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Short Communication

EGFP-Rhm51 foci enable the visualization and enumeration of DNA
double-strand breaks in *Magnaporthe oryzae*

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Abbreviations: DSBs, double-strand breaks; HR, homologous recombination; ORF, open
reading frame.

1 **Abstract**

2 In order to detect and enumerate DNA double-strand breaks (DSBs) during the life cycle
3 of *Magnaporthe oryzae*, an expression vector for GFP-Rhm51 fusion protein was
4 constructed and introduced into the strain Ina86-137. Rhm51-GFP foci were detected and
5 the number of foci in mitomycin-C-treated mycelia was higher than in untreated samples,
6 indicating that the foci visualized DSBs occurred during the life cycle. Rhm51-GFP foci
7 were observed in all stages of the asexual life cycle including the invasive hyphae formed
8 in an intact rice leaf sheath, demonstrating that *M. oryzae* suffers DSBs during vegetative
9 and infective growth.

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12 **Keywords:** *Magnaporthe oryzae*, DNA double-strand breaks, infective growth, rice blast
13 disease.

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1 Cells proliferate mainly by meiosis and mitosis and these processes need to be
2 tightly coordinated to preserve genome integrity and favor faithful genome propagation.
3 Coordination of DNA replication with DNA-damage sensing, repair and cell cycle
4 progression ensures genome integrity during cell divisions, thus preventing mutations and
5 DNA rearrangements (Aguilera and Gomez-Gonzalez 2008). Mutations and
6 chromosomal rearrangements in *Magnaporthe oryzae* (Couch), the causal agent of rice
7 blast disease have been shown to drive genetic variation and evolution at the molecular
8 level (Dean et al. 2005). For example, the appearance of new races of *M. oryzae* which
9 can infect previously resistant varieties of rice can be attributed to recombinational events
10 such as deletion of AVR genes (Miki et al. 2009). Changes in genetic linkage of two
11 DNA fragments such as homologous recombination (HR)-mediated events and end-
12 joining between non-homologous DNA fragments may result in genomic rearrangements
13 (Aguilera and Gomez-Gonzalez 2008). The common substrate of these rearrangement
14 events are DNA double-strand breaks (DSBs) (Agmon et al. 2009; Dudas and Chovanec
15 2004; Ljungman and Lane 2004; Symington 2002).

16 In plants, the induction of hypersensitive cell death is important in preventing pathogen
17 development (Heath 2000). Reactive Oxygen Species (ROS) which play crucial roles in
18 both symbiotic (Tanaka et al. 2006) and pathogenic (Egan et al. 2007) interactions is the
19 signal molecule in higher plants that triggers a variety of defense responses, such as
20 expression of defense-related genes and hypersensitive cell death (Bourett and Howard
21 1990; Koga et al. 2004; Ono et al. 2001; Tanabe et al. 2009). ROS is implicated in DNA
22 damage including the induction of DSBs in human cells (Bennett 2001; Cadet et al. 2004).
23 For *Magnaporthe* to cause disease, it must overcome the defense-related responses

1 mounted by the host. Information as to whether defense responses induce DSBs in
2 *Magnaporthe* during infection is unknown. It was therefore important to enumerate DSBs
3 during vegetative and infective growth to ascertain the contribution of the infection
4 process to pathogenic variability in *M. oryzae*.

5 Rad51p, the recombinational repair protein that forms a nucleofilament involved
6 in homology search and strand invasion plays a key role in DSB repair by HR (Mimitou
7 and Symington 2008; Rossi and Mazin 2008). In the absence of DNA damage, Rad51p is
8 not induced, but the constitutively expressed proteins are diffusely distributed within the
9 nucleus. In response to DNA damage, Rad51p is induced and re-localizes to the sites of
10 DNA damage to form distinct foci, the spots of GFP fluorescence which corresponds to
11 the DSBs, which are visualized by direct or indirect fluorescence (immuno-staining). The
12 number of Rad51 foci in a cell is an indication of the number of DSBs in that cell
13 (Gospodinov et al. 2009). GFP-RAD51 and RAD51-GFP have been used for the
14 visualization of foci respectively in *Ustilago maydis* (Kojic et al. 2006) and *Sordaria*
15 *macrospora* (Tesse et al. 2003). In this study we aimed to establish and visualize DSBs in
16 *M. oryzae*, with the recombinant fusion protein of *Rhm51* (the *RAD51* homolog in *M.*
17 *oryzae*) and EGFP. This fusion protein was expected to form protein foci.

18 The plasmid (pBARST-PPR-GFP-Rhm51A, Fig. 1) had an *Rhm51* promoter (PPR,
19 1121 bp) linked directly to EGFP gene followed by *Rhm51* open reading frame (ORF,
20 Accession No. AB562330). This plasmid was used for the transformation of strain Ina86-
21 137 and its *rhm51* deletion mutant Ina86-137 Δ *rhm51* (Ndindeng et al. unpublished).
22 After the protoplast-PEG transformation, the transformants with pBARST-PPR-GFP-
23 Rhm51A were selected based on the resistance to bialaphos (4 μ g/ml). The functionality

1 of GFP-Rhm51 fusion as Rhm51 was assessed by the complementation of the growth
2 defects (reduction in mycelial growth, conidiation, appressoria formation) of Ina86-
3 137 Δ *rhm51* in the pBARST-PPR-GFP-Rhm51A transformants of the mutant (data not
4 shown). Although the functionality of the transgenic fusion protein was checked, the
5 expression level was not determined and this may pose some risk when using such genes
6 for imaging experiments. However, the phenotypes of Ina86-137-GFP-Rhm51A were
7 similar to those of wild type Ina86-137 except for the constitutive expression of GFP
8 (Fluorescent signal) during normal growth in Ina86-137-GFP-Rhm51A. One
9 transformant of the wild type Ina86-137 named Ina86-137-GFP-Rhm51A was used for
10 further analysis.

11 Conidia of the transformant, Ina86-137-GFP-Rhm51A were used for the
12 inoculation of liquid medium (2YEG, 10 g/l glucose and 2 g/l yeast extract) and
13 incubated at 27°C for 3 days. Mycelia were collected by filtration and stained with DAPI
14 (4', 6-diamidino-2-phenylindole, 2 μ g/ml) for 1 h followed by fluorescence microscopy
15 (Fig. 2). GFP signal co-localized with DAPI signal without formation of foci in hyphae
16 showing distinct and compact nuclei. On the other hand, GFP foci were detected in the
17 hyphae, without the distinct and compact DAPI-stained nuclei (nuclei appeared
18 fragmented). The distinct nuclei have been revealed as mitotic nuclei, and the absence of
19 the distinct nuclei indicated the G₂-arrest in *Aspergillus nidulans* (Westfall and Momany
20 2002). Based on the fact that DSBs are revealed as the cause of G₂-arrest in other
21 organisms, the GFP foci detected in the vegetative hyphae of the transformant were
22 expected as caused by DSBs, which occurred in *M. oryzae* vegetative hyphae.

1 DNA DSBs can be induced by addition of DNA-damaging chemicals; therefore
2 the number of foci is expected to be increased by addition of such reagents. The number
3 of foci was then detected in the germinating conidia, germ tubes and growing hyphae,
4 with or without treatment by 0.1 μM mitomycin C (Wako, Osaka, Japan), a DNA-DSB
5 inducing agent. The liquid cultured hyphae were not used because the tightly entangled
6 hyphae prevented the accurate enumeration of foci. A conidial suspension (containing 0.1
7 μM mitomycin C when applicable) was spotted on a hydrophilic, frosted glass slide to
8 allow a maximum number of conidia to grow and form branching hyphae, then incubated
9 at 27°C in the dark for 5 or 10 h. As expected, foci were observed in conidia, germ tube
10 and branching hyphae and the number of foci were higher in treated samples ($P > 0.05$)
11 although foci were detected both in Mitomycin-C -treated and untreated samples (Fig. 3
12 and 4). These results indicated that the detected GFP foci correspond to DSBs which
13 occurred in the life cycle of *M. oryzae*.

14 Then conidia suspension of the transformant Ina86-137-GFP-Rhm51A was
15 spotted on the hydrophobic surface of Gelbond film (Lonza, Rockland, ME, USA) and
16 incubated at 27°C, in order to observe the Rhm51 foci during the appressoria formation
17 (Fig. 5). Foci were observed in the appressoria suggesting that DSBs also occur during
18 appressorium formation.

19 The intact leaf sheath assay (Koga et al. 2004) was used to observe Rhm51 foci
20 during fungal invasion of compatible rice (cultivar: Shin2) by Ina86-137-GFP-Rhm51A
21 strain. Conidia (1.5×10^5 /ml) of Ina86-137-GFP-Rhm51A suspended in distilled water
22 were used to inoculate intact leaf sheaths. Foci were observed and enumerated after 9, 18,
23 24 and 48 h post inoculation under fluorescent bright light at 25°C. Foci were observed

1 during conidia germination, germ tube elongation and appressoria formation and the
2 amount was comparable to those observed when the strain was grown on frosted glass
3 slides without mitomycin-C treatment. Foci were also observed in the appressoria during
4 penetration (data not shown) and in infective hyphae (Fig. 5) suggesting that *Rhm51* was
5 induced during infection. These results demonstrated that *M. oryzae* suffers DSBs during
6 infective growth although effective enumeration of foci in the infective hyphae was
7 hindered by their embedded nature inside the plant cell.

8 This is the first report of the enumeration of DSBs in *M. oryzae*. The functionality
9 of EGFP-Rhm51 fusion protein enables us to detect DSBs *in vivo* without further staining
10 or other treatment, and is applicable for further studies on DSB repair and its importance
11 for the pathogen's growth and pathogenicity. *M. oryzae* is revealed to suffer DSBs during
12 multiple stages in its life cycle, and recombinational repair of DSBs may contribute to
13 pathogen's genome variability.

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1 **References**

- 2 Abe A, Elegado EB, Sone T (2006) Construction of pDESTR, a gateway vector for gene
3 disruption in filamentous fungi. *Curr Microbiol* 52: 210-215.
- 4 Agmon N, Pur S, Liefshitz B, Kupiec M (2009) Analysis of repair mechanism choice
5 during homologous recombination. *Nucleic Acids Res* 37: 5081-5092.
- 6 Aguilera A, Gomez-Gonzalez B (2008) Genome instability: a mechanistic view of its
7 causes and consequences. *Nat Rev Genet* 9: 204-217.
- 8 Bennett MR (2001) Reactive Oxygen Species and Death: oxidative DNA damage in
9 atherosclerosis. *Circ Res* 88: 648-650.
- 10 Bourett TM, Howard RJ (1990) In vitro development of penetration structures in the rice
11 blast fungus *Magnaporthe grisea*. *Can J Bot* 68: 329–342.
- 12 Cadet J, Douki T, Gasparutto D, Ravanat JL (2003) Oxidative damage to DNA:
13 formation, measurement and biochemical features. *Mutat Res* 531: 5-23.
- 14 Dean RA, Talbot NJ, Ebbole DJ, Farman ML, Mitchell TK, Orbach MJ, Thon M,
15 Kulkarni R, Xu JR, Pan H, Read ND, Lee YH, Carbone I, Brown D, Oh YY,
16 Donofrio N, Jeong JS, Soanes DM, Djonovic S, Kolomiets E, Rehmeier C, Li W,
17 Harding M, Kim S, Lebrun MH, Bohnert H, Coughlan S, Butler J, Calvo S, Ma LJ,
18 Nicol R, Purcell S, Nusbaum C, Galagan JE, Birren B (2005) The genome sequence
19 of the rice blast fungus *Magnaporthe grisea*. *Nature* 434: 980–986.
- 20 Dudas A, Chovanec M (2004) DNA double-strand break repair by homologous
21 recombination. *Mutat Res* 566: 131-167.

1 Egan MJ, Wang Z-Y, Jones MA, Smirnov N, Talbot NJ (2007) Generation of reactive
2 oxygen species by fungal NADPH oxidases is required for rice blast disease. *Natl*
3 *Acad Sci USA* 104: 11772–11777.

4 Gospodinov A, Tsaneva I, Anachkova B (2009) Rad51 foci formation in response to
5 DNA damage is modulated by TIP49. *Int J Biochem Cell B* 41: 925–933.

6 Heath MC (2000) Hypersensitive response-related death. *Plant Mol Biol* 44: 321-334

7 Koga H, Dohi K, Nakayachi O, Mori M (2004) A novel inoculation method of
8 *Magnaporthe grisea* for cytological observation of the infection process using intact
9 leaf sheaths of rice plants. *Physiol Mol Plant P* 64: 67-72.

10 Kojic M, Zhou O, Lisby M, Holloman WK (2006) Rec2 interplay with both Brh2 and
11 Rad51 balances recombinational repair in *Ustilago maydis*. *Mol Cell Biol* 26: 678-
12 688.

13 Ljungman M, Lane DP (2004) Transcription-guarding the genome by sensing DNA
14 damage. *Nat Rev Genet* 4: 727-737.

15 Miki S, Matsui K, Kito H, Otsuka K, Ashizawa T, Yasuda N, Fukiya S, Sato J, Hirayae K,
16 Fujita Y, Nakajima T, Tomita F, Sone T (2009) Molecular cloning and
17 characterization of the *AVR-Pia* locus from a Japanese field isolate of *Magnaporthe*
18 *oryzae*. *Mol Plant Pathol* 10: 361-374.

19 Mimitou EP, Symington LS (2008) Sae2, Exo1 and Sgs1 collaborate in DNA double-
20 stranded break processing. *Nature* 455: 770-774.

21 Ono E, Wong HL, Kawasaki T, Hasegawa M, Kodama O, Shimamoto K (2001) Essential
22 role of the small GTPase Rac in disease resistance of rice. *Natl Acad Sci USA* 98:
23 759-764.

1 Rossi MJ, Mazin AV (2008) Rad51 protein stimulates the branch migration activity of
2 Rad54 protein. *J Biol Chem* 283: 24698-24706.

3 Saunders DDO, Aves SJ, Talbot NJ (2010) Cell Cycle–Mediated Regulation of Plant
4 Infection by the Rice Blast Fungus. *Plant Cell* 22: 497-507

5 Symington LS (2002) Role of *RAD52* epistasis group genes in homologous
6 recombination and double-strand break repair. *Microbiol Mol Biol Rev* 66: 630-670.

7 Tanabe S, Nishizawa Y, Minami E (2009) Effects of catalase on the accumulation of
8 H₂O₂ in rice cells inoculated with rice blast fungus *Magnaporthe oryzae*. *Physiol*
9 *Plant* 137: 148–154.

10 Tanaka A, Christensen MJ, Takemoto D, Park P, Scott B (2006) Reactive oxygen species
11 play a role in regulating a fungus–perennial ryegrass mutualistic interaction. *Plant*
12 *Cell* 18: 1052–1066.

13 Tesse S, Storlazzi A, Kleckner N, Gargano S, Zickler D (2003) Localization and roles of
14 Ski8p protein in *Sordaria* meiosis and delineation of three mechanistically distinct
15 steps of meiotic homolog juxtaposition. *Natl Acad Sci USA* 100: 12865-12870.

16 Westfall PJ, Momany M (2002) *Aspergillus nidulans* septin AspB plays pre- and post
17 mitotic roles in septum, branch, and conidiophore development. *Mol Biol Cell* 13,
18 110–118.

19

1 **Figure legends**

2

3 **Fig. 1.** Construction of pBARST-PPR-GFP-Rhm51A vector for the detection of Rhm51
4 foci in *Magnaporthe oryzae*. The vector was constructed by Gateway system (Invitrogen,
5 Carlsbad, CA). PPR (*Rhm51* Putative Promoter, 1121 bp), EGFP (Green Fluorescent
6 Protein), *Rhm51*ORF were ligated into pENTR-D-TOPO (Invitrogen, Carlsbad, CA,
7 USA), and the reporter structure insert was subcloned into bialaphos resistant destination
8 vector pBARST (Abe et al. 2006) using LR clonase (Invitrogen, Carlsbad, CA, USA).
9 White boxes in *Rhm51* ORF indicates the introns. The pBARST-PPR-GFP-Rhm51A was
10 digested with *Xba* I to be linearized prior to the transformation of fungal cells.

11

12 **Fig. 2.** Detection of Rhm51-foci in *Magnaporthe oryzae* during vegetative growth in
13 liquid media. Conidia were prepared from Ina86-137 wild-type strain carrying pBARST-
14 PPR-GFP-Rhm51A. Conidia were inoculated in 2YEG and incubated at 27°C for 3 days
15 and then treated with DAPI (4', 6-diamidino-2-phenylindole). The results presented are
16 based on analysis from three independent samples and 150 different images. Arrows
17 show points of foci. Scale bars = 10 µm.

18

19 **Fig. 3.** Detection of Rhm51 foci in *Magnaporthe oryzae* during vegetative growth.
20 Conidia were spotted onto frosted glass slides and incubated at 27°C for 5-10 h. Foci
21 were detected in the germinating conidia, germ tubes and growing hyphae, with or
22 without treatment by 0.1 µM mitomycin C. Arrows show points of foci. Scale bars = 10
23 µm.

1 **Fig. 4.** Enumeration of Rhm51 foci. The results are means of three independent
2 experiments. At least 50 images were analyzed at each stage of growth. Bar with different
3 letter signify statistical difference at the 0.05 level of significance using the Student's t-
4 test.

5
6 **Fig. 5.** Detection of Rhm51-foci in *Magnaporthe oryzae* during appressoria formation
7 and plant infection. Conidia from Ina86-137-GFP-Rhm51A (1×10^4 /ml) were spotted on
8 hydrophobic surface of a Gelbond film (Lonza, Rockland, ME, USA) and incubated at
9 27°C for 24 h and foci were observed. Conidia (1.5×10^5 /ml) were inoculated on intact
10 leaf sheath of compatible rice (cultivar Shin2) and incubated at 25°C and 60 % relative
11 humidity in a cultivation chamber for 48 h. GFP-Rhm51 foci were detected during plant
12 colonization. APP = Appressorium, HI = Infective Hyphae. Arrows show points of foci.
13 Scale bars = 10 μ m

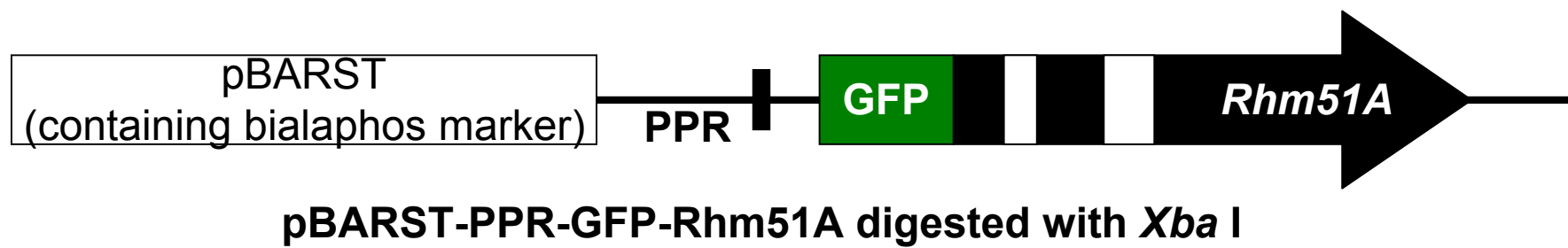


Fig. 1

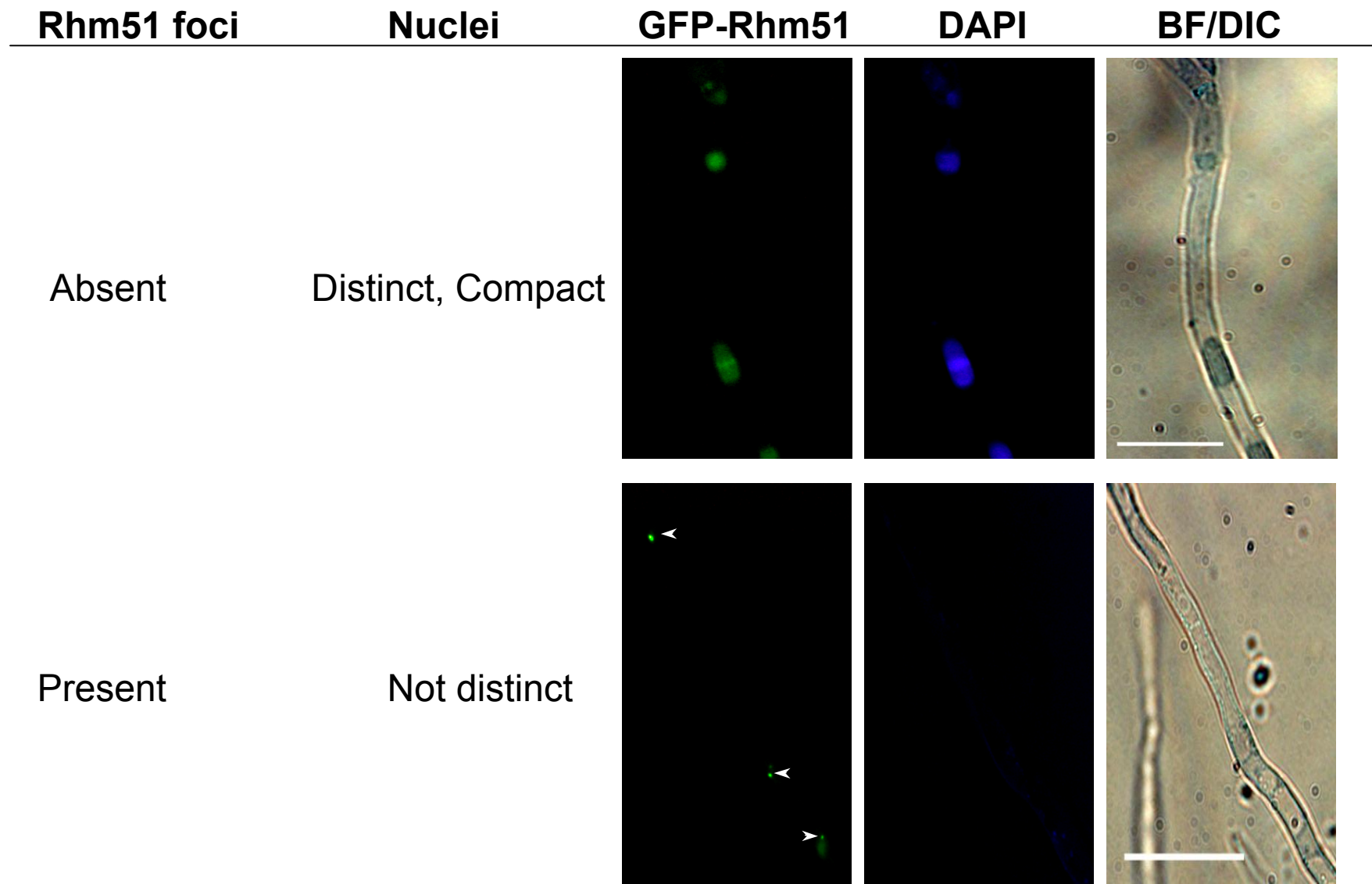


Fig. 2

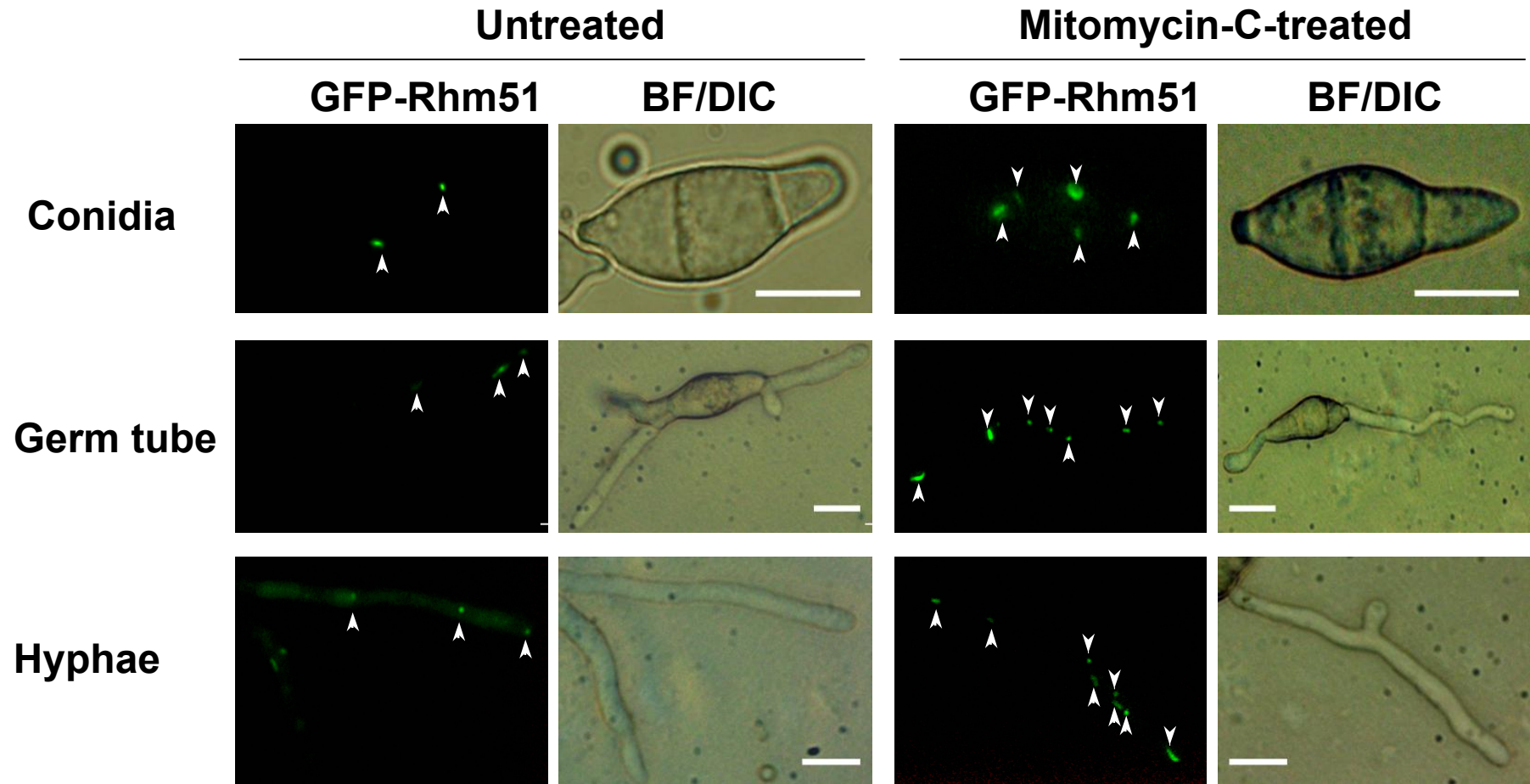


Fig. 3

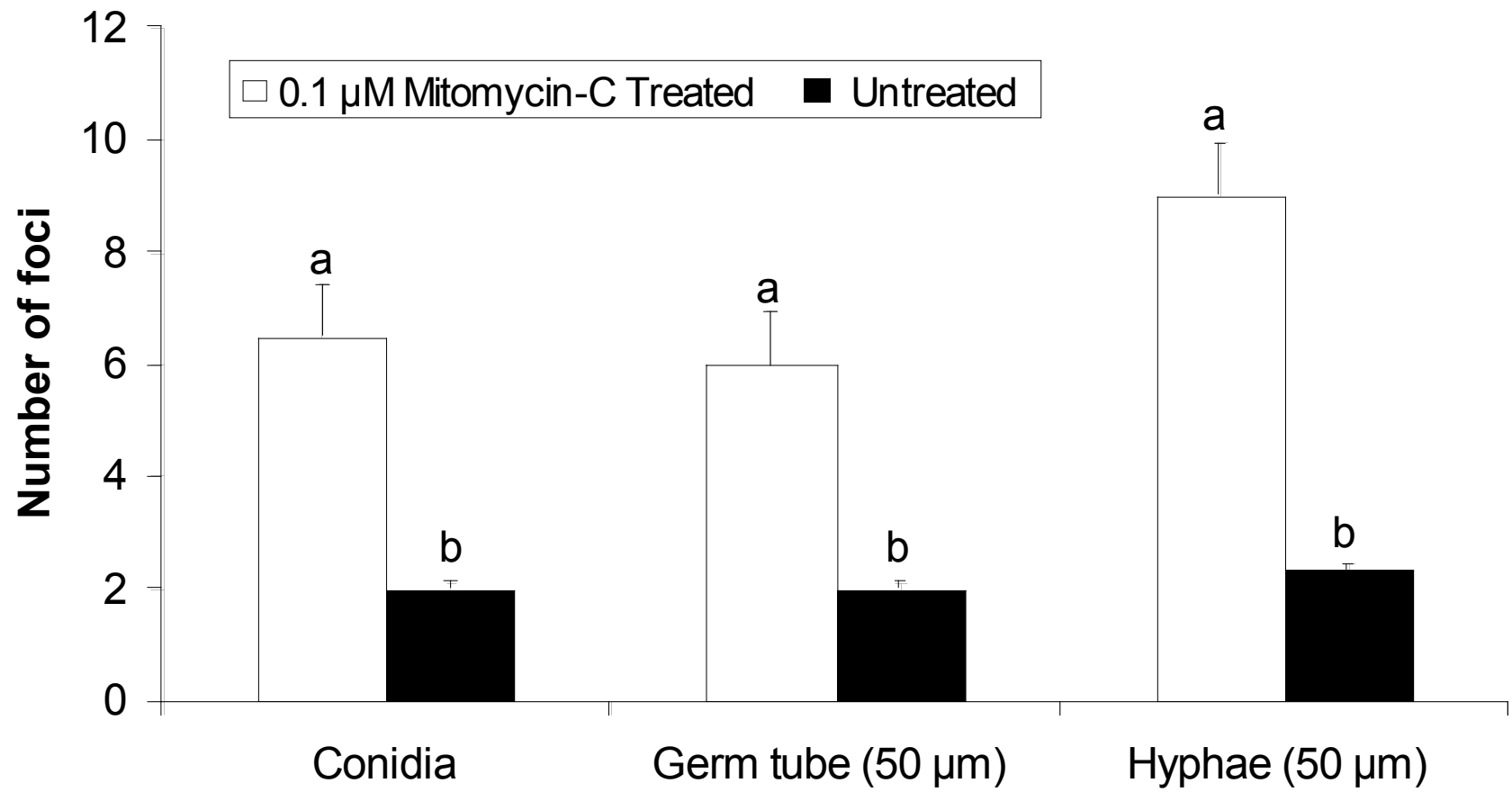


Fig. 4

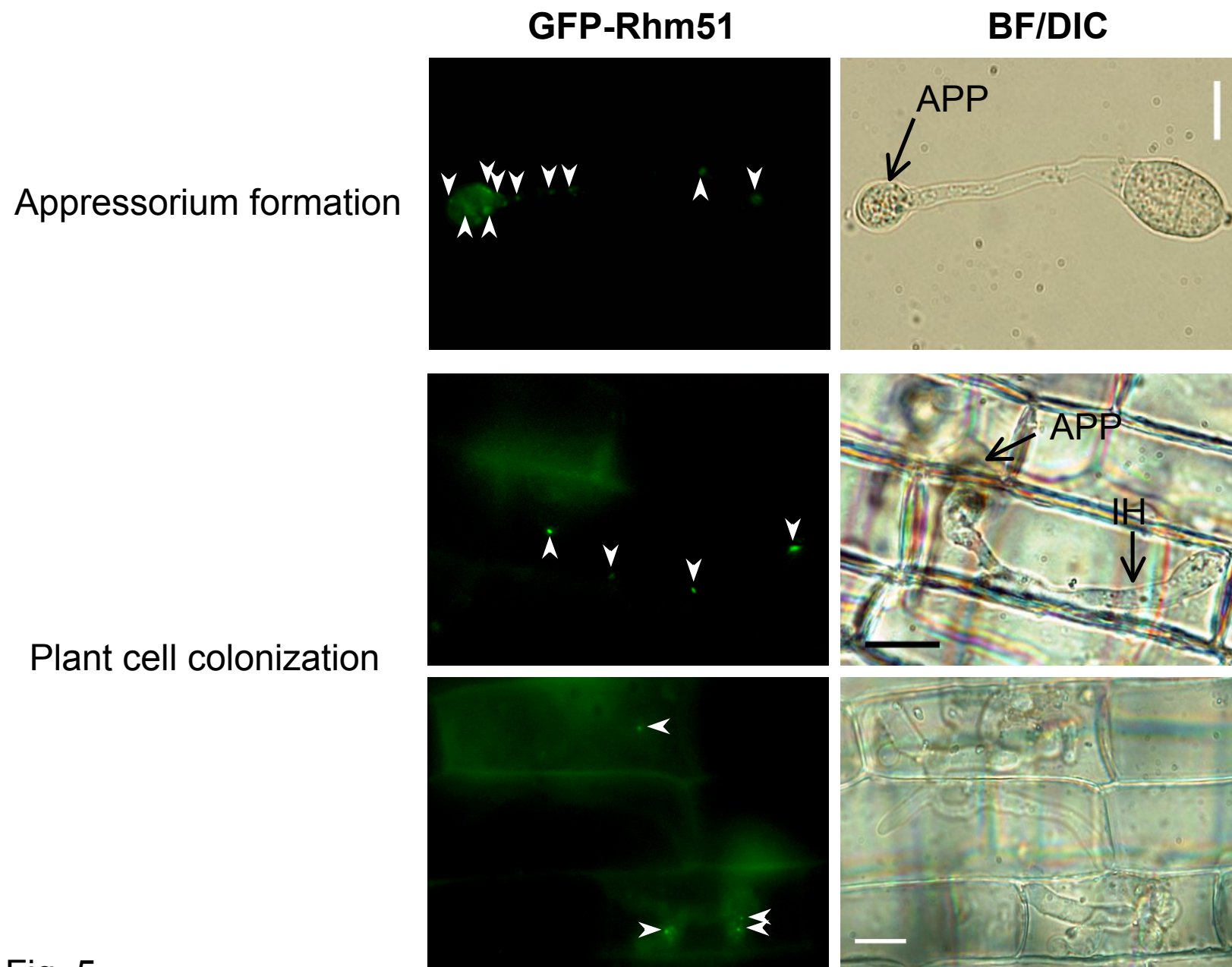


Fig. 5