 6 5-8 5 µm. No anamorph developed in examined cultures.

Thielavia pingtungia have several features in common with species assigned to *Chaetomidium*, for the moment, the latter groups only mesophilic ascomycetes (Silva & Hanlin, 1996)

Thielavia terrestris (Apinis) Malloch & Cain — Canadian Journal of Botany 50: 66. 1973.

basionym: *Allescheria terrestris* Apinis — Nova Hedwigia 5: 68. 1963.
anamorph: *Acremonium alabamense* Morgan-Jones as "*alabamensis*" — Canadian Journal of Botany 52: 429. 1974

Descriptions: Apinis (1963); Malloch & Cain (1973); von Arx (1975)

The original material was observed by Apinis (1963) in the course of his work on thermophilous fungi inhabiting alluvial soils in Great Britain. He described the fungus as *Allescheria terrestris* without providing any argument favouring such a decision, he also assigned the anamorph to *Cephalosporium* (now *Acremonium* Link Fr.). *Allescheria terrestris* was then transferred to *Thielavia* Zopf. Following its description, the fungus was reported from various habitats and is now known to display a wide geographic distribution. Ascospores are ovate or pyriform, brown, thick-walled, provided with a distinct germ pore at the attenuated end, 5.0-7.5 × 4.0-5.5 µm.

The hyphomycete *Acremonium alabamense* was described exclusive of a teleomorph, it was isolated from needles of *Pinus taeda*. Later on, Samson *et al.* (1977) found it to match the anamorph of *Thielavia terrestris*. For this ascomycete, sometimes only the anamorph is observed during isolation studies and appropriate matings are required for the development of the teleomorph. These authors conducted extensive mating experiments with several strains of *T. terrestris* and *A. alabamense*, they came to the conclusion that the mating behaviour of *Thielavia terrestris* could best be interpreted as indicating homothallism with cross-feeding.

Some species of *Chaetomium* also produce in culture a phialidic state approximating *Acremonium alabamense*. The latter was recently selected as the type of the new section *Chaetomioides* of *Acremonium* established to also accomodate phialidic states of some *Chaetomium* species (Morgan-Jones & Gams, 1982).

THERMOPHILIC HYPHOMYCETES

Acremonium alabamense Morgan-Jones as "*alabamensis*" — Canadian Journal of Botany 52: 429. 1974.

teleomorph: *Thielavia terrestris* (Apinis) Malloch & Cain — Canadian Journal of Botany 50: 66. 1973

Descriptions: Apinis (1963), Morgan-Jones (1974), Morgan-Jones & Gams (1982)

As underlined before, this hyphomycete was described exclusive of the teleomorph being isolated from needles of *Pinus taeda* collected in the state of Alabama (USA). The teleomorph was described before from alluvial soils in Nottingham (UK) with the anamorph being indicated as simply representing a *Cephalosporium* sp.

The repeated isolation of an *Acremonium* sp. from heated habitats led Samson *et al.* (1977) to compare it with the fungus described by Morgan-Jones and the anamorph of

Thielavia terrestris. All three hyphomycetes were found to represent the same fungus. This finding rose few questions concerning the developmental behaviour of the teleomorph. Extensive mating studies were then undertaken with isolates of *Thielavia terrestris*, *Acremonium* sp. and of *A. alabamense*. Although results allowed not a definite conclusion as to the heterothallic nature of the teleomorph, these support the hypothesis indicating the mating behaviours of *Thielavia terrestris* is a case of homothallism with cross-feeding (Samson *et al.*, 1977).

Acremonium alabamense could thus be observed alone in studies involving high temperatures incubation. It was recently selected as type of the new section *Chaetomioides* of the genus established to also accomodate the morphologically similar phialidic states of some *Chaetomium* species (Morgan-Jones & Gams, 1982). The fungus produces comparatively fast growing colonies, velvety, whitish, with yellowish to brownish runner hyphae, 3-4.5 µm wide. Conidiophores are simple, short, 8-25 × 1-1.5 µm. Conidia are obovoid to pyriform, smooth, with a truncated base, 3-6 × 2-3 µm (Morgan Jones, 1974).

Acremonium thermophilum W. Gams & Lacey — Transactions of the British mycological Society 59: 520. 1972.

The described material developed on self heated sugar cane bagasse in Trinidad. The fungus is regarded as unique among known *Acremonium* Link Fr. species on account of its thermophilic habit and production of submerged hyphae partly having pigmented walls. The species was assigned in *Acremonium* sect. *Nectrioidea* due to the development of thick-walled conidiophores with basitonous ramification. Growth is strong but slow at 20° C, very good between 25 and 40° C and very weak at 47° C. Conidia are ellipsoidal, 3.0-4.0 × 1.3-1.7 µm.

Humicola hyalothermophila Moubasher, Mazen & Abdel-Hafez — Transactions of the British mycological Society 72: 509. 1979.

Descriptions: Moubasher *et al.* (1979); Moubasher (1993).

This soil-borne hyphomycete was originally isolated from several localities in Jordan. No growth develops either at 28 or 55° C with good development being at 45° C, growth optimum value is not specified. This thermophile was distinguished from the mesophilic *Humicola fuscoatra* Traaen mainly by its slightly larger hyaline conidia (not colored light brown as in *H. fuscoatra*) and intercalary chlamydospores. It was later on observed in Saudi Arabian soils (Bokhary, 1986).

The taxonomic position of this fungus needs to be re-assessed.

Malbranchea cinnamomea (Libert) van Oorschot & de Hoog — Mycotaxon 20: 129. 1984.

basionym *Trichothecium cinnamomeum* Libert. *Plantae cryptogamae Arduenna*, Coll. I, Nr. 1013. 1830.

– *Geotrichum cinnamomeum* (Libert) Sacc. Revue Mycologique (Toulouse) 11: 55. 1881; *Michelia* 2: 636. 1882.

– *Thermoidium sulfureum* Miehe. Deutsche Botanische Gesellschaft 25: 515. 1907.

– *Malbranchea pulchella* Sacc. Sydow, Annales Mycologici, Ser. II, 6: 557. 1908, Sacc. & Traverso — *Sylloge Fungurom* 20. 11. 1911.

Malbranchea pulchella Sacc. & Penzig var. *sulfurea* (Miehe) Cooney & Emerson. Thermophilic Fungi: 102. 1964.

– *Malbranchea sulfurea* (Miehe) Pidoplichko In "Fungus Flora of Coarse Fodders (in Russian)", 170. 1953.
– *Malbranchea sulfurea* (Miehe) Sigler & Carmichael Mycotaxon 4 441 1976

Descriptions Cooney & Emerson (1964), Sigler & Carmichael (1976)

Miehe (1907) erected *Thermoidium*, type species *T. sulfureum*, for a hyphomycete he encountered during his pioneer investigation of the self-heating process of hay. He studied the fungus in culture and stressed its thermophilic nature. Saccardo (1908) however immediately considered this type species as matching the morphologically close mesophilic type species of his genus *Malbranchea*, *M. pulchella* Sacc.

In 1964, Cooney & Emerson provided an excellent account of a strain matching Miehe's description. For this fungus, they simply proposed the varietal name *sulfurea* pending a comprehensive comparison with the almost identical mesophile *Malbranchea pulchella*. The comparison was later undertaken by Sigler & Carmichael (1976), they concluded high temperature requirements are sufficient to warrant a specific status and provided the binomial *Malbranchea sulfurea* (Miehe) Sigler & Carmichael.

The combination *Malbranchea cinnamomea* was based on *Trichothecium cinnamomeum* Libert. It was established by van Oorschot & de Hoog (1984) after examining dried authentic material of the latter. However the possible similarity with *Malbranchea sulphurea* was not considered. Such was established later on by Sigler (1987) after a study of appropriate authentic material.

Malbranchea cinnamomea is an easily recognizable thermophilic hyphomycete being recorded on a variety of substrates under different conditions (Sigler & Carmichael, 1976).

Myceliophthora fergusii (van Klopotek) van Oorschot — Persoonia 9: 406. 1977.

basionym *Chrysosporium fergusii* van Klopotek Archives of Microbiology 98 366 1974
Teleomorph *Corynascus thermophilus* (Fergus & Sinden) van Klopotek Archives of Microbiology 98: 366. 1974.

Descriptions: van Klopotek (1974); van Oorschot (1977, 1980).

As underlined under the teleomorph, provision for the anamorph of this ascomycete was made several years after the discovery of the heterothallic nature of the perfect state. The anamorph was simply stated as being distinct from the close previously described hyphomycete now renamed *Myceliophthora thermophila*. Both anamorphs can thus be observed separately from their respective teleomorphs in mycological analyses conducted at high incubation temperatures.

Myceliophthora fergusii produces pinkish-cream floccose colonies, aleuriospores are pyriform to clavate, smooth and thick walled, nearly hyaline and with narrow basal attachments, 5-12 × 3-5 µm.

Myceliophthora hinnulea Awao & Udagawa — Mycotaxon 16: 438. 1983.

The type locality is cultivated soil in Japan. Fungal growth is extremely reduced at 20° C, optimal growth is at 40-45° C and maximum somewhat above 50° C. No connection with a teleomorph yet established.

Myceliophthora hinnulea differs from the five previously described species (van Oorschot, 1980) mainly by dull to greyish brown colonies and brownish conidia conspicuously verrucose to spinulose, 8.0-10.0 × 6.0-7.5 µm. Almost all known members of this genus are thermotolerant or thermophilic with sporulation often being good between 30-40° C.

Myceliophthora thermophila (Apinis) van Oorschot — Persoonia 9: 403. 1977.

basionym *Sporotrichum thermophilum* Apinis as *thermophile* — Nova Hedwigia 5: 74. 1963.

– *Chrysosporium thermophilum* (Apinis) van Klopotek — Archives of Microbiology 98: 366. 1974.

– *Myceliophthora indica* Basu — Nova Hedwigia 40: 85. 1984 (*nom. inval.*, Art. 37.1).

Teleomorph *Corynascus heterothallicus* (van Klopotek) von Arx — Sydowia 34: 25. 1981.

Descriptions: van Oorschot (1977, 1980), van Klopotek (1974).

As stressed before *Myceliophthora thermophila* was described exclusive of its correspond.ng teleomorph. Since the latter is heterothallic, the anamorph could thus be observed alone in studies involving thermophilic fungi. The species differs from other members of the genus by its dark colored colonies, occasionnally greenish and by smaller mostly obovate conidia, 4.5-11.0 × 3.0-4.5 µm, conidia are hyaline, thick-walled and rough. Fresh isolates always have some rough conidia but older cultures tend to produce only smooth ones. The species displays a wide geographic distribution being a common component of decaying manure, silage, wood chips and pulp, etc. (Cannon, 1990).

Myceliophthora indica was isolated from garden soil and from decomposed leaves of *Chloris* sp. Attemps to locate original material were unsuccessful although Basu (1984) underlined her intention to deposit both available strains at the CBS. The fungus was compared with the type culture of *Myceliophthora thermophila* considered by Basu as being thermotolerant. The "strongly thermophilic" Indian strain was found to deviate mainly by smaller definitely roughened conidia. No mating attempts were undertaken and the existence of a known teleomorph not stressed in the publication. Analysis of the protologue clearly indicates the Indian strain do represent *Myceliophthora thermophila*.

Scytalidium indonesicum Hedger, Samson & Basuki — Transactions of the British mycological Society 78: 365. 1982.

The original material was isolated from soil of the Bogor Botanic Garden, West Java. The fungus was also recovered from *Dipterocarp* forest soils in South Sumatra. It was reported as being simply "thermophilous" able to grow rapidly at 45° C 8.5 cm at 36 h. Later Straatsma & Samson (1993) stated it is thermophilic.

The Indonesian taxon is distinguished by the production of conidia (intercalary chlamydospores) thick-walled brown, ellipsoid to barrel shaped, often with irregular

outgrowths and also often constricted at the middle of the cell, 15-25 × 7-12 µm, on maturity these conidia secede rather easily and appear irregular in shape Dark brown and thick-walled similar but less wider conidia (termed arthroconidia) also develop in chains, 13-32 × 5-8 µm, these do not secede easily The presence of terminal conidia (or lateral) is not underlined

Scytalidium indonesicum approximates *S thermophilum* which mostly produces spherical to subspherical dark brown smooth conidia 9-14 µm wide, oblong or ellipsoidal ones measure 8-18 × 7-14 µm However, neither these *Scytalidium* develop the second hyaline arthroconidial state characteristic of the type species, *S lignicola* (Ellis M B, 1976) The description of *S indonesicum* is however in line with the introduction in *Scytalidium* of taxa only developing dematiaceous arthroconidia (Sigler & Wang, 1990) Such additions makes *Scytalidium* a heterogeneous entity.

Scytalidium thermophilum (Cooney & Emerson) Austwick — New Zealand Journal of Agricultural Research 19: 29. 1976; emend. Straatsma & Samson — Mycological Research 97: 327. 1993.

basionym. *Torula thermophila* Cooney & Emerson Thermophilic Fungi 92 1964

Humicola insolens Cooney & Emerson — Thermophilic Fungi: 79. 1964

– *Humicola fuscoatra* var *longispora forma insolens* (Cooney & Emerson) Fassatiova Ceska Mykologie 21: 80. 1967.

– *Humicola grisea* Traaen var *thermoidea* Cooney & Emerson Thermophilic Fungi: 79 1964

Humicola insolens Cooney & Emerson var *thermoidea* D H Ellis Transactions of the British mycological Society 78 133. 1982.

Humicola fuscoatra Traaen var *nigra* Subrahmanyam Hindustan Antibiotics Bulletin 24 41 1982 (*nom inval*, Art 36 1 description only), *Ibid* 25 62 1983 (latin diagnosis, *nom. inval*, Art. 37.1)

– *Humicola nigrescens* Omvik var *thermorongeura* Subrahmanyam Hindustan Antibiotics Bulletin 24 45 1982 (nom. inval, Art 36 1 description only), *Ibid* 25 62 1983 (latin diagnosis; *nom inval.*, Art. 37.1).

= *Scytalidium allahabadum* Narain, Srivastava & Mehrotra Zentralblatt fur Mikrobiologie 138: 570. 1983.

Descriptions Cooney & Emerson (1964), Ellis M B (1976), Straatsma & Samson (1993)

Cooney & Emerson (1964) while describing *Humicola insolens* and *H grisea* var *thermoidea* indicated "the problems concerned with the *Monotospora Humicola-Torula* can only be resolved when all forms, both thermophilic and mesophilic, can be studied and compared in detail" The genus *Monotospora* was cited in relation to Mason (1941) who had then concluded that *M dalae* Mason predates *Humicola fuscoatra* Traaen *Torula thermophila* was apparently not concerned by this statement since its description is found some twenty pages later *Humicola grisea* var *thermoidea* was considered as a variety (although not producing phialospores as the species) "chiefly because of the uncommon occurrence of intercalary chlamydospores" The abundance of these structures was then used to distinguish *Humicola insolens* Cooney & Emerson

Later, Emerson (1968) stressed "*Humicola grisea* var *thermoidea* has smooth-walled chlamydospores (aleuriospores) borne singly on short lateral branches with the almost absence of any intercalary chlamydospores, on the other hand, isolates of *Humicola insolens* regularly produces intercalary chlamydospores singly, in pairs or in short

chains in addition to solitary terminal spores on short lateral branches, in *Torula thermophila* chlamydospores are again smooth and brown, all formed in longer or shorter intercalary chains and rarely in a terminal position"

The taxonomic status of this *Humicola-Torula* complex remained unchanged until Austwick (1976) transferred *Torula thermophila* to *Scytalidium* Pesante sensu Ellis M. B. (1971), the latter had emphasized the dark pigmented arthroconidia of the type species *S. lignicola*. However Austwick did not provide any argument in favour of such transfer. Later Sigler & Carmichael (1976) in the course of their study of hyphomycetes with arthroconidia accepted *Scytalidium* as delimited by Ellis M. B., seven species were then retained with some developing only the dematiaceous chlamydosporic state. The additions introduced much heterogeneity in the genus (Sigler & Wang, 1990).

Ellis D. H. (1982) conducted ultrastructural studies of the conidial ontogeny of both *Humicola* proposed by Cooney & Emerson (1964). After examining type strains and other isolates, he concluded *H. grisea* var. *thermoidea* is a separate entity exhibiting considerable genetic variation among strains, further, it should rather be considered as a variety of *Humicola insolens*. This proposal was not in line with the suggestion entertained earlier by Awao & Otsuka (1974) stating that both Cooney & Emerson's *Humicola* and *Torula* represent the same fungus.

The respective status of these three hyphomycetes remained as such until the recent publication made by Straatsma & Samson (1993). They compared a large number of strains labeled *Torula thermophila*, *Humicola grisea* var. *thermoidea* or *H. insolens* including corresponding authentic material. Their conclusion was that all such strains represent one single variable species or a group of morphologically indistinguishable species complex for which the binomial *Scytalidium thermophilum* (Cooney & Emerson) Austwick was valid and continue to be applied pending further studies. Such a limitation accounts for the fact the type species of *Scytalidium* is a dimorphic fungus having in addition to its arthroconidial synanamorph the use of the binomial *Scytalidium thermophilum* as a whole is questioned.

Humicola grisea var. *nigra* Subrahmanyam was isolated form soil at Kanpur, India. The protologue almost duplicates that of *Humicola insolens* sensu Cooney & Emerson except that aleurospores of the Indian strain are indicated as being somewhat larger. Aleurospores are unicellular, rarely bicellular, single, rarely in chains of 2-3, smooth, hyaline, oval and (20-)26 µm diam., ovoid and 13.0-16.5 × 10.2-16.5 µm or pyriform, (5.1-)5.5 × (10.2-)14.0 µm. Chlamydospores intercalary with dimensions and description identical to those of the aleuriospores.

Humicola grisea var. *thermorangeata* Subrahmanyam was isolated from soil under *Ricinus* sp. at Maharashtran, India. The provided protologue stress the presence of aleurospores produced singly or in chains, globose (8.5-14.5 µm) or ovoid (11.0-14.0-)-12.0 µm) with similar intercalary chlamydospores. This description matches that of *Humicola grisea* var. *thermoidea sensu* Cooney & Emerson.

Scytalidium dimidiatum Narain *et al.* developed while examining mycoflora of refuse in the Allahabad region, India. It was first identified by P. M. Kirk (IMI 243118) as *Scytalidium thermophilum* (Narain *et al.*, 1983). However the Indian authors stressed that the strain deviates on account of its colonies colored grevish-black coupled with the formation of larger spores with shapes commonly other than globose. In *Scytalidium dimidiatum* the globose spores vary from 4.5-12.0 µm while those of other shapes measure 4.5-8.3-11.0 µm (10.0-12.5 × 7.5-10.0 µm) for an Indian strain of *Scytalidium thermophilum*. Re-examination of the type material (IMI 243118) confirm it represents a strain of *Scytalidium thermophilum*.

Thermophymatospora fibuligera Udagawa, Awao & Abdullah — Mycotaxon 37: 100-101. 1986.

Thermophymatospora Udagawa *et al* (1986) was proposed for an unusual soil-borne hyphomycete assignable to a basidiomycete anamorph. The original strain of the type species *T. fibuligera* derives from an Iraqi date palm plantation. It is characterized by holoblastic unicellular conidia being terminal or lateral, large, brownish, globose, thick walled and tuberculate, 20-25 µm wide. Such conidia are superficially reminiscent of some *Verticillophthora* species. However the hyphae of this hyphomycete are regularly provided with simple clamp connections at the transverse septa. No link with a particular teleomorph has yet been established.

The fungus growth and sporulation are optimal around 35-40° C, almost nil at 20° C, with maximum being at 45° C.

Thermomyces ibadensis Apinis & Eggins — Transactions of the British mycological Society 49: 631. 1966.

This hyphomycete was first recorded during studies of micro-organisms responsible for the biodeterioration of palm kernels in Nigeria. The minimum temperature for growth is between 31-35° C, optimum lies around 42-47° C and maximum at 60-61° C. This *Thermomyces* differs from the type species *T. lanuginosus* by its smaller unicellular, spherical, smooth, brown conidia, 4.0-8.0 µm wide, and by its slender and more frequently branched conidiophores.

Thermomyces lanuginosus P. Tsiklinsky (*sensu* Miehe 1907) — Annales de l'Institut Pasteur, Paris 13: 500-505. 1899.

Sepedonium lanuginosum ('Miehe') Griffon & Maublanc. Bulletin de la Societé Mycologique de France 27: 70. 1911.

Monotospora lanuginosa (Griffon & Maublanc) Mason. Mycological Papers 3: 59. 1933.

Humicola lanuginosa (Griffon & Maublanc) Bance as '*lanuginosus*'. Transactions of the British mycological Society 44: 375. 1961.

Acremoniella sp. Rege. Annales of Applied Biology 14: 28. 1927, *fide* Mason, 1933.

A. thermophila Carzi. Atti dell'Istituto botanico dell'Universita di Pavia, Ser. 4, 1: 54. 1929, *fide* Mason, 1933.

Humicola grisea Traaen var. *indica* Subrahmanyam. Current Science 49: 30. 1980 (*nom. inval.*, Art. 36.1).

Humicola lanuginosa (Griffon & Maublanc) Bance var. *catenulata* Morinaga in Morinaga, Kanda & Nomi. Journal of Fermentation Technology 64: 452. 1986.

Descriptions: Cooney & Emerson (1964), Barron (1968), Ellis M. B. (1971), Domsch *et al* (1980).

Thermomyces was introduced by Tsiklinsky (1899) for one species, *T. lanuginosus*, isolated from garden soil, the original isolate was however not maintained. Miehe (1907) retained this binomial for an isolate from composted hay. Griffon & Maublanc (1911) studied a culture identical with the strain figured by Miehe, but expressed doubts as to whether the corresponding hyphomycete would be conspecific with the fungus proposed by Tsiklinsky. They argued the protologue was insufficient for a definite conclusion.

since from published informations, the fungus examined by Tsiklinsky would have conidia definitely smaller than indicated by Miehe" Griffon & Maublanc then assigned their isolate to *Sepedonium* Link on account of the slightly verrucose nature of the conidial wall.

In 1933, Mason examined a culture of *Acremonella thermophila* Curzi, "kindly supplied by Mr Curzi", he noticed the similarity with *Sepedonium lanuginosum* and also with *Acremonella* sp. Rege As Mason had concluded before that *Acremonella* Sacc. was a synonym of the earlier *Monotospora* Corda (non *Monotospora* Vuill.), he proposed to rename the fungus of Griffon & Maublanc *Monotospora lanuginosa*. No mention of the binomial *Thermomyces lanuginosus* was made by Mason. In the meantime Curzi (1930) published an extensive cultural study of his *Acremonella thermophila*, a fungus he had previously submitted to Griffon & Maublanc for examination (*fide* Mason, 1933).

While describing *Thermomyces stellatus* (= *Humicola stellata*), Bunce (1961) questioned the maintenance of the Griffon & Maublanc fungus in *Monotospora* Corda since [and as also stressed by Mason (1933, 1941)], the concept of this genus was still under debate. Bunce rather favoured the transfer of *Monotospora lanuginosa* to *Humicola* Traaen established for mesophilic hyphomycetes sharing the same type of aleurospores. Cooney & Emerson (1964) followed Bunce proposal. On the other hand La Touche (1950) who had isolated this fungus from compost, considered the binomial *Thermomyces lanuginosus*. The latter name was also retained by Apinis (1963) on the basis all his isolates from alluvial soils agreed with the original description provided by Tsiklinsky (1899).

The status of *Thermomyces* was finaly definitively settled by Pugh *et al.* (1964) while describing the mesophilic *T. verrucosus*, in the latter a transverse septum is present just below the conidiophore apex delimiting a small apical cell. According to these authors, such a feature is evident from Tsiklinsky's photomicrographs and this provides arguments that her isolate is identical to the fungus now known as *Thermomyces lanuginosus*. Pugh *et al.* then provided a description and drawings for the latter based on the neotype strain [MI 84406 (= ATCC 22070)] isolated by Bunce from mouldy hay at the Rothamsted Experimental Station in 1959.

In the same year 1964, Cooney & Emerson in their treatment of thermophilic fungi underlined their first isolate of *Humicola* / *Thermomyces lanuginosus* was strain No. 20 obtained in 1945 by D. G. Cooney from retting guayule shrub. This strain was later on numbered M 206522 at the University of California Herbarium, Berkeley (= ATCC 16455, = CBS 632.91). It provided the material for the description and drawings reported in their monograph. The isolate selected by Pugh *et al.* (1964) was explicitely designated "neotype", it has to be regarded as such against M 206522.

Subsequent taxonomic treatments of hyphomycetes uniformly accepted *Thermomyces* (Carmichael *et al.*, 1980). An ultrastructural study of the conidial ontogeny of its type species was conducted by Ellis D. H. (1981). Further, recently Straatsma and Samson (1993) re-examined isolate CBS 153.75 (= ATCC 28402) belonging to the unpublished *Humicola brevis* (Gilman & Abbott) Gilman var. *thermoidea* Subrahmanyam, this was re-identified as *Thermomyces lanuginosus*. They also concluded the same for the similar unpublished taxon *Humicola brevispora* Subrahmanyam & Thiramalachar based on CBS 152.75 (= ATCC 28403).

Humicola grisea var. *indica* (Subrahmanyam 1983) was obtained as a laboratory contaminant at Pimpri, Poona. Trials to locate the representative strain were unsuccessful. According to the author, a critical study revealed "it belonged" to *Humicola grisea* (which produces intercalary chlamydospores) and approximates its var. *thermoidea* (which also produces intercalary chlamydospores). However, the general lay-out of the drawings and

features underlined in the description clearly stress the proposed variety represents *Thermomyces lanuginosus*. The only deviation is the smooth character of the conidia in the proposed variety against the wrinkled conidial surface of *Thermomyces lanuginosus*.

Humicola lanuginosa var. *catenulata* (Morinaga *et al*., 1986) was obtained in the course of a survey of soil borne thermophiles for high producer strains of lipase enzymes. Morphological details underlined in the publication clearly indicate it represents a deviant strain of *Thermomyces lanuginosus*.

The mesophilic *Thermomyces verrucosus* Pugh, Blakeman & Morgan-Jones (1964) displays no growth above 37° C. It has globose, dark brown conidia with conspicuously warted surfaces, 10-17 µm wide. These structures are definitely larger than aleuriospores of the type species.

Thermomyces stellatus (Bunce) Apinis — Nova Hedwigia 5: 75. 1963.

basionym: *Humicola stellata* Bunce as '*stellatus*'. Transactions of the British mycological Society 44: 372. 1961.

Descriptions: Bunce (1961); Apinis (1963); Ellis M. B. (1971).

The original material was isolated from mouldy hay in England and Wales. The fungus develops optimally at 40° C with growth being very slow at 24° C and not extending above 50° C. Conidia of the aleuriospore type, angular, lobed, smooth, pale to mid brown or greyish brown, 5·10 × 5·9 µm. The transfer to *Thermomyces* is based on account of the absence of phialospores in culture and similarity in conidiogenesis.

THERMOPHILIC MYCELIA STERILIA

Myriococcum thermophilum (Fergus) van der Aa — Verhandelingen Koninklijke Nederlandse Akademie van Wetenschappen Afd. Natuurkunde, seies II, 61: 60. 1973.

basionym: *Papulaspora thermophila* Fergus. Mycologia 63: 426. 1971.

Descriptions: Fergus (1971); van der Aa (1973)

This 'bulbil-producing fungus' was described from mushroom compost in Switzerland (Fergus, 1971). *In vitro*, such structures appear very rapidly at 45° C in the aerial and submerged mycelium. They are white at first, then yellow and finally orange at maturity, in mature bulbils, cells of the outer layers are narrower and more elongate than corresponding internal more intensely colored globose cells. The fungus shows no growth at 28° C and 53° C with the optimum being at 45° C. No connection with a perfect stage yet established.

From seedlings of a *Begonia* species heavily infected with small sclerotia, van der Aa (1973) isolated a fungus matching the description of the type of *Myriococcum* Fr., *M. praecox* Fr. Subsequent comparison with representatives strains of *Papulaspora byssina* Hotson confirmed similarity of both taxa. Also examination of the type of *Papulaspora thermophila* Fergus proved it to be congeneric with *Myriococcum praecox* except for

its thermophilic character As *Myriococcum* predates *Papulaspora* Preuss, van der Aa transferred Fergus fungus to the former generic entity

The term bulbil is now restricted to homogeneous pseudoparenchymatous bodies occurring only in the basidiomycetous genera *Burgoa* Goidanich and *Minimedusa* Weresub & LeClair. The term papulaspore is applied to thallodic propagules differentiated from the inception into central and sheathing cells (Weresub & LeClair, 1971) Such thallodic propagules occur amongst the mycelia of some species of *Melanospora* Corda and few probably related ascomycetes.

THERMOTOLERANT BASIDIOMYCETE

Phanerochaete chrysosporium Burdsall *apud* Burdsall & Eslyn — Mycotaxon 1: 124. 1974.

anamorph *Sporotrichum pruinosum* Gilman & Abbott Iowa State College Journal of Science 1: 306. 1927.
– *Chrysosporium pruinosum* (Gilman & Abbott) Carmichael Canadian Journal of Botany 40: 1166 1962.
Emmensia brasiliensis Batista *et al* Revista Facultad Medecina, Universidad de Ceara (Brazil) 3: 52. 1963.
– *Sporotrichum dehradunense* Sarbhoy & Saksena Sydowia, Annales Mycologici, Ser II, 19: 198. 1966 ("1965").
= *Chrysosporium lignorum* Bergman & Nilsson Department of Forestry, Proceedings of the Royal College of Forestry, Stockholm, Research Notes, 53 28 1966. (*nom inval*., Art. 36.1).
Sporotrichum pulverulentum Novobranova Novosti sistematiki nizshikh rastenii 9 184. 1972

Description: Stalpers (1984)

Sporotrichum pruinosum (also as *S pulverulentum* and *Phanerochaete chrysosporium*) is a thermotolerant hyphomycete that has become the subject of many recent physiological studies. The fungus is known to produce three types of hydrolytic enzymes active in the degradation of cellulose It is actually used as a model for the biodegradation of lignin and the production of protein from lignocellulosic waste material, a process designated single-cell protein (Stalpers, 1984) For these reasons, it is included in this study

The protologue of the anamorph is based on a strain isolated from soil The fungus was later on transferred to *Chrysosporium* Corda on account of the confusion surrounding the generic concept of *Sporotrichum* Link (Stalpers, 1978). As for the teleomorph, the first specimen was collected in the Sonoran Desert, Arizona (USA), when cultured, it produced a *Chrysosporium* state matching *Sporotrichum pruinosum* Later on the teleomorph could be obtained *in vitro* under particular cultural conditions. Reported cardinal temperatures are minimum 7° C, optimum 36-40° C, maximum 46-49° C

In culture *Sporotrichum pruinosum* is the most variable species of the genus and such accounts for the several published synonymies. The similarity with *S pulverulentum* has been the matter of a long debate (Burdsall, 1981) but recent studies provided

arguments in favour of such a synonymy (Stalpers, 1984). Citation in applied work of the teleomorphic name is favoured against the two commonly cited anamorphic binomials since several nomenclatural problems are still connected with the latter. The fungus has also been reported as a human pathogen being isolated from lungs and this explain its inclusion in the genus *Emmonsia* Ciferri & Montemartini.

TAXA OF UNCERTAIN POSITION

— *Mucor thermo-hyalospora* Subrahmanyam — Bibliotheca Mycologica 91: 421. 1983. (*nom. inval.*, Art. 37.1).

The examined strain was isolated from contaminated curd collected in the local market at Pimpri, Poona, India. The fungus is clearly thermophilic with growth starting at 24° C, being optimum at 45° C and maximum at 55° C. According to the author "careful study of monosporic cultures showed that is closely resembled *Mucor tauricus* Milko & Schkur but differs from it in being homothallic. Therefore it is described here as a new species".

The presence of weakly developed rhizoids in *Mucor tauricus*, accounted for its transfer to *Rhizomucor* by Schipper (1978). This information was however overlooked by Subrahmanyam (1983) who also provides no details concerning the presence or the absence of corresponding structures in his zygomycete. This taxon might simply represent a deviant strain of *Rhizomucor pusillus*.

Stilbella thermophila Fergus — Mycologia 56: 277. 1964.

This synnematous hyphomycete was first isolated from mushroom compost in Switzerland. Optimum growth is between 35-50° C, at 55° C, slight development still occurs but such is not the case below 25° C. In culture, the fungus produces white synnemata, up to 300 µm high, bearing whitish glistening mucoid conidial heads, conidia are hyaline, continuous, oblong-ellipsoid, 15-17 × 6-10 µm.

Seifert (1985) in his monographic treatment of *Stilbella* Lindau re-examined authentic material. Conidia were observed to develop from percurrently proliferating conidiogenous cells, i.e. annellophores, a feature enhancing its exclusion from the genus. Additionnal work is undertaken to establish the correct taxonomic position of this species (Seifert, pers. comm.).

CONFUSING BINOMIALS

— *Achaetomium thermophilum* Basu — Current Science 51: 524. 1982.

The original living strain was isolated from leaf litter at Bhattni, Uttar Pradesh, India. It was described as being similar to *Achaetomium macrosporum* Rai, Wadham. & Tewari but differ by being "thermophilic" in nature, although no minimum growth temperature had been indicated.

Cannon (1986) examined a culture (IMI 292262) derived from the holotype Growth and sporulation proved to be satisfactorily at 25° C indicating the fungus is rather thermotolerant Ascospores produced were also found to be uniporate rather than biporate as stressed in the protologue and thus matching those of *Achaetomium macrosporum* Based on these observations, Cannon concluded the ascomycete proposed by Basu is conspecific with *Achaetomium macrosporum*.

Species of *Achaetomium* Rai & Tewari are known to be good thermotolerants (von Arx *et al*., 1988) The concept of the genus is however still under debate. Thus von Arx *et al* (1988) excluded *A. macrosporum*, they also suggested the latter is rather similar to *Chaetomium vitellinum* Carter or *Ch. megasporum* Sörgel.

Calcarisporiella thermophila (Evans) de Hoog — Studies in Mycology 7: 68. 1974.

basionym *Calcarisporium thermophile* Evans Transactions of the British mycological Society 57: 247. 1971.

This is the type species of the mucedinaceous genus *Calcarisporiella* de Hoog (de Hoog, 1974) The original living culture was isolated from coal spoil tips at Staffordshire, England According to Evans (1971 a & b), the minimum growth temperature value is 16° C, optimum at 40° C and maximum at 50° C The fungus should thus be considered a thermotolerant

Endoblastomyces thermophilus Odinzowa — Microbiology, Moscow 16: 273. 1947 (descripion only); Die Systematik der Hefen: ?. 1960 (latin diagnosis but no type designated); (*nom. inval.*, Arts. 36.1 & 37.1).

This is the type species of *Endoblastomyces* Odinzowa The original protolgue was not accompanied by a latin diagnosis provided later on by Ozindowa in Kudryavtzev's book "Die Systematik der Hefen", the german translation of which was published in Berlin in 1960, however, Odinzowa then omitted to designate a holotype

This yeast was isolated from brewing wort inoculated with baker's yeast in a bread factory in Central Asia, USSR, it was considered to represent a new thermophilic taxon Carmo-Sousa (1970) was unable to locate the corresponding living strain and according to him, the original description strongly suggests similarity with *Trichosporon capitatum* Diddens & Lodder This was substantiated by the arrangement of the pseudomycelium, endoblastospores formation and maximum temperature of growth being identical in both taxa

Trichosporon capitatum is not thermophilic in the sense of Cooney & Emerson being able to develop below 20° C with a maximum at 44-46° C (Carmo-Sousa, 1970) The fungus was later on relocated in *Geotrichum* Link:Fr and its perfect state discovered by de Hoog *et al*. (1980).

Geotrichum candidum Link var. *thermoideum* Qureschi & Mirza — Biologia, Lahore 27: 144. 1981.

The original material was isolated from camel dung in Pakistan The fungus was regarded by van Oorschot & de Hoog (1984) as a possible synonym of *Arthrographis sulfurea* (Grev. Fr.) Stalpers & van Oorschot, a mesophilic hyphomycete.

Gilmaniella thermophila Qureschi & Mirza — Biologia, Lahore 29: 341. 1983.

The original material developed on goat dung collected in Pakistan. The species was overlooked by Sivanesan and Sutton (1985) while describing *Gilmaniella punctiformis* and also by Moustafa and Ezz-Eldin (1989) during their recent addition of *G. multiporosa*, isolated from Egyptian soils in North Sinai. These additions brings to five the number of known species.

Gilmaniella thermophila might be a later name of *G. macrospora* Moustafa, the final decision awaits comparison of authentic material. The latter was first encountered while investigating the mycoflora of salt-marsh soils of Kuwait. It was also subsequently recovered, although infrequently, from Iraqi soils analysed by Abdullah & Al-Bader (1990). The Iraqi strains developed optimal growth at 40° C with a maximum between 45-50° C thus confirming the thermotolerance abilities of *Gilmaniella macrospora*. The specific epithet refers to globose condia being larger than conidia of *Gilmaniella humicola*, the type species. 14-18 µm versus 7-10 µm for the latter.

Lagenidium thermophilum Nakamura, M. Nakamura, Hatai & Zafran — Mycoscience 36: 400. 1996.

The specific epithet coined for this newly described Oomycete is misleading. The fungus was found to infect the eggs and larvae of the mangrove crab, *Scylla serrata* Forsskal, in Bali, Indonesia. Isolated strains proved to represent a new species of *Lagenidium* Schenk having a unique discharge process. Growth range is from 15-45° C with the optimum being between 30-40° C. This taxon is thus a fast growing thermotolerant fungus.

Melanomphalia thermophila (Singer) Singer — Atas, Instituto de Micologia, Universidade de Recife 5: 482. 1963.

basionym *Tubaria thermophila* Singer. Papers of the Michigan Academy of Sciences, Arts and Letters 32: 145. 1948

The type specimen of this basidiomycete was collected by the author in the state of Florida (USA) at Highland Hammock State Park (Singer F 20, F 20a, FH). The habitat in which the carpophore developed was specified as "*In dumetis subtropicalibus humidissimus in terra humosa sabulosa vel nonnunquam ligno mucido*. *Carnae megacarpae, aestate*." The reason underlying the selection of the epithet *thermophila* seems to have simply been suggested by the very warm to hot humid weather prevailing in this southern state of the United States. The fungus is not a thermophile in the Cooney & Emerson's sense.

Similar cases concern *Russula roseipes* (Secr.) Sacc. *subsp. thermophila* Singer, collected under *Pinus taeda* in North Florida, and *Suillus hirtellus* (Peck) Kuntze var. *thermophilus* (Singer) Smith & Thiers (Singer, 1975).

Mucor thermophilus Prakash & Sarbhoy — Zentralblatt für Mikrobiologie 148: 531. 1993.

The specific epithet coined for this recently described zygomycete is misleading since "the species is able to grow and sporulate at 30° C and above 30° C" (Prakash & Sarbhoy, 1993), however, the minimum and maximum growth temperature values were not ascertained. Further the statement that "the specific epithet has been given on thermotolerant nature of the species" clearly indicates the fungus is not a thermophile in the Cooney & Emerson's sense.

Paecilomyces puntonii (Vuillemin) Nannfeldt *sensu* Eicker (1972):

The correct binomial for this hyphomycete is *Paecilomyces puntonii* (Vuillemin) Nannizi (Samson, 1974).

Eicker (1972) isolated a hyphomycete from the faeces of domestic fowls in South Africa strain UP 71 T (University of Pretoria) he identified as *Paecilomyces puntonii*. This isolate "did not grow at 20° C, neither at 30° C but good growth took place at 50° C. No perfect state developed on any of the cultures media at the various temperatures of incubation used". *Paecilomyces puntonii* is a mesophilic fungus with optimum growth being at 25° C (Samson, 1974).

Sporotrichum cellulophilum:

Durand *et al.* (1984) clearly specify this binomial correspond to a thermophilic fungus. Its ability to produce interesting enzymes of the cellulases and hemicellulases types were largely investigated by several workers (Kinoshito *et al.*, 1986). However, Stalpers in his 1984 revision of *Sporotrichum* makes no mention of this binomial in the check-list of epithets used in combination with the genus. Also publication of this binomial after this date following standard taxonomic rules could not be traced. It is thus evident that *Sporotrichum cellulophilum* has no taxonomic status.

With regard to literature on thermophilic fungi, the generic epithet *Sporotrichum* was first introduced by Apinis (1963) for a hyphomycete which ultimately will be renamed *Myceliophthora thermophila*, this will also prove to be the anamorph of *Corynascus heterothallicus*. A second *Sporotrichum* made its appearance in the last decades in papers dealing with biotechnological work *Sporotrichum pruinosum*, anamorph of the basidiomycete *Phanerochaete chrysosporium*. This thermotolerant hyphomycete was described also under several *Sporotrichum* names (see comment under *Phanerochaete chrysosporium*). It is sometimes erroneously indicated as being thermophilic (Deshpande *et al.*, 1978).

The common use of "ghost binomials" in publications dealing with applied studies involving fungi is a source of serious confusion. A similar case is forwarded by the binomial *Acremonium cellulophilum* (Satyanarayana *et al.* 1992). Such a practice should be definitely prohibited.

Sordaria thermophila Fields — Mycologia 60: 1117. 1968.

The original strain of this ascomycete developed on cow dung collected in Texas (USA) and incubated in a moist chamber. According to the protologue "the specific epithet refers to a high temperature requirement for ascospore germination. Ascospores of the new species germinated less than 1 % on media containing sodium acetate. With an additional treatment of 40-45° C for a period of 8-12 h, germination was increased to 40 %."

In the published description no data is reported on the *in vitro* linear variation of growth with temperature. Also the conditions at which moist chambers were incubated are not specified (Fields, 1968). The thermophilic nature of this taxon thus cannnot be ascertained. The selected specific epithet seems to relate to the heat treatment applied to enhance ascospore germination.

Guarro & von Arx (1987) regarded this heterothallic relative of *Sordaria fimicola* (Rob.) Ces. & de Not. as representing a good species. Further investigations are however required to underline the biological and taxonomical characteristics of this ascomycete which apparently has not been reported since its description.

***Zalerion thermophylii* Udaiyan — Journal of Economic and Taxonomic Botany 15: 664. 1991 (1992); (*nom. inval.*, Art. 37.1).**

The original material developed on beech wood test blocks immersed in the cooling tower and the collecting lagoon of a hydroelectric plant at Tamil Nadu, holotype was not indicated.

The dematiaceous hyphomycete genus *Zalerion* Moore & Meyers was established for a widely distributed mesophilic fungus trapped on wood blocks immersed in sea-water, *Z. maritima* (Linder) Anastasiou , described before under several names (Ellis M. B., 1976). *Zalerion thermophylii* is most probably identical to the type species. The epithet *thermophylii* must have been suggested by the high temperature of the water circulating in the cooling tower.

DISCUSSION

Thermophilic fungi dealt with in this contribution are found to form a small group of less than forty species and varieties. Growth at high temperatures is thus definitely a rare feature among fungi. Also several of these taxa were described in recent years. This ecological group is thus expected to expand rapidly in the near future, in particular if some credit is awarded to the estimate amounting the number of existing species to one million and half. A major emphasis for this trend is also embodied by the outcome of taxonomic work conducted in the last decades. Such achievements have provided adequate answers for long standing problems. A limited additionnal work of this type is still necessary to solve remaining minor ones.

Taxa treated here are considered as strict thermophiles based on the definition of thermophilism provided by Cooney & Emerson (1964). However the use of this simple classificatory system to segregate between thermophilic and thermotolerants is sometimes difficult to apply, this is particularly critical at the lower temperature threshold of 20° C. Thus following Bokhary *et al.* (1984), the well established thermophile *Melanocarpus albomyces* should be regarded a thermotolerant being able to grow below 20° C. It is possible the response of different strains of the same taxon accounts for such deviations. Further difficulties in defining true thermophiles results from the absence of reliable growth curves covering a wide range of temperatures for most taxa proposed as such. This basic simple type of data is needed to ascertain the true nature of few members of this group.

Based on available informations, the ability to only develop at high temperatures is disclosed by few Mucorales, Eurotiales and Sphaeriales (*sensu* von Arx, 1988) and by

several Hyphomycetes. No coelomycete and no basidiomycete was found to be thermophilic. Further the teleomorph of the sole thermophilic agonomycete, *Myriococcum thermophilum*, is hypothesized not to belong to Farotiales on the assumption it should have made its appearance since the fungus was described. However observations relating to mating experiments of this sterile fungus are uncommon in the literature.

The group of five thermophilic Mucorales comprise the still monospecific *Thermomucor* and several Rhizomucors including the type, the former differs mainly by having smooth zygospores, a character uncommon in the *Mucoraceae*. Also although regular production of zygospores by *Rhizomucor miehei* should prevent confusion with *Rh. pusillus*, the type species, the ecology of each taxon is not yet clearly understood. Further, the validity of both *Rhizomucor tauricus* and *Rh. namataiensis* is questioned.

The group of ascomycetous fungi brings together twenty species and three varieties, these relate to only nine genera. Following von Arx (1987, 1988), *Dactylomyces* (inclusive of *Thermoascus*) and *Talaromyces* belong to Family *Onygenaceae*, Order Eurotiales, as *Coonemeria* was established for taxa previously assigned in *Dactylomyces* and *Thermoascus*, then the new genus should also be accomodated in this family. The remaining six genera are representatives of Families *Chaetomiaceae* (*Chaetomium*), *Microascaceae* (*Canariomyces*) and *Thielaviaceae* (*Corynascus*, *Melanocarpus* and *Thielavia*).

Dactylomyces appears monospecific. *Canariomyces* and *Thermoascus* have one species each plus one variety for the latter, new informations about the variety might lead to the proposal of a specific rank. *Corynascus* and *Melanocarpus* have two species each, this number becomes three in the case of *Coonemeria*, *Talaromyces* and *Thielavia*. *Chaetomium* is represented by four species and two varieties but *Ch. britannicum* might prove not to be a true thermophile when a living culture becomes available. Also definite taxonomic decisions about *Chaetomium thermophilum*, its varieties and *Ch. virginicum* might reduce this group to only two accepted species, the genus would thus comprise only three thermophiles.

Not all thermophilic ascomycetes have an associated anamorphic state, also among these conidial states some do not develop concomitantly with the corresponding teleomorph. *Canariomyces thermophila* has no anamorph although the type was described with a catenate conidial state. Thermophilic Chaetomia do not develop conidia of any kind. *Thermoascus* can be regarded as not having an anamorph producing catenate conidia. *Dactylomyces* has a distinctive but yet unnamed *Polypaecilum* anamorph, the fungus remains not satisfactorily documented probably due to the taxonomic confusion with *Thermoascus* that prevailed. *Polypaecilum* anamorphs also characterise *Dichotomomyces* Saito Saito having 2 -3 described species (von Arx, 1981). The genus also has cleistothecia with a wall of *textura angularis* type but asci are produced in chains, it also belong to Family *Eurotiaceae sensu* von Arx (1987). *Melanocarpus* approximates *Canariomyces* since respective type species have distinctive conidial states but that of the latter is a mesophile. The former genus has now four taxa with the second thermophile, *M. thermophilus* not developing the characteristic arthroconidial state of the type, the same situation is disclosed by the two other members of the genus which do not develop at high temperatures.

Regarding the genus *Thielavia*, *Th. pungtungia* has no conidial state, a feature characteristic of all known Chaetomidia. Th. *australiensis* was reported with an anamorph of the *Trichosporiella* type, this is developed by other members of the genus (Mouchacca, 1973). The fungus is however badly documented being known only from the protologue. *Thielavia terrestris* is associated with a distinctive anamorphic state described exclusive of the teleomorph, *Acremonium alabamense*, due to the "homothallic with

cross-feeding ' nature of the perfect state, the anamorph could be encountered alone in studies involving high incubation temperatures. *Thielavia* is still admitted to represent a heterogeneous entity due to lack of informations about the behaviour in culture of *Thielavia basicola* (type species) and production of hyaline and dark coloured colonies by known members.

On the other hand, thermophilic *Talaromyces* all develop a conidial state, these belong either to *Paecilomyces* (*T. byssochlamydoides*) or to *Penicillium* (*T. emersonii* and *T. thermophilus*). Regarding *Paecilomyces*, von Arx (1987) suggested it be expanded to include Penicillia of Sections *Biverticillata* and *Sagenomella* known as anamorphs of genera he grouped in Family *Onygenaceae*, such a proposal was made to increase the degree of homogeneity among genera. A similar situation is disclosed by *Coonemeria* and *Corynascus*, all three taxa of the former have a well developed *Paecilomyces* state while both species of the latter have anamorphs now correctly assigned to *Myceliophthora*. Taxa of *Coonemeria* and *Corynascus* had very complicated respective taxonomic histories either due to cases of misidentification (species now placed in *Coonemeria*) or to the heterothallic nature of the *Corynascus* perfect states. For the latter, it follows that either *Myceliophthora* could develop singly in studies conducted on thermophile habitats with only appropriate mating leading to ascospore formation. The anamorph of *Corynascus heterothallicus* was proposed prior to the discovery of the teleomorph while the reverse is true for *C. thermophilus*.

The group of thermophilic hyphomycetes comprises thirteen species although for *Scytalidium thermophilum*, the term species appears inadequate in the present situation. These fungi belong to seven genera. *Acremonium*, *Malbranchea*, *Myceliophthora* and *Thermophilomatospora* are mucedinaceous entities, while dematiaceous thermophiles belong to *Humicola*, *Scytalidium* and *Thermomyces*.

Among mucedinaceous taxa, three are established anamorphs of "almost heterothallic to heterothallic" ascomycetes and thus could be observed alone in studies involving a self heating process. *Acremonium alabamense* is the conidial state of *Thielavia terricola* whose mating behaviour is not yet clearly understood. This is not a typical *Acremonium* species and such accounts for its inclusion in a new section with phialidic states of some Chaetomia. Such is not the case for *Acremonium thermophilum*, a not yet well documented thermophile. The perfect state of *Myceliophthora fergusii* is *Corynascus thermophilus* and care should be taken to avoid confusion with the teleomorph of *M. thermophila* (*C. heterothallicus*), the third member *M. hinnulea* has not yet developed a perfect state, a situation analogous to the mesophilic type species of the genus. *Malbranchea cinnamomea* is a very distinctive colored arthroconidial fungus actually displaying a wide distribution, it is the sole thermophile of a genus known to comprise mesophiles associated with well defined teleomorphs (von Arx, 1987). *Thermophilomatospora fibuligera* is unique with its septal clamp connections and an aleurosporic state, this peculiar fungus is apparently still known only from the type locality.

The remaining dematiaceous thermophiles were assigned to *Humicola*, *Scytalidium* and *Thermomyces*. But only the taxonomic status of the latter is now the subject of a large consensus. *Thermomyces lanuginosus* is the first assessed thermophilic fungus. His complex nomenclatural history has involved genera as *Acremonella*, *Humicola*, *Monotospora* and *Sepedonium*. The definite re-instatement of *Thermomyces* by Pugh *et al.* (1964) clarified its links with thermophilic species of *Humicola*. The genus now also comprises *Th. ibadanensis*, *Th. stellatus* and the mesophilic *Th. verrucosus*. However, only the type species is by far the most reported one.

The status of *Humicola hyalothermophila* needs to be re-assessed in conjunction with that of both *Humicola* recently proposed as synonyms of *Scytalidium thermophilum* (Straatsma & Samson, 1993). The introduction of *Scytalidium* in an attempt to relocate *Torula thermophila* added much confusion as the transfer was not substantiated by valid taxonomic arguments. This combination was however immediately reported by Ellis M. B. (1976). *Scytalidium lignicola*, type species of the genus, is a mesophile producing cultures with scanty aerial mycelium. The fungus develops conidiogenous cells of two kinds: hyaline fertile hyphae become septate, later producing thin-walled arthroconidia by fragmentation, brown fertile hyphae forming chains of brown arthroconidia, also chains of brown aleurio-spores could be observed (Ellis M. B., 1976). These intercalary conidia develop by transformation of pre-existing normal hyphal cells. The presence of solitary conidia terminal or lateral was never reported. In *Scytalidium indonesicum* chlamydospore formation and disarticulation follow the same pattern but no hyaline arthroconidia develops. Here too, terminal or lateral solitary conidia were not reported (Hedger *et al.*, 1982).

In species of *Humicola* solitary terminal and more commonly lateral aleurio-spores usually develop in addition to intercalary morphologically similar ones. Single terminal aleurio-spores (and less often lateral ones) may become intercalary by hyphal extension of their tip. Also chains of aerial or immersed "aleurio-spores" do not disarticulate to liberate individual elements but such is achieved by lysis of sustaining hyphal cells. Further, no hyaline arthroconidia are produced by any described member of the genus but mesophile taxa rather produces hyaline phialospores. Straatsma and Samson (1993) compared a large number of strains assigned to *Scytalidium thermophilum*, *Torula thermophila* or to both *Humicola* now regarded as synonyms of the former. They underlined two extreme types could be recognized, the first having simple very dark spores borne on short lateral branches matching the description of *Humicola grisea* var. *thermoidea*, the second type develop intercalary slightly pigmented spores in chains, representatives of *Scytalidium thermophilum* or more appropriately of its basionym *Torula thermophila*. Within the two types however, some isolates also develop short terminal chains of conidia making them intermediate between types 1 and 2.

Straatsma and Samson (1993) stress such intermediate isolates favours not the segregation of taxa "on the basis of the single character of conidia in the aerial mycelium" these rather support grouping of all types under one binomial whose placement in *Scytalidium* is to be reconsidered. As the particular mode of chlamydospore formation in this genus deviates from the pattern depicting species of *Humicola*, the exclusion of the above complex from the former is more than justified. *Scytalidium* is now regarded a heterogenous entity due to addition of species only developing dematiaceous "arthroconidia". Nevertheless, extension of *Scytalidium* characteristics for the understanding of *Humicola* species has shadowed features proper to the latter preventing sound taxonomic separation among its members.

From an ecological point of view, the equivocal application of the now widely accepted (inspite of its limitations) definitions of Cooney & Emerson (1964) lead to consider well established thermotolerants as thermophiles. Ellis D. H. (1981) regards all *Rhizopus* able to grow at 45° C as thermophilic although they display growth below 20° C. These zygomycetes and some other true mesophilic fungi are also currently considered as thermophiles in publications focusing on biotechnological problems (Satyanarayana *et al.*, 1992). Several authors also classify as thermophile all fungi developing in isolation plates incubated at 45° C (Abdel-Fattah *et al.*, 1977, Moubasher *et al.*, 1988).

Another type of misleading situations relates to epithets selected while describing a new taxon found to develop at elevated temperatures. The recent *Mucor thermophilus* is a good example among others here considered, from the protologue it is evident this *Mucor* should be regarded as a thermotolerant. A definitely critical situation is examplified by the frequent use in studies involving fungal enzymes of ghost binomials having no taxonmic status of any kind as *Sporotrichum cellulophilum*, such a practice needs to be totally banished for the confusion it introduces, in particular while attempting to analyse published data (Satyanarayana *et al.*, 1992, Schekkar & Johri, 1992).

Strict restriction to nomenclatural rules governing citations of fungal binomes is fundamental. Authors of applied research dealing with thermophiles should necessarily follow such regulations in order to stabilize names used in produced articles. This would bring an end to the chaotic state prevailing especially in publications relating to fungal ecology and biotechnology. The taxonomic and nomenclatural reappraisal of known thermophilic taxa here undertaken will definitely unravel informations already available. This should enable a sound synthesis of published data and foster the discovery of new elements of this interesting physiological group of fungi.

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REFERENCES

AA H. A. van der, 1973. *In* "Centraalbureau voor Schimmelcultures Baarn and Delft Progress Report 1972, J. A. von Arx. *Verhandelingen der Koninklijke Nederlandse Akademie van Wetenschappen Afd. Natuurkunde, Tweede Reeks* 61(4): 60-81.

ABDEL-HATTAH H. M., MOUBASHER A. H. & ABDEL HAFEZ S. I., 1977. Studies on mycoflora of salt marshes in Egypt. III. Thermophilic fungi. *Bulletin of the faculty of science Assiut university* 6: 225-235.

ABDULLAH S. K. & AL-BADER S. M., 1990. On the thermophilic and thermotolerant mycoflora of Iraq. *Sydowia* 42: 1-7.

AMES L. M., 1963. *A Monograph of the Chaetomiaceae*. U. S. Army Research and Development, Ser. 2, Reprint Cramer, Lehre, 1968, 125 pp.

APINIS A. E., 1963. Occurrence of thermophilous microfungi in certain alluvial soils near Nottingham. *Nova hedwigia* 5: 57-78.

APINIS A. E., 1967. *Dactylomyces* and *Thermoascus*. *Transactions of the british mycological society* 50: 573-582.

APINIS A. E. & CHESTERS C. G. C., 1964. Ascomycetes of some salt marshes and sand dunes. *Transactions of the british mycological society* 47: 419-435.

ARX J. A. von, 1970. *The genera of fungi sporulating in pure culture*. J. Cramer, Lehre, 288 pp.

ARX J A von 1971 Über die typusart zwei neue und einige weitere arten der gattung *Sporotrichum* *Persoonia* 6: 179-184

ARX J A von 1973 Further observations on *Sporotrichum* and some similar fungi *Persoonia* 7: 127-130

ARX J A von, 1975 On *Thielavia* and some similar genera of Ascomycetes. *Studies in mycology* 8: 1-29

ARX J A von 1981 (1982) On *Microthyriella stoplidia* and some families of Ascomycetes. *Sydowia* 34: 12-29

ARX J A von 1984 *Canariomyces notabilis*, a peculiar ascomycete from the Canary Islands *Persoonia* 12: 185-187.

ARX J. A. von, 1987 A re-evaluation of the Eurotiales. *Persoonia* 13: 273-300

ARX J A von FIGUERAS M J & GUARRO J., 1988 Sordariaceous ascomycetes without ascospore ejaculation *Beihefte zur nova hedwigia* 94: 1-104

ARX J A von, GUARRO J & FIGUERAS M J 1986 The Ascomycete genus *Chaetomium* *Beihefte zur nova hedwigia* 84: 1-162

AUSTWICK P K C., 1976 Environmental aspects of *Microtrichella wolfii* infection in cattle *New Zealand journal of agricultural research* 19: 25-33.

AWAO T & OTSUKA S 1974 Notes on thermophilic fungi in Japan (3) *Transactions of the mycological society of Japan* 15: 7-22

BARRON G L 1968 *The Genera of Hyphomycetes from Soil* The Williams & Wilkins Co Baltimore, 364 pp.

BASU M 1984 *Myceliophthora indica* a new thermophilic species from India *Nova hedwigia* 40: 85-90

BENNY G L & KIMBROUGH J W., 1980 A synopsis of the order and families of the Plectomycetes with keys to genera. *Mycotaxon* 12: 1-91

BILAY V T & ZAKHARCHENKO B A., 1987 *Opredelitel' Termofil'nykh Gribov* Kholodny Institute of Botany, Ukrainian Academy of Sciences, Kiev, 112 pp.

BIOURGE P., 1923 Les moisissures du groupe *Penicillium*. *La cellule* 33: 5-331.

BOKHARY F F M M 1986 *Studies on thermophilic and thermotolerant fungi in the soil of kingdom of Saudi Arabia* M Sc Thesis, Girls College of Education, Jeddah, Kingdom of Saudi Arabia

BUNCE M E 1961 *Humicola stellatus sp nov*, a thermophilic mould from hay *Transactions of the british mycological society* 44: 372-376

BURDSALL H H Jr. 1981 The taxonomy of *Sporotrichum pruinosum* and *Sporotrichum pulverulentum* / *Phaenerochaete chrysosporium* *Mycologia* 73: 675-680

CANNON P F 1986 A revision of *Achaetomium*, *Achaetomiella* and *Subramaniula* and some similar species of *Chaetomium* *Transactions of the british mycological society* 87: 45-76.

CANNON P F 1990 Name changes in fungi of microbiological industrial and medical importance *Mycopathologia* 111: 75-83

CANNON P F HAWKSWORTH D L & SHERWOOD-PIKE M A 1985 *The British Ascomycotina: An Annotated Checklist*. CMI, 302 pp.

CARMICHAEL J W, KENDRICK Bryce W CONNERS I L & SIGLER L., 1980 *Genera of Hyphomycetes* The University of Alberta Press, Alberta, Canada, 386 pp.

CARMO-SOUSA L de 1970 Genus II *Trichosporon* Behrend *In* "The yeasts. A taxonomic study 2nd revised and enlarged edition", J. Lodder (ed.), North-Holland Publishing Co. — Amsterdam London, pp. 1309-1357

CHEN K-Y & CHEN Z-C 1996 A new species of *Thermoascus* with a *Paecilomyces* anamorph and other thermophilic species from Taiwan *Mycotaxon* 50: 225-240

COONEY D G & EMERSON R., 1964 *Thermophilic Fungi: An Account of their Biology, Activities and Classification*. W H. Freeman and Co., San Francisco and London, 188 pp.

CORDA A C J 1842 *Icones fungorum hucusque cognitorum* Tome V, F Ehrlich Prague, 92 pp.

CRAVERI R MANACHINI P L & CRAVERI A 1964 Eumiceti thermofili presenti nel suolo *Annali di microbiologia ed enzimologia* 14: 13-26

CRISAN E. V. 1973 — Current concepts on thermophilism and the thermophilic fungi. *Mycologia* 65: 1171-1198.

CURRAH R. S., 1985 — Taxonomy of the Onygenales: *Arthrodermataceae, Gymnoascaceae, Myxotrichaceae* and *Onygenaceae*. *Mycotaxon* 24: 1-216.

CURZI M., 1930 — Ricerche morphologiche e sperimentali su muffa termofila (*Asperomiella thermophila* Curzi). *Bollettino stazione di patologia vegetale, Roma*, N.S., 10: 222-280.

DEPLOEY J. J., 1992 — Some factores affecting germination of *Rhizomucor miehei* sporangiospores. *Mycologia* 84: 77-81.

DESHPANDE V., ERIKSSON K. E. & PETTERSSON B., 1978 — Production, purification and partial characterisation of 1, 4-beta-glucosidase enzymes from *Sporotrichum pulverulentum*. *European journal of biochemistry* 90: 191-198.

DIX N. J. & WEBSTER J., 1995 — *Fungal Ecology*. Chapman & Hall, London, 549 pp.

DOMSCH K. H., GAMS W. & ANDERSON T. H., 1980 — *Compendium of Soil Fungi*. Vols. 1 & 2. Academic Press, London, 405 pp.

DURAND H., SOUCAILLE P. & TIRABY G., 1984 — Comparative study of cellulases and hemicellulases from four fungi: mesophiles *Trichoderma viride* and *Penicillium* sp. and thermophile *Thielavia terrestris* and *Sporotrichum cellulophilum*. *Enzyme microbial technology* 6: 175-180.

EGGINS H. O. W. & MALIK K. A., 1969 — The occurrence of thermophilic cellulolytic fungi in a pasture land soil. *Antonie van Leeuwenhoek* 35: 178-184.

EICKER A., 1972 — Occurrence and isolation of South African thermophilic fungi. *South African journal of science* 68: 150-155.

ELLIS D. H., 1981 — Sporangiospore ornamentation of thermophilic *Rhizopus* species and some allied genera. *Mycologia* 73: 511-523.

ELLIS D. H., 1981 — Ultrastructure of Thermophilic fungi IV. Conidial ontogeny in *Thermomyces*. *Transactions of the british mycological society* 77: 229-241.

ELLIS D. H., 1982 — Ultrastructure of thermophilic fungi V. Conidial ontogeny in *Humicola grisea* var. *thermoidea* and *H. insolens*. *Transactions of the british mycological society* 78: 129-139.

ELLIS M. B., 1971 — *Dematiaceous Hyphomycetes*. CMI, Kew, Surrey, England, 608 pp.

ELLIS M. B., 1976 — *More Dematiaceous Hyphomycetes*. CMI, Kew, Surrey, England, 507 pp.

EMERSON R., 1968 — Thermophiles. *In* "The Fungi, Vol 3" (Eds G.C. Ainsworth & A.S. Sussman), pp. 105-128, Academic Press, New York.

ERICKSSON O. E. & HAWKSWORTH D. L., 1993 — Outline of the ascomycetes — 1993. *Systema ascomycetum* 12: 51 — 257.

EVANS H. C., 1971 a — Thermophilous fungi of coal spoil tips. I. Taxonomy. *Transactions of the british mycological society* 57: 241-254.

EVANS H. C., 1971 b — Thermophilous fungi of coal spoil tips. II. Occurrence, distribution and temperature relationships. *Transactions of the british mycological society* 57: 255-266.

FERGUS C. L., 1964 — Thermophilic and thermotolerant moulds and actinomycetes of mushroom compost during peak heating. *Mycologia* 56: 267-284.

FERGUS C. L. & SINDEN J. W., 1969 — A new thermophilic fungus from mushroom compost: *Thielavia thermophila* spec. nov. *Candian journal of botany* 47: 1635-1637.

FIELDS W. G., 1968 — A new species of *Sordaria*. *Mycologia* 60: 1117-1118.

GOCHENAUR S. E., 1975 — Distributional patterns of mesophilous and thermophilous microfungi in two Bahamian soils. *Mycopathologia mycologia applicata* 57: 155-164.

GRIFFON E. & MALBLANC A., 19.. — Deux moisissures thermophiles. *Bulletin de la société mycologique de France* 27: 68-74.

GUARRO J. & ARX J. A. von, 1987 — The ascomycete genus *Sordaria*. *Persoonia* 13: 301-313.

GUARRO J., ABDULLAH S. K., AL-BADER S. M., FIGUERAS M. J. & GENE J., 1996 — The genus *Melanocarpus*. *Mycological research* 100: 75-78.

HEDGER J. H., 1974 — The ecology of thermophilic fungi in Indonesia. *In* Kilbertus G., Reisinger O., Mourey A. and Cancela da Fonseca J. A. (eds.), Biodegradation et Humification. Pierron Editeur, Sarreguemines, pp. 59-65.

HEDGER J. N. & HUDSON H. J., 1970 — *Thielavia thermophila* and *Sporotrichum thermophilum*. *Transactions of the british mycological society* 54: 497-500.

HOOG G. S. de, 1974 — The genera *Blastobotrys*, *Sporothrix*, *Calcarisporium* and *Calcarisporiella* gen. nov. *Studies in mycology* 7: 1-84.

HOOG G. S. de, SMITH M. TH. & GUEHO E., 1980 — A revision of the genus *Geotrichum* and its teleomorphs. *Studies in mycology* 29: 1-131.

JOSHI M. C., 1982 — A new species of *Rhizomucor*. *Sydowia* 35: 100-103.

KINOSHITA S., CHUA J. W., KATO N., YOSHIDA T. & TAGUSHI H., 1986 — Hydrolysis of cellulose by cellulases of *Sporotrichum cellulophilum* in an ultrafilter membrane reactor. *Enzyme microbial technology* 8: 691-695.

KLOPOTEK A. von, 1974 — Revision der thermophilen Sporotrichum arten. *Chrysosporium thermophilum* (Apinis) *comb. nov.* und *Chrysosporium fergusii sp. nov.* = *status conidialis* von *Corynascus thermophilus* (Fergus und Sinden) *comb. nov.* *Archives of microbiology* 98: 366-369.

KLOPOTEK A. von, 1974 — *Thielavia heterothallica spec. nov.* die perfekte form von *Chrysosporium thermophilum*. *Archives of microbiology* 107: 223-224.

LATOUCHE C. J., 1980 — On a thermophile species of *Chaetomium*. *Transactions of the british mycological society* 33: 94-104.

LAUREL L. L. & INGLE M. B., 1976 — Some effects of temperature on zygospore formation in *Mucor miehei*. *Mycologia* 68: 1145-1151.

MALLOCH D. & CAIN R. F., 1972 — The *Trichocomataceae*: Ascomycetes with *Aspergillus*, *Paecilomyces*, and *Penicillium* Imperfect states. *Canadian journal of botany* 50: 2613-2628.

MALLOCH D. & CAIN R. F., 1973 — The genus *Thielavia*. *Mycologia* 65: 1055-1077.

MARCY M. R., ENGELHARDT T. C. & UPADHYAY J. M., 1984 — Isolation, purification and some properties of protease I from a thermophilic mold *Thermoascus aurantiacus* var. *levisporus*. *Mycopathologia* 87: 57-65.

MASON E. W., 1933 - *Annotated account of fungi received at the Imperial Mycological Institute 1933 List II (Fasc. 2)*. *Mycological Papers* n° 3, London.

MASON E. W., 1941 — *Annotated account of fungi received at the Imperial Mycological Institute 1941 List 2 (Fasc. 3, special part)*. *Mycological Paper* n° 5, London.

MIEHE H., 1915 — Über die Selbsterhitzung der Heues. *Arbeiten der deutschen Landwirtschaftsgesellschaft* 111: 76-91.

MIEHE H., 1907 — *Die Selbsterhitzung des Heues. Eine Biologische Studie*. G. Fischer, Jena, 127 pp.

MILLNER P. D., 1977 — Radial growth responses to temperature by 58 *Chaetomium* species, and some taxonomic relationships. *Mycologia* 69: 492-502.

MILLNER P. D., MOTTA J. J. & LENTZ P. L., 1977 — Ascospores, germ pores, ultrastructure, and thermophilism in *Chaetomium*. *Mycologia* 69: 720-733.

MIRZA J. H., KHAN S. M., BEGUM S. & SHAGUFTA S., 1979 — *Mucorales of Pakistan*. University of Agriculture, Faisalabad, Pakistan.

MORGAN-JONES G., 1974 — Notes on Hyphomycetes. V. A new thermophilic species of *Acremonium*. *Canadian journal of botany* 52: 429-431.

MORGAN-JONES G. & GAMS W., 1982 — Notes on Hyphomycetes. XLI. An endophyte of *Festuca arundinacea* and the anamorph of *Epichloë typhina*, new taxa in one of two new sections of *Acremonium*. *Mycotaxon* 15: 311-318.

MORINAGA T., KANDA S. & NOMI R., 1986 — Lipase production of a new thermophilic fungus, *Humicola lanuginosa* var. *odtomadia*. Journal of fermentation technology 64 5): 451-453.

MOUBASHER A. H., 1993 — *Soil Fungi in Qatar and other Arab Countries*. The Scientific and Applied Research Centre, University of Qatar, 566 pp.

MOUBASHER A. H., ABDEL-HAFEZ S. I. I. & EL-MAGHRABY O. M. O., 1988 — Seasonal fluctuations of soil-borne and air-borne fungi of Wadi Bir-El-Ain in the Eastern Desert of Egypt. *Naturalia Monspeliensa*, Ser. Botanique 52: 57-69.

MOUBASHER A. H., MAZEN M. B. & ABDEL-HAFEZ A. I. I., 1979 - *Humicola hyaothermophila sp. nov.* *Transactions of the british mycological society* 72: 509-510.

MOUCHACCA J., 1973 — Les *Thielavia* des sols arides. Espèces nouvelles et analyse générique. *Bulletin trimestriel de la société mycologique de France* 89: 295-311.

MOUCHACCA J., 1994 — *Thermophilic and thermotolerant fungi in the Middle East. Biodiversity and taxonomic reappraisal.* VIth International Mycological Congress. ABSTRACTS. August 14-21, 1994, Vancouver, University of British Columbia, Canada, Lecture Abstract, p. 150.

MOUCHACCA J., 1995 — *Thermophilic Fungi in Desert Soils: a Neglected Extreme Environment.* In "*Microbial Diversity and Ecosystem Function*" (Allsopp *et al.*, eds.). CAB International and Royal Holloway, University of London, 10-13 August 1993, London, pp. 265-288.

MOUSTAFA A. F. & EZZ-ELDIN F. K., 1989 — *Gilmaniella multiporosa*, a new dematiaceous hyphomycete from Egyptian soils. *Transactions of the british mycological society* 92: 502-505.

NARAIN R., SRIVASTAVA R. B. & MEHROTRA B. S., 1983 — A new thermophilic species of *Scytalidium* from India. *Zentralblatt für mikrobiologie* 138: 569-572.

NOACK K., 1912 — Beitrage zur Biologie der thermophilen Organismen. *Jahrbucher für wissenschaftliche Botanik* 51: 593-648.

OORSCHOT C. A. N. van, 1977 — The genus *Myceliophthora*. *Persoonia* 9: 401-408.

OORSCHOT C. A. N. van, 1980 — A revision of *Chrysosporium* and allied genera. *Studies in mycology* 20: 1-89.

OORSCHOT C. A. N. van & HOOG G. S. de, 1984 — Some hyphomycetes with thallic conidia. *Mycotaxon* 20: 129-132.

PITT J. I., 1979 — *The genus Penicillium and its teleomorphic states Eupenicillium and Talaromyces.* Academic Press, London 634 pp.

PRAKASH R. & SARBHOY A. K., 1993 — *Mucor thermophilus* spec. nov. and other Mucorales from India. *Zentralblatt für mikrobiologie* 148 (8): 531-534.

PUGH G. J. F., BLAKEMAN J. P. & MORGAN-JONES G., 1964 — *Thermomyces verrucosus* sp. nov. and *T. lanuginosus*. *Transactions of the british mycological society* 47: 115-124.

RAPER K. B. & THOM C. h., 1949 — *A Manual of the Penicillia*. Williams & Wilkins, Baltimore. ix + 875 pp.

SACCARDO P. A., 1908 — *Notae mycologicae*. Ser. X. *Annales mycologici* 6: 553-569.

SAMSON R. A., 1974 — *Paecilomyces* and some allied hyphomycetes. *Studies in mycology* 6: 1-119.

SAMSON R. A. & TANSEY M. R., 1977 — *Guide to thermophilic and thermotolerant fungi*. Abstracts, Second International Mycological Congress, Tampa, Florida, 5 p.

SAMSON R. A., CRISMAN M. Jack & TANSEY M. R., 1977 — Observations on the thermophilous ascomycete *Thielavia terrestris*. *Transactions of the british mycological society* 69: 417-423.

SATYANARAYANA T., JOHRI B. N. & KLEIN J., 1992 — Biotechnological potential of thermophilic fungi. *In* "Handbook of Applied Mycology" vol 4, (Eds. D. K. ARORA, R. P. ELANDER & K. G. MUKERJI), pp. 729-761, Marcel Dekker, New York.

SCHIKKAK Sharma S. H. & JOHRI B. N., 1992 — The role of thermophilic fungi in agriculture. *In* "Handbook of Applied Mycology", vol 4 (Eds. D. K. ARORA, R. P. ELANDER & K. G. MUKERJI), pp. 707-728, Marcel Dekker, New York.

SCHIPPER M. A. A., 1978-2 — On the genera *Rhizomucor* and *Parasitella*. *Studies in mycology* 17: 53-71.

SCHIPPER M. A. A., 1979 — *Thermomucor* (Mucorales). *Antonie van Leeuwenhoek* 45: 275-280.

SHEERI K. A., 1985 — A monograph of *Stibella* and some allied hyphomycetes. *Studies in mycology*, 27: 1-235.

SIGLER L., 1987 — *Trichothecium cinnamomeum*, an earlier name for the thermophilic hyphomycete *Malbranchea sulphurea*. *Mycologia* 79: 142-143.

SIGLER L. & CARMICHAEL J. W., 1976 — Taxonomy of *Malbranchea* and some other hyphomycetes with arthroconidia. *Mycotaxon* 4: 349-488.

SIGLER L. & WANG C. J. K., 1990 - *Scytalidium circinatum* sp. nov., a Hyphomycete from utility poles. *Mycologia* 82: 399-404.

SILVA Denise M. W. & HANLIN R. T., 1996 — *Chaetomidium heterotrichum* from Venezuela, with a key to species and cladistic analysis of the genus *Chaetomidium*. *Mycoscience* 37: 261-267.

SMITH G., 1961 — *Polypaecilum gen. nov.* *Transactions of the british mycological society* 44: 437-440.

SINGER R., 1975 — *The Agaricales in modern taxonomy*. J. Cramer, 3rd edition, 912 pp.

SIVANESAN A. & SUTTON B. C., 1985. — Microfungi on *Xanthorrhoea*. *Transactions of the british mycological society* 85: 239-255.

SOPP J. O., 1912. — *Monographie der Pilzgruppe Penicillium mit besonderer Berücksichtigung der in Norwegen gefundenen Arten*. Videnskabs-Selskabets i Christiania, Skrifter, 1 Math.-Naturv. Kl., 1912, N° 11, i-vi + 208 pp.

STALPERS J. A., 1978. — Identification of wood-inhabiting Aphyllophorales in pure culture. *Studies in mycology* 16: 1-248.

STALPERS J. A., 1984. — A revision of the genus *Sporotrichum*. *Studies in mycology* 24: 1-105.

STOLK A. C., 1969. — Thermophilic species of *Talaromyces* Benjamin and *Thermoascus* Miehe. *Antonie van Leeuwenhoek* 31: 262-276.

STOLK A. C. & SAMSON R. A., 1972. — The genus *Talaromyces*. Studies on *Talaromyces* and related genera II. *Studies in mycology* 2: 1-65.

STOLK A. C. & SAMSON R. A., 1985. — A new taxonomic scheme for *Penicillium* anamorphs. *In*: Advances in *Penicillium* and *Aspergillus* Systematics, NATO ASI Series, pp. 163-197. Plenum Press, New York & London.

STRAATSMA G. & SAMSON R. A., 1993. — Taxonomy of *Scytalidium thermophilum*, an important thermophilic fungus in mushroom compost. *Mycological research* 97: 321-328.

SUBRAHMANYAM A., MEHROTRA B. S. & THIRUMALACHAR M. J., 1977. — *Thermomucor* - A new genus of Mucorales. *Georgia journal of science* 35: 1-4.

SUBRAHMANYAM A., 1981. — Studies on Thermomycology. *Mucor thermo-hyalosporus* n. sp. *Bibliotheca mycologica* 91: 421-423.

SUBRAHMANYAM A., 1983. — A new thermophilic variety of *Humicola grisea*. *Current science* 49: 30-31.

TANSEY M. R. & BROCK T. D., 1978. — Microbial life at high temperatures: ecological aspects. *In*: Kushner D. J. (ed.) Microbial Life in Extreme Environments. Academic Press, London, pp. 159-216.

TANSEY M. R. & JACK M. A., 1975. — *Talaromyces australiensis* sp. nov., a new thermophilic fungus from incubator bird (mallee fowl) nesting material. *Canadian journal of botany* 53: 81-83.

TROTTER A., 1931. — Saccardo's Sylloge Fungorum omnium hucusque cognitorum 25: 1-1093.

ISKLENSKY P., 1899. — Sur les mucédinées thermophiles. *Annales de l'Institut Pasteur, Paris* 13: 500-505.

UDAGAWA S.-I., AWAO T. & ABDULLAH S. K., 1986. — *Thermophymatospora*, a new thermophilic genus of basidiomycetous hyphomycetes. *Mycotaxon* 27: 99-106.

UDA S. & UDAGAWA S. I., 1983. — *Thermoascus aegyptiacus*, a new thermophilic ascomycete. *Transactions of the mycological society of Japan* 24: 135-142.

WERESUB L. K. & LECLAIR P. M., 1973. — On *Papulaspora* and bulbilliferous basidiomycetes *Bucgoa* and *Minimedusa*. *Canadian journal of botany* 49: 2203-2214.

YAGUSHI T., SOMEYA A. & UDAGAWA S.-I., 1995. — Two interesting cleistothecial Ascomycetes from soils. *Mycoscience* 36: 151-154.

ZHENG R. Y. & CHEN G. Q., 1991. — A non thermophilic *Rhizomucor* causing human primary cutaneous mucormycosis. *Mycosystema* 4: 45-57.

ZHENG R. Y. & CHEN G. Q., 1993. — Another non thermophilic *Rhizomucor* causing human primary cutaneous mucormycosis. *Mycosystema* 6: 1-12.

ZHENG R.-Y. & JIANG H., 1995. — *Rhizomucor endophyticus* sp. nov., an endophytic zygomycete from higher plants. *Mycotaxon* 56: 455-466.

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