

PLOS Science Wednesday: Hi reddit, my name is Nicholas Money and I published a paper in PLOS ONE which showed mushroom spores act as nuclei for raindrops using environmental electron microscopy – Ask Me Anything!

PLOSScienceWednesday¹ and r/Science AMAs¹

¹Affiliation not available

April 17, 2023

Abstract

Hi Reddit, My name is Nicholas Money. I'm a biologist at Miami University in Oxford, Ohio and specialize in the study of fungal growth and reproduction. I am fascinated by the extraordinary mechanisms of spore discharge in these organisms that include high-velocity spurts, exploding gas bubbles, and a catapult that launches mushroom spores. I am the senior author of a 2015 paper in PLOS ONE titled, "Mushrooms as rainmakers: How spores act as nuclei for raindrops". A couple of years ago I was struck by research by atmospheric chemists that suggested that 50 million tons of fungal spores are ejected into the atmosphere every year. This made me wonder whether the mechanism of drop expansion that powers the discharge of mushroom spores could be reactivated once the spores were airborne. If this happened in clouds, it could play a significant role in the condensation of water and stimulate rainfall. The PLOS ONE paper reports experiments that offer a proof of concept using environmental scanning electron microscopy. This work was co-authored by my doctoral student, Maribeth Hassett, and long-term collaborator Mark Fischer, a physicist at Mount St. Joseph University in Cincinnati. I'll be answering questions at 1pm ET – Ask Me Anything!

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PLOSSCIENCEWEDNESDAY [R/SCIENCE](#)

Hi Reddit,

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I am the senior author of a 2015 paper in [PLOS ONE](#) titled, "[Mushrooms as rainmakers: How spores act as nuclei for raindrops](#)". A couple of years ago I was struck by research by atmospheric chemists that suggested that 50 million tons of fungal spores are ejected into the atmosphere every year. This made me wonder whether the mechanism of drop expansion that powers the discharge of mushroom spores could be reactivated once the spores were airborne. If this happened in clouds, it could play a significant role in the condensation of water and stimulate rainfall. The PLOS ONE paper reports experiments that offer a proof of concept using environmental scanning electron microscopy. This work was co-authored by my doctoral student, Maribeth Hassett, and long-term collaborator Mark Fischer, a physicist at Mount St. Joseph University in Cincinnati.

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CORRESPONDENCE:

DATE RECEIVED:

June 02, 2016

DOI:

10.15200/winn.146477.78257

ARCHIVED:

June 01, 2016

CITATION:

PLOSScienceWednesday ,
r/Science , PLOS Science
Wednesday: Hi reddit, my
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ONE which showed mushroom
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Anything!, *The Winnower*

How important are fungal spores as cloud condensation nuclei compared to other sources?

Has their influence changed over time? And might their influence be altered due to climate change?

[IceBean](#)

With this publication we have shown that spores "grow water drops" in the lab in a way that makes it very likely that they would behave in the same fashion in the humid interior of a cloud. This finding that the special properties of spores cause water vapor to condense into liquid water on their surface shows that they are unlike other airborne particulates. The astonishing numbers of airborne spores suggests that they may contribute to drop formation in clouds and stimulate rainfall, but this is conjecture, not based on experiments. Relative to other particles in clouds, spores may be significant because they form droplets of a perfect size to stimulate rainfall.

The relevance of this process may have changed over time and may change in the future. At the end of the Pleistocene, 12,000-13,000 years ago, the palynological record (spores and pollen in sediment samples) is very rich in the spores of fungi associated with the dung of megaherbivores (wooly mammoth, mastodon, rhinoceros). The numbers of these spores crash, region by region, according to

3:e146477.78257 , 2016 , DOI:
[10.15200/winn.146477.78257](https://doi.org/10.15200/winn.146477.78257)

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human migration, hunting, and extirpation of the big animals. This observation shows that the mix of fungal spores in the atmosphere has changed over timescale of millennia.

The numbers and types of fungal spores in the air are certain to change in the future. It is inevitable that continuing deforestation and desertification will reduce the number of spores associated with mushrooms. Spores of some fungi associated with the decomposition of plant debris may increase as levels of carbon dioxide rise. This has been demonstrated in field experiments in which plants have been grown under conditions of elevated carbon dioxide.

Do you think there are any potential futures uses for this research? For example, could this help to create more rain in drought affected areas?

[ImNotJesus](#)

It is possible that a biomimetic dusting of particles with similar surface chemistry to fungal spores could be effective in driving the condensation of water in clouds. Rainmaking is an active area of research. The absence of the appropriate types of clouds in dry regions is probably a bigger problem than making rain fall from them. Mushrooms are not going to save the planet for us.

Do you know if spores are better or worse than other particles at starting drops? I see your paper shows spores under a microscope, did you test them against any other particulate?

[eak125](#)

Good question. We played with latex microspheres as controls, but every synthetic particle added its own complications to the experiment. For this paper we opted to compare the spores of mushrooms that use the active droplet-based launch mechanism with the spores of puffballs and other fungi that are close relatives of gilled mushrooms but have lost the mechanism. This is akin, perhaps, to comparing the biomechanics of flighty (what's the correct antonym here?) versus flightless birds.

Couple of questions for you:

1. Most cloud condensation nuclei are <1 micron whereas your spores are all in the 4-10 micron range. At this size they are similar sizes as cloud droplets themselves, is this a problem for nucleation?
2. I don't know how the estimate was obtained but if 50 million tons is accurate then it is reasonably small compared to the global annual CCN mass in the billions of tons. Add in the significantly larger size (>10 times in radius therefore >1000 times larger mass so 1000 times less particles per kg) then I expect they are making only a very small contribution to the average atmospheric nuclei density. With that in mind, would you consider fungal spores to be much more significant where the concentration of fungus is high rather than significant for cloud formation rates globally?

[Robo-Connery](#)

1. The droplet diameter is around 10 micrometers, but the drops attached to adjacent spores can merge to form larger drops that approach 30 micrometers in diameter. Based on this observation, we wonder if spores might work as giant cloud condensation nuclei.
2. I agree that the number of particles is very low compared with CCN mass. One possibility is that the spores could be significant in specific locations of concentration, e.g., above a forest canopy. The source of the 50 million tons is interesting. (The publication is [1] in the list of references in the

PLoS paper.) It is based on measurements of mannitol in air samples above forests. If the 50 million ton figure is correct, fungi provide an average of one million spores for every square meter of the earth's surface, and a collective surface area of 31 million square kilometers, which is the same as the land area of Africa.

Do you think this research could eventually be applied to cloud seeding initiatives? What about seeding exoplanets?

[firedrops](#)

Traveling at the top speed of NASA's New Horizons spacecraft it would take 78,000 years to reach our second nearest star (Proxima Centauri) and potential exoplanets. Homo sapiens is going nowhere.

Hello and thank you for this AMA! Your book, Mr. Bloomfield's Orchard, was one of the first books about fungi that I read to start my graduate career in soil and forest ecology. Your descriptions regarding spore dispersal, in particular, have stuck with me to this day.

My question is regarding the potential positive feedback loop between precipitation patterns and fungal growth described in the paper. Given decreases in precipitation or changes to fungal species composition that alter the amount of spores dispersed into the atmosphere, do you think the loop could potentially degrade to the point of no return? To where we see an irreversible change to the overall pattern of precipitation in a region attributed directly to the fungi, or vice versa?

Again, thanks!

[Propeller3](#)

I'm very glad you enjoyed my first book. How fast time flies. If there is a link between mushroom spores and rainfall, the loss of forest cover, or damage to the health of trees in an otherwise intact forest, would drive a debilitating feedback loop through the reduction in rainfall. Wood decay mushrooms, and yeasts related (very distantly) to mushrooms, are as effective at drop formation as mycorrhizal mushrooms. This means that more subtle damage to trees might be manifested in a loss of mycorrhizal diversity and increase in mushrooms that fruiting on rotting wood. This might keep things running for a while, but, ultimately, the ecosystem would be debilitated. I do not see mushrooms as a game changer. We are witnessing forest damage from so many sources at the moment.

Hello! What are the next stages needed for taking this proof of concept to studying the role of spores in actual water systems?

[thmeaningofhaste](#)

We played with a cloud chamber setup with a volume of a shoebox in which we introduced air saturated with water vapor and then introduced spores. I had fantasized that we might see the fog in the chamber disappear as the spores nucleated the water and fell to the bottom of the chamber. Miniature rainstorm. It did not work. A related experiment in a smaller chamber might be more effective. Laser imaging in clouds is another interesting avenue.

What is the mechanism for the spores being ejected into the atmosphere? What height can they typically achieve?

[dark_magnetar](#)

The spores of mushrooms and related basidiomycete fungi that use the same launch mechanism (called a surface tension catapult) jump over a maximum distance of 1 millimeter. This does not seem very impressive, but it is a marvel of evolutionary engineering. In a mushroom, the discharged spore is shot into the air space between the gills and is stopped dead by the viscosity of the air (the microscopic spore has negligible inertia). It then falls between the gills and is swept away by air currents circulating around the cap of the fruit body. Convection and wind are responsible for lifting the spore into the atmosphere. The diversity and distribution patterns of mushroom-forming fungi are evidence of the effectiveness of this process as a dispersal mechanism. A single mushroom can release 30,000 spores per second from its gills, billions of particles in a day.

Why did you choose to work with ESEM for this study? It is not the type of tool I would have thought about (though my experience with ESEM is limited. I've mostly used conventional SEM).

On a side note, have you gotten any really cool images from it that you just enjoy from an aesthetic/cool viewpoint? I always have enjoy using it, and am ending up with number of images that will never be included in any publications, but I still want to keep.

[kerovon](#)

Just restating what we wrote in the PLoS Paper, but environmental scanning electron microscopy (ESEM) has been used in a number of experiments to study the condensation of water on pollen and other particles that become aerosolized. This technique allows investigators to study the properties of untreated biological samples to preserve natural surface chemistry and to visualize the condensation of water in real time.

What is the altitude distribution density of spores into the atmosphere? Were air samples taken at altitude? Out of all nucleating sources, what percent do spores represent at various altitudes?

[Dosage_Of_Reality](#)

Data on the vertical distribution of fungal spores in the air column is VERY limited. Air sampling experiments from decades ago showed that spores were present in the stratosphere at altitudes between 18 and 30 kilometers. The majority of air-sampling studies that identify fungal species have relied upon ground level trapping, the sort of methods used for daily allergen forecasting. Molecular identification has become the key research method, but the literature is relatively sparse. Regarding the percentage of all nucleating particles spores are going to be swamped by other solids. But the devil is in the details: how effective are fungal spores relative to pollen grains, miscellaneous biological debris, organic and inorganic "soot," etc.? The PLoS paper has shown a novel way in which a particular type of fungal spore nucleates water and this raises the possibility that fungi may play an accessory role in stimulating rainfall. I am not anticipating a phone call from Sweden anytime soon.

If mushrooms weren't ejecting 50 million tons of spores into the atmosphere each year, would precipitation be noticeably different?

[M_Bus](#)

Perhaps we will live long enough to find out, before, as Jim Morrison said, "the whole shithouse goes up in flames." I think like Chicken Little.

You mentioned that you are interested in spore discharge mechanisms. Can you give some examples of neat mechanisms that they use?

[Jurshan](#)

Gorgeous fungal contraptions for discharging spores including the squirt gun of *Pilobolus* that launches a capsule filled with 90,000 spores at a speed of 32 kilometres per hour over a distance of 2.5 metres. Scaled to human dimensions, this is equivalent to a 9 kilometre flight!

Do you know how long it takes for a dispersed nuclei to become a nuclei?

[kylehe](#)

Spores dispersed from mushrooms can reactivate drop formation as soon as they encounter air saturated with water vapor.

Flora seeding clouds? Sounds reminiscent of the old idea that the rain follows the plow:

https://en.wikipedia.org/wiki/Rain_follows_the_plow

[LinguistHere](#)

This is the opposite of the rain following the plow (which was an exercise in gross wishful thinking), because it suggests that not plowing natural grasslands and not cutting down forests might be more conducive to sustaining rainfall.

Mushrooms are fascinating. They have a lot of potential environmental and health uses. Will you be using spores indigenous to the area or introducing new species.

[quakerorts](#)

Regarding the purported medicinal properties of mushrooms I refer you to a recent essay:

<http://www.sciencedirect.com/science/article/pii/S1878614616000180>