Light Sensing in Aspergillus fumigatus Highlights the Case for Establishing New Models for Fungal Photobiology

Alexander Idnurm
Division of Cell Biology and Biophysics, School of Biological Sciences, University of Missouri-Kansas City, Kansas City, Missouri, USA

ABSTRACT Microbes inhabit diverse environmental locations, and many species need to shift their physiology between different niches. To do this effectively requires the accurate sensing of and response to the environment. For pathogens, exposure to light is one major change between a free-living saprophyte lifestyle and causation of disease within the host. However, how light may act as a signal to influence pathogenesis, on the side of either the host or the pathogen, is poorly understood. Research during the last 2 decades has uncovered aspects about the machinery for light sensing in a small number of fungi. Now, Fuller et al. have initiated studies into the role that light and two photosensor homologs play in the behavior of the ubiquitous fungal pathogen Aspergillus fumigatus [K. K. Fuller, C. S. Ringelberg, J. J. Loros, and J. C. Dunlap, mBio 4(2):e00142-13, 2013, doi:10.1128/mBio.00142-13]. Light represses the germination of A. fumigatus spores and enhances resistance to ultraviolet light, oxidative stresses, and cell wall perturbations. The phenotypes of the strains with mutations in the LreA and FphA homologs revealed that these sensors control some, but not all, responses to light. Furthermore, interactions occur between blue and red light signaling pathways, as has been described for a related saprophytic species, Aspergillus nidulans. Genome-wide transcript analyses found that about 2.6% of genes increase or decrease their transcript levels in response to light. This use of A. fumigatus establishes common elements between model filamentous species and pathogenic species, underscoring the benefits of extending photobiology to new species of fungi.

One reason for this lack of research is the absence of a dramatic effect of light on A. fumigatus in culture, such as a change in sporulation. This is in contrast to laboratory strains of its relative A. nidulans, which, for experimental convenience, carry the velvet (wc-1) mutation that suppresses the effects of light and promotes asexual sporulation (3). This careful characterization of A. fumigatus indicates that light and two putative photosensors have many effects on the fungus (8). Light causes changes in growth rate, hyphal pigmentation, conidiospore germination, and resistance to ultraviolet irradiation, oxidative, and cell wall stresses. About 2.6% of genes have higher or lower transcript levels in response to light, as estimated from microarray analysis.

Light of both blue and red wavelengths affects A. fumigatus. The genome was searched for candidate photosensors, and Fuller et al. mutated two genes in A. nidulans that have characterized roles of perceiving blue (lreA, the wc-1 homolog) and red (fphA, encoding phytochrome) wavelengths. The loss of these genes abolished a subset of the responses to light but not all of them. For instance, the protective role of light to subsequent UV exposure was unaffected in fphA and lreA single mutants and in fphA lreA double mutants. The other photosensors or light responses in the absence of the two characterized photosensors are worth further investigation.

Light sensing may be involved in fungal virulence. Analysis of wc mutants of Cryptococcus neoformans revealed a contribution to disease causation (5). Fusarium oxysporum also requires the wc-1...
homolog for virulence; curiously, the decreased virulence of the
wc-1 mutant is in an animal disease model and not on its normal
plant host (6). Recently, wc-1 has been implicated in maize disease
caused by Cercospora zeae-maydis by reducing the tropism to the
stomata used for gas exchange on the leaf surface (7). The mech-
anisms by which wc-1 function affects pathogenesis are not estab-
lished, nor have roles for other photosensors in pathogenesis been
assessed.

A prediction based on the effects of light and the light-
regulated genes is that light and the two photosensors will contrib-
ute to the ability of A. fumigatus to cause disease. First, spore
germination is inhibited by light: the conditions in the lung would
support germination. Second, mutation of the lreA and fphA genes
reduces oxidative stress resistance and cell wall stress resistance,
properties important for hyphal growth within the host. These
findings provide possible explanations for how light sensing im-
pacts pathogenesis that could also be explored in other pathogenic
fungi. A key future experiment for A. fumigatus is to test the func-
tion in the pathogenesis of the lreA and fphA genes.

A comparison of A. fumigatus and A. nidulans, in which the
effects of blue and red light and the corresponding photosensors
have already been investigated, can help clarify the evolution of
photosensing. In particular, the two species have active red light
responses, which is thus far uncharacterized in other fungi despite
the presence of phytochrome homologs in their genomes. In the
two Aspergillus species, phytochrome regulates the inhibition of
conidiospore germination (11). A. nidulans exhibits physical and
genetic interactions between the blue and red light signaling com-
ponents, with a large photosensory complex formed that includes
the LreB protein acting in blue light responses, the FphA phyto-
chrome, and the VeA velvet protein (12). In A. fumigatus, there is
a genetic interaction between the two pathways, so a similar com-
plex may also function in this species. Exposure of A. nidulans to
light alters transcript levels of about 5% of the genes in the species
(13). Fuller et al. commented that there is little overlap between
the light-regulated genes identified in A. nidulans and the 2.6% that
they identified in A. fumigatus, with the caveat that the two
experiments used different culture conditions. A side-by-side
comparison of the wild-type and photosensor mutant strains of
the two species exposed to light and dark would be a powerful
approach toward understanding conservation and divergence in
the transcriptional responses to light. Thus, the use of A. fumigatus
can establish how common overlapping regulation is within the
Aspergillus genus or Eurotiomycetes class.

While N. crassa has led the research in light sensing in fungi,
especially the study of how the WC-1/WC-2 complex is integrated
into the circadian clock, other fungi have also emerged in the last
decade as models for research on the responses to light (Fig. 1).
Here, Fuller et al. demonstrated how rapidly a new species can
provide information about light sensing. This is facilitated by the
available genome sequence data, which can be used for bioinfor-
matic identification of photosensor homologs, the design of gene
replacement constructs, and expression profiling using microar-
rays or RNA sequencing. The one drawback for A. fumigatus
is that the tools of classical genetics that are available for
A. nidulans (14) are still in development for A. fumigatus (15).
This limits the ability to assemble strains, through crossing, with a suite of genetic
manipulations.

There are open questions about how fungi sense and respond
to light for which the development of new species for research
would be ideal. These questions include how photosensors are
distributed and function in different species (e.g., those taxa with
little research), what role photoperception plays in virulence (e.g.,
in plant pathogen), what is the central oscillator in the circadian
clocks of species without a homolog of the N. crassa frequency
gene, whether circadian time influences disease, and how the sig-

FIG 1 Fungi that have emerged or are emerging as models for research on sensing and response to light. The phylogeny (partial 18S rDNA) divides the species into the Ascomycota (red), Basidiomycota (blue), and Mucoromycotina (green). All nine species have saprophytic growth capabilities, and some can also cause disease. Wavelengths with a characterized response are red (R) or blue (B). Useful features in photobiology research or behavior modified by light for individual species are listed. Common research directions in these species can provide a better understanding of how light influences fungal biology.
nal transduction pathways from light cross talk with pathways signaling other environmental conditions. Future analysis of A. fumigatus will continue to provide insight into these matters, particularly with respect to the role of light sensing in pathogenesis.

REFERENCES

1. Corrochano LM, Garre V. 2010. Photobiology in the Zygomycota: multiple photoreceptor genes for complex responses to light. Fungal Genet. Biol. 47:893–899.
2. Sanz C, Rodriguez-Romero J, Idnurm A, Christie JM, Heitman J, Corrochano LM, Eslava AP. 2009. Phycomyces MADB interacts with MADA to form the primary photoreceptor complex for fungal phototropism. Proc. Natl. Acad. Sci. U. S. A. 106:7095–7100.
3. Blumenstein A, Vienken K, Tasler R, Purschwitz J, Veith D, Frankenberg-Dinkel N, Fischer R. 2005. The Aspergillus nidulans phytochrome FphA represses sexual development in red light. Curr. Biol. 15:1833–1838.
4. Bayram Ö, Biesemann C, Krappmann S, Galland P, Braus GH. 2008. More than a repair enzyme: Aspergillus nidulans photolyase-like CryA is a regulator of sexual development. Mol. Biol. Cell 19:3254–3262.
5. Idnurm A, Heitman J. 2005. Light controls growth and development via a conserved pathway in the fungal kingdom. PLoS Biol. 3:615–626.
6. Ruiz-Roldán MC, Garre V, Guarro J, Mariné M, Roncero MIG. 2008. Role of the white collar I photoreceptor in carotenogenesis, UV resistance, hydrophobicity, and virulence of Fusarium oxysporum. Eukaryot. Cell 7:1227–1230.
7. Kim H, Ridenour JB, Dunkle LD, Bluhm BH. 2011. Regulation of stomatal tropism and infection by light in Cercospora zeae-maydis; evidence for coordinated host-pathogen responses to photoperiod? PLoS Pathog. 7:e1002113. http://dx.doi.org/10.1371/journal.ppat.1002113.
8. Fuller KK, Ringelberg CS, Loros JJ, Dunlap JC. 2013. The fungal pathogen Aspergillus fumigatus regulates growth, metabolism, and stress resistance in response to light. mBio 4(2):e00142-00113. http://dx.doi.org/10.1128/mBio.00142-13.
9. Latgé J-P, Steinbach WJ (ed). 2009. Aspergillus fumigatus and aspergillosis. ASM Press, Washington, DC.
10. Grahl N, Puttikamonkul Š, Macdonald JM, Gamcsik MP, Ngo LY, Hohl TM, Cramer RA. 2011. In vivo hypoxia and a fungal alcohol dehydrogenase influence the pathogenesis of invasive pulmonary aspergillosis. PLoS Pathog. 7:e1002145. http://dx.doi.org/10.1371/journal.ppat.1002145.
11. Rohrig J, Kastner C, Fischer R. 6 February 2013. Light inhibits spore germination through phytochrome in Aspergillus nidulans. Curr. Genet. doi:10.1007/s00294-013-0387-9.
12. Purschwitz J, Müller S, Kastner C, Schöser M, Haas H, Espeso EA, Atoui A, Calvo AM, Fischer R. 2008. Functional and physical interaction of blue- and red-light sensors in Aspergillus nidulans. Curr. Biol. 18:255–259.
13. Ruger-Herreros C, Rodríguez-Romero J, Fernández-Barranco R, Olmedo M, Fischer R, Corrochano LM, Canovas D. 2011. Regulation of conidiation by light in Aspergillus nidulans. Genetics 188:809–822.
14. Tod BB, Davis MA, Hynes MJ. 2007. Genetic manipulation of Aspergillus nidulans: meiotic progeny for genetic analysis and strain construction. Nat. Protoc. 2:811–821.
15. Sugui JA, Losada L, Wang W, Varqa J, Ngamskulrungroj P, Abu-Asab M, Chang YC, O’Gorman CM, Wickes BL, Nierman WC, Dyer PS, Kwon-Chung KJ. 2011. Identification and characterization of an Aspergillus fumigatus “supermater” pair. mBio 2(6):e00234-00211. http://dx.doi.org/10.1128/mBio.00234-11.

The views expressed in this Commentary do not necessarily reflect the views of the journal or of ASM.
Author/s:
Idnurm, A

Title:
Light Sensing in Aspergillus fumigatus Highlights the Case for Establishing New Models for Fungal Photobiology

Date:
2013-05-01

Citation:
Idnurm, A. (2013). Light Sensing in Aspergillus fumigatus Highlights the Case for Establishing New Models for Fungal Photobiology. MBIO, 4 (3), https://doi.org/10.1128/mBio.00260-13.

Persistent Link:
http://hdl.handle.net/11343/262514

License:
CC BY-NC-SA