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Opinion Article

The importance of fungi for a more sustainable future on our planet

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ABSTRACT

Fungal products are essential building block for change towards a more sustainable future for our planet. We need to be able to convert plant materials to provide renewable substitutes for the products we now get from fossil resources. In nature, fungi are specialized in breaking down plant materials by the means of a rich spectrum of plant cell wall degrading enzymes. In industry such fungal products can be brought in use for converting bio-waste and agricultural crop residues into bioenergy, biomaterials, biochemicals, biofertilizer etc. But we need to understand fungal biology and diversity better before we can use it fully and efficiently. Increased mycological research efforts are needed to unlock this potential. We have excellent tools in our hands as genomics and bioinformatics. Now time is right to use such tools to focus on biodiversity, biology and interactions. Frontier mycological research is what is needed also for fulfilling the needs of applied use of fungi and fungal products. It is a part of the social responsibility of the mycological sciences, to ensure that mycological research from all over the world contributes to forwarding more sustainable solutions built on fungi.

1. Fungal products are essential for sustainable solutions

Depletion of easily accessible fossil energy resources, threat of climate change, and political priority to achieve energy self-sufficiency and develop more sustainable solutions give a strong push towards the use of renewable resources to substitute for the use of fossil fuels. The use of fungi and fungal products is essential for this paradigm shift towards use of renewable plant materials instead of fossils. Increased mycological research efforts are needed to unlock this potential. Mycological research, bridging between basic and applied approaches and between academia and industry is the vehicle to move this area forward in a timely manner. New ways of sharing knowledge can enhance the process, and open source innovations will allow for developing countries to access the technologies needed for development of more biological solutions to important problems.

2. Fungi and fungal products brought in use in biorefineries

Renewable energy for electricity supply will in a future, non-fossil based society, be provided primarily through wind and solar energy technologies. Biomass-based fuel will most probably in most parts of the world be used only for a shorter span of years for private cars until other solutions for renewable transport have been developed, while biofuel in a foreseeable future will be used for ships, aeroplanes and industrial vehicles. In this way we need fungi and fungal enzymes to convert biomass to fuel both in the shorter and in the longer time perspectives. Mycological research efforts in these areas are

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a good investment, allowing for improved understanding of fungal physiology, composition of the secretome and the ecological role in nature of filamentous fungi at the same time as it gives rise to novel discoveries of potentially interesting fungal proteins for industrial use.

So far most effort has been focused on converting corn to bioenergy, and here fungal products are already making up the major components of the enzyme blends used commercially (www.Novozymes.com; www.Genencor.com). But many more types of fungal enzymes and other fungal proteins are needed to efficiently harness the potentials embedded in the wide spectrum of biological waste materials found abundantly in a modern industrial world: large amounts of municipality waste and agroindustrial side streams will in this way supplement the feed stock gained from agricultural crop residues.

But what about development of the substitutes for all the other products (as materials, chemicals, plastics, etc.) we currently get from oil refineries? The option is here to design and develop specialized biorefineries, which based on conversion of plant biomass can supply us with all the types of products we today get from oil refineries. Biorefinery technologies can be developed to produce products also higher up the value chain such as pharmaceuticals, nutraceuticals, food ingredients, enriched animal feed, etc.

In biorefineries the plant biomass (composed primarily of plant cell wall polymers) is first broken down to smaller building blocks (sugars and oligomers) and secondly built into a range of new and more valuable products. Essential for all these biorefinery processes are microbial enzymes and microbial metabolites. For improved conversion of plant biomass, fungi have proven to hold the richest combination of plant cell wall degrading enzymes. This relates directly to the ecological role of filamentous fungi in nature being to a large extent responsible for breaking down plant materials. Further, filamentous fungi will also be used in biorefineries for synthesis of higher value products but most importantly also yeasts and a wide spectrum of prokaryotes will be used.

3. Fungi as friends and foes

Plant diseases are not a battle overcome and gone. It is a continuous fight. And it keeps giving serious surprises as, for example, the collapsing of resistance against stem rust on wheat, starting in Uganda with the finding of the strain UG99 in 1999. Continuous mycological research efforts are needed! Furthermore, plant pathologists may in the future serve in a new role, as they are basically experts in studying interactions between microbes and plants, which is the same field as the new discipline “biomass conversion” is operating in.

Also human mycoses are a moving target. The increase of the number of immune compromised people in society is giving much more room to human mycoses. This not only increases the frequency of patients attacked by fungal infections, but also a broader spectrum of fungal species which can give rise to attacks in humans. The increased international travelling as well as the foreseen future rise in global temperature are other preconditioning factors of making fungal infections in man and animals a more serious threat.

On top of this is one more impact-escalating factor: human mycoses are difficult to cure. Basically this stems from the fact that man and fungi are quite closely related evolutionary. Similarity and relatedness between human beings and fungi make the compounds which have potentials to eradicate the fungal pathogens also to take a heavy toll on the human body. The need for additional, basic as well as applied studies within medical mycology is obvious.

Feeding and fuelling the 9 billion people that inhabit the planet is the most important of all the global challenges. One aspect, hitherto not addressed with sufficient seriousness, is to limit the post-harvest loss (it keeps on taking a heavy toll of almost one-third of the total global primary production). Fungi also play an important role here, both as saprotrophs, living on decomposing plant materials, and also through production of mycotoxins making the harvest unfit for both human food and animal feed. This adds one more important area for future mycological research and development. We need to be able to take better care of the harvest.

4. Fungi as work horses, providing both solutions and business

Fungal products, produced in fermentation tanks have for centuries been brought in use all over the world. *Aspergillus* has been used in the fermentation industry in Japan and China for centuries. Sake, soy sauce and fish sauce are good examples. Production of useful blends of microbial enzymes, for example in textile- and brewing-industries, was brought in for widespread use early on in North America, Europe and the Far East. The fungal genera most often used for production of such enzyme mixtures were *Trichoderma* spp., *Aspergillus* spp., *Fusarium* and *Humicola insulens*; and to a smaller extent species of the Basidiomycete genus *Trametes*. Filamentous ascomycetous genera, colonizing abundant biomasses in nature, were the fungi selected because they were found to be the most efficient in doing the job, including in fermentation tanks. More research in this area will reveal more species with interesting industrial potentials.

The impact of molecular biology, enabling the practice of gene splicing technologies gave rise to a new generation of biological production: production of monocomponent enzymes. The first global example was the Novo production of lipase by *Aspergillus oryzae*. The subsequent development within Novo Nordisk A/S, succeeding in producing human insulin in baker’s yeast, was revolutionary at the time of introduction. Again a fungus (*Saccharomyces cerevisiae*) was found to be the most suitable production host also for the large-scale production of this important human drug. In the future more drugs and also nutraceuticals (e.g. selenium-enriched yeast) will be produced in yeasts. Of special interest is the new progress made in transferring entire synthesis pathways from plants, allowing for high yield production in yeast of new drugs of plant origin.

Use of GMO technologies for the production of monocomponent proteins opened up a new era in industrial enzyme production: the fermentation yields went up significantly and the recovery process was much more efficient. Furthermore, a precise specification of the product, resulted in benefit for both the industrial customer and regulatory approval and eventually enduser acceptance.

The era of monocomponent products was based on two types of production organisms: Gram-positive bacteria (primarily *Bacillus* spp.) and filamentous fungi (with *Aspergillus* spp. as the dominant production host, although *Trichoderma* species and *Fusarium venenatum* were also used). The record high fermentation yield per litre is achieved by *Bacillus*. However *A. oryzae* is following, giving impressive levels of yield, while use of yeast species for high yielding production of secreted proteins never made it. Basically filamentous fungi have the most efficient protein production and secretion machinery. They are designed and developed evolutionary to produce enzymes to break down substrates surrounding the regions where the filamentous hyphae are growing into, ensuring that small molecules are available for fungal uptake when the fungal hyphae subsequently grow to colonize the substrate. The yeast has no need for efficient dissemination of secreted proteins as they do not grow through the environment like filamentous fungi.

The biological production of monocomponent enzymes stimulated the growth of global industrial biotech enterprises, providing enzymes and ingredients to a multitude of industries (detergent, baking, paper and pulp, textile, leather, cereals, animal feed, starch and brewing industries). Basically industrial biotech business shaped up around one business concept: one gene, one protein, one product. However for biomass conversion one monocomponent protein is not sufficient to do the job of converting lignocellulose. An entire cocktail of enzymes is required. With this change in bioproduction, understanding of heterologous expression of multiple proteins and of fungal fermentation physiology must be developed to allow for process optimization.

Currently production plants of the industrial biotechnology sector are found in all parts of the world; much more decentralized than for pharma production. The enzyme products as well as the substrates required for the production are bulky and regional production is therefore the obvious choice (on all continents, e.g. in US, Europe, Brazil, China, and India). However the biomass conversion plants and biorefineries will most likely be even more decentralized in their placement, close to where the local biomass feed stock is. Interestingly and importantly, this provides basis for development of knowledge intensive jobs also in rural areas around the world.

5. Fungal products are an essential part of future sustainable solutions

As exemplified in this article, more mycological research is needed to provide the needed basis for building more sustainable solutions to important global problems. Therefore mycological research has to expand. We have been through decades in which mycology has experienced cuts in funding, for example within plant pathology, taxonomy, evolution, and molecular biology research areas. However, it seems to be turning around now, at least in some countries. Large-scale sequencing projects have given priority to fungi; not only within genomics but also transcriptomics and proteomics. This upward trend for mycological research should be exploited for attention to develop the mycological parts of new disciplines such as synthetic biology, synthesis biology, non-coding RNA, etc., and not the least to studies of ecological niche interaction of fungi with eubacteria, archaea, bacteria and protozoa.

Much more mycological research, giving insight and understanding is needed for unlocking and exploiting the potentials of fungi for more sustainable solutions and to enable us to control the fungal invasion and infections of man, animals, plants and materials.

6. Mycology and outreach

Fungi are important and therefore more people should know more about fungi, about what they are, how they function and the role they play in nature and in attacking man, plants and materials but not the least also about the important role they play for making more sustainable solutions to important problems. Mycologist should take on this responsibility to provide inspiring and informative outreach materials, made easily accessible on the internet, and openly accessed. It is great to see that the International Mycological Association takes new outreach initiatives and not the least that the 9th International Mycological Congress that was held in 2010 in Edinburgh, also in an impressive way proactively included outreach aspects. Let us hope this will serve as examples to be followed!

7. Social responsibility of the mycological sciences

It is a part of the social responsibility of the mycological sciences, to ensure that mycological research from all over the world contributes to forwarding more sustainable solutions built on fungi. Mycologists can deliver!