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THE *ASPERGILLUS OCHRACEUS* GROUP: TWO NEW SPECIES FROM WESTERN SOILS AND A SYNOPTIC KEY

MARTHA CHRISTENSEN

Department of Botany, University of Wyoming, Laramie, Wyoming 82071

ABSTRACT

Two new species in the *Aspergillus ochraceus* group are described and compared to related taxa. *Aspergillus bridgeri*, from soils collected in a native community dominated by *Atriplex gardneri* in Wyoming, somewhat resembles *A. elegans* and *A. lanosus*, but differs in cultural and morphological details. *Aspergillus campestris*, from a native prairie in northern North Dakota, resembles *A. dimorphicus* in having metulae that are up to 35–45 μm long, but is a more restricted form with yellow conidial heads, taller conidiophores, occasionally septate metulae, and ellipsoidal conidia. A synoptic key is presented as an aid to identification of species in the *A. ochraceus* group—an assemblage which has increased considerably since 1965 and currently embraces 15 species. Brief descriptions of the species accompany the key along with distributional and ecological analyses prepared from species lists in more than 130 published surveys.

Key Words: *Aspergillus*, *Aspergillus ochraceus* group, soil fungi, synoptic key.

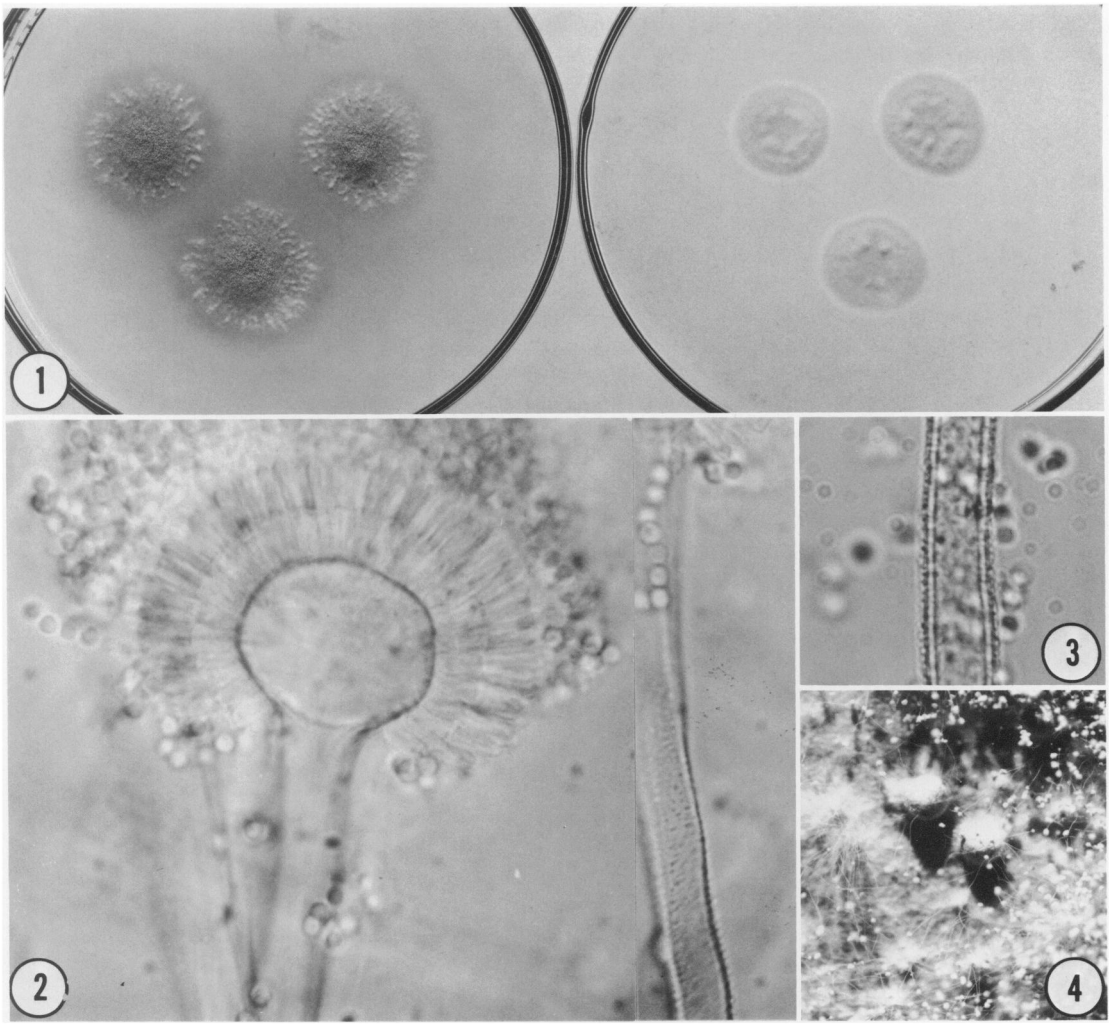
The species described below were isolated in 1979 from soils collected in southcentral Wyoming and in northcentral North Dakota. The species from Wyoming is characterized particularly by its pale yellow conidial heads, orange-red conidiophores with coarsely roughened walls, light colored sclerotia, and salmon-pink mycelial turf and reverse on Czapek's solution agar. The species from North Dakota is slow-growing on malt and Czapek's agars, has pale yellow conidial heads, and produces diminutive biseriate heads intermixed with larger heads wherein metular elongation, swelling and septation occur as the heads mature.

Aspergillus bridgeri Christensen, sp. nov. FIGS. 1–4

Coloniae in agaro Czapekii 2.8–3.3 cm diam post dies 10 sub calore 24–26 C crescentes; capitula conidica luteola (**51**, IV 19 f; XXX 21″ d); facies mycelii salmonea seu cinnamomea (**51**, XV 13′ d; XXIX 13″); facies autem reversa armeniaca seu corallina, postea ferruginea (**51**, XIV 9′ b; XIII 5′; XIV 7′ k), agaro circumdata simili modo colorato pigmento diffundenti. Capitula conidica radiantia, usque ad 200–260 μm diam, biseriata; conidiophori plerumque 900–1400(–2100) μm × 9–13 μm, membranis 1.5–2 μm crassis, post dies 10–12 mutati in colorem aurantiacum, concretiones verrucosas habentes; vesiculae globosae vel subglobosae, 19–35 μm diam, sine colore; metulae primo prope 8 × 4–5 μm, deinde 11–19 × 5–6.2 μm, non septatae; phialides plerumque 3–6 in quaque metula insidentes, 7–9 × 2.2–2.8 μm; conidia laevia, globosa, 2–3 μm, plerumque 2.2–2.5 μm diam, membranis non crassis; sclerotia cremea, globosa vel subglobosa, 900–1300 μm diam, matura circa dies 14–18.

Cultura typica: JB 26-1-2, anno 1979 collecta et isolata e solo sub ramis *Atriplex gardneri* (Moq.) D. Dietr. in Wyoming, U.S.A.; in herbario NY deposita.

Colonies on Czapek's solution agar (FIG. 1) 2.8–3.3 cm in diam after growth for 9–10 da at 24–26 C, white marginally but mycelial mat salmon-colored near light ochraceous-salmon (**51**, XV) to orange-cinnamon (**51**, XXIX) centrally with conidial heads pale yellow, naples yellow (**51**, XVI) to maize yellow (**51**, IV) or deep colonial buff (**51**, XXX) in age; colony reverse flesh-ocher (**51**, XIV) or coral red (**51**, XIII) to Hay's russet and liver brown (**51**, XIV) beneath sclerotia with surrounding agar similarly colored by diffusing pigment; odor not distinctive. *Conidial heads* up to 200–260 μm in diam, radiate, splitting into divergent col-



FIGS. 1–4. *Aspergillus bridgeri* JB 26-1-2. 1. Colonies on Czapek's agar after growth for 7 da at 25 C and 37 C, respectively. 2. Typical vesicle with biseriate appendages bearing globose conidia, and portion of an adjacent conidiophore to show the distinctive wall, roughened with warty concretions, in surface aspect, ×1100. 3. Cross-sectional view of the roughened, orange colored conidiophore wall, ×1100. 4. Surface view of two creamy white sclerotia surrounded by radiate, pale yellow conidial heads in a 1-month-old colony on Czapek's agar, ×7.

umns; *conidiophores* up to 2100 μm long, mostly 900–1400 × 9–13 μm narrowed to near 6–7 μm at the base, wall becoming prominently orange-pigmented, 1.5–2 μm thick, with uniformly-spaced warty concretions after 10–12 da (FIGS. 2, 3); *vesicles* globose to subglobose (FIG. 2), 19–35 μm mostly 22–29 μm in diam, uncolored, thin-walled (1.0 μm), often collapsing in liquid mounts; *metulae* consistently present, somewhat wedge-shaped, near 8 × 4–5 μm in young cultures but expanding after 7–10 da to 11–19 × 5–6.2 μm, non-septate; *phialides* often 3–6 per metula, 7–9 × 2.2–2.8 μm; *conidia* smooth, thin-walled, globose or nearly so, 2–3 μm mostly 2.2–2.5 μm in diam. *Diminutive conidiophores* not observed. *Sclerotia* few to numerous, scattered, well-developed at 14–18 da, globose to

subglobose, mostly 900–1100 μm in diam but up to 1300 μm, cream-colored, formed at the agar surface in a weft of hyphae (FIG. 4); constructed of heavy-walled hyaline contorted hyphae and swollen cells near 3.5–8 μm in diam; no evidence of asci through 18 wk.

Colonies on malt extract agar reaching diam of 5.2–6.2 cm in 8 da at 24–26 C; mycelium thin, mostly submerged, with a velvety growth of conidiophores and yellow conidial heads near baryta yellow (**51**, IV) to deep colonial buff (**51**, XXX); reverse uncolored or nearly so. Conidial stage morphology and measurements as given above except metulae slightly shorter: 6.5–11 × 3.5–5.5 μm elongating to 12–14 × 6 μm. Sclerotia not produced.

Colonies incubated in the dark at 25 C with abundant sporulation on both malt extract and Czapek's agars; on the latter medium, colonies similar in appearance to colonies in ambient light but sclerotia more numerous and ochraceous-salmon color of vegetative hyphae more pronounced.

Colonies 1.6–2 cm in diam after 7 da on Czapek's agar at 37 C (FIG. 1); mycelium white, conidiophores few or lacking, reverse uncolored; sclerotia numerous, developing beneath the felt-like mycelial mat. After 18 da, russet conidiophores 1 mm in length are conspicuous centrally but lack conidia; vegetative mycelium and colony reverse remain colorless.

HOLOTYPE: dried plate culture, JB 26-1-2, deposited in the Cryptogamic Herbarium of The New York Botanical Garden. Living cultures of *A. bridgeri* JB 26-1-2 are on deposit in the American Type Culture Collection, Rockville, Maryland (ATCC 44562), at the Commonwealth Mycological Institute, Kew, Surrey, England (IMI 259098), and with the Centraalbureau voor Schimmelcultures, Baarn, Netherlands (CBS 350.81).

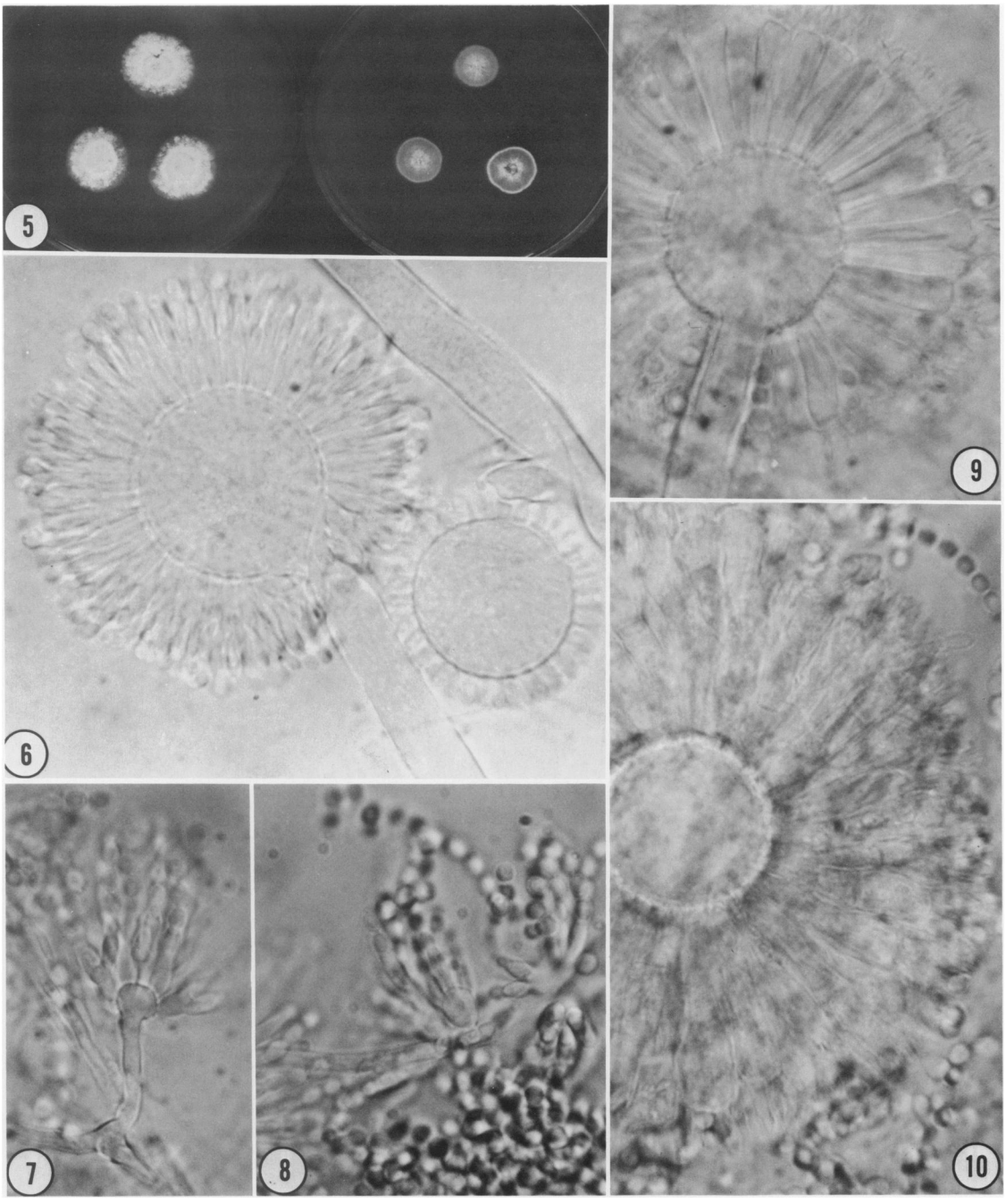
The outstanding characteristics of this species are 1) its salmon-colored vegetative mycelium and production of a diffusible red-orange pigment on Czapek's agar; 2) conidiophores 1000–2000 μm tall with orange-pigmented walls ornamented with warty concretions; 3) radiate heads of pale yellow conidia that are globose and small (2–3 μm diam), and 4) creamy white sclerotia up to 1300 μm diam, formed on Czapek's agar at room temperature in ambient light but with density and development enhanced by dark incubation, or incubation at 37 C, or both.

Aspergillus bridgeri, represented by JB 26-1-2, was isolated by R. Michael Miller and Sheila M. Pippen from soil collected beneath *Atriplex gardneri* (Moq.) D. Dietr., a desert shrub. It was a principal species in one sample and was present in several others obtained in the community of *A. gardneri.* The type locality is a native *Atriplex* community near the Jim Bridger power plant in Sweetwater County, Wyoming.

Aspergillus bridgeri clearly is related to species in the *A. ochraceus* group (**48**) and somewhat resembles *A. elegans* Gasperini in certain microscopic features. The latter species, however, has larger and ellipsoidal conidia, smaller sclerotia, slightly roughened yellow- or brown-tinged conidiophores, and does not grow at 37 C. *Aspergillus sclerotiorum* Huber, *A. melleus* Yukawa and *A. lanosus* Kamal & Bhargava resemble *A. bridgeri* in vesicle size and color and shape of the conidial heads, but those species and *A. elegans* lack *A. bridgeri*'s orange, warty conidiophore wall and pigmented turf, and differ additionally in form, size or presence of sclerotia, size and shape of the conidia, length of the conidiophores, length of the metulae, or a combination of these features.

Aspergillus campestris Christensen, sp. nov. FIGS. 5–10

Coloniae in agaro Czapekii attingentes usque ad 1–1.2 cm diam post dies 10 sub calore 24–26 C, mycelia tenuia, sine colore, subfuniculosa, paene sterilia. Coloniae in agaro maltoso attingentes usque



FIGS. 5–10. *Aspergillus campestris* ST 2-3-1. 5. Colonies on malt and Czapek's agars, respectively, grown for 14 da at 24–26 C. 6. Young heads (at approximately third-conidium stage and before phialide formation, respectively) prior to elongation of metulae, ×975. 7. Diminutive conidiophore with biseriate appendages, ×975. 8. Diminutive structures suggesting metulae that are sessile on trailing hyphae, with ellipsoidal, smooth conidia typical of the species, ×975. 9. Mature vesicle with characteristic elongated metulae, ×975. 10. Vesicle at cessation of conidium formation, with swollen, elongate, occasionally septate metulae, ×975.

ad 1.4–1.5 cm diam post dies 10 sub calore 24–26 C, velutinae; facies reversa sine colore. Capitula conidica radiantia, sulphurea (**51**, IV 21 d, f; XVI 19′ d, 23′ d), usque ad 375 μm diam, biseriata; conidiophori plerumque 400–800(–1300) μm × 7–12 μm, membranis omnino seu paene enodibus, sine colore; vesiculae globosae vel subelongatae, 18–46 μm diam; metulae primo prope 6.5–12 × 3.5–5.5 μm, deinde 8–16 × 5.5–7 μm seu saepius elongatae, tempore conidiogenesis latiores, elongatae, saepe septatae, 20–45 × 6–10 μm (4–5 μm ad radicem); phialides 2–6 in quaque metula insidentes, 7–10 × 2.4–3 μm; conidia laevia, ellipsoidea, 3–4 × 2.3–3 μm, membranis non crassis; conidiophori diminuti non rari.

Cultura typica: ST 2-3-1, anno 1979 collecta et isolata e solo campi herbarum indigenarum (*Agropyron* spp.) prope Zap, North Dakota, U.S.A.; in herbario NY deposita.

Colonies on Czapek's solution agar (FIG. 5) restricted, 1–1.2 cm in diam after growth for 9–10 da at room temperature; mycelium thin, uncolored, funiculose, producing a few scattered conidiophores in age; reverse uncolored. Conidiophores smooth-walled and somewhat shorter with smaller vesicles on Czapek's agar, but microscopic features otherwise similar on Czapek's and malt extract agars. Sclerotia not observed.

Colonies on malt extract agar (FIG. 5) slow-growing, attaining diam of 1.4–1.5 cm in 9–10 da at 24–26 C, velvety, with conidial heads abundant and sulfur yellow in color near baryta yellow to pinard yellow (**51**, IV), graying slightly to barium yellow to naples yellow (**51**, XVI) in age; reverse uncolored; odor faint, pleasant. *Conidial heads* radiate, splitting in age, up to 375 μm diam, with consistently biseriate elements; *conidiophores* infrequently ranging to 1300 μm long, mostly 400–800 × 7–12 μm, occasionally becoming septate, with the wall smooth or nearly so and uncolored in contrast to the bright yellow color of fluid within some conidiophores and vesicles in age (brownish or purple in acidified mounting media; soluble in alcohol); *vesicles* globose to somewhat elongate, 18–46 μm in diam mostly 24–36 μm, moderately thick-walled in age (1–2.5 μm), fertile over the entire surface (FIGS. 6, 9); *metulae* wedge-shaped, at first near 6.5–12 × 3.5–5.5 μm, sometimes remaining short (8–16 × 5.5–7 μm) but more often enlarging through the course of conidium formation to 20–45 × 6–10 μm (4–5 μm proximally) and frequently becoming 1- or 2-septate as spore production ceases (FIGS. 6, 9, 10); *phialides* about 2–6 per metula, 7–10 × 2.4–3 μm; *conidia* thin-walled, smooth, ellipsoidal to egg-shaped, hyaline, 3–4 × 2.3–3 μm, mostly near 3.6 × 2.8 μm. *Diminutive conidiophores* (FIG. 7) common, less than 100 μm × 2.4–4.5 μm, with biseriate elements; vesicles, metulae and phialides reduced in size to dimensions near 4–12 μm in diam, and 5–6 × 3.5–4 μm (elongating to 10–13 × 5–6 μm) and 6–7 × 2.8 μm, respectively; conidia as described above. Anomalous conidium-bearing structures, possibly metulae that are sessile on trailing hyphae, infrequently present (FIG. 8). *Sclerotia* not observed.

Colonies incubated in the dark at 25 C on Czapek's and malt extract agars similar in appearance to colonies in ambient light.

No growth at 37 C on Czapek's agar or malt extract agar.

HOLOTYPE: dried plate culture, ST 2-3-1, deposited in the Cryptogamic Herbarium of The New York Botanical Garden. Living cultures of *A. campestris* ST 2-3-1 are on deposit in the American Type Culture Collection, Rockville, Maryland (ATCC 44563), at the Commonwealth Mycological Institute, Kew, Surrey, England (IMI 259099), and with the Centraalbureau voor Schimmelcultures, Baarn, Netherlands (CBS 348.81).

The outstanding characteristics of this species are 1) its restricted growth on the given media; 2) conidial masses pale yellow produced on vesicles mostly less than 40 μm in diam; 3) metulae elongating, swelling and often becoming septate in age; 4) conidia smooth, pale, 3–4 × 2.3–3 μm; 5) diminutive conidiophores with biseriate elements common, and 6) sclerotia apparently lacking.

Aspergillus campestris, represented by ST 2-3-1, was isolated by R. Michael Miller and Sheila M. Pippen from a storage pile of topsoil displaced from a native, mixed prairie (*Agropyron* spp., *Bouteloua gracilis* (H.B.K.) Lag. ex Steud.) situated near Zap, North Dakota. It was an infrequent isolate from several soil samples; *Penicillium restrictum* Gilman & Abbott sensu Raper and Thom (**49**), known from grassland soils worldwide (**8**), was a principal species in the soils examined.

Aspergillus campestris is a highly distinctive species in the *A. ochraceus* group. It possesses features in common with several other members in the group, e.g., 1) pale yellow, smooth, ellipsoidal conidia and diminutive conidiophores with biseriate elements are characteristic in *A. campestris, A. elegans, A. lanosus,* and *A. melleus*; 2) elongation of metulae to 25 μm or more is common in *A. campestris, A. dimorphicus* Mehrotra & Prasad, and *A. alliaceus* var. *macrosterigmatus* Glinksukon, Thamavit & Sittiracha, and occasional in *A. ochraceus* Wilhelm and *A. elegans*; and 3) restricted growth on malt agar, relatively short conidiophores, vesicles less than 55 μm in diam, and elongating metulae occur in *A. campestris* and *A. dimorphicus,* but the new species is unique in the combination of cultural and morphological features noted above. *A. campestris* differs from *A. dimorphicus,* perhaps its closest relative, in color of the mature heads (yellow vs pinkish tan), length of conidiophores, and in size and morphology of both metulae and conidia.

FEATURES OF THE ASPERGILLUS OCHRACEUS GROUP AND USE OF THE SYNOPTIC KEY

Historically, the *A. ochraceus* group has embraced Aspergilli with biseriate sterigmata and heads of yellow or ochraceous conidia that are small, thin-walled, and smooth or nearly so (**56, 57**). Raper and Fennell (**48**) treated the nine species comprising the *A. ochraceus* group in 1965 in detail and pointed out that they appeared to form a natural group, readily recognized by specific structural features.

Since 1965, seven additional species interpreted as belonging to the *A. ochraceus* group have been isolated and described as new [*A. dimorphicus, A. insulicola* Montemayer & Santiago, *A. lanosus, A. ochraceoroseus* Bartoli & Maggi, *A. robustus* Christensen & Raper, *A. bridgeri* Christensen, and *A. campestris* Christensen (**3, 10, 29, 35, 38**)], and varieties have been designated in *A. alliaceus* Thom & Church and *A. sulphureus* (Fres.) Wehmer [*A. alliaceus* var. *macrosterigmatus* and *A. sulphureus* var. *crassa* Rai, Agarwal & Tewari (**21, 46**)]. Except for the two species described above from western U.S. soils, all of the species erected since 1965 have been isolated from tropical or subtropical soils.

The unifying features in the *A. ochraceus* group are: *conidiophores* variable in length, not constricted beneath the vesicle, with the wall smooth to coarsely roughened and hyaline to yellow-, orange-, or brown-pigmented, bearing mostly radiate heads that are pale yellow, pinkish tan, orange-yellow or ochraceous; *vesicles* globose, rarely somewhat elongate, with biseriate appendages (metulae and phialides) at first nearly equal in length; *metulae* mostly wedge-shaped, elongating, broadening, and occasionally becoming septate in several species with cessation of conidium formation; *diminutive heads* common in most species and characteristically biseriate (in contrast to uniseriate in the *A. flavus* group); *phialides* mostly numerous (3–8) per metula; *conidia* thin-walled, smooth to finely roughened, ellipsoidal to globose, and small, i.e., never exceeding 4–5 μm in longest dimension; *sclerotia* common in 10 of the 15 species, creamy white or

yellow, rufous, vinaceous, or black at maturity, subglobose to ovate or irregular, 200–2200 μm diam; thick-walled *Hülle cells* in aerial hyphae unknown, but enlarged cells with slightly thickened walls (1.5 μm) reported in the submerged mycelium in one variety; teleomorphic stage reported in one species: *asci* subglobose, 8-spored, developing within the sclerotioid structures in *A. alliaceus* (**3**, **10**, **29**, **35**, **38**, **46**, **48**, **56**, **57**).

Species in the *A. ochraceus* group appear to be most closely related to *A. candidus* Link, *A. wentii* Wehmer and biseriate species in the *A. niger* group. Common features include predominantly globose vesicles that are wholly or mostly with biseriate appendages, metulae characteristically with multiple phialides and often elongating and widening in age, conidia mostly relatively small, and sclerotium formation common but Hülle cells lacking. In several species in those four groups, the metulae in age both elongate and become septate [e.g., in *A. robustus, A. campestris, A. candidus, A. niger* v. Tieghem, and *A. phoenicis* (Cda.) Thom]. Secondary production of biseriate diminutive heads is exhibited by species in three sections of the genus (*A. ochraceus, A. candidus* and *A. niger* groups). Color of mature conidial heads, which correlates with group-specific morphological features, is a reliable basis for distinguishing species in the *A. wentii, A. candidus,* and *A. niger* groups from species in the *A. ochraceus* group. *Aspergillus thomii* Smith and species in the *A. flavus* group have uniseriate diminutive heads, green- or olive-tinged conidial masses, conidia mostly larger than those in the *A. ochraceus* group, and their metulae characteristically bear relatively few phialides. *Aspergillus wentii* and the varieties of *A. terricola* Marchal (*A. wentii* group) differ from *A. ochraceus* group members in seriation and conidial features, but the robust, brown-spored *A. wentii* somewhat resembles the latter group macroscopically. Species in the *A. ornatus, A. flavipes,* and *A. terreus* groups probably are only distantly related to species in the *A. ochraceus* group: *A. ornatus* Raper, Fennell & Tresner and its relatives have subclavate vesicles with strictly uniseriate appendages, whereas members in the other two groups have columnar heads on vesicles that are hemispherical or subglobose to vertically elongate and small (less than 25 μm in diameter) (**9**, **10**, **48**). Species in the *A. cremeus* and *A. sparsus* groups have conidiophores that are prominently constricted beneath the vesicle; the wall is weak at that point and thus the vesicles often break off in liquid mounts (**3**, **48**).

The 15 species herein interpreted as comprising the *A. ochraceus* group are the species in TABLE I with omission of "5," "8," and "12." *Aspergillus coremiiformis* probably is a yellow-spored member in the *A. flavus* group, i.e., it has large conidia and uniseriate anomalous heads, but it has been included in the Key because of its macroscopical resemblance to certain members in the *A. ochraceus* group (**3**, **9**, **53**). *Aspergillus ochraceoroseus* has conidiophores that are conspicuously constricted beneath the vesicle; it clearly belongs with *A. cremeus* rather than with *A. ochraceus,* but is treated here because of its slight cultural resemblance to the latter species (**3**, **53**). *Aspergillus fresenii* is listed because of its acceptance in two recent publications (**53**, **55**); in the present study, it is not considered to be the valid name for *A. sulphureus* (see below).

To use the synoptic key, isolates should be grown for 7 da on Czapek's solution agar at 37 C (Set 1), and on Czapek's and malt extract agars (**48**) at 24–26 C for 9–10 da. Sclerotia often are formed in abundance on Czapek's agar, but growth is rapid and conidial development occurs earlier on malt agar. After colony diameters on malt agar have been measured at 9–10 da (Set 5), further cultural (Sets 2, 3, 4, 6, 7) and morphological (Sets 8–14) observations can be made using colonies grown on the medium specified for 10–14 da. Many characteristics, including head color and microscopic features, are essentially similar on Czapek's

TABLE I

SPECIES TREATED IN THE SYNOPTIC KEY AND THEIR REFERENCE NUMBERS IN THAT KEY

1. *A. alliaceus* Thom & Church
2. *A. auricomus* (Guéguen) Saito
3. *A. bridgeri* Christensen
4. *A. campestris* Christensen
5. *A. coremiiformis* Bartoli & Maggi (*A. flavus* group?)
6. *A. dimorphicus* Mehrota & Prasad
7. *A. elegans* Gasperini
8. *A. fresenii* Subramanian (see *A. sulphureus* (Fres.) Wehmer)
9. *A. insulicola* Montemayor & Santiago
10. *A. lanosus* Kamal & Bhargava
11. *A. melleus* Yukawa
12. *A. ochraceoroseus* Bartoli & Maggi (*A. cremeus* group)
13. *A. ochraceus* Wilhelm
14. *A. ostianus* Wehmer
15. *A. petrakii* Vörös
16. *A. robustus* Christensen & Raper
17. *A. sclerotiorum* Huber
18. *A. sulphureus* (Fres.) Wehmer

and malt agars. Because of some slight differences, however, no identification should be accepted until morphological features have been checked in detail against full descriptions of the candidate species. Techniques for using synoptic keys have been given in previous papers (**11**, **31**).

When the cultures under study have been tentatively identified, examination of the "Brief descriptions . . ." section of this paper may further aid discovery of concordances in outstanding features. Finally, however, the user of this key should examine a detailed description of the tentatively selected species. Complete descriptions for most species can be found in Raper and Fennell (**48**); citations to full descriptions for recently described species are given with the brief descriptions that follow the key.

SYNOPTIC KEY TO SPECIES

Isolates must be grown on Czapek's solution agar at 37 C for 7 da and on malt extract and Czapek's agars (**48**) at 24–26 C for 9–10 da. Species names, indicated below by number, are in TABLE I.

Colony features

1. Colony diam after incubation on Czapek's agar at 37 C for 7 da.
   - No growth. 2, 4, 5, 6, 7, 12, 13, 14, 15, 16
   - Diam less than 0.5 cm. 9, 13, 17
   - Diam 1–1.8 cm. 3, 11, 18
   - Diam more than 2 cm. 1, 10
2. Color of conidial heads after growth of colonies for 10–14 da at 24–26 C.
   - Strong yellow near orange-yellow. 2
   - Clear, pale yellow. 3, 4, 5, 7, 10, 11, 12, 14, 16, 17, 18
   - Ochraceous buff, pinkish tan, cinnamon-buff (not pure, pale yellow). 1, 6, 7, 9, 10, 11, 12, 13, 14, 15
3. Color of mycelial or spicular turf on Czapek's agar after 10–14 da at 24–26 C.
   - Bright yellow. 10
   - Ochraceous salmon (pinkish yellow). 3
4. Color of colony reverse on malt extract agar after 10–14 da at 24–26 C.
   - Translucent greenish black and with that pigment diffusing. 16
   - Reddish brown. 2, 7, 9, 11, 13, 16, 18
   - Dull dark brown. 9, 11, 13, 14, 17, 18
5. Colony diam after growth on malt extract agar at 24–26 C for 9–10 da.
   - Diam 1–2 cm. 4
   - Diam 2–4 cm. 2, 6, 16
   - Diam more than 4 cm. 1, 2, 3, 5, 7, 9, 10, 11, 12, 13, 14, 15, 17, 18
6. Colony texture.
   - Some strains becoming coremiate. 5

7. Shape of conidial heads at 10–14 da.
   Heads tending toward columnar, i.e., chains mostly in single and double columns in age, especially on malt agar. 17
   Heads radiate and remaining so or splitting irregularly into divergent columns. (All other species)

Morphology

8. Length of conidiophores.
   Up to 400–800 μm. 6, 9, 17, 18
   Up to 800–1500 μm. 4, 12, 13, 14, 15, 17, 18
   Up to 1600–3500 μm. 1, 2, 3, 5, 7, 10, 11, 12, 14
   Up to more than 3500 μm. 2, 5, 7, 10, 16
9. Form of the conidiophore.
   Prominently constricted beneath the vesicle. 12; see *A. cremeus* and *A. sparsus* groups (**48**)
   Not constricted. (All other species)
10. Conidiophore wall.
   Smooth or nearly so. 1, 4, 6, 7, 10, 12, 16, 17, 18
   Roughened. 2, 3, 5, 7, 9, 11, 13, 14, 15, 17, 18
   Uncolored. 2, 4, 5, 6, 9, 10, 12, 18
   Yellow-tinged. 1, 2, 5, 6, 7, 11, 12, 13, 14, 15, 16, 17, 18
   Orange to red-orange. 3, 14
   Brown. 5, 7, 12, 13, 14, 15, 16, 17, 18
11. Vesicle diam.
   Less than 30 μm. 4, 9, 10, 17, 18
   Up to 30–55 μm. 2, 3, 4, 6, 7, 9, 10, 11, 12, 13, 14, 15, 17, 18
   Up to 55–80 μm. 1, 2, 7, 13, 18?
   Up to more than 80 μm. 1, 5, 16, 18?
12. Biseriate-uniseriate condition.
   Diminutive heads commonly or occasionally uniseriate. 5, 15; see *A. flavus* group (**9**)
   Diminutive heads biseriate. (All other species)
13. Conidia.
   Smooth. 1, 2, 3, 4, 6, 7, 9, 10, 11, 12, 15, 17, 18
   Finely roughened. 5, 6, 7, 11, 12, 13, 14, 15, 16, 17
   Ellipsoidal to subglobose, 4–5 or 6 × 3–4.5 μm. 12, 14
   Ellipsoidal to subglobose, up to 3.5–4.5 μm long. 1, 2, 4, 7, 10, 11, 12, 13, 15, 16
   Globose, 3–4.5 μm, mostly 3.3–3.8 μm. 6.
   Subglobose to globose, 2.4–3.5 μm long. 11, 13, 15
   Globose, 2–3 μm, mostly 2.2–2.5 μm. 3, 9, 10, 13, 17, 18
   Variable: globose, oval, oblong or cylindrical; 2.5–12 × 2.5–6.9 μm. 5
14. Color, form, and size of sclerotia (lacking in some strains).
   Black; consistently ovate to elliptical or nearly cylindrical; 900–3000 × 500–700 μm. 1
   Black; irregular in form; up to 600–900 μm long; beneath very tall, phototropic conidiophores. 16
   Covered with lavender to vinaceous hyphae to maturity; irregular in form; up to 1000–2200 μm diam. 13
   Creamy white to flesh-colored or pale yellow; globose to subglobose; 600–1300 or 1500 μm diam. 3, 7, 17
   Yellow to rufous; globose to subglobose; 500–700 or 1000 μm diam. 2, 14
   Yellow to dull yellow, golden or rufous at maturity; subglobose; 250–470 μm diam. 2, 11, 18

BRIEF DESCRIPTIONS OF INCLUDED TAXA

Where no citation is given following the brief description, the complete description may be found in Raper and Fennell (**48**). WB (Wisconsin Bacteriology Collection), ATCC, and CBS numbers following species names indicate cultures used in preparing the key and descriptions.

1. ASPERGILLUS ALLIACEUS (WB 315). Colonies spreading rapidly on malt agar (6–8 cm diam, 10–14 da); conidiophores tall, developing uniformly over a thin substrate mycelium, with large tan-colored heads; vesicles mostly 40–93 μm

diam; metulae elongating slightly to 7–18 μm at maturity; conidia smooth, ovate, mostly 3–3.5 × 2.5 μm; sclerotia abundant, black, reportedly developing asci after several months. Growth enhanced at 37 C.

Isolated from rotting onion and garlic bulbs, peanuts grown in Israel, dead blister beetles (*Leptinotarsa*), and from primarily grassland, desert or cultivated soils in Arizona, South Dakota, Texas, Mexico, Australia, Peru, India, Italy, Turkey, Great Britain, and the United Arab Republic (**6**, **8**, **12**, **22**, **28**, **40**, **48**, **54**, **56**).

Aspergillus alliaceus var. *macrosterigmatus* Glinsukon, Thamavit & Sittiracha (**21**) reportedly differs from the typical variety in that its metulae become elongate, up to 15–30 × 3–5 μm, sclerotia are lacking, growth is slower at 37 C than at 25 C, and the conidia are globose to subglobose and mostly 2–3 μm diam; its toxigenic properties also appear to differ from those of the typical *A. alliaceus*. It was isolated from market foods in Bangkok.

2. ASPERGILLUS AURICOMUS (WB 391). Conidial heads golden yellow to orangish yellow, color more intense than in any other member in the group; conidiophores and vesicles with conspicuously thick walls (2.5–3.5 μm or more); vesicles mostly 30–50 μm in diam, globose to elongate, with metulae near 10–15 μm long; conidia smooth, mostly 3–4 × 2.5 μm; sclerotia abundant on Czapek's agar, pale yellow to rufous in age.

Originally isolated in France from an aqueous solution of potassium iodide (**25**).

3. ASPERGILLUS BRIDGERI (JB 26-1-2). Described above.

4. ASPERGILLUS CAMPESTRIS (ST 2-3-1). Described above.

5. ASPERGILLUS COREMIIFORMIS (ATCC 38576). Colonies on malt agar 5.8–6.6 cm diam in 9–10 da at 25 C, lightly floccose with conidiophores sparse; conidial heads yellow; conidiophore branches, near 1500–2600 × 50–60 μm or more and with very thick walls, commonly arising sympodially from a short basal hypha; conidia pale yellow, highly variable in size and shape; diminutive conidiophores characteristically with uniseriate conidium-bearing appendages. Colonies grown on Czapek's agar for 6 da: 4–5 cm diam at 25 C, no growth at 37 C. Recently treated as probably belonging to the *A. flavus* group and very similar to *Stilbothamnium nudipes* Hauman. (**3**, **9**, **53**).

Isolated and described from the soil of a tropical rainforest, Tai National Park, Ivory Coast, Africa (**3**).

6. ASPERGILLUS DIMORPHICUS (CBS 649.74). Colonies on malt agar 3–3.4 cm diam in 9–10 da at 25 C, velvety, with conidial heads uniformly chamois to fawn-colored near cinnamon-buff; conidiophores mostly 300–400 × 6–14 μm occasionally up to 750 μm tall, with wall thin, smooth, hyaline to pale yellow; vesicles mostly 22–30(–45) μm diam; diminutive conidiophores with vesicles 6–12 μm diam common; metulae consistently present, non-septate, 4.5–12 μm long in young cultures but reportedly reaching 12–37.5 × 13.5–25.5 μm in secondary heads; conidia globose to subglobose, finely roughened, mostly 3–3.6 μm diam; sclerotia not observed. No growth at 37 C. (**35**, **53**).

Isolated from garden soil from Patna, India (**35**).

7. ASPERGILLUS ELEGANS (WB 4850). Conidial heads large, pale yellow to ochraceous buff; color of the colony shifting toward light brown with darkening of the conidiophores; conidiophore wall 2–2.5 μm thick, becoming brown-pigmented, slightly to coarsely roughened; vesicles up to 45–65 μm diam, brown-

tinged and heavy walled; metulae mostly 5–10 μm long but reportedly 25–30 μm in some heads; conidia ellipsoidal, smooth to delicately roughened, mostly 3.5–4 × 2.8 μm.

Isolated from onion bulbs and dead Colorado potato beetles (*Leptinotarsa*) (**48**).

8. ASPERGILLUS FRESENII. See *A. sulphureus*.

9. ASPERGILLUS INSULICOLA (ATCC 26220). Colonies on malt agar 5.7–7.3 cm diam after 9–10 da at 25 C, lightly floccose; conidial heads pinkish tan; conidiophores mostly 200–400 × 7–10 μm occasionally up to 600 μm, with wall thick (2 μm), hyaline, coarsely roughened; vesicles up to 25–35 μm diam, globose to elongate; metulae 4–10 × 3.5–4.5 μm; conidia small, globose, smooth or nearly so, 2.5–3 μm diam; diminutive conidiophores common, biseriate, with vesicles often near 8–10 μm diam. Colonies grown on Czapek's agar: 3.5–3.8 cm diam in 10 da at 25 C, white, becoming pale brown in age; 4–5 mm diam in 7 da at 37 C. Differs from *A. dimorphicus* culturally and in morphology of the conidia and conidiophores. (**38**).

Isolated from soil collected on the Aves Islands, north of Venezuela (**38**).

10. ASPERGILLUS LANOSUS (WB 5347). Colonies on malt agar growing rapidly, 6–7 cm diam in 10–12 da at 25 C; colony surface consisting of spicular and trailing hyphae bright yellow in color near lemon chrome to light cadmium (**51**, IV); conidial heads pale yellow, at first sparse and not affecting colony color, becoming ochraceous in age; conidiophores mostly 1–2 mm × 5–15 μm but up to 3–5 mm, with wall appearing hyaline and smooth in liquid mounting media; vesicles 15–40 μm diam; metulae 8–14 × 3.3–4.5 μm, with relatively long phialides up to 9–10 μm; conidia thin-walled, smooth, ovate, mostly 3.2–3.7 × 2.7–3, and globose to subglobose 2.5–3 μm; sclerotia not observed. Teratological heads infrequent. Conidiophore production reportedly enhanced on Czapek's agar with 4.2% sucrose. Colonies on Czapek's agar at 37 C 2–2.3 cm diam in 7 da. (**29**).

Isolated from teak (*Tectona*) forest soil, India (**29**).

11. ASPERGILLUS MELLEUS (WB 5103). Colonies on malt agar characterized by production of yellow conidial heads and sclerotia mostly 350–400 μm diam that are cream-colored, golden, or rufous; conidiophores with pale yellow, distinctively roughened walls; vesicles mostly globose, 15–45 μm diam; metulae commonly 9–12 × 4.5–6.5 μm, occasionally reaching 18–20 μm and once-septate; conidia faintly roughened, mostly 3 × 2.8 μm. Colonies on Czapek's agar at 37 C 1.1–1.4 cm diam in 7 da, with sclerotial and conidial development repressed.

Reported from dried fish, dates, soybeans grown in Louisiana, peanuts grown in Israel, Sudanese and Indian soils, and desert soils in Israel and Peru (**5**, **17**, **22**, **28**, **45**, **55**, **56**); pathogenic in soybean (**17**).

Continued use of the name *A. melleus* Yukawa is recommended rather than *A. quercinus* (Bainier) Thom & Church as proposed by Subramanian (**55**). After careful consideration of the earlier name, Raper and Fennell (**48**) concluded that *A. melleus* was nomenclaturally correct because Bainier's description fails to mention the sclerotia which are a prominent feature in this taxon.

12. ASPERGILLUS OCHRACEOROSEUS (CBS 550.77). Interpreted by its describers as a member in the *A. ochraceus* group, but in my opinion clearly related to *A. cremeus* Kwon & Fennell by 1) form and microscopic features of the conidiophore, and 2) conidial size and morphology. Vegetative mycelium on malt agar thin, giving rise to tall, uncolored conidiophores with large (400–500 μm), radiate

conidial heads, dull yellow becoming pinkish tan in age; reverse uncolored or pale pink-yellow. Conidiophores commonly up to 1500–1750 × 15–23 μm, conspicuously narrow (often 5–10 μm) beneath the vesicle; according to Bartoli and Maggi (**3**), "gradually narrowing towards the vesicle." Conidiophore wall smooth, hyaline or nearly so, thin (>1.0 μm) beneath the vesicle and through apical portion of the conidiophore; vesicles often breaking off in liquid mounts, globose, entirely fertile, mostly 22–55 μm diam; metulae 5–9 × 4–4.5 μm; phialides mostly 9–11 μm; conidia heavy walled, smooth or very faintly roughened, highly variable in shape and size, globose 2.5–4.5 μm diam to ellipsoidal 3.6–5.5 × 2.8–4 μm; sclerotia not observed. No growth on Czapek's agar at 37 C; colonies on malt and Czapek's agars at 25 C reaching 6–7 cm diam and 1.5 cm diam, respectively, after growth for 9 da. (**3**).

Isolated from soil collected in a rainforest in Tai National Park, Ivory Coast, Africa (**3**).

13. ASPERGILLUS OCHRACEUS (WB 5063, WB 398). Conidial heads warm buff to cinnamon buff; conidiophores mostly 700–1500 × 10–14 μm, with wall yellow-brown to brown and coarsely roughened; vesicles globose to somewhat elongate, mostly 35–50 μm diam; metulae up to 15–20 μm long; conidia globose to subglobose, finely roughened, 2–3.5 μm diam mostly 2.5–3 μm; sclerotia produced in some strains, irregular in form, up to 1–2 mm diam, lavender to vinaceous at maturity.

Reported from corn, sorghum, peanuts in the southern U.S., small grains, cotton seed and leaves, black pepper, potatoes in Ghana, rubber, talc, bread, human scalp lesions, dead ladybugs and Colorado potato beetles (*Leptinotarsa*), dried fish, and from various soils but primarily desert, grassland, and cultivated soils in tropical, subtropical or warm temperate regions, i.e., Arizona, southern California, Colorado, Georgia, Iowa, Louisiana, Nevada, New Mexico, New York, Oklahoma, Texas, southern Utah, Africa, Bahamas, Canada, Egypt, Haiti, India, Iraq, Israel, Kuwait, Libya, Panama, and Peru (**1**, **2**, **4**, **5**, **6**, **12**, **13**, **14**, **16**, **18**, **19**, **20**, **22**, **23**, **24**, **27**, **29**, **30**, **32**, **34**, **36**, **41**, **42**, **43**, **47**, **48**, **50**, **54**, **55**, **56**, **58**).

Continued use of the name *A. ochraceus* Wilhelm is recommended rather than *A. alutaceus* Berk. & Curt. as proposed by Subramanian (**55**). According to Thom and Raper (**57**), *A. alutaceus,* while apparently a member of this group, is "unidentifiable to strain or series."

14. ASPERGILLUS OSTIANUS (WB 420). Colonies on Czapek's agar characterized by conidial heads pale yellow shifting toward tan especially near the agar surface, and exudate droplets, abundant and amber-colored, beneath the canopy of heads; conidiophores mostly 600–1000 × 8–12 μm, with the wall orange to yellow-brown, coarsely roughened, commonly 2.5–3 μm thick; vesicles similarly thick-walled, mostly 25–40 μm diam; metulae 7–19 × 3.5–6 μm; conidia subglobose to ellipsoidal, roughened, 4–5 × 3–4 μm (larger than in any other species in the group); sclerotia in some strains, yellow, up to 1 mm diam.

Reported from animal feed, and from chicory seed and *Ipomoea* in Kenya and New Guinea, respectively (**2**, **12**).

15. ASPERGILLUS PETRAKII (WB 4369). Colonies on malt agar with sparse sporulation at 10 da, heads pale yellow becoming pinkish tan, small, on conidiophores arising in and beneath the weft of white aerial hyphae; conidiophores mostly 400–800 × 3–8 μm, with the wall conspicuously roughened especially just beneath the vesicle, pale yellow to uniformly brown-pigmented; vesicles thick-walled, globose to elongate, up to 30–35 μm diam; metulae mostly 5–10 × 3–4

μm; conidia subglobose to ellipsoidal, smooth or nearly so, mostly 3–3.5 × 2.5–3 μm; diminutive conidiophores abundant, biseriate or rarely uniseriate, with vesicles 5–9 μm diam; sclerotia not observed.

Isolated from dead Colorado potato beetles (*Leptinotarsa*) (**48**).

16. ASPERGILLUS ROBUSTUS (WB 5286). Colonies on Czapek's and malt agars less than 4 cm diam after growth at 25 C for 10–12 da; conidial heads large, radiate, cream buff to near naples yellow; conidiophores commonly 2500–5000 × 10–21 μm, rarely 8–9 mm tall, positively phototropic, with the wall 2.5–7 μm thick; vesicles globose to elongate, mostly 40–80 μm but up to 95 μm diam; metulae elongating to 11–21 × 4.5–7 μm, frequently once-septate; conidia thin-walled, delicately echinulate, ellipsoidal, 3.2–4.5 × 2.6–3.4 μm; diminutive conidiophores common, biseriate, from thigmotactic trailing hyphae; sclerotia yellow-brown to black, irregular in form, 250–900 μm in longest dimension. (**10**).

Isolated from native forest soils in Kenya and Tanzania (**10**).

17. ASPERGILLUS SCLEROTIORUM (WB 415). Colonies on malt agar 5–6.5 cm diam after 9–10 da at 25 C; chains of conidia strongly laterally adherent; heads mostly single or double columns at 10–12 da, pale yellow; conidiophores up to 800–1200 μm tall, with the wall yellow to yellow-brown, usually echinulate; vesicles less than 40 μm diam, heavy walled; metulae 6.5–12 μm long; conidia globose, smooth or delicately roughened, 2–3 μm diam mostly 2–2.5 μm; diminutive conidiophores common, biseriate; sclerotia produced in some strains, pale, 1–1.5 mm diam.

Reported from rotting apples and pears, peanuts harvested in southeastern U.S. and Israel, *Crotalaria* seed in Zambia, and from native and cultivated soils in Arizona, Hawaii, India, Israel, and Pakistan (**5**, **12**, **14**, **27**, **28**, **29**, **33**, **48**, **54**, **55**, **57**).

The morphological features of *A. sachari* Chaudhuri & Sachar (**7**) strongly indicate synonymy with *A. sclerotiorum*.

18. ASPERGILLUS SULPHUREUS (WB 4077). Colonies on malt agar 4–7 cm diam after growth at 25 C for 9–10 da, with conidial heads pale yellow and contrasting with the colony reverse which often becomes greenish dark brown to red-brown or nearly black; conidiophores up to 1000 μm, mostly 300–600 × 6–8 μm, often somewhat sinuous, with the wall variable in color and ornamentation; vesicles originally described as up to 90 μm diam (**55**), but "mostly 12–25 μm" in recent isolates (**48**); metulae 4.5–10 × 3.3–4.4 μm; conidia very small, 2–2.5 μm diam, globose, thin-walled, smooth; sclerotia in some strains, yellow, subglobose, mostly 250–450 μm diam. Colonies of WB 4077 on Czapek's agar at 37 C 1.5–1.7 cm diam after 7 da; sclerotia abundant but conidiophores not formed.

Reported from rice, Brazil nuts, peanuts harvested in Israel, rabbit dung, foodstuffs in Ghana, and from cultivated and native soils in Arizona, Iowa, Louisiana, Nevada, New Mexico, Oklahoma, southern Utah, Bahamas, Barro Colorado, India, Israel, and Italy (**2**, **5**, **12**, **13**, **15**, **18**, **19**, **20**, **23**, **26**, **28**, **29**, **30**, **32**, **37**, **39**, **44**, **48**, **54**).

Continued use of the name *A. sulphureus* (Fres.) Wehmer is recommended rather than *A. fresenii* Subram. as proposed by Subramanian (**55**). According to Subramanian (**55**), the epithet *sulphureus* was used by Desmazieres for "another *Aspergillus*." However, the published description of *A. sulphureus* Desm. (**52**) is fragmentary in that it notes just three features, all of which are features also in *A. sulphureus* (Fres.) Wehmer. Until the holotype has been examined, there is insufficient knowledge of Desmazieres' fungus; if the taxa are indistinguishable, the correct name may be "*A. sulphureus* Desm." At present, there is no justification for a change in name.

Aspergillus sulphureus var. *crassus* Rai, Agarwal & Tewari differs from the typical variety in its production of "thick-walled hyphae in the submerged mycelium that resemble the Hülle cells of *A. flavipes*" (**46**).

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