Recent Advances in the Intellectual Property Landscape of Filamentous Fungi

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Abstract

Filamentous fungi have been used for centuries in making food and beverages, and for decades for the production of enzymes and pharmaceuticals. New trends in the fields of fungal technology include mycoprotein, wastewater treatment, integrated biorefinery and biological pest agents. With this whitepaper, we highlight the most recent trends in the last five years (2015-2020) in the intellectual property (IP) landscape concerning filamentous fungi, identify the key players in each field, and analyse future trends.

Keywords: intellectual property; filamentous fungi; patents; biotechnology

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1. Introduction

1.1 Filamentous Fungi

Fungi are eukaryotic sporulating organisms that have characteristics of both plants and animals but are placed in a distinct kingdom (Choi & Kim, 2017). Fungi in general can be microscopic to macroscopic, and include unicellular organisms, such as yeasts, and multicellular organisms, such as filamentous fungi and mushrooms. Filamentous fungi grow as long, 2-10 μm thin filaments (hyphae) into intricate network structures (mycelium) that are observable to the naked eye and can grow to centimetre- to metre-scale. Filamentous fungi represent an incredibly rich and diverse group of species, with tens of thousands of fungal strains that have been identified, characterised, utilised and modified to this day. Still, there is significant growth in the number of catalogued fungal strains, with an estimated 95 % of fungal species estimated to be undescribed yet (Mueller & Schmit, 2007), and the scientific community is building an increasingly vast body of knowledge around these complex and valuable organisms. The large and growing interest in filamentous fungi mostly stems from the fact that their metabolic processes can be used to produce and refine a wide range of products and solutions (Mei et al., 2019) that create value for science, for industries, and for consumers.

Filamentous fungi, along with other microorganisms such as bacteria, yeast and algae, have been proven to be very useful for industrial applications (Waites et al., 2001). Historically, their metabolites have created massive values in areas ranging from pharmaceuticals (Alberti et al., 2017) to cosmetics (Gmoser et al., 2017) and commodity chemicals (Wösten, 2019), and the production of these metabolites has had significant impact across the entire biotechnology spectrum. Starting with breakthrough developments of antibiotics in the early 20th century, filamentous fungi have since then been used for applications that include producing biological control agents, enzymes, alcoholic beverages, organic acids, and food & feed (Rao et al., 2011; Gupta et al., 2015). With the rapid developments in strain discovery, strain engineering and industrial product development, it is certain that filamentous fungi will continue to be a key contributor in the creation of a biotechnology-based future.

1.2 Filamentous Fungi and Intellectual Property Rights

As a result of these breakthrough solutions taking shape, activity in the intellectual property (IP) space is increasing as well. As the value and potential of filamentous fungi become more and more established and recognized, efforts to capture and control that value through the use of intellectual property rights (IPRs) have been intensified across the globe (Singh et al., 2019). Patents are arguably the most important IPRs for protection solutions, and the landscape unveils a growing body of patents surrounding novel processes and products related to filamentous fungi. This is indeed a strong indicator that international markets are realising the great potential that these organisms have, and that key industry players are doing what they can to secure value creation and value capturing through the use of IPRs.
Protecting filamentous fungi and other microorganisms with patents and other IPRs is challenging for two reasons. The first reason is that inventions relating to biological material are, by their nature, much more difficult to disclose than inventions in other areas. Patent law requires that a patentable invention be disclosed in a manner elaborate and clear enough so that a person skilled in the art can carry it out. With inventions relating to microorganisms, such disclosure is usually impossible. The Budapest Treaty, first signed in 1977 and entered into force in 1980, attempts to circumvent this problem by allowing instead for depositing samples of biological material to recognized institutions (WIPO (n.d.)). Thus, all patenting procedures of new and modified strains of microorganisms, including filamentous and yeast-type fungi, follow the provisions of the treaty. The second reason is that much of the legislation around patenting of microorganisms is highly bureaucratic and difficult to comply with (Finger, J. M., 2000). An example can be found in the Trade-Related Aspects of Intellectual Property Rights (TRIPS) agreement, whose provisions are well-known among industry players as very challenging to understand and live up to. A range of other issues have been created as a result of the ratification of TRIPS, all of which deserve analysis and discussion, but for the scope of this report it is sufficient to mention that many challenges are present.

Clearly, protecting filamentous fungi with patents and other types of IPRs is not an entirely easy ordeal. To truly realise and capture the great potential value of filamentous fungi, these challenges need to be thoroughly understood and taken care of. Related to this fact is that any industrial player should be mindful and attentive of past and current trends within the patent landscape of filamentous fungi. Despite the obvious past and future importance of filamentous fungi in developing ground-breaking biotechnology, efforts to summarise critical, current IPR trends around filamentous fungi is lacking. This report therefore sets out to provide a thorough analysis of the patent landscape surrounding filamentous fungi and its various industrial applications. In addition, we seek to identify the key global players on the most important markets, and to make predictions about developments within this technological area during the coming years.
2. Patent Trends

Before analysing more specific fields of application, we will discuss the general patent landscape regarding filamentous fungi. First of all, it can be clearly seen that there has been a significant increase in publications of patent families discussing filamentous fungi starting in 1990 (Fig. 1 & 2). For the patent search and analysis the Orbit Intelligence software form Questel was used (details in the Methods section).

The top 5 players in terms of numbers of patents in the field over the last 30 years are Novozymes (311); Dupont (289) incl. Danisco & Genencor; DSM (133); Meiji Holdings (44); AIST (38) - International Institute of Advanced Industrial Science Technology. All are established biotechnology institutions that provide biological solutions for a variety of applications. The distribution of technology areas over the same time
frame is the following: 37.6% biotechnology; 15% basic chemical materials; 10.9% food chemistry. The majority of the patents analysed are found within the subgroup of biotechnology (enzymes and microorganisms).

During the last five years the distribution of patent classification in the field has not changed much, with 36.8% of patent applications being classified as belonging to the domain of biotechnology, while 15.7% were classified as basic materials chemistry, and 10% as food chemistry. The biggest observable trend concerns the countries of origin of patent applications. Here, an increase in patent families originating from Asian countries (mostly China and Japan) is noticeable. The key players of the last five years are: Dupont (137) incl. Danisco & Genencor; Novozymes (99); DSM (57); Toray Industries (24) and Dalian Institute of Chemical Physics (23).

2.1 Food Chemistry

Filamentous fungi have been used all over the world in the food industry for millennia in various fermented foods and beverages (Troiano, 2020; Hyde, 2019). Traditional fermentation processes that use filamentous fungi are for example soy sauce and miso, but also “mould-cheeses” and beer & wine (Table 1).

Because of the many challenges related to global supply and demand of food, biotechnology has become an increasingly important solution for creating ways to feed the world. More recently, during the last decades, several types of microorganisms such as bacteria, yeast and algae have been heavily researched for their ability to create various types of biomass and compounds that can be used in production of food and animal feed (Bourdichon, 2012), with filamentous fungi being no exception as they can produce a variety of useful food ingredients like enzymes, fatty acids, flavouring; organic acids; pigments & vitamins (Table 2).
**Table 1. Overview of different fungal species in food applications.** Adapted from Hyde et al., 2019.

| Application | Product | Fungal Species |
|-------------|---------|----------------|
| Beverages   | Beer, rum, wine | *Saccharomyces cerevisae* |
|             | Sake    | *Aspergillus oryzae* |
| Cheeses     | Roquefort, Blue cheese | *Penicillium roqueforti* |
|             | Camembert, brie, soft ripened | *Penicillium camemberti* |
| Oriental food fermentation | Ang-Kak | *Monascus purpureus* |
|             | Doenjang | *Aspergillus oryzae* |
|             | Miso | *Aspergillus oryzae, A. sojae* |
|             | Hamanatto | *Aspergillus oryzae* |
|             | Ontjom | *Neurospora intermedia* |
|             | Rennet | *Rhizomucor miehei; Rhizomucor pusillus* |
|             | Shoyu (soy sauce) | *Aspergillus oryzae, A. sojae* |
|             | Tempeh | *Rhizopus oligosporus* |

**Table 2. Overview of some metabolites obtained from filamentous fungi.** Adapted from Copetti (2019).

| Ingredient | Compound | Producing fungus | Application |
|------------|----------|------------------|-------------|
| Enzymes    | Amylase  | *Aspergillus niger;*  
|            |          | *Aspergillus oryzae* | Production of glucose syrup, bread improvement, and so on |
|            | Invertase| *Saccharomyces cerevisiae;*  
|            |          | *Saccharomyces uvarium* | Soft-centred candies, artificial honeys, confectioneries, liqueurs, and so on. |
|            | Galactosidase | *Mortierella vinacea* | Beet sugar refining |
|            | Lactase  | *Aspergillus niger;*  
|            |          | *Aspergillus oryzae;*  
|            |          | *Kluyveromyces marxianus;*  
|            |          | *Kluyveromyces fragilis* | Production of lactose-free milk and dairy products, upgrading cheese whey |
|            | Pectins  | *Aspergillus niger;*  
|            |          | *Aspergillus spp.* | Juice clarification, improvement of grape juice yield, removing coffee mucilage, and so on. |
|            | Proteases| *Aspergillus oryzae;*  
|            |          | *Aspergillus spp.* | Bread improvement, chill proofing of beer, milk coagulation, meat tenderization, and so on. |
| Fatty Acids| O3 & O6  | *Mortierella alpina;*  
|            |          | *Saccharomyces cerevisiae;*  
|            |          | *Candida lipolytica* | Addition of polyunsaturated fat acids (bioactive compounds) to the composition of food and food products. |
| Flavouring | Blue cheese flavour | *Penicillium roqueforti* | Impress blue cheese flavour in food products |
|            | Bitter almond flavour | *Ischnoderma* spp. | Impress almond flavour in food products |
|            | Roselike odor | *Saccharomyces* spp.; | General food flavouring |
Within this area, two main patenting sub-trends can be identified: production of food additives and using fungi as the main ingredient in new food products. All patents mentioned in this section can be found in Table 3.

2.1.1 Food additives

Looking at the patent landscape regarding food chemistry and filamentous fungi it can be seen that most patents relate to the production of enzymes or other compounds by either using a fungus as recombinant production host (i.e. inserting genes into its genome to produce new substances), or by using specific metabolites or enzymes native to the fungus. Filamentous fungi are highly important for their ability to selectively produce certain nutrients of interest than can be used for areas such as supplementation, dyeing, and texture improvement. To name just a few examples of this, the patent landscape reveals new methods for producing beta-glucan and other polysaccharides (US20030050279), sweeteners like steviol (EP3063286, WO2019/006244) and other flavouring agents like sesaminol (WO2018/056388), as well as special dietary proteins (CN110746494) and a range of vitamins and minerals. Even some enriched nutritional products that include the whole fungi biomass have been developed, such as an iron supplement made with *Aspergillus oryzae* (EP3462915) or fungi that are enriched in vitamin D through UV irradiation (US20180021405). When looking at proteins and enzymes as food additives, the patents focus mostly on ones that improve textures and processability of materials, such as glucose oxidases for baking processes (EP3182829), xylanase to improve the storage of crisps (EP2869701) or ice structuring proteins to improve the freezing process of foods (EP3302076).

Even though fermentation with filamentous fungi has been used in food production for a long time, there are still improvements to be made. Accordingly, there is a surprisingly high number of new patents that relate to traditional food products and traditional food production processes. Improvements include
hydrolases to increase soy sauce production (JP2016136843A), pre-cultures for faster koji production (US20190159495) and tea fermentation (CN107494809), removing off flavours in rice wine (KR20180055255), increased fermentable sugars in beer production (WO2019/067287) and better production of tempeh and other fermented bean-based foods (JP2016123395, JP2019129802).

2.1.2 Fungi as the main ingredient in food products

One area that has seen a noticeable increase in patent applications in the last years is the production of food products that contain biomass or proteins of filamentous fungi as a or the main ingredient. Often, the application of the fungi here is called mycoprotein or, if the target area is animal feed, single cell protein (SCP). So far, there are only a handful of players in this field, but the trend certainly points towards an increase in this segment. The reasons for this are the high demands by consumers for more variety in the vegetarian and vegan product segment (e.g. to have an alternative to soy), the general increase of vegetarian and vegan products on the market, as well as the increased knowledge about the nutritional advantages and benefits of fungi-based protein.

Mycoprotein is becoming an increasingly popular alternative to meat and even meat alternatives, like soy and pea, due to a very favourable amino acid profile and texture. There are also examples of inventions related to further improving the attractiveness of filamentous fungi as a nutrient source by further boosting the contents, ratios or availability of nutrients, as discussed below.

One of the earliest patents in this area were filed by Marlow Foods and describe production of what is now known as Quorn. Even though the original patents were filed in the 80ies (e.g. EP0804086), continuous improvements and inventions have been made, such as different ways to bind the proteins together (EP3474685) or reducing RNA levels in the final product (WO2018/002581). In recent years, the landscape has diversified, with more actors starting to file patents in the sector, in particular companies and organisations from Sweden, the UK and the US. They differ mostly in the use of different edible fungal species; while Quorn-related patents typically only use Fusarium graminearum, others use Neurospora crassa (WO2019/121697, US20190373934) or Zygomycete species. However, we are seeing a clear indication that actors are moving to develop and protect more industrially focussed processes. Examples include patents that describe a possible integration of production of filamentous fungi for food (and feed) applications with bioethanol production (EP3464555, EP3080282, EP3209789). Furthermore, most patents describing mycoprotein production use a form of submerged fermentation (WO2017/181085), but some actors developed solid-state or surface-growth fermentation (WO 2019/046480 Al).

2.1.3 Animal feed

Patents related to animal feed are mostly focussed improving the digestibility of feed for the animal (IPC code A23K+). Most of these patents are protected in China and an increase has been seen in the last couple of years. Interestingly, many of the patents showing up in this category can also have applications
for human food, but do not necessarily mention this in the patent, nor is the patent categorised in human food applications.

Many examples of new patents related to animal feed, as will be expanded in more detail further below, are enzyme-related patents, such as the production of mannanases (EP3385376) and xylanases (WO2020/009964), as well as enzymes that break down fish guano for aquafeed (CN106805002). Other areas are related to preparing functional feed additives by using fungal fermentation (CN108450656, CN109497259). Pet food is another area where IP regarding filamentous fungi has increased in the last years, either as supplements produced by fungi, or as the whole fungi biomass to produce vegetarian pet food (CN108719578).

Table 3. Overview of selected patent families associated with Food Chemistry

| Patent number (one of the family) | Country | Assignee (1st application date) | Details |
|----------------------------------|---------|---------------------------------|---------|
| **Food additives**               |         |                                 |         |
| US20030050279                    | AU, ZA, MX | Nestec - Nestlé (2001)           | A method to produce a Beta-glucan from filamentous fungi and improving food structure |
| EP3063286                        | AT, AU, BE, CH, DE, DK, EP, ES, FR, GB, IE, JP, MX, NL, RU, SE, US, BR, CA, CN, ID, IN | Conagen (2014) | Recombinant production of steviol glycosides |
| WO2019/006244                    | AU, BR, CA, CN, EP, IN, KR, PCT WO | Conagen (2018) | Hydrolysis of steviol glycosides by beta-glucosidase |
| WO2018/056388                    | CN, JP, TW, PCT WO | Suntory (2017) | Method for production sesaminol or sesaminol glycoside |
| CN110746494                      | CN | Shenzhen Novojin Biotechnology (2019) | A group of special dietary proteins |
| EP3462915                        | AU, BR, CA, CN, EP, IN, JP, KR, MX, US | Cura Global Health (2016) | Process for forming iron enriched nutritional products |
| US20180021405                    | Lapsed | Entia Biosciences (2017) | Nutritional approach to the control of anemia, diabetes and other diseases or conditions and prevention of associated comorbid states with the use of ergothioneine |
| EP3182829                        | EP | DSM (2015) | Combination of glucose oxidases for improvements in baking |
| EP2869701                        | Lapsed | DSM (2013) | Crisp baked products comprising xylanases |
| EP3302076                        | AU, EP, MX, US | DSM (2016) | Use of ice structuring protein afp19 expressed in filamentous fungal strains for preparing food |
## Traditional fermentation related patents

| Patent Number | Country | Inventor | Description |
|---------------|---------|----------|-------------|
| JP2016136843A | JP      | Kikkoman (2015) | Filamentous-fungus mutant in which hydrolase activity is improved |
| US20190159495 | JP, US  | Yamasa (2018) | Method for short-time koji production using pre-cultured filamentous fungi |
| CN107494809  | CN      | Anhui Zhonghui Te (2017) | Black tea yeast starter and preparation method thereof |
| KR20180055255 | KR      | RDA - Korea Rural Development Administration (2016) | Method for manufacturing rice wine with reduced heat flavor, and rice wine manufactured by same |
| WO2019/067287 | EP, PCT WO | DuPont (2018) | Production of brewer’s wort having increased fermentable sugars |
| JP2016123395  | JP      | Akita Konno Shoten (2015) | Method for producing tempeh fermentation product |
| JP2019129802  | JP      | Kikkoman (2018) | Bean body structure solubilized product-containing food composition and process for producing same |

## Fungi as main ingredient

| Patent Number | Country | Inventor | Description |
|---------------|---------|----------|-------------|
| EP0804086     | Expired | Marlow Foods (1995) | TEXTURISED FOODSTUFFS FROM GELLED EDIBLE FUNGUS AND HYDROCOLLOID MIXTURE |
| EP3474685     | GB, EP, TW, US | Marlow Foods (2016) | Foodstuff |
| WO2018/002581 | GB, TW  | Marlow Foods (2016) | Edible fungus |
| WO2019/121697 | EP, PCT WO | Lantmännens energi (2018) | Process for industrial production of food-graded fungal biomass |
| US20190373934 | EP, US, PCT WO | Emery (2019) | Edible compositions including fungal mycelium protein |
| EP3464555     | EP, IN  | Mycorena AB (2016) | Process for edible filamentous fungi cultivation and its integration in conventional sugar to ethanol production |
| EP3080282     | CA, US, EP | Lantmännens energi (2014) | Integration of first and second generation bioethanol processes |
| EP3209789     | AU, CN, EP, US | University of Strathclyde (2014) | Bioprocesses for co-production of ethanol and mycoproteins |
| WO2017/181085 | US, AU, BR, CA, CN, EP, IN, JP, KR, MX, SG | Mycotechnology (2017) | Methods for the production and use of myceliated high protein food compositions |
| WO 2019/046480 Al | BR, CA, EP, TW, US, PCT WO | Sustainable bioproducts (2018) | Edible composition with filamentous fungi and bioreactor system for the cultivation thereof |
### Animal feed

| Application | Patent Details | Description |
|-------------|----------------|-------------|
| EP3385376   | EP, PCT WO AB Enzymes (2017) | Fungal mannanases |
| WO2020/009964 | EP, PCT WO Danisco-Dupont (2019) | Xylanase-containing feed additives for cereal-based animal feed |
| CN106805002 | CN Zhejiang Baihui Biological Technology (2016) | Ferment fish guano for aquarium fishes |
| CN108450656 | CN Hunan Weigufang Biotechnology (2016) | Method for preparing functional feed additive by performing orientated fermentation on Chinese herbal medicine residues |
| CN109497259 | CN Zhengzhou Green Agriculture (2018) | Starter feed of sucking pig with disease-resistant function |
| CN108719578 | CN CAF - Chinese Academy of Forestry (2018) | Complete vegetarian pet food and preparation method thereof using beneficial fungus mixed culture technique |

### 2.1.4 Key players

Historically, food-related applications of filamentous fungi have mainly been developed within the world of academia, however nowadays the landscape is dominated by established biotech companies which produce enzymes used in the food production.

More specifically, of 324 identified relevant patent families in the field of food products, 38% are owned by the top 10 organisations. The key players from the last five years are DuPont (47 patents), DSM (16), AB Enzymes (13), Novozymes (11), Toray Industries (10). Marlow Foods had seven patents solely related to meat alternatives based on filamentous fungi. From a geographical perspective, the majority of patents were filed in China, closely followed by Europe, the US and Japan. Patents originating from Asia were heavily focussed on traditional fermentation products, such as Kikkoman and Yasama, while Europe and the US were focussed on patents related to the protein shift towards mycoprotein as a complete food source.

### 2.1.5 Future Trends

Because of the constantly increasing demand for food, and the many challenges facing the food and feed industries, we believe that microbiological solutions for the production of food products and nutrients will become hugely important in the future. While other microorganisms show great promise for rising up to the challenge as well, filamentous fungi have excellent prospects for assuming the role of the single most important source of microbial nutrition. This is related not only to the already high degree of consumer acceptance, but also to the robustness, (substrate) versatility, and speed of metabolic processes of filamentous fungi, as well as their favourable nutrient composition.

Many of the identified patents relate to products and ingredients for consumers, with a wide scope of inventions from supplements to fungi-based foodstuffs. With the incredible versatility of filamentous
fungi, we will continue to find novel application areas within the entire value chains of the food industries. In the coming years, we foresee a more clear-cut division being created, with public research organizations focusing on the deeply technical microbiological aspects of filamentous fungi cultivation, whereas industry players continue to assume the responsibility of creating technology transfer and implementing new technologies into industrial solutions.

2.2 Pharmaceuticals

The economic significance of filamentous fungi to the pharmaceutical industry cannot be overstated. Fungi have been widely exploited due to their capacity of producing a wide range of valuable bacterial-control agents. Antibiotics are possibly the best-studied secondary metabolites in fungal cultivation due to their long-dated history. Antibiotics are low-molecular compounds that are known to inhibit the growth of other microorganisms, particularly bacteria (NHS, 2019). Although over a thousand antibiotic substances have been discovered in the past decades, less than around a hundred have been granted permission by regulatory agencies to be used in humans and animals, due to their toxic and adverse effects (Kallberg, 2018). Most currently available antibiotics of fungal origin are found within the *Aspergillus* and *Penicillium* groups. Other fungi-produced pharmaceuticals include immunosuppressants, anti-infectives, and statins.

Most new inventions are not related to native fungal compounds, but compounds produced in fungi as a production host, and therefore related to the optimisation of cultivation techniques by genetically engineering the fungus (see section 2.6). To identify the most important trends related to production of antibiotics, we have to consider ongoing activities both outside as well as within the healthcare and life science sectors. All discussed patents can be found in Table 4.

2.2.1 Applications outside the life sciences

Contrary to popular belief, antibiotics are not only used within the health care and pharmaceuticals industries, but also to a growing extent in agricultural areas. The contents of recently published patents reveal for example that the growth inhibitory activity of certain antibiotics can be used against agricultural pests such as nematodes, arthropods (US2007032545) and other parasites (EP3058939). Other compounds related to agricultural use of pharmaceuticals include biological fertilisers (CN107828699) and pesticides (WO2017188049).

2.2.2 Applications within the life sciences

A major area of antibiotics and pharmaceuticals applications is of course the healthcare industries. This is well reflected in the patent landscape of filamentous fungi as well. In recent years, there have been publications of patents for very diverse solutions, ranging from biomaterials for the treatment of wounds (EP3165233) to the development of products for inhibition of oral bacteria in humans (WO201965124). As mentioned above, a large number of inventions in this field relate to the production host being a fungus, such as for the production of antibodies (WO2019/175477, CN109575130, CN110256557) and glycan-
based antibody-drug conjugates (EP3426288, US2017036233), compounds for treating neuromuscular
diseases (EP3442553), or for improving the production system itself (EP3004145).

### Table 4. Overview of selected patent families related to pharmaceuticals

| Patent number (one of the family) | Country | Assignee (1st application date) | Details |
|----------------------------------|---------|---------------------------------|---------|
| **Outside the life sciences**     |         |                                 |         |
| US2007032545                     | Lapsed  | Kisasata Institute (2004)       | Antibiotic fki-1778 and process for producing the same |
| EP3058939                        | JP      | NAI (2014)                      | Antiparasitic agent - Siccanin |
| CN107828699                      | CN      | Weifang Huabin Biotechnology (2017) | Agricultural composite microbial agent and preparation method of same |
| WO2017188049                     | AR, CN, JP, KR, TW | Kumai Chemical Industry (2017) | Composition for microbial pesticide formulation, method for producing same, and method for use thereof |
| **Application within the life sciences** | | | |
| WO201965124                      | EP, PCT WO | Ikeda Shokken (2018) | Composition to inhibit proliferation of oral bacteria |
| EP3426288                        | US, AU, CA, CN, EP, IL, JP, KR, MX, SG, TW | Alder Biopharmaceuticals (2017) | Anti-pacap antibodies and uses thereof |
| US20170362338                    | US      | Merck (2017)                    | Glycan-based antibody-drug conjugates |
| EP3442553                        | EP      | CNRS - French National Centre for Scientific Research (2016) | Use of a withania extract for the treatment of neuromuscular disease |
| EP3004145                        | US      | DTU - Technical University of Denmark (2014) | Genetically modified filamentous fungi and uses thereof |
| WO2019/175477                    | EP, PCT WO | VTT - Technical Research Centre of Finland (2019) | A subunit vaccine against porcine post-weaning diarrhoea |
| CN109575130                      | CN      | Aituojin Bio Pharmaceutical (2018) | Monoclonal antibody for detecting hpv18 e7 protein as well as preparation and application of monoclonal antibody |
| CN110256557                      | CN      | Northeastern University of China (2019) | Anti-bap31 single-domain antibody and application thereof |
| EP3165233                        | EP      | Latvijas University (2015)      | Biomaterial for treatment of acute and chronic skin wounds |

#### 2.2.3 Key players

In the performed patent search, 23% of patents could be assigned to the top 10 players, the top ones being Merck, Alder, DuPont, CNRS and Novozymes. Large players are still present, though it seems that their presence is not as prevalent compared to other fields. Even though the top players are mostly established biotech/pharmaceutical companies, still a lot of IP is generated by universities or research centres such as CNRS and Shandong University, both of which are also among the top 10.
2.2.4 Future Trends

When looking at antibiotic research, there has been a clear decreasing trend among both scientific communities and industrial environments. Novel antibiotic discovery has been stagnating for many years (Kmietowicz, 2017), and any newly created antibiotics are mere iterations of previous core concepts. The search for novel antibiotics is now considered a low-reward effort by research funding agencies. As for private players, the incentives for novel antibiotics research often do not match the effort required for development. Lack of interest comes not only from the high investment costs required, but also that if discovered, novel antibiotics will only be prescribed as a last line of defence in order to prevent acquired resistance to these new drugs, generating rather low revenues to pharmaceutical companies.

Instead, however, the recombinant production of pharmaceuticals in fungal production systems is steadily increasing, in particular with the rise of personalised medicine and antibody-focused treatments. With an efficient secretion system, and the ability to produce complex and glycosylated proteins and chemicals, fungi are well-suited as efficient production hosts, and genetic engineering tools will certainly make them even more efficient in the future.

2.3 (Bulk) Chemicals

The production of bulk chemicals - such as low molecular weight organic acids - by filamentous fungi have attracted considerable attention due to their industrial applications. The demand for sustainable alternatives to petroleum as a source of fuel and a precursor for chemicals is high and has driven advancements in synthetic biology, genetic engineering and microbiology. Filamentous fungi are natural producers of a variety of molecules with potential applications. In addition, their metabolism is prone to a high production of organic acids (e.g. citric acid, AU2008223787B2), which are often used as food additives and cosmetic ingredients. Organic acids are fully biodegradable molecules and can also be used as chemical intermediates for the production of biodegradable polymers. Furthermore, filamentous fungi are used to produce dyes, artificial aromas and flavours. Chemically speaking, these include a wide range of aromatic molecules (US9637763, EP2754716), polypeptides, oligo- and polysaccharides (CN101018869B, CN107987183) and phenolic compounds. An interesting feature of the literature around fungi-based production of organic acids, and also of the patents covering the same, is that it is often sharply focused on the ability to produce individual compounds, and not so much on the general production processes of the fungi.

Organic acids can be used for a wide variety of other applications as well, and this is well reflected in the patenting landscape of filamentous fungi. Several patents disclose novel methods for production and uses of C4-dicarboxylic acid (WO2018051837A1, US2013288321A1, EP2473608B1) which has potential to create commercial value in several ways. Other patents disclose fungi-based methods for production of oxalyl-CoA, glyoxylate and glycolic acid (WO2019020870A). It is clear that the impressive versatility of
filamentous fungi continues to show up in all parts of the patent landscape. All patents mentioned in this section can be found in Table 5.

Table 5. Overview of selected patent families associated with (bulk) chemicals production

| Patent number (one of the family) | Country | Assignee (1st application date) | Details |
|-----------------------------------|---------|---------------------------------|---------|
| AU2008223787B2                    | MY, CO  | Adcuram Nutrition Holding (2008)| Process for the preparation of citric acid employing filamentous fungi in a culture medium comprising glycerol |
| US9637763                         | AU, CH, DE, EP, GB, IE, JP, KR, MX, NL, NZ, RU, US, ZA, BR, CA, CN, IN| Rho Renewables (2012) | Recombinant production systems for aromatic molecules |
| EP2754716                         | CH, CN, DE, EP, FR, GB, IT, JP, US, IN | Shonan Technology Center (2012) | Method for producing shikimic acid and an antitumour agent from basidiomycetes by light stimulation |
| CN101018869B                      | CA, CN, IN, JP, EP, HK, MX, NZ, TW, ZA | GlykaNova (2005) | Immune modulating compounds from fungi |
| CN107987183                       | CN      | Zhejiang University of Technology (2017) | A kind of method that chitosan oligosaccharide is extracted from filamentous fungi |
| WO2018051837A1                    | CN, JP, US, VN | KAO (2017) | Mutant filamentous fungus and method for producing C4 dicarboxylic acid using same |
| US2013288321A1                    | IN      | Novozymes (2011) | Methods for Improved C4-Dicarboxylic Acid Production in Filamentous Fungi |
| EP24736008B1                      | MX, IN  | Novozymes (2010) | Methods for improving malic acid production in filamentous fungi |
| WO2019020870A                     | EP, PCT WO | VTT - Technical Research Centre of Finland (2018) | Improved production of oxalyl-coa, glyoxylate and/or glycolic acid |

2.3.1 Key players

As with several of the other trend areas described, some major biotechnological industry players show up in this field as well, such as Novozymes and DSM. There are, however, actors who are less active in other use areas of filamentous fungi that are present within this patenting space. Examples of such companies are RHO Renewables, KAO and Shonan Technology Center. On the academic side, Technical Research Centre of Finland Teknologian Tutkimuskeskus (VTT) reappears as an important organization, and we also see a strong presence of institutions such as biology-oriented research organizations.

2.3.2 Future Trends

Production of chemicals using microbial fermentation and the types of chemicals that are produced by fermentation processes will increase in the future. Traditional processes, such as citric acid production, fall into this category, but we also see constant innovation with new products entering the market and enhanced microbes being used for improved production processes. The fermentation step to produce the chemicals is now in many cases a mature technology in different sectors, and the main innovation area is by bioengineering of the organisms.

Even though it is easy to foresee the rise of interest in products produced through fermentation, it is hard to predict which organisms will take the lead on this interest. Filamentous fungi have many favourable characteristics for a robust process. However, when it comes to specific chemical production, there might be difficulties in the improvement of both the microbes and the processes.
2.4 Enzymes

Enzymes have clearly marked a new era in industrial biotechnology, and the advances brought by filamentous fungi have been fundamental within this context (Meyer et al., 2016). Filamentous fungi are natural producers of a variety of different enzymes and are good at secreting them into the culture medium. For that reason, they are often successfully used as a chassis for the development of recombinant enzyme production strains (as discussed above).

The production of the various enzymes using a few different fungal families and growth conditions have been considered novel inventions within the context of patents. Again, this area is indicative of the incredible versatility and flexibility that can be obtained by using filamentous fungi for the production of various compounds of interest, and we see a very wide range of topics and inventions covered in the patent landscape of fungi-based enzyme production (Table 6).

2.4.1 Production of specific enzymes of interest

There is a wide variety of disclosed inventions that relate to the production of specific enzymes and related compounds of interest, such as laccases (EP1799816, WO2012/023021) xylanases (EP3099794), phytases, cellulases (EP2766471, WO2019/122520, WO2019/219804, WO2016/090474), amylases (EP2906692) and mannanases (EP3385376) to give a few examples. As would be expected, we see that these patents have very diverse application areas, and there are clear connections to industries ranging from pharma to food to pulp & paper. Competition between actors producing these valuable enzymes appears to be high, as the patent landscape reveals several patent disputes and invalidity actions between some of the strongest companies working within the field. This is perhaps not entirely surprising, as the following section shows that this part of the market space is inhabited by some very strong players with high levels of IP sophistication.

2.4.2 Processes for enzyme production

Patents in this area are heavily focused on the general ability and potential of filamentous fungi to produce enzymes for a vast variety of purposes. The patents related to this field will be discussed in more detail further down in the section “Fungi Cultivation Methods”.
### Table 6. Overview of selected patent families associated with enzymes

| Patent number (one of the family) | Country | Assignee (1st application date) | Details |
|----------------------------------|---------|---------------------------------|---------|
| EP1799816                        | CA, CN, DE, DK, EP, FR, GB, IN, JP, MA, MX, SE, TN | AB Enzymes (2005) | Novel laccase enzyme and use thereof |
| WO2012/023021                    | CN, IN, BR, DE | Council of Scientific & Industrial Research (2010) | Method for obtaining laccase enzyme from arthroporhis sp |
| EP3099794                        | US, AR, AU, BR, CA, CN, EP, KR | DuPont (2014) | Compositions and methods comprising a xylanase enzyme variant |
| EP2766471                        | AT, AU, CA, CN, CZ, DE, DK, EP, ES, FI, FR, GB, HR, HU, IN, IT, NL, NO, PL, PT, RO, SE, SK, US, BR | IFP Energies Nouvelles (2011) | Process for the continuous production of cellulases by a filamentous fungus using a carbon substrate obtained from an acid pretreatment |
| WO2019/122520                    | EP, PCT WO | AB Enzymes (2018) | Variants of fungal cellulases |
| WO2019/219804                    | EP, PCT WO | DSM (2019) | Process for producing a polypeptide |
| WO2016/090474                    | Lapsed | Concordia University (2015) | Novel cell wall deconstruction enzymes of chaetomium olivicolor, acremonium thermophilum, and myceliophthora hinnulea, and uses thereof |
| EP2906692                        | IN, MX | Danisco - Dupont (2013) | Method of using alpha-amylase from talaromyces emersonii for saccharification |
| EP3385376                        | EP, PCT WO | AB Enzymes (2017) | Fungal mannannases |

#### 2.4.3 Key players

Among the most prominent developers of fungi-based solutions for enzyme production are Novozymes, a leading Denmark-based biotechnology group. AB Enzymes stands out as a rising actor within the field, having filed several significant applications during the last few years. Other renowned names from the biotechnology space, such as Dupont, DSM, Codexis and Toray Industries, appear in the records as well. Academia is of course also well represented, with reputed organizations such as the Technical University of Denmark (DTU), India’s Council of Scientific & Industrial Research, VTT and Nagakoa University of Technology showing up repeatedly.

#### 2.4.4 Future Trends

Despite its long history, production of enzymes using microorganisms is still an important topic of innovation today. Enzyme production has had a tremendous impact not only in technical industries, but also in healthcare and biochemical synthesis processes. The advancements of biotechnology in these fields paves the way towards lower production costs of enzymes, improved gene discovery methods and faster development of production hosts, which results in shorter investment payback periods. The increased access to fungal enzyme production systems also increases the accessibility of industries dealing with bulk and low value products. As a prime example, low enzyme production costs will enable viability of lignocellulose fermentation processes for biofuel and greener bulk chemical production.

With the increased accessibility of technologies for enzyme discovery and "bench-to-market" routines, we foresee the IP landscape for enzyme patents to maintain its increase in volume. This is expected to be
populated mostly by large private players with access to high-throughput pipelines for enzyme discovery and testing.

### 2.5 Environmental technology

The technology domain of environmental technology holds a variety of inventions, with most patent inventions being associated with treatment of water (wastewater, sewage or sludge) or biological processes for separation. There has been a significant increase in inventions in this technical domain in recent years. And, also within this field, the versatile uses of microorganisms are not left unexploited.

Interestingly, the area of using filamentous fungi in wastewater treatment is predominantly protected in China. The fungus is in most inventions integrated in the solution in the shape of biomats (US20190316077), microbial sludge (CN206886941U) or composition (CN109370943, CN109092048, WO2018/014037). However, some patents are seen where enzymes from filamentous fungi are used, such as cellulases (EP3219797) and amylases, to break up compounds in the waste stream.

Recent patents also include examples of degrading solid waste and transforming it into something with more value (CN108219887, EP2576213). The mentioned patents can be found in Table 7.

| Patent number          | Country | Assignee                                           | Details                                                                 |
|------------------------|---------|---------------------------------------------------|-------------------------------------------------------------------------|
| US20190316077          | US      | Sustainable Bioproducts (2018)                    | Filamentous fungal biomat, methods of their production and methods of their use |
| CN206886941U           | CN      | Jiangnan University (2017)                        | Sludge dewatering system is taken care of in online fermentation of filamentous fungi |
| CN109370943            | CN      | Hefei Huagai Biotechnology (2018)                 | Microbial deodorant suitable for sewage treatment and preparation method thereof |
| CN109092048            | CN      | Wuhan Boyang Guangwu Technology (2018)            | Microbial deodorant                                                     |
| WO2018/014037          | US      | University of California (2017)                   | Clarifying water and wastewater with fungal treatment/bioflocculation   |
| EP3219797              | JP      | Riken (2015)                                      | Cellulase activator and method for saccharifying lignocellulosic biomass by using same |
| CN108219887            | CN      | Shandong Zhongrong Biotechnology (2017)           | Method for producing biomass fuel blocks from sludge of sewage plant     |
| EP2576213              | ARipo AP, AU, CA, CN, IL, IN, KR, MX, NZ, UA, ZA, BR, Eapo EA, JP, SG, US | Xyleco (2011)                                         | Processing biomass                                                      |

### 2.5.1 Key Players

Most of the patents we analysed that fall into the area of biological water treatment are filed and protected in China (around 70%). The key players are Asia-based universities such as Central South University, Beijing University of Technology and Hohai University. Currently most patents are coming from research-based institutions, as it is still such a recent field for some applications. Another reason why the adoption by companies has not been as fast as in other segments is perhaps that it is not quite as straightforward
to make money with wastewater treatment as it is through production and sales of chemicals, enzymes or pharmaceuticals. However, it is expected that in the future more companies will enter this landscape due to (governmental) incentives, penalties for environmental pollution and increasing value of clean production processes.

2.5.2 Future trends
A significant increase of patents in fungi-related environmental technology can be seen in the last couple of years, and it is expected to continue increasing as the need for efficient and benign waste(water) treatment becomes more crucial. Scarcity of water in several parts of the world will demand more advanced water treatment applications. Furthermore, our resource efficiency will have to increase as more resources are needed and less are available. To protect our environment and ecosystems the problematic eutrophication due to usage of fertilizers or others is yet to be solved. Due to their versatile character filamentous fungi offer an excellent opportunity for solving these problems. Filamentous fungi are identified as crucial players in the circular economy (Bulkan, 2020). And it is expected that more integrated processes, where filamentous fungi are part of adding value to resource streams that are seen as waste, will be seen in upcoming patents.

2.6 Fungi Cultivation Methods
To keep up with the rapid developments within all aspects of filamentous fungi applications, the methods and tools for cultivation need to improve accordingly. It is clear from the patent landscape that companies and public actors are working hard to find new ways in which we grow and manage these interesting microorganisms. Different needs sprout these solutions, but the common goals to improve fungal cultivation have to do with increases in titre, rate or yield (TRY) of the process in question, as well as the efficient genetic modification of the production strain.

Two main patenting sub-trends are identified: one that relates to novel cultivation techniques and molecular biology methods, and one that relates to physical equipment for improved production.

2.6.1 Novel cultivation techniques
In this subcategory fall patents that deal with metabolic and genetic engineering, as well as the ways that fungi are cultivated, maintained, manipulated and stored. Examples include methods for continuous production of filamentous fungi (FR3071507), innovative solutions for producing fungi pellets of extraordinary density (WO2018/221482) and changing the viscosity phenotype of the organism (EP2673290). Furthermore, several novel processes have been disclosed in conjunction with the product patents described in the section below.

Furthermore, many patents in the area are heavily focused on the general ability and potential of filamentous fungi to produce enzymes for a vast variety of purposes. In this regard, many patents describe methods for modifying the fungal strains themselves at a molecular level. Examples include, but
are not limited to, methods for continuous enzyme production (FR3071507), methods for regulating gene expression in fungi (WO2012/030827), methods for improving protein secretion (EP1499739), methods for improved protein production in fungi (EP2576793, US9499826B2, US9512415), and how to use genetically modified filamentous fungi for producing various biosynthetic products (EP3004145). Notable is not only the general versatility of the microorganisms, but also the wide range of fungal strains used for development of the aforementioned methods.

2.6.2 Cultivation equipment
The majority of patent-protected inventions in this field relates to equipment and physical tools. Here we find not only new cylinders for efficient fermentation of filamentous fungi (CN207062292), but also equipment for mechanical control of filamentous fungi ball size (CN108893254) and devices for maintaining fungi cultures (CN209002501U, CN109628275).

When it comes to cultivation, filamentous fungi are also often different from other microorganisms in the sense that they form mycelial macrostructures, and depending on the process, this can be either a benefit or a challenge. Aside from aspiring to improve fungi cultivation in general, we interpret this apparent demand for improved hardware as originating from increasing interest from commercial players in integrating these solutions into existing industrial infrastructure.

2.6.3 Key players
There is not a particularly strong presence of the otherwise dominating actors in this particular field, even though they are present (e.g. Novozymes, Dupont, KAO). A rising player in this landscape that has appeared in recent years is AB7 Industry. However, most inventions relating to cultivation methods and equipment seem to come from actors within academia, with organizations such as Shandong University of Medical Sciences, Lingnan Normal Universitym, VTT and Jiangnan University appearing repeatedly in the publications.
### Table 8. Overview of selected patent families associated with fungi cultivation methods

| Patent number (one of the family) | Country | Assignee (1st application date) | Details |
|-----------------------------------|---------|--------------------------------|---------|
| **Novel cultivation techniques**  |         |                                |         |
| FR3071507                         | FR      | AB7 Industry (2017)            | Continuous production of filamentous fungi |
| WO2018/221482                     | CN, EP, IN, JP, PCT wo | Kao (2018)                     | Production method of filamentous fungus pellet |
| EP2673290                         | AU, BE, CN, DE, DK, EP, FI, GB, HK, JP, KR, NL, US , BR, CA | DuPont - Danisco (2012) | Filamentous fungi having an altered viscosity phenotype |
| WO2012/030827                     | CA, CN, US | Intrexon (2011)               | Regulatory element for heterologous protein production in the fruiting body of filamentous fungi |
| EP1499739                         | BE, EP, NL, US | Novozymes (2003)            | Methods for increasing homologous recombination of a nucleic acid sequence |
| EP2576793                         | CA, CH, CN, DE, DK, EP, ES, FI, FR, GB, IN, IT, MX, NL, US, BR | VTT - Technical Research Centre of Finland (2010) | Method for improved protein production in filamentous fungi |
| US9499826B2                       | DE, DK, EP, FR, GB, NL, US | VTT - Technical Research Centre of Finland (2010) | Production of proteins in filamentous fungi |
| US9512415                         | DE, DK, EP, FR, GB, NL, US | VTT - Technical Research Centre of Finland (2010) | Method for protein production in filamentous fungi |
| EP3004145                         | US      | DTU - Technical University of Denmark (2014) | Genetically modified filamentous fungi and uses thereof |
| **Cultivation Equipment**         |         |                                |         |
| CN207062292                       | CN      | Shandong Academy of Medical Sciences (2017) | Filamentous fungi is fermentation cylinder for fermentation |
| CN108893254                       | CN      | Yixing Boden Teco Industrial Equipment(2018) | Equipment for mechanically controlling sizes of filamentous fungi balls in fermenting process |
| CN209002501U                      | CN      | Lingnan Normal University (2018) | Filamentous fungus mycelium culture device |
| CN1090628275                      | CN      | Shanghai Hosome Biotechnology (2019) | Improved small culture device for filamentous fungi and culture method thereof |

### 2.6.4 Future Trends

Future developments in this section are difficult to predict. The creation of new IP for new equipment and techniques for cultivating microbes could logically follow the trend of fermentation technology developments in general. However, with the development of breakthrough gene engineering techniques and increasingly permissive regulation when it comes to GMOs, biotechnology as a field is shifting from a traditional fermentation-technology focus to a more microbe-engineering focus, so it would not be surprising if IP creation in the field of cultivation equipment will be decreasing over time, while the amount of patents being filed related to metabolic and genetic engineering will increase.
2.7 Materials

A nascent field that has been picking up momentum in recent years is the application of mycelium of filamentous fungi as a material. A recent paper by Cerimi et al. (2019) gives an overview over patents that cover the production or use of fungi as biomaterial between 2009-2018. Applications of fungi biomaterials include textiles, insulations (US20130224840), packaging (CN108249037, US20180148682), leather and composite materials in the automotive industry (US20130202855), see Table 9 for more details. In most cases, the mycelium is grown into moulds or as a biofilm, inactivated, dried and processed to become a stiff or elastic material. A variety of different fungal strains, mostly Basidiomycetes, have been mentioned in the associated patents.

Table 9. Overview of selected patent families associated with materials

| Patent number   | Country               | Assignee                        | Details                                                        |
|-----------------|-----------------------|---------------------------------|----------------------------------------------------------------|
| US20130224840   | AT, AU, BE, BG, CA,   | Ecovative (2007)                | Production method for fabricating mycelium panels for construction |
|                 | CH, CN, CZ, DE, DK,  |                                 |                                                                 |
|                 | EP, ES, FI, FR, GB, HU|                                 |                                                                 |
|                 | IE, IL, IN, JP, LT,  |                                 |                                                                 |
|                 | LV, NL, NZ, PL, PT,  |                                 |                                                                 |
|                 | RO, SE, SI, SK, SU   |                                 |                                                                 |
| CN108249037     | Revoked               | Dongguan Hopeway Packaging Tech | Production method for organic packaging material                |
|                 |                       | Co Ltd (2017)                   |                                                                |
| US20180148682   | US, MX                | Mycoworks Inc. (2011)           | Production method for dehydrated mycelium elements using molding systems |
| US20130202855   | Lapsed                | Ford (2010)                     | Production method for dehydrated mycelium elements for outfitting vehicle interiors |

2.7.1 Key Players

Currently the patent landscape for fungi-based materials is still fairly small with only four main players: Ecovative (21 patents), Ford (9), Shenzhen Technical University (8) and Mycoworks Inc. (3).

2.7.2 Future Trends

Inventions and IP in the field of fungal biomaterials will surely grow in the next decade, as the need and desire for renewable and biodegradable materials, that replace petroleum-based products, increases. Fungal biomaterials will shape the future of material sciences, design, fashion and other material applications.
3. Conclusions

As outlined in this report, the immense versatility of filamentous fungi as producers of a plethora of different compounds has been responsible for their past and continued industrial importance in a wide variety of sectors. The key trends that we identified regarding the patenting landscape of fungal biotechnology and applications in the last five years (2015-2020) are the use of filamentous fungi as a food source (mycoprotein) by a wider variety of players, the continued improvement of cultivation techniques mostly due to metabolic engineering, and the use of filamentous fungi biomass as a biodegradable alternatives to petroleum-based materials. Furthermore, the use of fungi in environmental technology is increasing, with China spearheading the inventions in this field, and filamentous fungi are also becoming an increasingly important part in pesticide formulation and agricultural practices. We will certainly see a further increase of IP being generated in the area of filamentous fungi, since the need for green and sustainable technology in all areas of industry is increasing. With only a fraction of fungi characterised and still a lot to learn regarding their metabolism and production of secondary metabolites, the potential of these fascinating organisms has by far not reached its peak yet.

4. Mycorena’s role in the fungal fermentation landscape

Mycorena is a Swedish company that produces food products by using filamentous fungi in a fermentation process. At Mycorena, we are staunch believers in the amazing potential and power of filamentous fungi. Judging by the high global levels of activity within the entire intellectual property space, we are not alone. Every single year for the past decade, and for a long time before that, industrial and academic players have had a steady output of new discoveries and innovations relating to this intriguing and resourceful group of microorganisms. The large and increasing activity in patent filing and other actions relating to intellectual property is an important sign of the continued importance of filamentous fungi in the shift of global markets into large-scale bioeconomies. As an aspirant to become the world’s leading brand for fungi-based product development, Mycorena welcomes these developments with great enthusiasm.

Since our focus lies within the production of fungi-based edible protein for food applications, we are observing with particular interest the developments in this field. Commercial actors are developing not only foodstuffs composed of fungal biomass, but also a range of specialized compounds that have various uses within the field. With our flagship product Promyc®, we are aiming to replace economically and environmentally unsustainable protein sources with superior alternatives. Seeing that a range of other actors with expertise in fungi cultivation and fermentation technology are inhabiting other parts of the food & feed markets makes us excited to build the future of microbial nutrition together.
Mycorena’s ambition for the future is to build an extensive portfolio of patents and other intellectual property rights that can be used to create technology transfer and diffusion through licensing, extensive cross-industry collaborations, and joint venture formation. We are therefore very positive towards seeing such high activity within patenting and other types of intellectual value creation within various fields related to filamentous fungi. Our hope is that regulation and conventions will continue to develop in a direction that supports and incentivizes innovation.

5. Methods

In this study, most patents were searched and analysed by using Orbit Intelligence (v.1.9.8) a software provided by Questel. The patents were searched not by individual record but by invention-based families (FamPat). In addition, they were searched without a restriction on countries or regarding their legal status, hence patents that were lapsed, expired or revoked would also show up in the search.

Initially a set of defined key words in the title or claims served as a basic set of patents for the search. With or without a specifically set time limit focusing either on patents with a publication date from 2015-01-01 to 28-02-2020 or patents dating as far back as possible in the Orbit Intelligence database. Next, within these basic searches, we looked at specific technology domains as provided by the software based on IPC (International Patent Classification) and CPC (Cooperative Patent Classification) codes. In addition, a combination of the provided technical domains at IPC/CPC code was sometimes used to get a better understanding. As an example, to search within the field of food chemistry in relation to animal feed, IPC: A23K+ was used.

The standard script that was used for the searches was:

\[("FILAMENTOUS" "FUNGI" OR "FILAMENTOUS" "FUNGUS" OR "FILAMENTOUS" "FUNGAL" OR "FILAMENTARY" "FUNGUS" OR "FILAMENTARY" "FUNGI" OR "MYCOPROTEIN" "FUNGI" OR "MYCOLOGICAL" "FUNGI" OR "MYCOLOGICAL" "FUNGUS" OR "MYCOLOGICAL" "FUNGAL" OR "ASPERGILLUS NIGER" OR "ASPERGILLUS ORYZAE" OR "RHIZOPUS OLIGOSPORUS" OR "RHIZOPUS ORYZAE" OR "FUSARIUM VENENATUM" OR "MYCOPROTEIN" "FUNGUS" OR "MYCOPROTEIN" "FUNGAL" OR "FUNGI-BASED BIOMASS" OR "FUNGAL BIOMASS")/CLMS/TI\]

The statistical analysis was performed by the Orbit Intelligence software, however additional rules were added (if necessary) to group assignees if they were from the same mother company (e.g. Danisco & Genencor are grouped with DuPont), or from the same company/institute but applied their patents with slightly different assignee names.

This search and analysis techniques were used as the basis for the paper; however, the search does not include all relevant patents in this field. There are quite some patents which do not comply with the search words used but do describe a filamentous fungi application. Hence, the paper discusses some patents
that fall outside the search. It should also be mentioned that the patents in "basic" search were not filtered regarding their relevance nor were they validated, hence the search could still include patents that have the right ‘words’, but do not have anything to do with the usage of filamentous fungi. Furthermore, especially within the technical domain of pharmaceuticals patents show up that include inventions protecting against filamentous fungi instead of using them for the better.
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