National Biofilms Innovation Centre

Biofilms in Agriculture

WORKSHOP REPORT

24 OCTOBER 2022 - LOS COCOS, ARGENTINA

SAMIGE
Sociedad Argentina de Microbiología General

Ministerio de CIENCIA Y TECNOLOGÍA

CÓRDOBA entre todos

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Executive Summary

The National Biofilms Innovation Centre (NBIC), in collaboration with a group of Argentine researchers, organised a workshop on biofilms in agriculture, which took place in Los Cocos, Córdoba, Argentina on 24 October 2022.

Microbial biofilms play a crucial role in the global economy with an estimated value of $5 trillion USD. In the agricultural sector, biofilms are utilised as biofertilizers, biostimulants, soil bioremediators, and biocontrol agents. Despite their potential benefits, there is still much to learn about the complex interactions between biofilms and plants, and how to harness these interactions for enhanced plant growth and disease prevention. A deeper understanding of biofilms in this context is essential for effectively managing and directing microbial communities towards creating a sustainable environment.

The 'Biofilms in Agriculture' workshop brought together researchers and industry representatives from the UK's National Biofilms Innovation Centre (NBIC) and Argentina, to address this knowledge gap and improve agricultural productivity in both countries by reducing the use of chemical treatments and their environmental impact.

The objectives of the meeting were to:

- Bring together complementary academic / industrial expertise from these countries on exploitation of biofilms in agriculture.
- Identify key knowledge gaps and research challenges in this area of agricultural impact.
- Develop a white paper that establishes priority research areas to address these gaps.
- Create future research collaborations on the use of biofilms in crop production between the UK and Argentina.

The meeting was organised within the framework of the SAMIGE (Argentine Society for General Microbiology) annual congress and was funded by a UK Biotechnology and Biological Sciences Research Council (BBSRC) Global Partnering Award.

Background

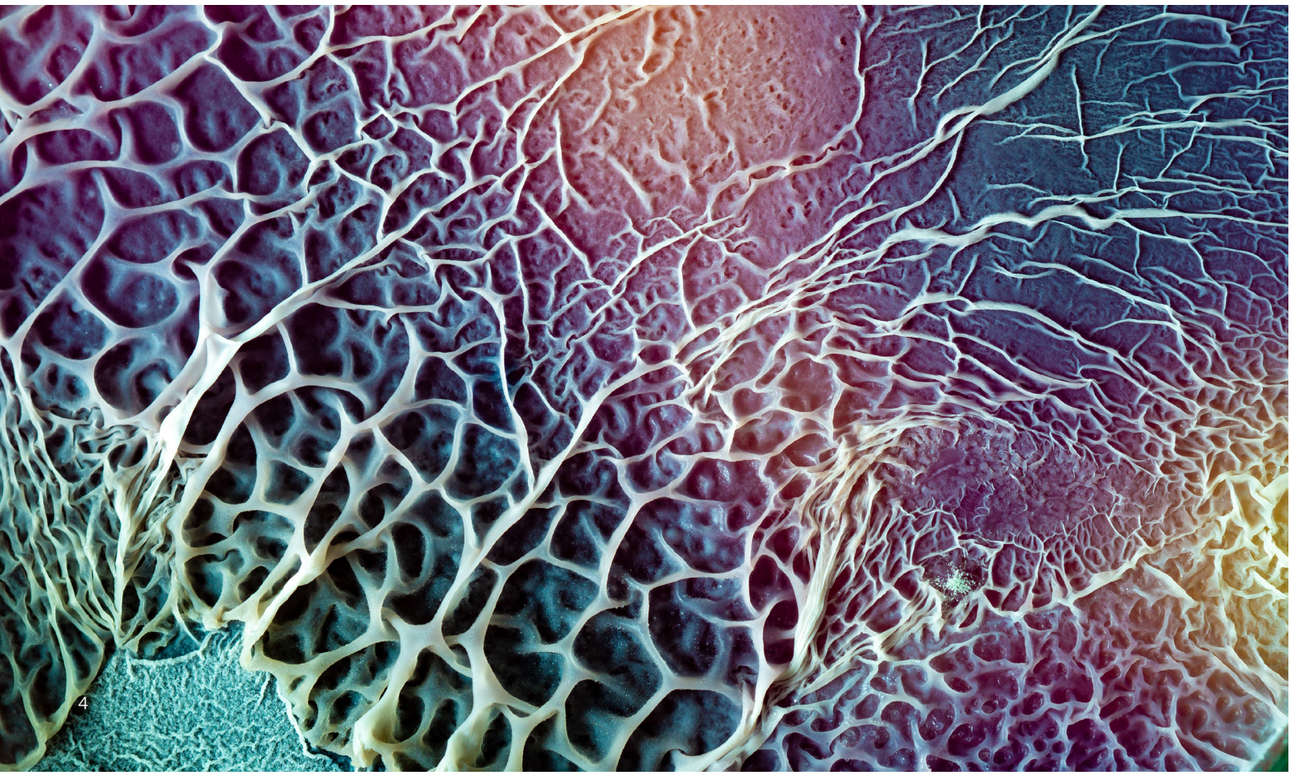
BIOFILMS IN CONTEXT

Microbial biofilms are interactive communities of interface-associated microbial cells, enclosed in an extracellular polymeric matrix made of compounds such as polysaccharides, proteins, extracellular DNA, and lipids. While relatively unknown to the general public, they are ubiquitous in nature and human-built environments.

Biofilms have an estimated $5 trillion USD impact on global economic activity[1]. Importantly, their engineering and management can be highly beneficial e.g., in the removal of pollutants, the potential production of pharmaceuticals and the production of biofuels on an industrial scale. In addition, biofilms on plant roots produced by microorganisms can help to preserve and unlock vital nutrients. Their role in the stabilisation of microbial communities is of ecological importance.

Investigation into the manipulation, control and exploitation of biofilms has gained momentum and seen an increase in research activity and funding in the UK in the last decade.

In agriculture, biofilms have proven useful as biofertilizers, biostimulants, soil bioremediators, and biocontrol agents. Despite these benefits, there remain significant gaps in the understanding of the mechanisms of interaction between natural polymicrobial biofilms and plants, as well as how to harness these interactions to promote plant growth and protect crops from diseases. Therefore, a deeper understanding of biofilms in this context is crucial to gaining control over microbial communities and creating a sustainable environment.



NATIONAL BIOFILMS INNOVATION CENTRE (NBIC)

NBIC was formed in December 2017 as an Innovation Knowledge Centre (IKC) funded by BBSRC, and Innovate UK. NBIC has the mission of harnessing the UK's Industrial and Academic strength in biofilms.

NBIC is the recognised UK hub for accessing biofilm expertise, capability, science, and innovation capacity. Its aim is to catalyse growth in the UK's scientific, technological, and industrial expertise in biofilms with the goal of delivering:

- World class science and scientists
- Breakthrough innovations
- Economic and societal value

NBIC is working to create a network and community of researchers and industrial/commercial partners, across the UK and internationally, who together are working to progress all these elements.

ARGENTINE SOCIETY FOR GENERAL MICROBIOLOGY (SAMIGE)

The Argentine Society of General Microbiology, SAMIGE, was formed to gather the fundamental and applied research expertise in topics related to general microbiology.

The mission of the Society is to promote basic and applied microbiology research and collaborations, in order to advance the understanding of the central role microorganisms play in the functioning of ecosystems and their impact on human activities. The vision is to enhance the contribution of microbiology to support the sustainability of the environment, economy, and society towards an improved quality of life.

Since its formation, the main objectives of SAMIGE have been to promote the exchange of scientific information and support training. Currently, SAMIGE has nearly 200 active members and more than 150 associated members across the country. As an interdisciplinary body, the society is organised in the six following areas:

- Microbiology of interactions
- Molecular microbiology and physiology
- Environmental, agricultural and soil microbiology
- Bioremediation, biodegradation and biodeterioration
- Biotechnology and bioprocesses
- Education and dissemination

Workshop on Biofilms in Agriculture

SETTING AND AIMS

The workshop was held in Los Cocos, Córdoba, Argentina on the 24 October 2022.

Over 30 delegates attended the workshop, including representatives from industry, academic institutions and from government institutions and agencies, from the UK and Argentina, working directly and indirectly on state-of-the-art research and technologies that enable the exploitation of microbial biofilms in crop production, to map the current landscape, the needs, trends and expectations in the role of biofilms in agriculture within both countries.

The intended outputs of the meeting were to:

- Identify the key knowledge gaps and research challenges in this area of agricultural impact.
- Develop a scope of a white paper that establishes priority research areas to address these gaps and challenges.

PRESENTATIONS

The meeting started with a welcome and introduction to the workshop by Claudio Valverde (Universidad Nacional de Quilmes-CONICET) & Andrea Smania (SAMIGE-CIQUIBIC-CONICET), followed by an introduction to NBIC given by Jo Slater-Jefferies. Then, there were a series of presentations divided into two sessions to provide both industrial and academic perspectives on microbial biofilms in agriculture. The following talks were given:

Industrial perspective:

Current issues and developments across Agri-Tech and the fresh produce sector in the UK.
Duncan Ross, Agri-EPI Centre, UK.

Farmers needs and strategy to adopt precision agriculture and engineering technology.
Claire Hodge Agri-EPI Centre, UK.

BIOX: open architecture model of products development.
Ezequiel Marchionni Base, Bioceres Crop Solutions, Argentina.

Agriculture plant by plant.
Federico Cola, Seed Matriz Sas, Argentina.

Transform microbes into global biosolutions.
Cristopher Killmurray, Ceres Demeter, Argentina.

Ethanol and carbon reduction by microbes.
Manuel Ron, Bioetanol Rio Cuarto SA, Argentina.

Academic perspective:

Defining the molecular mechanisms of plant-microbiota interactions relevant to plant nutrition.
Gabriel Castrillo, University of Nottingham, UK.

The role of microbes in sustainable agriculture and the circular economy.
Ana Winters, Aberystwyth University, UK.

Microbial biofilms in agriculture: Overview of research in Argentina.
Patricia Abdian, CONICET, Argentina.

Microbes and agriculture: Current situation and prospects from the industry.
Gustavo Gonzalez Anta, Indrasa Biotecnologia S.A, Argentina.

Lastly, an overview of the funding landscape in the UK and Argentina, which could be considered to support the development of future collaborations between the two countries was given by Paulina Rakowska (NBIC, UK) and Enzo Moriconi (Ministerio de Ciencia y Tecnología, Córdoba, Argentina).

ROUND-TABLE DISCUSSION

The presentations were followed by a round-table discussion, where consideration was given to the impact of plant-associated microbial biofilms in developing innovation in agriculture. The discussion focused on:

1. Identifying needs:
   - Areas of research and industrial strength in agriculture in Argentina and the UK.
   - Areas of unmet need in research and innovation in agriculture in the two countries that would benefit from international collaboration.

2. Priority areas:
   - What type of programme and level of funding would be required to address the identified unmet needs and the timelines to fulfil it.

Presentation session to provide industrial and academic perspectives on microbial biofilms in agriculture.

IDENTIFIED PRIORITIES

Three interlinked priority areas that could benefit from the future research collaborations between the UK and Argentina emerged from the discussions:

1. Plant root biofilm composition as a sensor to optimise intervention.

Root microbiomes play a key role in plant health. They provide essential functions to enhance plant nutrition and confer protection against biotic and abiotic stressors[2,3]. The interactions of a soil microbiome with plant roots are complex and enable the formation of biofilms on roots, which assist with nutrient acquisition, growth proliferation, removal of contaminants, protection against plant pathogens but also promoting the establishment of other beneficial microorganisms in the soil.

Comparison between environments in the UK and Argentina will enable the establishment of core differences and similarities between the two countries on healthy vs unhealthy root microbiota in a wider range of environmental conditions with a focus on wheat and potatoes as two main crops in both countries, with similar climatic conditions for cropping. The two crops were chosen as they represent two different plant groups, one being a monocot (wheat) and the other dicot (potato) and having different characteristics and growth habits that influence how they are cultivated, propagated, and used. They present two different scenarios of farming: extensive and intensive, respectively.

By understanding the correlations between root biofilm composition and the resistance/sensitivity of the root to biotic and abiotic stresses, it is proposed to use plant root biofilms, as part of the wider microbiome, as a natural sensor to optimise interventions which promote plant health and crop production. To achieve this, the following collaborative activities are proposed:

- Establishing the microbial composition of biofilms in roots from wheat and potatoes grown in rich and poor soils from different environments in the UK and Argentina, utilising advanced multi-omics technologies.
- Establish correlations between plant sensitivity and resistance to biotic and abiotic stresses (pathogens, drought, salinity, extreme temperatures) and the composition of microorganisms in the root biofilms using multi-omics approaches. This will also include changes in root structure and healthy growth parameters.
- Develop databases to store the above data and use artificial intelligence to analyse these data, establishing correlations and allowing predictions to be made on plant health and crop yield based on the composition of plant-associated microbiomes.
- Design strategies, based on the predictions above, to manipulate soil and root biofilms/ microbiomes to restore healthy soil biodiversity and aid crop production under adverse conditions. This could be achieved using bespoke seed inoculants with the appropriate healthy microbial composition.

2. Targeting climate change and soil health.

Soil is a natural resource for global food production but also provides an essential environment for ecosystems, biodiversity, carbon sequestration and water availability[4]. Climate change can have a major impact on soil and changes in the use of land and soil can drastically influence climate change[4]. The increasing human population and demand for food and land use have posed pressure on soils in recent decades. It has been estimated that a third of global soils are now degraded[5]. We have to understand the principles determining interaction between soil and climate to design faster, original, and environmentally friendly strategies such as utilising biofilm-forming microbiota, to preserve natural resources and develop more resilient crops and agricultural practices[2].Maintaining healthy soils is paramount for sustainable crop production under increasing stress conditions imposed by climate change.

Targeting soil health and climate change has been identified as one of the priority areas, where the UK-Argentina collaboration could bring complementary knowledge, expertise, and know-how from and to both countries. As an example, global warming signs can be seen in the UK in the recent years with extreme weather leading to droughts and flooding becoming a problem in crop production. While the climate in Argentina differs from that of the UK, predictions by the Intergovernmental Panel on Climate Change (IPCC) suggest it is likely to get aggravated with the addition of increased localised torrential falls in some areas[6]. Therefore, knowledge on how to manage soil health and crop production in drought and flood conditions could be transferred between the UK and Argentina. this area interlinks strongly with the actions proposed in the ‘Priority Area 1’. The proposed collaborative activities discussed include:

- Focus on two different crop types, which are common to both regions: wheat (grain) and potatoes (root).
- Sampling and sequencing the microbiota from biofilms commonly associated with potatoes and wheat roots in both countries under different environmental conditions (temperatures, rain fall, and compaction). Build collections of fully sequenced microbial isolates that contain the main taxonomic categories found.
- Identification of environment-specific beneficial microbiota across the two countries, which can be exploited in agricultural practices to confer crop protection against drought, flood, and soil compaction. These combinations of microbes should be designed to contain also beneficial traits associated to an increased carbon sequestration in roots, producing stable organic matter, and to protect against plant pathogens. These approaches should lead to a sustained crop production under changing environmental conditions.

Round-table discussion on the priority areas for collaboration.

3. Intelligent seeds.

For many important crops, the cultivation cycle begins with a direct sowing of seeds. The use of seed coating technologies enables uniform distribution of inoculants, including plant beneficial microbes[2,7], to the surface of the seeds. This maximises stable crop production while reducing the use of pesticides.

There is an unmet need for the development of technologies which enable large scale field monitoring of the impact of different inoculants on crop health to allow agile optimisation of inoculants which maximise crop production.

Argentina has been developing state-of-the-art multipurpose seed coatings that can incorporate both chemicals and digital technologies (seed-chips) providing real-time data on the impact of these chemicals on plant health parameters. These coatings have the potential to incorporate microbes which can form beneficial biofilms on plant roots, upon germination. This would enable real-time monitoring of the impact of different inoculants on plant health.

Currently, these technologies are only used in small field trials and would require suitable monitoring systems for large scale trials.

The UK has been developing advanced soil and growth monitoring technologies such as drone-based field monitoring and ground penetrating radars (GPR) which are increasingly applied by farmers for scouting and logistics in large fields. In addition, it has also been developing the next generation of sensor capabilities to monitor soil environmental parameters.

Based on the above complementary capabilities between Argentina and the UK, the following collaborative activities were proposed to develop intelligent seeds and innovative monitoring systems which enable agile optimisation of inoculants based on their impact on plant health and soil parameters:

- Incorporate beneficial biofilm-forming microbes in seed coatings containing the chip technology developed in Argentina, using already tested and well-performing microbial inoculants to provide a solid starting point.
- Develop drone-based monitoring systems in the UK for real-time reading of chips used in seeds.
- Develop pilot experiments in green houses to monitor effectiveness of drones on recording plant/soil health parameters induced by coated seeds related to plant infection control, and to assess performance of the system.
- Perform large field trials using optimised ground penetrating radars on fields seeded with intelligent coated seeds with different inoculants, containing biofilm-forming microorganisms, to compare their performance via monitoring plant/soil health parameters.
- From the collected data, build standardised databases to inform on and optimise seed biofilm-forming inoculant performance.

Conclusions and Next Steps

The participants of the workshop shared a plethora of different experiences, ideas and many unique views on the subject. There is an understanding that international collaboration is essential in providing global agricultural innovation and developing more sustainable food systems. Clearly, there is the opportunity and desire from both countries to cooperate and make progress. Three priority areas, as described above, that could benefit from the future research collaborations between the UK and Argentina emerged from the discussions.

For all the three identified priority areas, the early engagement of end users (farmers) will be paramount to maximise technology adoption. Business models of long-term cooperation will have to be established to maximise impact.

The commitment from the governments and support from funding bodies in both countries will be essential for the establishment of robust research programmes and long-term successful collaborations between researchers, industry and end-users across both countries.

NBIC's goal is to support the biofilm community in dialogue and in bringing together complementary expertise to support progress in the areas where biofilms have an important role.

NBIC will support initiatives to establish a joint international programme in the exploitation of biofilms in agriculture, with the aim of addressing knowledge gaps, improving agricultural productivity through the uptake of new technologies in both countries, and tackling the global issue of climate change by promoting soil health, reducing the use of chemical treatments and their environmental impact.

As an immediate output from the workshop, NBIC is leading on the publication of a white paper describing the identified priority areas and the benefits that the international collaboration will bring to accelerate progress in the field. In parallel, NBIC is raising awareness of the UK-Argentina initiative amongst decision makers, funders and learned societies, and within existing agritech networks through engaging with the UK Agri-Tech Innovation Centres.

REFERENCES

1. Cámara, M. *et al.* Economic significance of biofilms: a multidisciplinary and cross-sectoral challenge. *npj Biofilms Microbiomes* 8, 42. 2022.
2. Custódio, V. *et al.* Sculpting the soil microbiota. *Plant J* 109, 508-522. 2022.
3. Finkel, O. M., Castrillo, G., Herrera Paredes, S., Salas González, I. & Dangl, J. L. Understanding and exploiting plant beneficial microbes. *Curr Opin Plant Biol* 38, 155-163. 2017.
4. Eckardt, N. A. *et al.* Climate change challenges, plant science solutions. *Plant Cell* 35, 24-66. 2022.
5. *Global Land Outlook*. Second Edition. United Nations Convention to Combat Desertification. 2022.
6. *IPCC*. Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. (Cambridge, UK and New York, NY, USA). 2022.
7. Simonin, M. *et al.* Seed microbiota revealed by a large-scale meta-analysis including 50 plant species. *New Phytol* 234, 1448-1463. 2022.

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