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General Description of *Rhizoctonia* Species Complex

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1. Introduction

The genus concept of *Rhizoctonia* spp. was established by de Candolle (1815) (Sneh *et al*., 1998). However, the lack of specific characters led to the classification of a mixture of unrelated fungi as *Rhizoctonia* spp. (Parmeter and Whitney, 1970; Moore, 1987). Ogoshi (1975) enhanced the specificity of the genus concept for *Rhizoctonia* by elevating the following characteristics of *R. solani* to the genus level. Based on this revised genus concept, species of *Rhizoctonia* can be differentiated by mycelia color, number of nuclei per young vegetative hyphal cell and the morphology of their teleomorph. The teleomorph of *Rhizoctonia* spp. belongs to the sub-division Basidiomycota, class Hymenomycetes.

The anamorphs of *Rhizoctonia* are heterogeneous. Moore (1987) placed the anamorphs of *Thanatephorus* spp. in *Moniliopsis*. She reserved the genus *Rhizoctonia* for anamorph of ustomycetous fungi which have septa with simple pores. Moniliopsis species have smooth, broad hyphae with brown walls, multinucleate cells, dolipore septa with perforate parenthesomes and teleomorphs in the genera *Thanatephorus* and *Waitea*. Of the binucleate *Rhizoctonia* spp., the anamorphs of the *R. repens* group (teleomorph *Tulasnella*) were assigned to the new genus *Epulorhiza.* Anamorph of *Ceratobasidium* was assigned to the new genus *Ceratorhiza* (Moore, 1987). Moore's system is taxonomically correct and justified. At present, the concept of genus *Rhizoctonia* has become clear from these taxonomical studies at the molecular level (Gonzalez *et al*., 2001). However, many researchers (Sneh *et al*., 1998) in the world still retain the name *Rhizoctonia* for Moore's *Moniliopsis* spp., *Ceratorhiza* spp. and *Epulorhiza* spp.. Hence, I used the name of *Rhizoctonia* in this study.

Affinity for hyphal fusion (anastomosis) (Parmeter *et al*., 1969; Parmeter and Whitney, 1970; Ogoshi *et al*., 1983a; Burpee *et al*., 1980a) has been used to characterize isolates among *R. solani*, *R. zeae*, *R. oryzae*, *R. repens* and binucleate *Rhizoctoni*a spp. with *Ceratobasidium* teleomorphs. To date, isolates of *R. solani* have been assigned to 13 anastomosis groups (AG) and those of *R. zeae* and *R. oryzae* have each been assigned to their own one group (Sneh *et al*., 1998; Carling *et al*., 1999, 2002c).

Anastomosis reactions between hyphae of paired isolates of *R. solani* consist of several types; such as perfect fusion, imperfect fusion, contact fusion and no reaction (Matsumoto *et al*., 1932). At present, four categories of anastomosis (C3 to C0) defined by Carling *et al*. (1996)

have been accepted by many researchers. These are useful for a better understanding of the genetic diversity of *R. solani* populations, because of the background genetically supported by vegetative or somatic compatibility (VC or SC) of confronted isolates (MacNish *et al*, 1997). Each of categories is as follows:

C3: walls fuse; membranes fuse, accompanied with protoplasm connection; anastomosis point frequently is not obvious; diameter of anastomosis point is equal or nearly equal hyphal diameter; anastomosing cells and adjacent cells may die, but generally do not. This category occurs for the same anastomosis group, same vegetative compatibility population (VCP) and the same isolate.

C2: wall connection is obvious, but membrane contact is uncertain; anastomosing and adjacent cells always die. This category occurs in same AG, but not between different VCPs.

C1: wall contact between hyphae is apparent, but both wall penetration and membrane-membrane contact do not occur; occasionally one or both anastomosing cells and adjacent cells die. This category occurs between different AGs or in the same AG.

C0: no reaction. This category occurs between different AGs.

In general, hyphal fusion occurs at a high frequency (50%≥) within members of the same AG, with the exception of non-self-anastomosing isolates (Hyakumachi and Ui, 1988). On the other hand, hyphal fusion among members of different AGs occurs at either a low frequency (≤30%) or no fusion occurs. *Rhizoctonia* isolates giving C3 to C1 reactions in anastomosing test have been taken to be the same AG.

To date, isolates of multinucleate *R. solani* have been assigned to 13 anastomosis groups (AG-1 to AG-13), some of which include several subgroups and isolates of *R. zeae* and *R. oryzae* have been assigned to WAG-Z and WAG-O, respectively (Sneh *et al*., 1998; Carling *et al*., 1999, 2002c). Isolates of binucleate *Rhizoctonia* spp. with *Ceratobasidium* teleomorphs have been reported. A system developed in Japan (Ogoshi *et al*.,1979, 1983 a,b; Sneh *et al*., 1998; Hyakumachi *et al*., 2005) includes 21 anastomosis groups designated AG-A to AG-U, in which at present AG-J and AG-M still are in question as members of binucleate *Rhizoctonia*. Another system developed in the USA (Burpee *et al*., 1980a) includes 7 anastomosis groups designed as CAG-1 to CAG -7. CAG-1 corresponds to AG-D, CAG-2 to AG-A, CAG-3 and CAG-6 to AG-E, CAG-4 to AG-F, CAG-5 to AG-R, and CAG-7 to AG-S (Sneh *et al*., 1998; Ogoshi *et al*., 1983a). At present, the anastomosis system based on AG-A through AG-U used in this review paper is widely accepted by many researchers.

Some homogenous groups of isolates of *R. solani* are well known as bridging isolates (AG-BI) that anastomose with members of different AGs (Carling, 1998). In general, there is no contradiction in the conventional anastomosis grouping system by taking anastomosis frequency into consideration. However, two exceptional cases where anastomosis frequency mismatched with morphological, physiological and pathogenic characteristics have been reported from tobacco (Nicoletti *et al*., 1999) and soybean (Naito and Kanematsu, 1994). These demonstrate the limitations of using hyphal anastomosis as the sole criteria for characterization and identification of closely related fungi. In addition, it is not easy to determine the subgroup of isolates within the same AG because no differences occur in their anastomosis reaction. Thus, in order to determine AGs or subgroups in *R. solani*, genetic analysis using molecular approaches that employ multiple genetic loci is needed.

Isolates of *R. solani* that exhibits DNA base sequence homology and affinities for hyphal anastomosis may represent a diverging evolutionary unit (Kuninaga and Yokosawa, 1980). This hypothesis is supported by analysis of restriction fragment length polymorphisms (RFLPs) and the sequences with in ribosomal RNA genes (rDNA) among different anastomosis groups of *R. solani* (Vilgalys and Gonzalez, 1990; Gonzalez, *et al*., 2001; Carling *et al*., 2002b).

As mentioned above, many AGs and subgroups of *R. solani* and binucleate *Rhizoctonia* spp. have been reported as causal of agents Rhizoctonia diseases on a wide range of host species. However, little is known about the Rhizoctonia diseases and the anastomosis groups and subgroups of their causal fungi on vegetables, ornamentals and food crops in the Asian tropics especially the southern parts of China.

2. Characteristics of anastomosis groups and subgroups of *Rhizoctonia solani* and binucleate *Rhizoctonia* spp.

Disease symptoms and host range of each AG and its subgroups are summarized as follows. In this review, the book by Sneh et al., 1998 entitled "Identification of *Rhizoctonia* Species" provided a substitute for the reference before 1998.

2.1 Multinucleate *Rhizoctonia* spp.

1. **AG-1: IA, IB, IC, ID**

AG-1 IA (Li and Yan, 1990; Sneh *et al.*, 1998; Fenille *et al*., 2002; Naito, 2004).

Symptoms: sheath blight, foliar blight, leaf blight, web-blight, head rot, bottom rot, and brown patch.

Host: rice (*Oryza sativa* L.), corn (*Zea mays* L.), barley (*Hordeum vulgare* L.), sorghum (*Sorghum vulgare* Pes.), potato (*Solanum tuberosum* L.), barnyard millet, common millet, soybean, peanut (*Arachis hypogaea* L.), lima bean, cabbage, leaf lettuce, Stevia, orchard grass, crimson clover, tall fescue (*Festuca arundiacea* Schreb), turfgrass, creeping bentgrass, perennial ryegrass, gentian (*Gentiana scabra*), and camphor.

Note: This group has a tendency to attack aerial parts of the plants. Basidiospore infection of rice has been reported, but sclerotia are more important as an infection source. The optimum growth temperature is higher than those of AG-1 IB.

AG-1 IB (Sneh *et al*., 1998; Naito, 2004;Yang *et al*., 2005b).

Symptoms: sheath blight, leaf blight, foliar blight, web-blight, root rot, damping-off, head rot, and bottom rot.

Host: corn, sugar beet, gay feather (*Liatris* spp.), common bean, fig (*Ficus* L.), adzuki bean, soybean, cabbage, leaf lettuce, redtop, bentgrass, orchard grass, leaf lettuce, apple (*Malus pumila* Mill), Japanese pear, European pear, lion'ear (*Leonotis leonurus*), hortensia (*Hydrangea* spp.), *Larix* spp., gazania (*Gazania* spp.) *Cotoneaster* spp., Egyptian atar-cluster (*Pentas lanceolata*), Chinese lantern plant (*Physalis alkekeng* var. franchetii), *Hypericum patulum*, marigold, *Acacia* spp., rosemary, *Eucalyptus* spp., pine (*Pinus* L.), *Larix* spp., cypress (*Cupressus* spp.), and elephant foot (*Amorphophallus Konjac*).

AG-1 IC (Sneh *et al.,* 1998; Naito, 2004).

Symptoms: damping-off, summer blight, foot rot, crown rot canker, and root rot.

Host: sugar beet, carrot (*Daucus carota* L.), buckwheat (*Eriogonum* Michx), flax (*Linum usitatissimum* L.), soybean, bean (*Phaseolus* L.), cabbage, pineapple (*Ananas comosus* (Linn.) Merr.), panicum (*Panicum* spp.), spinach (*Spinacia oleracea* L.), and radish (*Raphanus sativus* Linn).

AG-1 ID (Priyatmojo *et al.*, 2001).

Symptom: leaf spot.

Host: coffee (*Coffea* Linn).

Note: this subgroup was recently reported in the Philippines (Priyatmojo *et al.*, 2001)

Undetermined subgroup: buckwheat, flax, spinach, radish, and durian (*Durio zibethinus* Murr.).

2. **AG-2: 2-1, 2-2 IIIB, 2-2 IV, 2-2 Lp, 2-3, 2-4, 2-BI.**

AG-2-1 (Satoh *et al*., 1997; Camporota and Perrin, 1998; Sneh *et al*., 1998; Rollins *et al*., 1999; Khan and Kolte, 2000; Naito, 2004)

Symptoms: damping-off, leaf rot, leaf blight, root rot, foot rot, bottom rot, and bud rot.

Host: sugar beet, wheat (*Triticum aestivum* Linn.), potato, cowpea (*Vigna unguiculata* (Linn.) Walp), canola, rape (*Brassica napus* Linn.), cauliflower (*Brassica oleracea* var. *botrytis* Linn.), mustard (*Sinapis* Linn.), turnip (*Brassica rapa* Linn.), pepper (Piper Linn.), *Silene armeria,* spinach, leaf lettuce, strawberry (*Fragaria ananassa* Duchesne), tulip (*Tulipa gesneriana* Linn.), tobacco (*Nicotiana* Linn.), clover (*Medicago* Linn.), and table beet.

Note: This group includes the AG-2-1 tulip strain (former AG-2t) and the AG-2-1 tobacco strain (former homogenous Nt-isolates) (Kuninaga *et al*., 2000).

AG-2-2 III B (Sneh *et al*., 1998; Priyatmojo *et al*., 2001; Naito, 2004).

Symptoms: brown sheath blight, dry root rot, root rot, brown patch, large patch, black scurf, stem rot, stem blight, *Rhizoctonia* rot, damping-off, stem rot, collar rot, and crown brace rot.

Host: rice, soybean, corn, sugar beet, edible burdock (*Arctium lappa*), taro (*Colocasia esculenta*), *Dryopteris* spp., elephant foot, crocus, saffron (*Crocus sativus* Linn.), redtop, bentgrass, St. Augustine grass, turf, balloon flower (*Platycodon grandiflorum*), Christmas-bells (*Sandersonia aurantiaca*), *Hedera rhombea*, mat rash, *gladiolus*, ginger, and *Iris* Linn..

AG-2-2 IV: (Sneh *et al*., 1998; Naito, 2004).

Symptoms: leaf blight, foliage rot, root rot, and stem rot.

Host: sugar beet, carrot, eggplant (*Solanum* Linn), pepper, spinach, stevenia (*Stevenia* Adams et Fisch), and turfgrass.

AG-2-2 LP: (Aoyagi *et al*., 1998).

Symptoms: large patch.

Host: Zoysia grass.

AG 2-3: (Naito and Kanematsu, 1994; Sumner *et al*., 2003).

Symptoms: leaf blight and root rot.

Host: soybean.

Note: basidiospores cause leaf spot of soybean.

AG-2-4: (Sumner, 1985).

Symptoms: crown rot, brace rot, and damping-off.

Host: corn and carrot.

AG-2-BI: (Carling *et al*., 2002b).

Symptoms;:nonpathogenic.

Host: isolates, obtained only from soils and plants in forests.

Note: former name is AG-BI.

Undetermined subgroup: sesame (*Sesamum* Linn.), white mustard (*Sinapsis alba*), primrose *(Primula* spp.), white lace flower (*Ammi majus*), carnation, baby's-breath (*Gypsophila paniculata*), rusell prairie gentian (*Eustoma grandiflorum*), snap bean, lima bean, and Chinese radish.

3. **AG 3: PT, TB** (Sneh *et al*., 1998; Kuninaga *et al*., 2000).

Symptoms: black scurf, leaf spot, target leaf spot, and damping-off.

PT: potato with black scurf symptoms.

TB: tobacco with target leaf spot symptoms.

Note: Undetermined subgroup: eggplant, sugar beet, tomato, and wheat. Their pathological and ecological information is less.

4. **AG-4: HG-I, HG-II, HG-III** (Baird, 1996; Holtz *et al*., 1996; Sneh *et al*., 1998; Fenille *et al*., 2002; Ravanlou and Banihashemi, 2002; EI Hussieni, 2003; Kuramae *et al*., 2002, 2003; Naito, 2004; Yang *et al*., 2005c).

Symptoms: damping-off, root rot, stem canker, fruit rot, and stem rot.

Host: pea, sugar beet, melon, soybean, adzuki bean, common bean, snap bean, lima bean, carrot, spinach, taro, tomato (*Lycopersicon esculentum* Mill.), potato, alfalfa (*Medicago sativa* Linn.), elephant foot, arrowleaf clover, beans, barley, buckwheat, cabbage, canola, turnip, carnation, cauliflower, Chinese chive, chrysanthemum, corn, cotton (*Gossypium* Linn.), table beet, tobacco, turfgrass, wheat, white lupine, parsley (*Petroselinum* Hill), *Cineraria* Linn., stock, poinsettia, primrose, hybrid bouvardia, *Citrus* Linn., cauliflower, *Euphorbia* spp., geranium (*Pelargonium* spp.), Russel prairie gentian, statice (*Limonium* spp.), baby's-breath, and *Astragalus membranaceus*

5. **AG-5** (Li, *et al*., 1998; Demirci, 1998; Sneh *et al*., 1998; Ravanlou and Banihashemi, 2002; Eken and Demirci, 2004; Naito, 2004).

Symptoms: root rot, damping-off, black scurf, brown patch, and symbiosis (orchids).

Host: soybean, adzuki bean, apple, barley, chickpea, common bean, lima bean, potato, strawberry, sugar beet, table beet, tobacco, turfgrass, wheat, and white lupine.

6. **AG-6: HG-I, GV** (Mazzola, 1997; Meyer *et al*., 1998; Sneh *et al*., 1998; Carling *et al*., 1999; Pope and Carter, 2001; Naito, 2004)

Symptom: root rot, crater rot, and symbiosis (orchids).

Host: apple, wheat, carrot, and carnation.

Note: all isolates from forests are nonpathogenic.

7. **AG-7:** (Naito, *et al*., 1993; Baird and Carling, 1995; Carling, 1997, 2000; Carling *et al*., 1998)

Symptoms: damping-off, root rot, and black scurf.

Host: carnation, cotton, soybean, watermelon (*Citrullus lanatus* (Thunb.) Mansfeld), *Raphanus* Linn., and potato.

8. **AG-8:** (Sneh *et al*., 1998; Naito, 2004).

Symptoms: bare patch.

Host: barley, cereals, green pepper, potato, and wheat.

9. **AG-9:** (Sneh *et al*., 1998; Naito, 2004).

Symptoms: black scurf.

Host: potato, crucifers, wheat, and barley.

10. **AG-10:** (Sneh *et al*., 1998.)

Symptoms: weak pathogenic.

Host: barley and wheat.

11. **AG-11:** (Kumar *et al*., 2002).

Symptoms: damping-off and hypocotyls rot.

Host: barley, lupine, soybean, and wheat.

Note: this group is considered as bridging isolates (anastomose with each members of AG-2-1, AG-2 BI, AG-8) (Carling *et al*., 1996).

12. **AG-12:** (Kumar *et al*., 2002).

Symptoms: symbiosis (orchids).

Host: *Dactylorhiza aristata* (Orchidaceae).

13. **AG-13:** (Carling *et al*., 2002a).

Symptoms: none.

Host: cotton.

2.2 Binucleate *Rhizoctonia* spp.

1. **AG-A:** (Mazzola, 1997; Sneh *et al*., 1998).

Symptoms: root rot, damping-off, browning, and tortoise shell.

Host: strawberry, sugar beet, bean, pea, sunflower (*Helianthus annuus* Linn.), tomato, melon, cucumbear (*Cucumis sativas* Linn.), leaf lettuce, spinach, peanut, potato, *Solanum tuberosum*, and apple.

Note: Some isolates in this group form mycorrhizal associations with orchids.

2. **AG-B: a and b.**

AG-Ba (Sneh *et al*., 1998).

Symptoms: grey sclerotium disease, sclerotium disease, gray southern blight.

Host: rice, *Echinochloa crugalli* subsp. *submitica* var. typica, and foxtail millet.

AG-Bb (Sneh *et al*., 1998).

Symptoms: brown sclerotium disease, grey sclerotium disease, and sheath spot.

Host: fox tail, millet, and rice.

3. **AG-C** (Sneh *et al*., 1998; Hayakawa *et al*., 1999).

Symptoms: symbiosis (orchids).

Host: orchids, sugar beet seedlings, subterranean clover, and wheat.

Note: No important pathogens have been reported.

4. **AG-D: I, II** (Sneh *et al*., 1998; Toda *et al*.,1999).

Symptoms: sharp eye spot, yellow patch, foot rot, Sclerotium disease, snow mold, root rot, damping-off, lesions on stems, and winter stem rot.

Host: cereals, turf grass, wheat, barley, sugar beet, clove, pea, onions (*Allium cepa* Linn.), potato, cotton, bean, soybean, mat rush, foxtail millet, and subterranean clover.

Note: Recently this group is classified into subgroup AG-D (I) that causes Rhizoctonia patch and winter patch diseases. AG-D (II) causes elephant footprint disease.

5. **AG-E** (Sneh *et al*., 1998).

Symptoms: web-blight, damping-off, seedlings, and symbiosis (orchids).

Host: bean, pea, radish, onion, leaf lettuce, tomato lima bean, snap bean, soybean, peanut, cowpea (*Vigna Savi*), flax, sugar beet, *Rhododendron* Linn., long leaf pine (*Pinus palustris* Mill.), slash, lobolly pine (*Pinus taeda* Linn.), and rye (*Secale cereale* Linn.).

6. **AG-F** (Sneh *et al*., 1998; Eken and Demirci, 2004).

Symptoms: none.

Host: bean, pea, radish, onion, peanut, leaf lettuce, tomato, subterranean clover radish, tomato, cotton, taro, strawberry (source: DDJB), and *Fragaria x ananassa*.

7. **AG-G** (Mazzola, 1997; Sneh *et al.*, 1998; Leclerc *et al.*, 1999; Martin, 2000; Botha *et al.*, 2003; Fenille *et al.*, 2005).

Symptoms: damping-off, root rot, and browning.

Host: strawberry, sugar beet, bean, pea, tomato, melon, sunflower, peanut, yacoon, apple, *Rhododendron* Linn., and *Fragaria x ananassa*.

Note: Non-pathogenic binucleate *Rhizoctonia* spp. provide effective protection to young bean seedlings against root rot caused by *R. solani* AG-4 (Leclerc *et al.*, 1999).

8. **AG-H** (Hayakawa *et al.*, 1999).

Symptoms: symbiosis (orchids).

Host: *Dactylorhiza aristata* (Orchidaceae).

9. **AG-I** (Mazzola, 1997; Sneh *et al.*, 1998; Ravanlou and Banihashemi, 2002)

Symptoms: root rot and symbiosis (orchids).

Host: strawberry, sugar beet, wheat, apple, orchids, and *Fragaria x ananassa.*

10. **AG-J**: (Sneh *et al.*, 1998).

Symptoms: none.

Host: apple.

11. **AG-K** (Demirci, 1998; Li *et al.*, 1998; Sneh *et al.*, 1998; Ravanlou and Banihashemi, 2002).

Symptoms: none.

Host: sugar beet, radish, tomato, carrot, onion, wheat, maize, *Allium cepa* (source: DDJB),

Pyrus communis (pear) (source: DDJB), and Fragaria x ananassa.

12. AG-L: No special diseases have been reported (Sneh *et al.*, 1991).
13. **AG-N:** No special diseases have been reported (Sneh *et al.*, 1991).
14. **AG-O:** No special diseases have been reported (Mazzola, 1997; Sneh *et al.*, 1998).

Host: apple.

15. **AG-P:** (Sneh *et al.*, 1998; Yang *et al.*, 2006).

Symptoms: black rot and wirestem.

Host: tea (*Camellia* Linn.), red birch.

16. **AG-Q:** (Sneh *et al.*, 1998).

Symptoms: none.

Host: (Bentgrass).

17. **AG-R:** (Sneh *et al.*, 1998;Yang *et al.*, 2006).

Symptoms: wirestem

Host: bean, pea, radish, onion, leaf lettuce, tomato, lima bean, snap bean, soybean, cowpea, peanuts, red birch, and azalea.

18. **AG-S** (Demirci, 1998; Sneh *et al*., 1998).

Symptoms: no specific diseases.

Host: azalea, wheat, barley, and azalea.

19. **AG-T:** (Hyakumachi *et al.,* 2005).

Symptoms: stem rot and root rot.

Host: miniature roses.

20. **AG-U:** (Hyakumachi *et al*., 2005).

Symptoms: stem rot and root rot.

Host: miniature roses (*Rosa rugosa* Thunb.).

3. Summary

In this chapter, we described the classification of *Rhizoctonia* spp. complex. Mutinucleate *Rhizoctonia* spp. included 13 anastomosis, of which AG 1-4 were strong pathogenic on many plants and AG 6-10 were orchid mycorrhizae. Binucleate *Rhizoctonia* spp. included 18 anastomosis groups, but AG-U belonged to AG-P and AG-T belonged to AG-A (Sharon et al., 2008), which were weak or nonpathogenic to plants and some AGs were orchid mycorrhizae.

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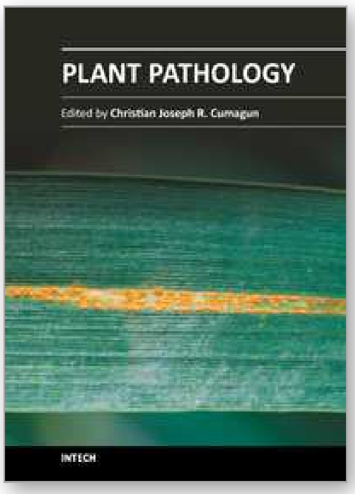

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