**INTRODUCTION**

The genus *Pythium* as defined by Pringsheim in 1858 was divided by Lévesque & de Cock (2004) into 11 clades based on molecular systematic analyses. These clades are generally well supported by morphological features. In particular, *Pythium* species belonging to clade K were observed to be phylogenetically distinct from the rest of the species belonging to clade K were observed to be phylogenetically and as a separate phylogenetic entity. *Phytophthora* is morphologically intermediate between the genera *Pythium* and *Phytophthora*. It is unique in having papillate, internally proliferating sporangia and cylindrical or lobate antheridia. The formal transfer of clade K species to *Phytophthora* and a comparison with morphologically similar species of the genera *Pythium* and *Phytophthora* is presented. A new species is described, *Phytophthora miripenurens*.

**MATERIALS AND METHODS**

**Morphological studies**

The strains used for the phylogenetic study were morphologically examined to verify their identity and to find the characteristic features of the group. The methods used for cultivation of the strains for study of morphology and zoospore development are the same as described by de Cock & Lévesque (2004).

**DNA extraction, amplification and sequencing**

Almost 300 strains of *Pythium*, *Phytophthium*, *Phytophthora*, *Halophytophthora* and *Albugo* were used in this study (Table 1). DNA was extracted using the protocols as described in Bala et al. (2010a). PCR amplifications for the rDNA LSU and ITS1-5.8S-ITS2 regions and mitochondrial DNA COI were done using the protocols and primer sequences as provided in Robideau et al. (2011). The LSU region was amplified using forward primer NS1 (5'-TAGTGCATATGCTTGTCC-3') (White et al. 1990) and reverse primer OomLo5.8S47B (3'-CGCATTACG-TATCGCACTTCGAC-5') (Mazzola et al. 2002), with an internal denaturation at 95 °C for 3 min, 35 cycles of denaturation at 95 °C for 30 s, primer annealing at 55 °C for 45 s, elongation at 72 °C for 2 min and final elongation at 72 °C for 8 min. Sequencing primers used for the LSU region were NS1, NS2 (5'-GGCT-GCTGCGACCACTTGCG-3'), NS3 (5'-GCAAATGCGTGCC-CAGCCAGCC), NS4 (5'-CTTCGCTCAATCTTTAAG-3'), NS5
| Species                        | Strain Number | Clade     | SSU,ITS     | SSU         | COI     | LSU     | ITS     |
|-------------------------------|---------------|-----------|-------------|-------------|---------|---------|---------|
| Albugo candida               | AC2V          | Clade 1   |             |             |         |         |         |
| Phytophthora                   |               |           |             |             |         |         |         |
| Ph. avicenniae                | CBS158.85     | Clade 4   | HQ708184    | HQ656549    |         |         |         |
| Ph. cerea                     | CBS241.83     | Clade 8   | HQ656549    | HQ656549    |         |         |         |
| Ph.distinctica                | CBS5680.84    | Clade 9   | HQ708183    | HQ656505    |         |         |         |
| Ph. macrochlamydospora        | P10564        | Clade 7   |             |             |         |         |         |
| Ph. allii                      | P16503        | Clade 4   |             |             |         |         |         |
| Ph. cornelliae                | P13660        | Clade 1   |             |             |         |         |         |
| Ph. cornelliae                | CBS305.62     | Clade 4   | HQ708219    | HQ656514    |         |         |         |
| Ph. c. aureae                 | P16040        | Clade 8   |             |             |         |         |         |
| Ph. c. balearenkensis         | CBS679.84     | Clade 6   | HQ708220    | HQ656528    |         |         |         |
| Ph. c. b. biehnii             | P10117        | Clade 2   |             |             |         |         |         |
| Ph. c. b. bohmeriae           | CBS291.29     | Clade 10  | HQ708221    | HQ656519    |         |         |         |
| Ph. c. bulbosa                | P1257         | Clade 10  |             |             |         |         |         |
| Ph. c. clavata                | P6950         | Clade 10  |             |             |         |         |         |
| Ph. c. botryosa               | P1044         | Clade 2   |             |             |         |         |         |
| Ph. c. brassicae              | CBS178.87     | Clade 8   | HQ708225    | HQ656514    |         |         |         |
| Ph. c. brassicae              | P10155        | Clade 6   |             |             |         |         |         |
| Ph. c. clavata                | P3273         | Clade 8   |             |             |         |         |         |
| Ph. c. cactorum               | CBS108.09     | Clade 1   |             |             |         |         |         |
| Ph. c. cinicala               | P7014         | Clade 1   |             |             |         |         |         |
| Ph. c. clavata                | P10365        | Clade 1   |             |             |         |         |         |
| Ph. c. capiscii               | CBS554.88     | Clade 2   |             |             |         |         |         |
| Ph. c. capitata               | P6522         | Clade 2   |             |             |         |         |         |
| Ph. c. cinnamomi              | CBS144.22     | Clade 7   | HQ708257    | HQ656512    |         |         |         |
| Ph. c. cinnamomi var. parvispora | CBS411.96  | Clade 7   | HQ708268    | HQ656521    |         |         |         |
| Ph. c. cinnamomi var. robiniae | P16351    | Clade 7   |             |             |         |         |         |
| Ph. c. cinnamomi              | CBS221.88     | Clade 2   | HQ708269    | HQ656516    |         |         |         |
| Ph. c. citrophthora            | CBS950.87     | Clade 7   | HQ708272    | HQ656530    |         |         |         |
| Ph. c. c. clavata             | P1212         | Clade 2   |             |             |         |         |         |
| Ph. c. c. clavata             | P3942         | Clade 2   |             |             |         |         |         |
| Ph. c. c. clavata             | P6102         | Clade 2   |             |             |         |         |         |
| Ph. c. c. cryptogea            | P16165        | Clade 8   |             |             |         |         |         |
| Ph. c. drechleri              | CBS468.81     | Clade 8   | HQ708276    | HQ656528    |         |         |         |
| Ph. c. drechleri              | P10331        | Clade 8   |             |             |         |         |         |
| Ph. c. drechleri              | P1087         | Clade 8   |             |             |         |         |         |
| Ph. c. ebracteptica           | CBS129.23     | Clade 8   | HQ708286    | HQ665121    |         |         |         |
| Ph. c. eupaea1                 | P10324        | Clade 7   |             |             |         |         |         |
| Ph. c. falax                    | P10722        | Clade 9   |             |             |         |         |         |
| Ph. c. foliorum                | P10969        | Clade 8   | HQ261307    | EU709704    |         |         |         |
| Ph. c. fragaria1               | CBS209.46     | Clade 7   | HQ708294    | HQ656519    |         |         |         |
| Ph. c. fragaria1               | P1435         | Clade 7   |             |             |         |         |         |
| Ph. c. frigida                 | P16051        | Clade 2   |             |             |         |         |         |
| Ph. c. goranopodiinae         | CBS363.79     | Clade 6   | HQ708297    | HQ656526    |         |         |         |
| Ph. c. goranopodiinae         | CBS554.87     | Clade 6   |             |             |         |         |         |
| Ph. c. goranopodiinae         | P10337        | Clade 6   |             |             |         |         |         |
| Ph. c. goranopodiinae         | P3700         | Clade 6   |             |             |         |         |         |
| Ph. c. hedranda                | CBS118732     | Clade 1   | HQ708300    |             |         |         |         |
| Ph. c. heveae                  | PDA331        | Clade 1   |             |             |         |         |         |
| Ph. c. heveae                  | CBS296.29     | Clade 5   | HQ708301    | HQ656194    |         |         |         |
| Ph. c. hibernalis            | P10167        | Clade 5   |             |             |         |         |         |
| Ph. c. himalayensis            | CBS357.59     | Clade 6   |             |             |         |         |         |
| Ph. c. himalayensis            | CBS200.81     | Clade 6   |             |             |         |         |         |
| Ph. c. idaei                    | P3826         | Clade 6   |             |             |         |         |         |
| Ph. c. idaei                    | P3909         | Clade 3   |             |             |         |         |         |
| Ph. c. infestans               | CBS366.51     | Clade 1   |             |             |         |         |         |
| Ph. c. insolita                | P6703         | Clade 9   |             |             |         |         |         |
| Ph. c. inostata                | CBS215.85     | Clade 6   | HQ708311    | HQ656154    |         |         |         |
| Ph. c. loamella                | P8478         | Clade 6   |             |             |         |         |         |
| Ph. c. ipomoeae                | P10225        | Clade 1   |             |             |         |         |         |
| Ph. c. iranicum                | CBS374.72     | Clade 1   |             |             |         |         |         |
| Ph. c. katsuriae               | CBS557.85     | Clade 5   |             |             |         |         |         |
| Ph. c. katsuriae               | P10187        | Clade 5   |             |             |         |         |         |
| Ph. c. kemania                  | P10613        | Clade 8   |             |             |         |         |         |
| Ph. c. kemania                  | P10958        | Clade 10  | HQ708324    | HQ656159    |         |         |         |
| Ph. c. lateralis               | CBS168.42     | Clade 8   |             |             |         |         |         |
| Ph. c. lateralis               | Lev1213       | Clade 8   | HQ708320    |             |         |         |         |
| Ph. c. macrochlamydospora      | P1026         | Clade 9   |             |             |         |         |         |
| Ph. c. medicaginis              | CBS219.88     | Clade 2   |             |             |         |         |         |
| Ph. c. megakarya               | P8072         | Clade 8   |             |             |         |         |         |
| Ph. c. megakarya               | P1672         | Clade 4   | HQ708235    |             |         |         |         |
| Ph. c. metarhizina             | P1672         | Clade 4   |             |             |         |         |         |
| Ph. c. metarhizina             | P6516         | Clade 4   |             |             |         |         |         |
| Ph. c. megasperma              | CBS402.72     | Clade 6   | HQ708329    | HQ665228    |         |         |         |
| Species                        | Strain Number | Clade | SSU,ITS_28S | SSU,ITS | SSU | COI | LSU | ITS |
|-------------------------------|---------------|-------|-------------|---------|-----|-----|-----|-----|
| Phytopythium megaspermum      | P10340        | Clade 6 |             |         |     |     |     |     |
| Phytopythium melonis          | CBS552.69     | Clade 7 |             |         |     |     |     |     |
| Phytopythium menglei          | P10139        | Clade 2 |             |         |     |     |     |     |
| Phytopythium mirabilis        | CBS577.85     | Clade 1 |             |         |     |     |     |     |
| Phytopythium multivesiculata  | CBS545.96     | Clade 2 |             |         |     |     |     |     |
| Phytopythium multivora        | P1233         | Clade 2 |             |         |     |     |     |     |
| Phytopythium nemorosa         | P10288        | Clade 3 |             |         |     |     |     |     |
| Phytopythium nicotianae       | CBS303.29     | Clade 1 |             |         |     |     |     |     |
| Phytopythium palivora         | CBS528.29     | Clade 4 |             |         |     |     |     |     |
| Phytophthora parisiensis      | P21281        | Clade 9 |             |         |     |     |     |     |
| Phytophthora pinifolia        | P16100        | Clade 6 |             |         |     |     |     |     |
| Phytophthora polonica         | P15004        | Clade 9 |             |         |     |     |     |     |
| Phytophthora porri            | CBS567.86     | Clade 9 |             |         |     |     |     |     |
| Phytophthora phaseoli         | CBS556.88     | Clade 1 |             |         |     |     |     |     |
| Phytophthora phaseoli         | P10145        | Clade 1 |             |         |     |     |     |     |
| Phytophthora pinifolia        | P16100        | Clade 6 |             |         |     |     |     |     |
| Phytophthora polonica         | P15004        | Clade 9 |             |         |     |     |     |     |
| Phytophthora primulae         | P10220        | Clade 8 |             |         |     |     |     |     |
| Phytophthora primulae         | P10333        | Clade 8 |             |         |     |     |     |     |
| Phytophthora pseudosyringae   | P10443        | Clade 3 |             |         |     |     |     |     |
| Phytophthora pseudosyringae   | P16355        | Clade 3 |             |         |     |     |     |     |
| Phytophthora pseudosyringae   | P10218        | Clade 1 |             |         |     |     |     |     |
| Phytophthora quercetorum      | P15555        | Clade 4 |             |         |     |     |     |     |
| Phytophthora quercetorum      | P0113         | Clade 4 |             |         |     |     |     |     |
| Phytophthora quercina         | P10334        | Clade 4 |             |         |     |     |     |     |
| Phytophthora quinoa           | CBS407.48     | Clade 9 |             |         |     |     |     |     |
| Phytophthora ramorum          | CBS101553     | Clade 8 |             |         |     |     |     |     |
| Phytophthora roseaearum       | P8048         | Clade 6 |             |         |     |     |     |     |
| Phytophthora roseaearum       | P8049         | Clade 6 |             |         |     |     |     |     |
| Phytophthora rubi             | CBS967.95     | Clade 7 |             |         |     |     |     |     |
| Phytophthora sambaeana        | P3163         | Clade 8 |             |         |     |     |     |     |
| Phytophthora sambaeana        | CBS557.88     | Clade 7 |             |         |     |     |     |     |
| Phytophthora sambaeana        | P15122        | Clade 2 |             |         |     |     |     |     |
| Phytophthora sexigera         | CBS382.61     | Clade 7 |             |         |     |     |     |     |
| Phytophthora sexigera         | P15880        | Clade 6 |             |         |     |     |     |     |
| Phytophthora sexigera         | P16355        | Clade 3 |             |         |     |     |     |     |
| Phytophthora sexigera         | P10301        | Clade 8 |             |         |     |     |     |     |
| Phytophthora sexigera         | P2876         | Clade 8 |             |         |     |     |     |     |
| Phytophthora sexigera         | P8048         | Clade 6 |             |         |     |     |     |     |
| Phytophthora sexigera         | P8049         | Clade 6 |             |         |     |     |     |     |
| Phytophthora sexigera         | P10456        | Clade 9 |             |         |     |     |     |     |
| Phytophthora sexigera         | P10456        | Clade 9 |             |         |     |     |     |     |
| Phytophthora sexigera         | P15506        | Clade 6 |             |         |     |     |     |     |
| Phytophthora sexigera         | P10506        | Clade 4 |             |         |     |     |     |     |
| Phytophthora sexigera         | P11555        | Clade 6 |             |         |     |     |     |     |
| Phytophthora sexigera         | P3036         | Clade 6 |             |         |     |     |     |     |
| Phytophthora syringae         | CBS132.23     | Clade 8 |             |         |     |     |     |     |
| Phytophthora syringae         | P10330        | Clade 8 |             |         |     |     |     |     |
| Phytophthora tabaci           | CBS305.29     | Clade 1 |             |         |     |     |     |     |
| Phytophthora tentaculata      | CBS552.96     | Clade 7 |             |         |     |     |     |     |
| Phytophthora tentaculata      | P10363        | Clade 1 |             |         |     |     |     |     |
| Phytophthora thermophilum     | P1896         | Clade 9 |             |         |     |     |     |     |
| Phytophthora trifoli          | P1482         | Clade 8 |             |         |     |     |     |     |
| Phytophthora tropicalis       | CBS543.91     | Clade 2 |             |         |     |     |     |     |
| Phytophthora tropicalis       | P10329        | Clade 2 |             |         |     |     |     |     |
| Phytophthora uliginosa        | P10328        | Clade 7 |             |         |     |     |     |     |
| Phytophthumum boreale         | CBS551.88     | Clade 7 |             |         |     |     |     |     |
| Phytophthumum boreale         | CBS11254      | Clade 7 |             |         |     |     |     |     |
| Phytophthumum carnicum       | CBS529.30     | Clade 9 |             |         |     |     |     |     |
| Phytophthumum carnicum       | CBS119171     | Clade 7 |             |         |     |     |     |     |
| Phytophthumum delawarrense   | CBS5212304    | Clade 1 |             |         |     |     |     |     |
| Phytophthumum delawarrense   | CBS286.31     | Clade 1 |             |         |     |     |     |     |
| Phytophthumum delawarrense   | CBS131.91     | Clade 1 |             |         |     |     |     |     |
| Phytophthumum delawarrense   | CBS119360     | Clade 7 |             |         |     |     |     |     |
| Phytophthumum delawarrense   | CBS12262      | Clade 6 |             |         |     |     |     |     |
| Phytophthumum delawarrense   | A89 (GENBANK) | Clade 6 |             |         |     |     |     |     |
| Phytophthumum delawarrense   | CBS122443     | Clade 6 |             |         |     |     |     |     |
| Phytophthumum delawarrense   | CBS124523     | Clade 6 |             |         |     |     |     |     |
| Phytophthumum delawarrense   | CBS124524     | Clade 6 |             |         |     |     |     |     |

Table 1 (cont.)
Table 1 (cont.)

| Species                        | Strain Number | Clade          | SSU_ITS_28S | SSU_ITS | SSU    | COI    | LSU    | ITS    |
|--------------------------------|---------------|----------------|-------------|---------|--------|--------|--------|--------|
| **Phytophthora**               |               |                |             |         |        |        |        |        |
| Phytopythium montanum          | CBS111349     | A              |             |         |        |        |        |        |
| Phytopythium oedochilum        | CBS292.37     | A              |             |         |        |        |        |        |
| Phytopythium o squidoceras     | CBS768.73     | D              |             |         |        |        |        |        |
| Phytopythium sindthum          | CBS124518     | A              |             |         |        |        |        |        |
| Phytopythium vexans            | CBS119.80     | A              |             |         |        |        |        |        |
| Phytium abapressorum           | CBS110198     | F              |             |         |        |        |        |        |
| Phytium acanthicum             | CBS377.34     | D              |             |         |        |        |        |        |
| Phytium acanthophorum          | CBS337.29     | E              |             |         |        |        |        |        |
| Phytium acropygium             | CBS549.88     | E              |             |         |        |        |        |        |
| Phytium adhaerens              | CBS520.74     | B              |             |         |        |        |        |        |
| Phytium amasculus              | CBS552.88     | D              |             |         |        |        |        |        |
| Phytium anantheridum           | CBS285.31     | C              |             |         |        |        |        |        |
| Phytium anisoporum             | CBS252.74     | A              |             |         |        |        |        |        |
| Phytium aphanidermatum         | CBS118.80     | A              |             |         |        |        |        |        |
| Phytium apiculatum             | CBS120945     | E              |             |         |        |        |        |        |
| Phytium apiculatum             | CBS772.81     | B              |             |         |        |        |        |        |
| Phytium aquatilis              | CBS215.80     | B              |             |         |        |        |        |        |
| Phytium atriplex              | DADC320338    | F              |             |         |        |        |        |        |
| Phytium buismiaae              | CBS288.31     | J              |             |         |        |        |        |        |
| Phytium camuranum              | CBS124096     | E              |             |         |        |        |        |        |
| Phytium canispora              | CBS112353     | G              |             |         |        |        |        |        |
| Phytium capillorum             | CBS222.94     | D              |             |         |        |        |        |        |
| Phytium carolinianum           | CBS122659     | E              |             |         |        |        |        |        |
| Phytium catalanum              | CBS842.68     | B              |             |         |        |        |        |        |
| Phytium chondroica             | CBS203.85     | A              |             |         |        |        |        |        |
| Phytium coloratum              | CBS154.64     | C              |             |         |        |        |        |        |
| Phytium coniochlorum           | CBS223.88     | B              |             |         |        |        |        |        |
| Phytium contiglashum           | CBS221.94     | J              |             |         |        |        |        |        |
| Phytium coryloclavella         | CBS119731     | A              |             |         |        |        |        |        |
| Phytium cylindrosporum         | CBS216.94     | F              |             |         |        |        |        |        |
| Phytium cytophages              | CBS675.85     | J              |             |         |        |        |        |        |
| Phytium debaryanum             | CBS752.96     | F              |             |         |        |        |        |        |
| Phytium delense               | CBS314.33     | A              |             |         |        |        |        |        |
| Phytium dicilium              | CBS664.79     | B              |             |         |        |        |        |        |
| Phytium dimorphium             | CBS406.72     | H              |             |         |        |        |        |        |
| Phytium distilicoica           | CBS153.64     | J              |             |         |        |        |        |        |
| Phytium dissotocum             | CBS166.68     | B              |             |         |        |        |        |        |
| Phytium echinulatum            | CBS281.64     | C              |             |         |        |        |        |        |
| Phytium eumoneuseum            | BR479         | F              |             |         |        |        |        |        |
| Phytium erinaceus              | CBS550.80     | E              |             |         |        |        |        |        |
| Phytium flevoense              | CBS234.72     | B              |             |         |        |        |        |        |
| Phytium fuscsulcicola          | CBS228.81     | B              |             |         |        |        |        |        |
| Phytium glomeratum             | CBS120914     | C              |             |         |        |        |        |        |
| Phytium graminicola            | CBS327.62     | D              |             |         |        |        |        |        |
| Phytium grandisporangium       | CBS286.79     | C              |             |         |        |        |        |        |
| Phytium helicandrum            | CBS393.54     | H              |             |         |        |        |        |        |
| Phytium heterotrophospora       | CBS450.87     | I              |             |         |        |        |        |        |
| Phytium hydroporospora          | CBS253.60     | D              |             |         |        |        |        |        |
| Phytium hypogyonum             | CBS234.94     | C              |             |         |        |        |        |        |
| Phytium infulatum              | CBS168.68     | B              |             |         |        |        |        |        |
| Phytium insulosa               | ATCC 58643    | C              |             |         |        |        |        |        |
| Phytium intermedium             | CBS574.85     | C              |             |         |        |        |        |        |
| Phytium irregolare             | CBS250.26     | F              |             |         |        |        |        |        |
| Phytium iswamaei               | CBS156.64     | G              |             |         |        |        |        |        |
| Phytium kashmirensae           | ADO819        | –              |             |         |        |        |        |        |
| Phytium kuenningense           | CBS122908     | B              |             |         |        |        |        |        |
| Phytium longisporangium        | CBS122646     | E              |             |         |        |        |        |        |
| Phytium lucens                 | CBS113342     | F              |             |         |        |        |        |        |
| Phytium lutariu                | CBS222.88     | B              |             |         |        |        |        |        |
| Phytium lycuriici               | CBS122909     | D              |             |         |        |        |        |        |
| Phytium macrospororum          | CBS574.80     | F              |             |         |        |        |        |        |
| Phytium marsipium              | CBS773.81     | E              |             |         |        |        |        |        |
| Phytium mastophorium           | CBS375.72     | J              |             |         |        |        |        |        |
| Phytium megacarpum             | CBS113051     | A              |             |         |        |        |        |        |
| Phytium milladonii             | CBS552.74     | E              |             |         |        |        |        |        |
| Phytium minus                  | CBS122657     | E              |             |         |        |        |        |        |
| Phytium monospermum            | CBS158.73     | A              |             |         |        |        |        |        |
| Phytium multisporum            | CBS470.50     | A              |             |         |        |        |        |        |
| Phytium myrtifolia             | CBS254.70     | B              |             |         |        |        |        |        |
| Phytium nagais                 | CBS779.90     | G              |             |         |        |        |        |        |
| Phytium neglectum              | CBS10274      | C              |             |         |        |        |        |        |
| Phytium nunn                   | CBS806.96     | J              |             |         |        |        |        |        |
| Phytium okanogense              | CBS315.81     | G              |             |         |        |        |        |        |
| Phytium oligarum               | CBS362.34     | D              |             |         |        |        |        |        |
| Phytium oopapillum             | BR632         | B              |             |         |        |        |        |        |
| Phytium omnacarpum             | CBS113250     | E              |             |         |        |        |        |        |
Table 1 (cont.)

| Species                              | Strain Number | Clade | SSU/ITS_28S | SSU/ITS_28S | SSU/ITS_28S | COI | LSU | ITS |
|--------------------------------------|---------------|-------|-------------|-------------|-------------|-----|-----|-----|
| Pythium ornatum                    | CBS12265      | D     |             |             |             |     |     |     |
| Pythium orthogonon                  | CBS376.72     | J     |             |             |             |     |     |     |
| Pythium pachycaule                  | CBS227.88     | B     |             |             |             |     |     |     |
| Pythium paddicum                    | CBS698.83     | G     |             |             |             |     |     |     |
| Pythium parvocaudum                 | CBS157.64     | F     |             |             |             |     |     |     |
| Pythium parvum                      | CBS225.88     | E     |             |             |             |     |     |     |
| Pythium pectinolyticum              | CBS12243      | C     |             |             |             |     |     |     |
| Pythium peritrichum                 | CBS169.68     | B     |             |             |             |     |     |     |
| Pythium peritrichum                 | CBS285.31     | D     |             |             |             |     |     |     |
| Pythium pleasirificum               | CBS674.85     | J     |             |             |             |     |     |     |
| Pythium plentilicium                | CBS776.81     | E     |             |             |             |     |     |     |
| Pythium plutostrorum                | CBS100530     | C     |             |             |             |     |     |     |
| Pythium polymastum                  | CBS811.70     | J     |             |             |             |     |     |     |
| Pythium porphyrae                   | CBS369.79     | A     |             |             |             |     |     |     |
| Pythium proletum                    | CBS845.68     | H     |             |             |             |     |     |     |
| Pythium pyriforme                   | CBS158.64     | B     |             |             |             |     |     |     |
| Pythium radiosus                    | CBS217.94     | E     |             |             |             |     |     |     |
| Pythium rhizooryzae                 | CBS119169     | C     |             |             |             |     |     |     |
| Pythium rhizoscacharum              | CBS112356     | E     |             |             |             |     |     |     |
| Pythium rostratilvensis             | CBS115464     | E     |             |             |             |     |     |     |
| Pythium rostratum                   | CBS533.74     | E     |             |             |             |     |     |     |
| Pythium salpingophorum              | CBS471.50     | B     |             |             |             |     |     |     |
| Pythium scrobiculosum               | CBS294.37     | C     |             |             |             |     |     |     |
| Pythium segnitium                   | CBS112354     | A     |             |             |             |     |     |     |
| Pythium senticulum                  | CBS122490     | H     |             |             |             |     |     |     |
| Pythium sp balticum                 | CBS122649     | D     |             |             |             |     |     |     |
| Pythium sp                          | CBS113341     | F     |             |             |             |     |     |     |
| Pythium sp CAL-201a                  | CBS122647     | D     |             |             |             |     |     |     |
| Pythium sp CAL-201e                  | CBS122648     | E     |             |             |             |     |     |     |
| Pythium sp CAL-201f                  | CBS101187     | J     |             |             |             |     |     |     |
| Pythium spicum                      | CBS122645     | D     |             |             |             |     |     |     |
| Pythium spinosum                    | CBS275.67     | C     |             |             |             |     |     |     |
| Pythium splendens                   | CBS462.48     | I     |             |             |             |     |     |     |
| Pythium stenli                        |              |      |             |             |             |     |     |     |
| Pythium sutoria                      | CBS1100030    | D     |             |             |             |     |     |     |
| Pythium sylvaticum                  | CBS453.67     | F     |             |             |             |     |     |     |
| Pythium takaayamanum                | CBS122491     | E     |             |             |             |     |     |     |
| Pythium terrestris                  | CBS112352     | F     |             |             |             |     |     |     |
| Pythium torulosum                   | CBS316.33     | C     |             |             |             |     |     |     |
| Pythium trachephyllum               | CBS323.65     | B     |             |             |             |     |     |     |
| Pythium ultimum var. sporangiferum   | CBS219.65     | I     |             |             |             |     |     |     |
| Pythium ultimum var. ultimum        | CBS396.51     | I     |             |             |             |     |     |     |
| Pythium uniculatum                  | CBS518.77     | J     |             |             |             |     |     |     |
| Pythium undulatum                   | CBS157.69     | H     |             |             |             |     |     |     |
| Pythium vanterpolii                 | CBS295.37     | C     |             |             |             |     |     |     |
| Pythium viniferum                   | CBS119168     | F     |             |             |             |     |     |     |
| Pythium violae                      | CBS132.37     | G     |             |             |             |     |     |     |
| Pythium volutum                     | CBS159.64     | G     |             |             |             |     |     |     |
| Pythium zingibers                   | CBS699.83     | B     |             |             |             |     |     |     |
| Pythium zingibers                   | CBS216.82     | B     |             |             |             |     |     |     |

(‘-AACCTAAAGAAGAATTGACGAGAAG’ and NS8 (‘-TCCGCA-GTCTCCACTCAGGAAG’) (White et al. 1990) as well as Oom_Lo-5.8547 (‘-ATTACGTATCGCAGTTGCCAGA’) (Man in’t Veld et al. 2002) for full bidirectional coverage. Sequencing reactions were prepared using the Big Dye Terminator (BdT) v. 2 protocols (Applied Biosystems, Foster City, CA). Sequencing of the PCR product was performed in an Applied Biosystems Prism Genetic Analyzer model 3130XL.

**Phylogenetic analyses**

Sequences were edited manually using the DNAsStar Lasergene 9 Suite (Bioinformatics Pioneer DNAStar, Inc., WI) or Geneious v. 6.1.6 (Biomatters http://www.geneious.com/). Multiple alignments of each gene region were generated using MAFFT (Katoh et al. 2005). The genera included in the phylogenetic analyses were Albúgo, Halophytophthora, Phytophthora, Pythiomyum and Pythium. Isolates of Albúgo candida from the order Albuginales were included as an outgroup.

In order to include the maximum molecular data for clade K *Pythium* the invalid species *Pythium sterile* and *Pythium megacarpum* as well as two strains of the novel species *Phytophthium mirpurense* are considered in a cladogram generated based on ITS sequence data. *Pythium ultimum* from clade I and *Pythium dimorphum* from clade H are outgroups in these analyses and representatives of *Phytophthora*, *P. infestans*, *P. ramorum* and *P. sojae* are included. The aligned data matrix from 23 strains contained 1 096 characters from the ITS1, ITS2 and the 5.8S gene.

The aligned data matrices were assessed to find the best-fit model of substitution using jMODELTEST (Posada 2008). In each case this was identified as General Time Reversible (GTR+I+G). Redundant sequences were identified and those with 100 % identity to other included taxa were removed from the analyses. These duplicates are catalogued in Table 2. The aligned data matrices contained 1 374 bp of D1–D3 regions of LSU with 176 strains, 1 724 bp of SSU rRNA with 159 strains and 680 bp of COI with 174 strains. The sequence alignments were subjected to maximum likelihood analysis using the GTR+I+G substitution model and the Best option for tree topology search with PhyML v. 3.0 (Guindon & Gascuel 2003) to obtain ML trees which were rooted to *Albúgo* (LSU, COI and SSU) or *Pythium* (ITS). Nonparametric ML bootstrap calculations were calculated with 1 000 bootstrap replicates. Bayesian inferences (BI) were generated using MrBayes v. 3.2.1 (Ronquist & Huelsenbeck 2003) with Markov Chain Monte Carlo (MCMC) methodology to calculate posterior probabilities of the phylo-
| Species Strain | Clade | GenBank | Identical sequences not included in phylogenies |
|----------------|-------|---------|-----------------------------------------------|
| **SSU**        |       |         |                                               |
| Phytophthora allicola | P16053 | Clade 4 | JN635264 | Phytophthora frigida | P16051 | Clade 2 | JN635162 |
| Phytophthora asparagi | P10707 | Clade 6 | JN635226 | Phytophthora roseae | P6048 | Clade 6 | JN635062 |
| Phytophthora cactorum | P0714  | Clade 1 | JN635210 | Phytophthora cactorum | P10365 | Clade 1 | JN635194 |
| Phytophthora capsici | P10719 | Clade 9 | JN635227 | Phytophthora capsici | P10720 | Clade 9 | JN635229 |
| Phytophthora cryptogea | P16165 | Clade 8 | JN635259 | Phytophthora pseudosyringae | P16355 | Clade 3 | JN635257 |
| Phytophthora eryotheospora | P1693  | Clade 8 | JN635249 | Phytophthora gonapodyides | P17097 | Clade 6 | JN635141 |
| Phytophthora richardiae | CBS876 | Clade 1 | JN635254 | Phytophthora richardiae | P3876 | Clade 8 | JN635045 |
| Phytophthora sansomea | CBS163 | Clade 8 | JN635047 | Phytophthora infolia | P1462 | Clade 6 | JN635065 |
| Phytophthora viniferum | P10328 | Clade 7 | JN635175 | Phytophthora uliginosa | P10413 | Clade 7 | JN635202 |
| Phytophthora lagioriana | CBS220 | Clade 9 | JN635085 | Phytophthora lagioriana | P8223 | Clade 9 | JN635086 |
| Phytophthora palmivora | P0113  | Clade 4 | JN635188 | Phytophthora palmivora | P0555 | Clade 4 | JN635186 |
| Phytophthora primulae | P10220 | Clade 8 | JN635180 | Phytophthora primulae | P10333 | Clade 8 | JN635187 |
| Pythium flevense CBS23472 Clade B AY598691 | Pythium pectinoliticum CBS12643 Clade B HQ643739 |
| Pythium minus CBS22688 Clade E AY598698 | Pythium plicaticlum CBS776.81 Clade E AY598642 |
| **LSU**         |       |         |                                               |
| Phytophthora arecae CBS30562 Clade 4 HQ665200 | Phytophthora palmivora CBS29829 Clade 4 HQ665195 |
| Phytophthora boehmeriae CBS29129 Clade 10 HQ665190 | Phytophthora boehmeriae P6950 Clade 10 EU80166 |
| Phytophthora brassicace CBS17787 Clade 8 HQ665144 | Phytophthora brassicace CBS178.87 Clade 8 HQ665144 |
| Phytophthora eryotheospora CBS12923 Clade 8 HQ665121 | Phytophthora hialumlaysia CBS53579 Clade 8 HQ665215 |
| Phytophthora fragariae CBS20946 Clade 7 HQ665150 | Phytophthora rubi CBS65795 Clade 7 HQ665306 |
| Phytophthora gonapodyides CBS55467 Clade 6 HQ665265 | Phytophthora gonapodyides CBS36379 Clade 6 HQ665216 |
| Phytophthora inundata P8478 Clade 6 EU79946 | Phytophthora humicola CBS20081 Clade 6 HQ665148 |
| **COI**         |       |         |                                               |
| Phytophthora arecae CBS30562 Clade 4 HQ708218 | Phytophthora primulae CBS29829 Clade 4 HQ665195 |
| Pythium amasculinum CBS55288 Clade D HQ709481 | Pythium lycopersicum CBS122909 Clade D HQ643863 |
| Pythium conidiphorum CBS22388 Clade B HQ708555 | Pythium salpingophorum CBS47150 Clade B HQ643768 |
| Pythium debaryanum CBS75296 Clade F HQ708565 | Pythium viniferum CBS19168 Clade B HQ643956 |
| Pythium diclinum CBS66479 Clade B HQ708570 | Pythium lutanum CBS22288 Clade B HQ643862 |
| Pythium erinaceus CBS55080 Clade E HQ708578 | Pythium ornacum CBS112350 Clade E HQ643721 |
| Pythium folliculosum CBS22094 Clade B HQ708584 | Pythium torulosum CBS31633 Clade B HQ643859 |
| Pythium minus CBS12657 Clade E HQ708739 | Pythium plicaticlum CBS77618 Clade E HQ643748 |
| Pythium myriotylum CBS25470 Clade B HQ708745 | Pythium zingiberis CBS21682 Clade B HQ643973 |

**Statistical analyses of pairwise distances**

The alignments of COI, LSU and SSU used for phylogeny were also used to generate pairwise distance as was done for DNA barcode analyses (Robideau et al., 2011, Schoch et al., 2012). Statistical analyses and plots were performed with R (R Development Core Team, 2011). All pairwise distances involving a species against every 1 of evolution for each gene. The first 25 % of the iterations were discarded as burn-in and every 1 000th iteration was sampled from the remainder. The trees were considered to be fully converged when the average standard deviation of split frequencies reached a level less than 0.01. FigTree v. 1.3.1 (http://tree.bio.ed.ac.uk/software/figtree/) was used to view and edit ML and Bayesian phylogenetic trees. Consensus trees were generated using the 50 % majority rule tree criteria and rooted to Albugo (LSU, COI and SSU) or Pythium (ITS).
as variables. Plots were generated with `ggplot` for R. The 0.05 confidence interval for 60 multiple comparisons was adjusted using the Bonferroni method. The average pairwise distance by marker was normalised to remove the bias from the difference in number of species between *Pythium* and *Phytophthora*.

**Isolation and identification of Phytopythium mirpurens**

Stagnant water was collected and immediately brought to the laboratory for the isolation of oomycetous fungi by the baiting technique of Harvey (1925). Grass blades, dicot leaves, hemp seeds, sesame seeds, lemon leaf and young cucumber stems were used as baits. Plates were incubated at room temperature, between 22–25 °C. Hyphae were observed on the baits after 5–8 days of incubation. The baits were rinsed in sterilised water to remove excess contaminants and transferred to fresh plates half-filled with sterile water. New fresh baits were then added and monitored daily for colonisation by oomycetes. After 2 d of incubation, the baits colonised by oomycetous fungi were transferred onto corn-meal agar (CMA) medium for purification by hyphal tip transfer. To obtain a pure culture a small disc of the CMA culture was placed into the centre of water agar plates. After 15–24 h growing apical hyphae were cut with the aid of a microscope in the laminar flow hood and transferred onto the surface of a fresh plate containing culture media.

For the assessment of cardinal temperatures, the isolates from this study were sub-cultured in two replicates on CMA in 90 mm Petri plates, and incubated at 10, 15, 20, 25, 30, 35 and 40 °C for 5 d. Radial growth was measured daily along

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**Fig. 1** Sporangia of Phytopythium species. a. *P. sindhum*, four stages of sporangium development showing a young, globose sporangium, a mature, papillate sporangium, internal proliferation and pythium-like zoospore development; b. *P. vexans*, subglobose, non-papillate sporangia; c–g. *P. citrinum*: c. normal sporangia; d. outgrowing papillae; e. outgrowing and branching papilla; f. empty sporangium with internal proliferation and short discharge tube; g. empty sporangium with internal proliferation and long discharge tube (arrow indicating tip); h–j. *P. helicandrum*: h. sessile, globose, papillate sporangium; i. outgrowing papilla; j. empty sporangium with intermediate sized discharge tube (arrow indicating tip). — Scale bars = 20 µm.
RESULTS AND DISCUSSION

**Morphological comparison of Phytopythium with Phytophthora and Pythium**

Most species in the genus *Phytopythium* produce papillate, internally proliferating sporangia (Fig. 1). The shape of the sporangia is more or less similar to the shape of papillate *Phytophthora* sporangia: (sub-)globose to ovoid and papillate (Fig. 1). However, in *Phytophthora* the papillate sporangium type never shows internal proliferation. The combination of internal proliferation and papillulation (Fig. 1) is unique to sporangia of *Phytopythium* and some *Pythium* species (see below). Also, the papillae in *Phytopythium* are different from the papillae in *Phytophthora* sporangia. In *Phytopythium* the sporangia are initially non-papillate, and the papillae develop at maturity and do not consist of a hyaline ‘apical thickening’ as in *Phytophthora* (Blackwell 1949). They may grow out to form a shorter or larger discharge tube (Fig. 1d, f, g, i, j), which does not occur in *Phytophthora*. In some species the papilla is not the place where the plasma flows out, rather one or more discharge tubes are formed more basally of the sporangium. In some species the papilla grows out and develops branches (Fig. 1e). Another difference with *Phytophthora* is the zoospore discharge which is pythium-like in *Phytopythium*: the plasma flows out of the sporangium through a discharge tube to form a plasma-filled vesicle at the tip. Zoospores are developed outside the sporangium, within the vesicle membrane and are released after rupture of the membrane (Fig. 1a). According to Marano et al. (2014), *Phytopythium kandeliae* has zoospore release mostly like *Pythium* and occasionally in between *Pythium* and *Phytophthora*: zoospores developed (partly) inside a sporangium and partly in a vesicle.

Another unique characteristic of *Phytopythium* is the shape of the antheridium (Fig. 2). In most species the antheridia are elongate, cylindrical, often with constrictions. The fertilisation tube is mostly not apical but in ‘navel position’ (Fig. 2a–d, arrows). Occasionally club-shaped antheridia with apical attachment occur. In *P. vexans*, the antheridia are often very broadly attached to the oogonium and lobed (Fig. 2e, f).

Papillate sporangia with internal proliferation also occur in a small number of *Pythium* species: three members of clade E (*P. marsipium, P. middletonii, P. multisporum*), one member of clade G (*P. nagaii*) and clade C (*P. grandisporangium*) and all members of clade H (*P. anandrum, P. dimorphum, P. helicandrum, P. prolatum, P. undulatum*). However, none of these species except three has elongate, cylindrical or lobate antheridia. Only *P. helicandrum* has elongate antheridia, however, this species has ornamented oogonia and much bigger sporangia than any of the species in *Phytopythium*. *Pythium marsipium* has bell-shaped antheridia as they occur in *Phytopythium vexans*, however, its sporangia are utriform instead of ovoid. *Pythium grandisporangium* has lobate antheridia but this is a marine species with extremely large sporangia with a tapering neck rather than a distinct papilla.

**Phylogenetic position of Phytopythium**

Maximum likelihood analyses of nuclear (LSU and SSU) and mitochondrial DNA (COI) with Bayesian probability values mapped onto the trees are shown (Fig. 3A–C). These cladograms place all the strains belonging to the genus *Phytopythium* as a monophyletic group with bootstrap support (85–100 %) and high probabilities (0.99–1.00). Phylogenetic trees of the LSU

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**Fig. 2** Oogonia and antheridia of *Phytopythium* species. a. *P. sindhum*, slightly elongated antheridium; b–c. *P. oedochilum*, long cylindrical antheridia; d. *P. mironpurense*, elongate antheridium with slight constriction; e–f. *P. vexans*: e. elongate antheridium with distinct constrictions; f. antheridium with two lobes. Arrows indicate the fertilisation tube in navel position (a–d). — Scale bars = 10 µm.
and COI regions support this group as intermediary between Phytopythium and Pythium. There is phylogenetic support with two of the genes to group Phytopythium with Phytophthora (95% / 1.00 for LSU and 79% / 0.99 for COI). The SSU tree has Pythium clades A–D as grouping closer to Phytophthora and Halophytophthora, with very low bootstrap support and probabilities (≤ 50% / 0.65). This suggests that given the SSU dataset, the major clades are unresolved in relation to the outgroup.

Our results from phylogenetic analysis of nuclear (LSU and SSU) and mitochondrial (COI) genes with all available species of Pythium and Phytophthora support that Phytopythium is a distinct genus. Its placement as intermediate between Pythium and Phytophthora is supported by two of these datasets. In the three gene trees, this new genus clade was strongly supported by both ML bootstrap replicates and Bayesian probability values, which unambiguously confirmed the status of Phytopythium as a novel monophyletic genus. The maximum likelihood and Bayesian analyses did not clearly delineate the relationships between the different groups in the part of the oomycete evolutionary tree we focused on. Inclusion of some of the more basal groups such as the Salisapiliaceae (Hulvey et al. 2010) and additional markers in future analyses would likely lead to greater resolution of these relationships.

The ITS tree (Fig. 4) shows that the two strains of species P. mirpurense are both well embedded within Phytopythium with strong support (91% / 0.96) and demonstrated the close relationships between P. litorale and Pythium sterile (100 / 1) as well as Phytopythium boreale and Pythium megacarpum (99 / 1).

**Statistical analyses of pairwise distances**

Markers, genera and clades as well as interactions between them all had a significant effect on pairwise distances of Phytophthora against Pythium and Phytophthora species (p < 10^-16). The average pairwise distance of all Phytophthora species against all Phytopythium species using COI was 13.7% whereas it was 14.5% for all Pythium species against all Phytopythium, showing that Phytopythium is significantly closer to Phytophthora than Pythium (p < 10^-16). For LSU, these differences were 10.4% and 10.9%, respectively, and were also significant (p < 10^-16). For SSU, the trend was reversed, still significant, with the average pairwise distance between Pythium and Phytopythium being 2.5% whereas the average between Phytophthora and Phytopythium was 2.7%. The clade effect was significant, including a significant interaction with markers; therefore, the results are presented by clades and markers in Fig. 5. Each clade is compared against Phytophthora to show clades that have a significant difference from the average pairwise distance. The significant trend of Phytophthora being closer to Phytophthora clades than Pythium clades can be seen with COI and LSU whereas it is more difficult to visualise the reverse trend in SSU. With all markers, Pythium clades H and I were significantly closer to Phytophthora than were the other Pythium clades but for SSU there were three additional clades (B, F and G) that were significantly closer to Phytopythium than were the other clades.
Strains used in circumscription of the genus

There are two invalid species that were investigated for the sake of examining the complete range of *Pythium* species from clade K, namely *Pythium megacarpum* and *P. sterile*. *Pythium megacarpum* is an invalid species because no type was indicated at the time of publication. Lévesque & de Cock (2004) placed it as potentially synonymous with *Phytopythium boreale* and in the barcode analyses of Robideau et al. (2011) these two species were only distinguishable through COI sequence data analysis, not by ITS. *Pythium sterile* is an invalid taxon based on the nomination of two herbarium specimens as the type of this species; this contravenes Art. 40.3 of the Melbourne convention (McNeill et al. 2012). *Pythium sterile* possesses identical ITS sequences to *Phytopythium litorale*. Other sequences from this organism could not be compared since no strain of *Pythium sterile* is available. Both species do not produce sexual stages. A more extensive study of these pairs of species, namely, *Phytopythium boreale / Pythium megacarpum* and *Phytopythium litorale / Pythium sterile* including more isolates and more DNA regions should reveal whether *P. sterile* and *P. megacarpum* should be validated as legitimate species.

There were some clade K species which were not included in the phylogenetic analyses presented here. In the studies by Lévesque & de Cock (2004) and Robideau et al. (2011) the species *Pythium indigoferae* appeared in clade K, which is now the genus *Phytopythium*. In stark contrast to the other species in clade K, *Pythium indigoferae* produces filamentous sporangia according to its original description (Butler 1907). The strain of *Pythium indigoferae* in the study of Lévesque & de Cock (2004) was the strain CBS 261.30 which was used by
van der Plaats-Niterink (1981) in her publication ‘Monograph of the genus Pythium’, as the ex-type strain was no longer available. However, CBS 261.30 is also no longer viable. Under observation by van der Plaats-Niterink and more recently while it was still culturable, this strain did not sporulate. The identity of this strain can therefore not be confirmed. Other strains with DNA sequences very close to CBS 261.30 have been identified (unpubl. data) which produced, however, subglobose, proliferating, papillate sporangia. These findings agree with Spies et al. (2011) who suggested that this strain be re-identified as *Pythium vexans*. CBS 261.30 and related strains are clearly part of a *Pythium vexans* complex that needs to be resolved through further phylogenetic study. This *P. vexans* complex also contains the invalid taxon *Pythium cucurbitacearum*, which was not included in our analyses. This taxon is invalid as it is missing a Latin diagnosis and based on Art. 36 of the Melbourne convention (McNeill et al. 2012). The representative strain of *P. cucurbitacearum* CBS 748.96 is no longer viable. The ITS sequence of this strain was reported by Spies et al. (2011), to be related yet distinct from a novel strain isolated from *Acacia* which was very different among the isolates in the monophyletic *Pythium vexans* complex studied. Most likely strain CBS 748.96 represents a distinct species from the *P. vexans* complex, which as of yet is not validly described. Once this complex is resolved it is likely that it will represent a number of new species for the genus *Pythium*.

Two other *Pythium* species not included in the phylogenetic analyses are *P. palingenes* and *P. polytylum*. Because no living strains of these species are available, they could not be included in the DNA studies. Morphological data for *P. palingenes* and *P. polytylum* show the typical characters of *Phytophthorum*: ovoid, papillate, internally proliferating sporangia and cylindrical antheridia. Therefore we consider *P. palingenes* and *P. polytylum* as members of *Phytophthorum*.

A new species of *Phytophthorum* was isolated from water samples collected in District MirpurKhas of Sindh province, Pakistan. It is described and illustrated here as *P. mirpurens* (see section New Species). Genetically, *Phytophthorum mirpurens* is shown to nestle within the genus *Phytophthorum*, in all of the phylogenetic trees presented. The most obvious morphological characters of this new species are the proliferating, subglobose sporangia, terminal and intercalary oogonia, antheridia with lengthwise application to oogonia over their entire length, aplerotic to nearly plerotic oospores, and high optimum temperature for growth. These characters are shared with many other members of *Phytophthorum*. The main differentiation of this species is shown through the molecular analyses of DNA sequences and the phylogenetic trees (Fig. 3, 4).

*Halophytophthorum* s.l. is a heterogenous, polyphyletic genus (Hulvey et al. 2010) with species of marine origin. Two species of this genus clustered within the clade of *Phytophthorum*: *H. operculata* (originally described as *Phytophthorum operculata*) and *H. kandelae*. Further, only species of *Halophytophthorum* s.str. (Hulvey et al. 2010) show some morphological similarity to *Phytophthorum*. However, their sporangia are in average two or more times the size of sporangia in the *Phytophthorum* species (length av. 64–117 µm, resp. 20–40 µm). They develop zoospores inside the sporangium and not in a vesicle like *Pythium*, though the formation of a vesicle may be part of the release process. Moreover, no internal proliferation was observed in these species. *Halophytophthorum kandelae* was previously transferred to *Phytophthorum* (Marano et al. 2014, Thines 2014). The strains of *Halophytophthorum kandelae* used in barcode analyses of ITS and COI regions were CBS 111.91 and CBS 113.91 and they were both found to be associated with the *Phytophthorum* clade (Robideau et al. 2011). However, neither of these strains is the type strain of this species. Marano et al. (2014) have published...
the ITS sequence of the type strain of *H. kandeliae* from ATCC and this sequence was identical to that of CBS 111.91 and 113.91. We have then included data from strain CBS 113.91 in our analyses here and are certain that it well represents the systematic placement of *Pythium kandeliae*. There are some difficulties with *Halophytophthora operculata*’s lack of fit in this clade by morphological measures and we have decided not to rename it at this time. This marine species has zoospore development fully within the sporangium; no vesicle occurs. Zoospore discharge is unique, via an operculum at the apex of the sporangium and no internal proliferation was observed. The size of the sporangium is significantly much larger than those of the *Pythium* species (up to 175 μm). The strain CBS 241.83, which is the ex-type strain of *H. operculata*, did not sporulate during our investigations, so the identity of the strain could not be confirmed. However the current molecular data available about this strain, the sequence data presented here and the organisation of the SS gene family as reported by Bedard et al. (2006), does indicate that it belongs in a monophyletic circumscription of *Pythium*. More investigation of this species is clearly required in order to confirm its identity.

New combinations were deposited in MycoBank (see below in section Taxonomic and Nomenclatural Changes; Crous et al. 2004).

**CONCLUSIONS**

The genus *Phytophthium* was first proposed to the community in 2008 (see www.phytophthoradb.org/pdf/O8LevesquePM.pdf) and it was formally published in June 2010 (Bala et al. 2010b), with *Pythium sindhium* as the type species. In 2010, Uzuhashi et al. (2010) proposed another name *Ovatisporangium* for clade K using a partial sampling of *Pythium* and *Phytophthora* species and published their findings in September of 2010. Comparison of their circumscription of the genus *Ovatisporangium* to our molecular analyses clearly shows that the type of *Pythium*, *P. sindhium* is a member of the group described as *Ovatisporangium* (Fig. 1, 2). *Ovatisporangium* is thus recognised as a synonym of *Pythium*.

We demonstrated with three different phylogenetic markers that all species belonging to *Pythium* clade K represent a monophyletic genus that includes the type species of the previously described genus *Phytophthium*. The taxonomic circumscription of other *Pythium* clades remains unresolved. The species with filamentous and globose sporangia are well separated as reported before in many studies, however, both LSU and COI suggest that clades A–J could be divided into subgroups but provide no support for any particular arrangement. The inclusion of species from other genera closely related to *Pythium* such as *Pythiogeton*, *Lagenidium* or *Mycocytispora* can change these conclusions but clade support remains very low (Schroeder et al. 2013, Hyde et al. 2014). Therefore, we recommend avoiding any further changes in the generic status of *Pythium* Pringsheim species belonging to clade A–J until better phylogenetic markers are found and multigene phylogenies are available with the closely related genera.

**TAXONOMIC AND NOMENCLURAL CHANGES**

*Phytophthium* Abad, De Cock, Bala, Robideau, Lodhi & Lévesque, Persoonia 24: 137. 2010

Type species. *Phytophthium sindhium*, Lodhi, Shahzad & Lévesque, Persoonia 24: 137. 2010.

Etymology. Named after combined features of the genera *Phytophthora* and *Pythium*.

Common morphological characteristics of the species of *Phytophthium* are globose to ovoid shape of sporangia, often with a more or less distinct papilla or non-papillate and often proliferating internally like those in *Phytophthora* with non-papillate sporangia. Zoospore discharge is like *Pythium*. Most species have large, smooth oogonia, thick-walled oospores, and 1–2 elongate or lobate antheridia, laterally applied to the oogonium. Cultures are mostly homothallic, occasionally sterile.

Notes — *Phytophthium* (Bala et al. 2010b) is emended to include species of *Pythium* in clade K from Lévesque & de Cock (2004) and described after that. It is morphologically and phylogenetically between *Pythium* and *Phytophthora*.

**NEW COMBINATIONS**

*Phytophthium boreale* (R.L. Duan) Abad, De Cock, Bala, Robideau, Lodhi & Lévesque, comb. nov. — MycoBank MB563326

*Basionym*. *Pythium boreale* R.L. Duan, Acta Mycol. Sin. 4: 1. 1985 (as ’borealis’) (MB105742).

≡ *Ovatisporangium boreale* (R.L. Duan) Uzuhashi, Tojo & Kakish., Mycologia 51: 360. 2010 (MB517560).

Representative strain — CHINA, soil under Brassica caulis, CBS 551.88 (ex-type strain not available).

*Phytophthium carbonicum* (B. Paul) Abad, De Cock, Bala, Robideau, Lodhi & Lévesque, comb. nov. — MycoBank MB563328

*Basionym*. *Pythium carbonicum* B. Paul, FEMS Microbiol. Lett. 219: 270. 2003 (MB489329).

≡ *Ovatisporangium carbonicum* (B. Paul) Uzuhashi, Tojo & Kakish., Mycologia 51: 360. 2010 (MB517561).

Representative strain — FRANCE, soil on top of soil heap, CBS 112544 (ex-type strain).

*Phytophthium chamaehyphon* (Sidersis) Abad, De Cock, Bala, Robideau, Lodhi & Lévesque, comb. nov. — MycoBank MB563329

*Basionym*. *Pythium chamaehyphon Sidersis, C.P, Mycologia 24: 33. 1932 (as ’chamaehyphon’) (MB260414).

≡ *Ovatisporangium chamaehyphon* (Sidersis) Uzuhashi, Tojo & Kakish., Mycologia 51: 360. 2010 (MB517562).

Representative strain — USA, Hawaii, Carica papaya, CBS 259.30 (ex-type strain).

*Phytophthium citrinum* (B. Paul) Abad, De Cock, Bala, Robideau, Lodhi & Lévesque, comb. nov. — MycoBank MB563330

*Basionym*. *Pythium citrinum* B. Paul, FEMS Microbiol. Lett. 234: 273. 2004 (MB368597).

≡ *Ovatisporangium citrinum* (B. Paul) Uzuhashi, Tojo & Kakish., Mycologia 51: 360. 2010 (MB517563).

Representative strain — FRANCE, Marsaunay la cote, vineyard soil, CBS 119171 (ex-type strain).

*Phytophthium delawarense* (Broders, P.E. Lipps, M.L. Ellis & Dorrance) Abad, De Cock, Bala, Robideau, Lodhi & Lévesque, comb. nov. — MycoBank MB807542

*Basionym*. *Pythium delawarense* Broders, P.E. Lipps, M.L. Ellis & Dorrance, Mycologia 104: 789. 2012 (MB563353).

Representative strain — USA, Ohio, Delaware county, Glycine max, CBS 123040 (ex-type strain).
**Phytopythium helicoides** (Drechsler) Abad, De Cock, Bala, Robideau, Lodhi & Lévesque, comb. nov. — MycoBank MB563332

Basionym. *Pythium helicoides* Drechsler, J. Wash. Acad. Sci. 20: 413. 1930 (MB266912).
≡ *Ovatisporangium helicoides* (Drechsler) Uzuhashi, Tojo & Kakish., Mycologia 51: 360. 2010 (MB517559).
≡ *Phytophthora fagopyri* S. Takim. ex S. Ito & Tokun., Trans. Sapporo Nat. Hist. Soc. 14: 15. 1935 (MB472184).

Representative strain — **USA**. Phaseolus vulgaris, CBS 286.31 (authentic strain).

**Phytopythium litorale** (Nechw.) Abad, De Cock, Bala, Robideau, Lodhi & Lévesque, comb. nov. — MycoBank MB563335

Basionym. *Pythium litorale* Nechw., FEMS Microbiol. Lett. 255: 99. 2006 (MB521454).
≡ *Ovatisporangium litorale* (Nechw.) Uzuhashi, Tojo & Kakish., Mycologia 51: 360. 2010 (MB517566).

Representative strain — **GERMANY**. Lake Konstanz, rhizosphere soil (*Phragmites australis*), CBS 118360 (ex-type strain).

**Phytopythium mercuriale** (Belbahri, B. Paul & Lefort) Abad, De Cock, Bala, Robideau, Lodhi & Lévesque, comb. nov. — MycoBank MB563337

Basionym. *Pythium mercuriale* Belbahri, B. Paul & Lefort, FEMS Microbiol. Lett. 284: 20. 2008 (MB511433).
≡ *Ovatisporangium mercuriale* (Belbahri, B. Paul & Lefort) Uzuhashi, Tojo & Kakish., Mycologia 51: 360. 2010 (MB517568).

Representative strain — **SOUTH AFRICA**. Limpopo Province, ex rhizosphere *Macadamia integrifolia*, CBS 122443 (ex-type strain).

**Phytopythium montanum** (Nechw.) Abad, De Cock, Bala, Robideau, Lodhi & Lévesque, comb. nov. — MycoBank MB563338

Basionym. *Pythium montanum* Nechw., Mycol. Progr. 2: 79. 2003 (MB373239).
≡ *Ovatisporangium montanum* (Nechw.) Uzuhashi, Tojo & Kakish., Mycologia 51: 360. 2010 (MB517569).

Representative strain — **GERMANY**. Bavarian Alps, wet soil under *Picea abies*; CBS 111349 (ex-type strain).

**Phytopythium oedochilum** (Drechsler) Abad, De Cock, Bala, Robideau, Lodhi & Lévesque, comb. nov. — MycoBank MB563339

Basionym. *Pythium oedochilum* Drechsler, J. Wash. Acad. Sci. 20: 414. 1931 (MB272763).
≡ *Ovatisporangium oedochilum* (Drechsler) Uzuhashi, Tojo & Kakish., Mycologia 51: 360. 2010 (as ‘oedochilum’) (MB517570).

Representative strain — **USA**. CBS 292.37 (authentic strain).

**Phytopythium ostracodes** (Drechsler) Abad, De Cock, Bala, Robideau, Lodhi & Lévesque, comb. nov. — MycoBank MB563340

Basionym. *Pythium ostracodes* Drechsler, Phytopathology 33: 286. 1943 (MB290364).
≡ *Ovatisporangium ostracodes* (Drechsler) Uzuhashi, Tojo & Kakish., Mycologia 51: 360. 2010 (MB517571).

Representative strain — **SPAIN**. clay soil, CBS 768.73 (strain used by van der Plaats-Niterink (1981), ex-type strain not available).

**Phytopythium palingenes** (Drechsler) Abad, De Cock, Bala, Robideau, Lodhi & Lévesque, comb. nov. — MycoBank MB807543

Basionym. *Pythium palingenes* Drechsler, J. Wash. Acad. Sci. 20: 416. 1930 (MB272364).

Representative strain — None available.

**Phytopythium polytylum** (Drechsler) Abad, De Cock, Bala, Robideau, Lodhi & Lévesque, comb. nov. — MycoBank MB807544

Basionym. *Pythium polytylum* Drechsler, J. Wash. Acad. Sci. 20: 415. 1930 (MB275012).

Representative strain — None available.

**Phytopythium vexans** (de Bary) Abad, De Cock, Bala, Robideau, Lodhi & Lévesque, comb. nov. — MycoBank MB563322

Basionym. *Pythium vexans* de Bary, J. R. Agric. Soc. 12 (Ser. 2): 255. 1876 (MB174427).
≡ *Ovatisporangium vexans* (de Bary) Uzuhashi, Tojo & Kakish., Mycologia 51: 360. 2010 (MB517573).
≡ *Pythium compositum* M. Braun, J. Agric. Res. 29: 415. 1924 (MB261556).
≡ *Pythium allantocladon* Sideris, Mycologia 24: 27. 1932 (MB256394).
≡ *Pythium ascosphallon* Sideris, Mycologia 24: 29. 1932 (MB257476).
≡ *Pythium polycladon* Sideris, Mycologia 24: 32. 1932 (MB274913).
≡ *Pythium euthephyphon* Sideris, Mycologia 24: 34. 1932 (MB536649).
≡ *Pythium piperinum* Dastur, Proc. Indian Acad. Sci., B 1, 11: 803. 1935 (MB274563).

Representative strain — **IRAN**. soil, CBS 119.80 (strain used by van der Plaats-Niterink (1981) ex-type strain not available).

**NEW SPECIES**

**Phytopythium mirpurense** Lodhi, De Cock, Lévesque & Shahzad, sp. nov. — MycoBank 809691; Fig. 6

Etymology. Name refers to the District MirpurKhas of Sindh province, Pakistan from where this species was frequently isolated.

Main *hyphae* up to 6 μm wide. *Sporangia* papillate, proliferating, subglobose, limoniform, ovoid or ovoid 20–25 μm diam. Discharge tube short 5–8 × 5–6 μm diam. *Oogonia* large smooth globose, terminal, intercalary, occasionally unilaterally intercalary, (27–)34–37–(40) (av. 34) μm diam. *Antheridia* 1–3 per oogonium, mostly monoclinous or distantly monoclinous, occasionally clinous. Oogonia and antheridial stalk originate from same hyphae. Antheridia apply lengthwise to the oogonium producing lateral or occasionally apical fertilisation tubes. *Oospores* aplerotic or nearly plerotic (22–)29–32–(34) (av. 29.45) μm diam. Oospore wall thickness is 2.5–3 (av. 2.8) μm.

The optimum growth occurred at 30 °C. Daily growth at 20 °C. Maximum growth temperature was 35 °C. The colony colour was cream on PDA and CMDA, on PCA produces profuse white cottony growth on PDA and CMDA, on PCA submerged without any patterns, and on CMA with a rosette pattern. The optimum growth occurred at 30 °C. Daily growth at 25 °C on PDA 19 mm, PCA 20 mm, CMA 23.5 mm and CMDA 26 mm. The maximum growth temperature was 35 °C.

Material examined. **PAKISTAN.** Sindh, District MirpurKhas, MirWah, N25°25'23'E69°02', stagnant water, 12 Jan. 2006, A.M. Lodhi (holotype CBS 124523, maintained in inactive state. Culture ex-type also deposited as DAOM 238991 in CCFC).

Additional material examined. **PAKISTAN.** Sindh, from water pond at Sindhri, District MirpurKhas (DAOM 238992, CBS124524) (N25°37' E69°12').
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