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 telemorph 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 ustomyccetous 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 Cetatorhiza (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., Cetatorhiza 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 Rhizoctonia 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.


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.

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 (Sinapis alba), primrose (Primula spp.), white lace flower (Ammi majus), carnation, baby’s-breath (Gypsophila paniculata), russell 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.

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, poinsetta, 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.
   

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.
   
   
   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.
   

   **AG-Bb** (Sneh *et al*., 1998).
   
   Symptoms: brown sclerotium disease, grey sclerotium disease, and sheath spot.
   
   Host: fox tail, millet, and rice.

   
   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).
   

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*. 

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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.

### 4. Acknowledgments

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### 5. References


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Plant pathology is an applied science that deals with the nature, causes and control of plant diseases in agriculture and forestry. The vital role of plant pathology in attaining food security and food safety for the world cannot be overemphasized.

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