Mapping Key Facilities for Seaweed R&D (Deliverable 5.1)

Published on 26/01/2024. Written by **Prof. Sheng Qi**, Professor of Pharmaceutical Material Science and Technology, Associate Dean for Science (Innovation), University of East Anglia.

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As discussed in previous sections, seaweeds have a wide range of industrial applications. In many recent reviews, these applications are grouped into 1. human food; 2. animal feed; 3. nutraceuticals; 4. beauty and skincare; 5. fertiliser/biostimulant; 6. the extraction of industrial biopolymers; 7. biofuel; 8. carbon capture.

Seaweed in some applications, such as human food, are used as whole plant. In most applications, seaweed extracts (SE) obtained from a wide range of extraction methods are used. These SEs can be minerals, vitamins, carbohydrate, protein, lipid, proline, chlorophyll and biopolymers, such as agar, carrageenan, alginate, and polyhydroxyalkanoates.

In order to facilitate the development of new products and applications of seaweed in our region, fit-for-purpose R&D facilities are required. This section of the report evaluates the research and development tools needed for these different applications. Based on the applications, we mapped out the R&D facility needs for analysis whole seaweed plant and SEs. Locators of these facilities either being on the NRP or outsourced by service provided externally are summarised below.

If seaweed is used as an ingredient in any of the above applications, detailed whole seaweed biomass analysis should be conducted to have a full understanding of the quality and composition of the biomass. These analysis should be ideally conducted when quality of the seaweed is suspected to vary due to factors such as extreme sea water temperature and climate change.

- Carbohydrates: Fucose, Mannitol, Glucose, Xylose, Mannose, Arabinose, Galactose, Rhamnose, Total Sugars, Glucuronic Acid, Galacturonic Acid, Mannuronic Acid, Guluronic Acid,

- Amino Acids: Alanine, Arginine, Aspartic Acid, Cystine, Glutamic Acid, Glycine, Histidine, Isoleucine, Leucine, Lysine, Methionine, Phenylalanine, Proline, Serine, Threonine, Tyrosine, Valine,
- Elemental Analysis: Carbon, Hydrogen, Nitrogen, Sulphur, Oxygen, Ash,
- Metal analysis: Aluminium, Calcium, Iron, Magnesium, Phosphorus, Potassium, Silicon, Sodium, Titanium,
- Lipids as Fatty Acids: Arachidic Acid, Behenic Acid, Decanoic Acid, Erucic Acid, Lauric Acid, Linoleic Acid, Linolenic Acid, Myristic Acid, Caprylic Acid, Oleic Acid, Palmitic Acid, Palmitoleic Acid, Stearic Acid, Lignoceric Acid,
- Pigments: Fucoxanthin, Astaxanthin, Chlorophyll-c, Chlorophyll-a, Chlorophyll-b, Lutein, beta-Carotene, Neoxanthin, Antheraxanthin, Violaxanthin,
- Phytohormones: Gibberellic Acid, Indole-3-acetic acid, Indole-2-acetic acid, Indole-3-propionic acid, Indole-3-butyric acid, 6-Benzylaminopurine, Kinetin riboside, Abscisic acid, Salicylic acid,
- Vitamins (Fat-Soluble): beta-Carotene, Ergocalciferol (Vitamin D2), Alpha-tocopherol (vitamin E), Phylloquinone (Vitamin K1),
- Vitamins (Water-Soluble): Thiamine (Vitamin B1), Riboflavin (Vitamin B2), Niacin (Vitamin B3), Niacinamide (vitamin B3), Pantothenic Acid (Vitamin B5), Pyridoxine (Vitamin B6), Folate (Vitamin B9), Cobalamin (Vitamin B12), Ascorbic Acid (Vitamin C),
- Total Phenolics content and Phenolics Profiling: Gallic acid, Vanillic acid, Protocatechuic acid, Caffeic acid, Chlorogenic Acid, Ferulic acid, Coumaric acid, Catechin, Quercetin, Phloroglucinol,
- Total Tannins
- Alginate Molecular Weight Analysis
- Total Phlorotannins Estimation
- Fibre Analyses
- Toxicity Screening: Aflatoxins, Aflatoxin B1, Aflatoxin B2, Aflatoxin G1, Aflatoxin G2,

As human food, feedstock and nutraceutical applications, the seaweed biomass can often be used as whole plant. The key nutrient and mineral compositions that are widely cited and reported are protein, ash, dietary fiber, carbohydrate, lipid, Na, K, P,

Ca, Mg. When being used as food and animal feed, seaweed can be used as an alternative source of protein. For these applications, the analysis of the protein quality and concentration of essential amino acids (EAAs) is essential to determine the nutritional value of the algae biomass. The physical properties including swelling capacity, water holding capacity, oil holding capacity are very important for food, feed and nutraceutical product development.

For beauty and skin care, in recent years, SEs with potential antioxidant activity, MMPs, and tyrosinase inhibitory activity in order to reduce ROS caused by UV radiation and also to delay skin aging, such as polyphenols, fucoidan, phlorotannins, carotenoids have been widely studied [1].

Seaweed extracts constitutes more than 33% of the total biostimulant market worldwide and reached a value of €894 million in 2022 [2]. For being developed into biostimulant, the flowchart below demonstrated the developmental pathway and the type of analysis involved. Depending on the extraction methodology, the biostimulant products are complex mixtures of biologically active compounds. Consequently, plant responses are often inconsistent. In order to precisely understand the mechanisms of action of the biostimulants and quality control of the product, a range of elemental and composition analysis are essential for the product development of biostimulants.

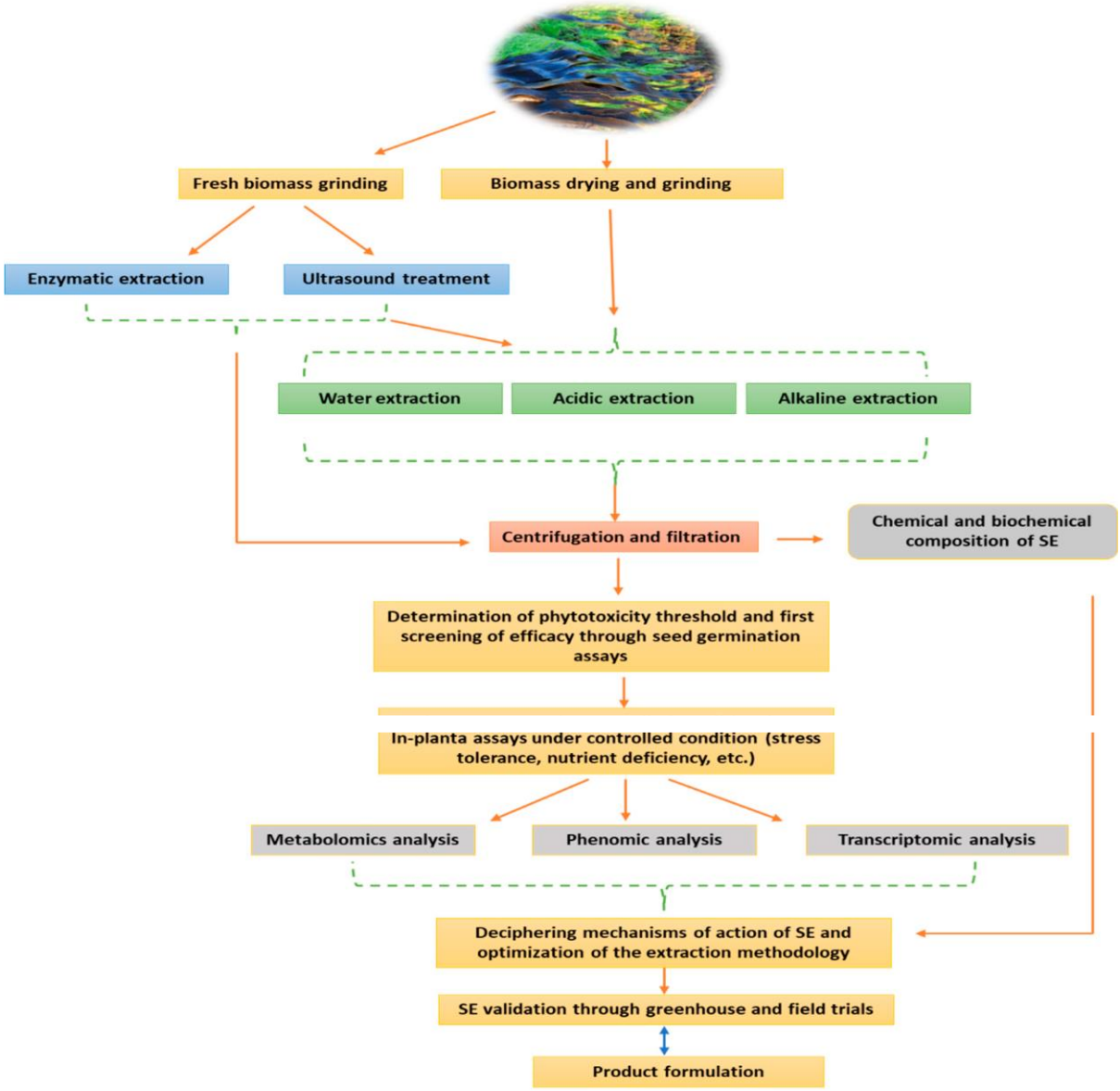


Figure 1. Proposed flowchart of seaweed extraction process from collected algal biomasses until being used as biostimulant product validation [3].

The most well-known and widely used industrial biopolymers produced from seaweed are polysaccharides, such as agar, carrageenan and alginate, and more recently polyhydroxyalkanoates (PHAs) obtained using saltwater microbe to ferment seaweed. These polymers are produced at an industrial scale and the quality of the polymers is highly controlled. Key quality attributes such as molecular weights, impurities, heavy mental content, ash content are very important as most of these polymers are used in food, medical and pharmaceutical products. Figure 2 shows an example of analytical methods that could be used for characterisation compounds extracted from seaweed.

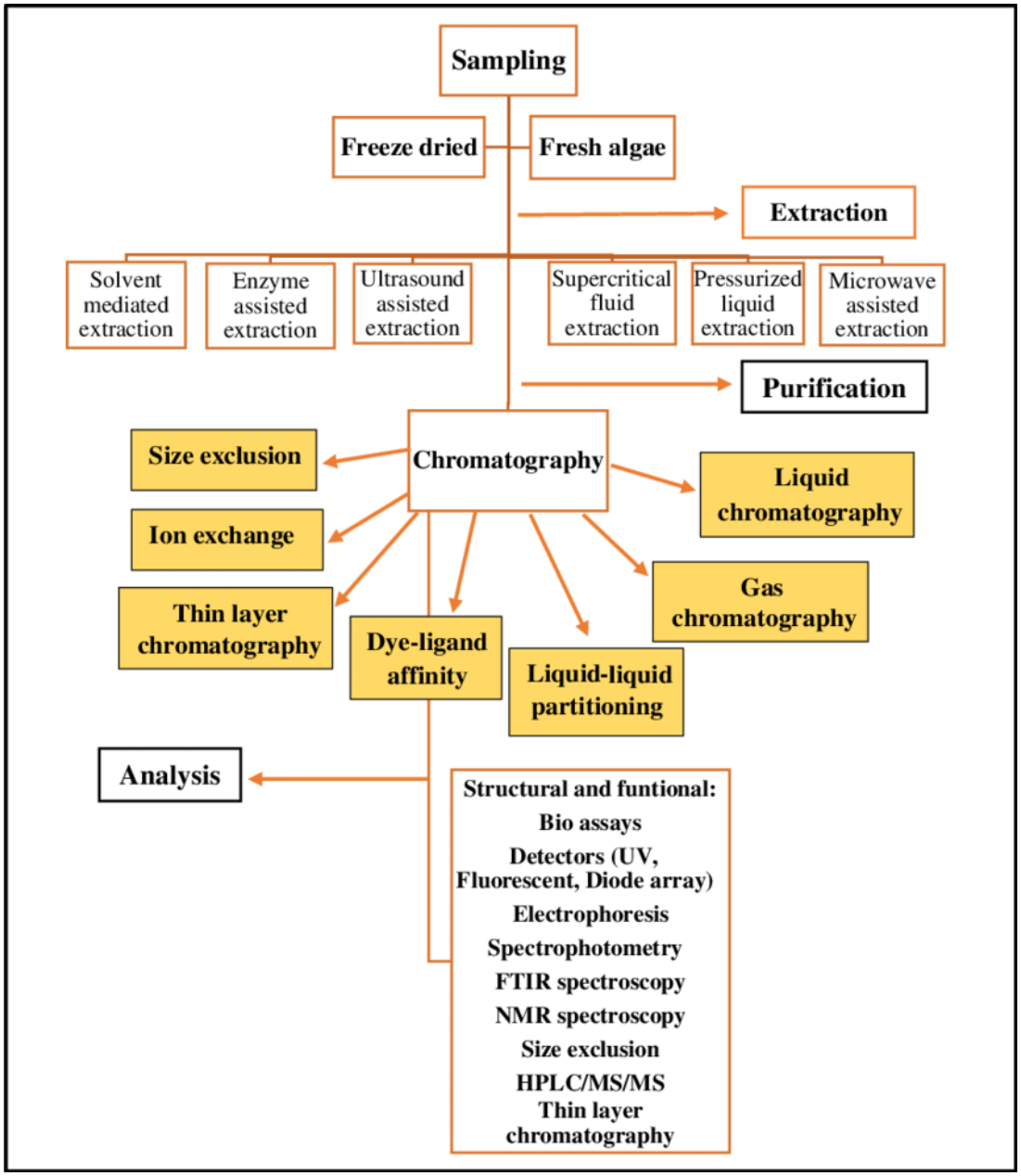


Figure 2. Analytical methods for seaweed components obtained from extraction [4].

For the biofuel application, seaweed is highly suitable candidate. As fresh seaweed contains 85 and 90% of water, it makes seaweed very suitable for biofuel-making methods like anaerobic digestion to make biogas and fermentation to make ethanol. Many seaweed species, like sugar kelp, have high carbohydrate and low lignin content that is perfect for making bioethanol. For carbon capture, because seaweed grows very fast, it can absorb up to 66 tonnes CO_2 per hectare. The higher carbon capture capability and their fast growth rates means CO_2 emissions from producing biofuels using seaweed are quickly reabsorbed by new growth. For this emerging

application, the similar whole seaweed analysis and biofuel purity analysis would be needed.

Table 1 summarised the key types of R&D facility and expertise needed for developing different applications and products from seaweed.

Table 1. Summary of the R&D tools and expertise needed for developing specific seaweed-based products and applications.

Applications	**R&D tools and expertise**
Human food	Seaweed biomass analysis, physical characterisation, formulations development, food processing, nutritional value analysis, FSA regulation
Animal feed	Seaweed biomass analysis, physical characterisation, formulations development, food processing, nutritional value analysis, regulatory approval, GMP production
Nutraceuticals	Seaweed biomass analysis, physical characterisation, formulations development, food processing, nutritional value analysis, MHRA regulatory approval, GMP production
Beauty and skincare	Seaweed biomass analysis, physical characterisation, formulations development, *in vitro* dermatology testing, toxicity testing, packaging, GMP production
Fertiliser/biostimulant	Seaweed biomass analysis, analysis of biomass process liquids, soil composition and microbe analysis, field trials
Industrial biopolymers and their application in packaging	Seaweed biomass analysis, for packaging application, processing engineering, polymer science, formulations development, and physical specification testing (such as moisture and gas permeability)
Biofuel	Seaweed biomass analysis
Carbon capture	Simplified seaweed biomass analysis, LCA

Table 2. Mapping of local partners who may have the R&D expertise and facilities needed and alternative external service provider.

	Matched expertise locator on NRP and within Norfolk	**Potential external service provider**
Seaweed biomass analysis	UEA Science Analytical Facility (SAF) Platforms, QIB	Celignis, https://www.celignis.com/index.php
Physical characterisation	UEA School of Pharmacy, QIB	
Formulations development	UEA School of Pharmacy, QIB	
Food processing	QIB and UEA School of Pharmacy, Pasta food Ltd, Snack Creations Ltd.	
Nutritional value analysis	QIB Extra, Nutritional Information Systems- QIB Food analysis solutions and food labelling advice https://www.qibextra.co.uk/ Food Forensics Ltd, https://www.foodforensics.co.uk/ in Norwich	https://www.eurofins.co.uk/food-testing/ https://brewlab.co.uk/laboratoryservices/nutritional-analysis/ https://www.paslabs.co.uk/nutrition-food-chemistry/ https://www.rpsgroup.com/services/laboratories/food-safety-analysis/ https://www.intertek.com/food/locations/uk-testing-services/ https://www.campdenbri.co.uk/services/nutritional-analysis.php https://foodtestlab.co.uk/chemical-testing-nutritional-analysis/ https://www.als-testing.co.uk/services/foodanddrinktesting/chemicalandnutritional https://www.sgs.com/en-gb/services/nutritional-analysis
FSA regulation	QIB	FSA direct email communication
MHRA regulation and approval	-	MHRA innovation team via email communication (potential project specific meeting is possible)

GMP production	Typharm, https://www.typharm.com/	MHRA GMP team via email communication
***in vitro* dermatology testing**	UEA School of Pharmacy, NRP Skin platform	https://www.eurofins.co.uk/consumer-product-testing/cosmetics-personal-care/ https://adslaboratories.com/ https://sheffielddermatologyresearch.com/skin-barrier
Skin toxicity testing	NRP Skin platform	https://gentronix.co.uk/
Packaging (food)	UEA Productivity East, RedPack Ltd	
Analysis of biomass process liquids	Fragments of analysis could be performed by UEA Science Analytical Facility (SAF) Platforms	Celignis, https://www.celignis.com/index.php
Soil composition and microbe analysis	UEA School of Environmental Science, JIC, EI	
Field trials	JIC	
Processing engineering	UEA Productivity East, School of Pharmacy	
Polymer science	UEA Schools of Chemistry and Pharmacy	
Life cycle analysis (LCA)	UEA School of Environmental Science (not accredited)	SAC Consulting, https://www.sruc.ac.uk/business-services/sac-consulting/

In summary, within NRP and the wide groups of businesses within Norfolk, there is a weather of expertise and facilities to assist the product and new application development of seaweed. We would highly recommend the use of local expertise and partner to collaborate at the early stage of the product development. When it reaches the validation and scale-up stage, external CRO and service providers with specific certifications would be recommended to be used to provide independent validation of the product properties and performance.

Reference:

1. Jesumani V, Du H, Aslam M, Pei P, Huang N. Potential Use of Seaweed Bioactive Compounds in Skincare-A Review. Mar Drugs. 2019 Dec 6;17(12):688. doi: 10.3390/md17120688. PMID: 31817709; PMCID: PMC6950024.
2. Eef, B.; Marlies, D.; van Swam, K.; Veen, A.; Burger, L. Identification of the Seaweed Biostimulant Market (Phase 1); The North Sea Farm Foundation: AD Den Haag, The Netherlands, 2018.
3. El Boukhari MEM, Barakate M, Bouhia Y, Lyamlouli K. Trends in Seaweed Extract Based Biostimulants: Manufacturing Process and Beneficial Effect on

Soil-Plant Systems. Plants (Basel). 2020 Mar 12;9(3):359. doi: 10.3390/plants9030359. PMID: 32178418; PMCID: PMC7154814.

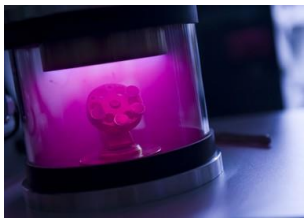
4. Amna Batool, Farid Menaa, Concentration and purification of seaweed components by chromatography methods. Sustainable Seaweed Technologies, 2020, p. 315-370

Appendix of relevant R&D Facility on the Norwich Research Park

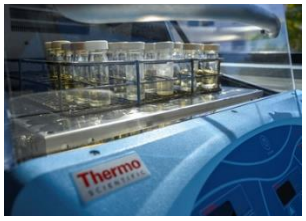
UEA Science Analytical Facility (SAF) Platforms
Platform Manager: A.Hinchliffe@uea.ac.uk

UEA Structural Imaging Platform
Specialist microscopes and high-resolution imaging services
https://www.uea.ac.uk/about/faculties-and-schools/faculty-of-science/facilities/structural-imaging-platform

UEA NMR Platform
The facility provides unique opportunities to study molecules, their assemblies, colloids, soft solids and functional materials over different time scales and physical states
https://www.uea.ac.uk/about/faculties-and-schools/faculty-of-science/facilities/nuclear-magnetic-resonance-platform

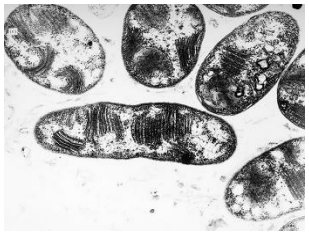


UEA Element Analysis
Specialist instrumentation providing quantitative and qualitative element analysis on a wide range of solid and liquid samples
https://www.uea.ac.uk/about/faculties-and-schools/faculty-of-science/facilities/elemental-analysis-platform



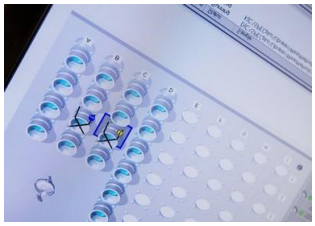
UEA Stable Isotope Platform
Analytical services in bulk solid samples

https://www.uea.ac.uk/about/faculties-and-schools/faculty-of-science/facilities/bio-imaging-platform



UEA Bioimaging Platform
State-of-the art microscopes and image analysis systems.
https://www.norwichresearchpark.com/sciencefacility/uea-bioimaging-platform

UEA Mass Spectrometry
Mass Spectrometry instruments offering analysis of a range of different samples.
https://www.uea.ac.uk/about/faculties-and-schools/faculty-of-science/facilities/mass-spectrometry-platform



UEA X-ray Platform
X-ray crystallography analysis using single crystal and powder diffractometers.
https://www.uea.ac.uk/about/faculties-and-schools/faculty-of-science/facilities/x-ray-platform

Norwich Medical School
Home to a host of cutting-edge facilities, services and equipment, designed with education, collaboration and innovation in mind.
https://www.uea.ac.uk/about/norwich-medical-school

Relationship Manager: K.lang@uea.ac.uk

Nutritional Information Systems- QIB
Food analysis solutions and food labelling advice
https://www.qibextra.co.uk/

QIB Extra Contract Research and Analytics
Bespoke research and market-leading services for the food, health and allied industries.
https://www.qibextra.co.uk/

Managing Director: Dr Reg Wilson: reg.wilson@quadram.ac.uk
Head of Operations Dr Alan Brailsford: alan.brailsford@qibextra.co.uk

Food Databanks National Capability - QIB
Providing data and knowledge on food composition and intake for the UK
https://fnnbri.quadram.ac.uk/

FNNBRI@Quadram.ac.uk
Head: paul.finglas@quadram.ac.uk

Gastroenterology and Endoscopy Unit
The Gastroenterology Unit at Norwich is a dedicated provider of diagnostic and therapeutic endoscopy services, delivered by a team of experts
https://teamnnuh.co.uk/divisions/medicine/gastroenterology-endoscopy/

Professor Alastair Watson MD, FRCP, LRSM
Service Director of Gastroenterology
Consultant Gastroenterologist
Professor of Translational Medicine
Alastair.Watson@uea.ac.uk

Biorepository
The Norwich Research Park Biorepository offers state-of-the-art freezer and retrieval systems to provide material for researchers locally, nationally and internationally
https://biorepository.org.uk/

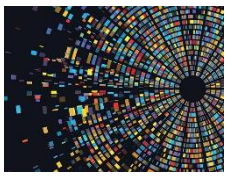
Email: biorepository@nnuh.nhs.uk

Clinical Research Facility
A state-of-the-art home to a host of research initiatives to aid the development of new treatments and improve patient care.
https://quadram.ac.uk/our-science/clinical-research-facility/

business.development@quadram.ac.uk

Single Cell Genomics - EI
Expertise providing single-cell genomics, from isolation to analysis.
https://www.earlham.ac.uk/single-cell-and-spatial-analysis

Lead: Iain Macaulay, Technical Development Group Leader. Iain.Macaulay@earlham.ac.uk
Andrew Goldson, Platform Manager. andrew.goldson@earlham.ac.uk



Next Generation Sequencing - EI
Bespoke genomics services from genome experts.
https://www.earlham.ac.uk/advanced-sequencing

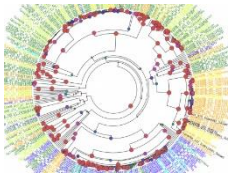
Karim Gharbi, Head of Genomics Pipelines. karim.gharbi@earlham.ac.uk

Biofoundry - EI
A resource for the UK biology and biotechnology communities, providing a platform to undertake large-scale projects
https://www.earlham.ac.uk/earlham-biofoundry

Platform Lead: Carolina Grandellis, Earlham Biofoundry Manager.
Carolina.Grandellis@earlham.ac.uk

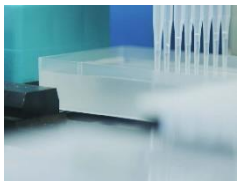
High Performance Computing - EI
Leading computational infrastructure, software, data resources, protocols and networks.
https://www.earlham.ac.uk/high-performance-computing

Lead: Dr Rob Davey, Head of e-Infrastructure



Informatics - JIC
Deep and wide-ranging expertise across the many areas in which biology and computing intersect.
https://www.jic.ac.uk/research-impact/technology-research-platforms/informatics/

Platform Manager Dr Burkhard Steuernagel. Burkhard.Steuernagel@jic.ac.uk



Genotyping and DNA Extractions - JIC
The John Innes Centre offers four Genotyping and DNA extraction services
https://www.jic.ac.uk/research-impact/technology-research-platforms/genotyping-and-dna-extractions/

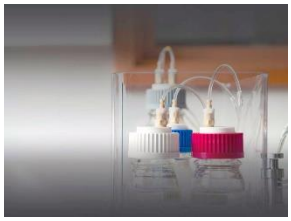
Research Assistant Richard Goram Richard.Goram@jic.ac.uk

Field Trials - JIC
There are a range of facilities on-site and at a nearby farm, that allow field experiments in an agricultural situation
https://www.jic.ac.uk/research-impact/technology-research-platforms/field-trials/

Support Specialist: Darryl.Playford@jic.ac.uk

Chemistry - JIC
Providing expertise and staff training in various aspects of organic chemistry to scientists across the Norwich Research Park and commercial partners.
https://www.jic.ac.uk/research-impact/technology-research-platforms/chemistry/

Platform Manager: Martin.Rejzek@jic.ac.uk



Biophysical Analysis - JIC
Observation and measurements analysing the strength of interactions between biomolecules.
https://www.jic.ac.uk/research-impact/technology-research-platforms/biophysical-analysis/

Platform Manager: abbas.maqbool@jic.ac.uk

Germplasm Resource Unit - JIC
World-leading resource of genetic diversity in crops.
https://www.jic.ac.uk/research-impact/germplasm-resource-unit/

Group Leader: Simon.Griffiths@jic.ac.uk

Metabolomics - JIC
Supporting studies of plant and microbial metabolism and carrying out metabolomic studies and small molecule analysis
https://www.jic.ac.uk/research-impact/technology-research-platforms/metabolomics/

Platform Manager: Lionel Hill. Lionel.Hill@jic.ac.uk

National Collection of Yeast Cultures
One of the largest yeast collections in the world and provides strain data and expert knowledge.
https://www.ncyc.co.uk/

Head of Unit & Business Development. carmen.nueno-palop@qibextra.co.uk

Crop Transformation - JIC
Providing the wider research community with access to a range of crop transformation and genome editing resources.
https://www.jic.ac.uk/research-impact/technology-research-platforms/entomology-and-insectary/

Lead Scientist. Penny Hundleby. Dr. Penny.Hundleby@jic.ac.uk

Entomology and Insectary - JIC
Offers numerous services, including a low containment laboratory and glasshouse areas, training and supervision.
https://www.norwichresearchpark.com/sciencefacility/entomology

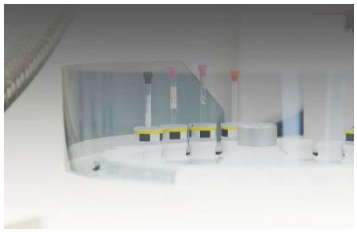
Platform Manager: Victor.Soria-Carrasco@jic.ac.uk

Horticultural Services - JIC
Glasshouses and controlled environment rooms are available, ranging in growing area from 2 to 8 square metres
https://www.jic.ac.uk/research-impact/technology-research-platforms/horticultural-services/

Support Specialist: John Lord. John.Lord@jic.ac.uk

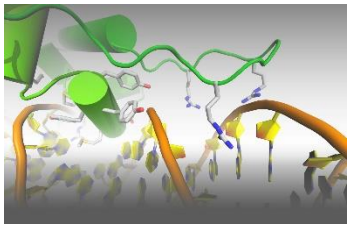
Bioimaging - JIC
State-of-the-art imaging equipment and technologies with full technical support and training.
https://www.jic.ac.uk/research-impact/technology-research-platforms/bioimaging-microscopy/

Platform Manager: Kim Findlay Kim.Findlay@jic.ac.uk



Nuclear Magnetic Resonance - JIC
High-resolution NMR spectrometers for structural elucidation and analysis.
https://www.jic.ac.uk/research-impact/technology-research-platforms/nuclear-magnetic-resonance/

Research Assistant: Sergey.Nepogodiev@jic.ac.uk



Structural Biology - JIC
A wide variety of crystallisation screens and consumables, an in-house x-ray facility for testing and access to Diamond synchrotron
https://www.jic.ac.uk/research-impact/technology-research-platforms/structural-biology/

Senior Scientist: Professor David Lawson. David.Lawson@jic.ac.uk

Proteomics - JIC
The John Innes Centre Proteomics Facility provides proteomic services using mass spectrometry.

https://www.jic.ac.uk/research-impact/technology-research-platforms/proteomics/

Senior Scientist: Dr Gerhard Saalbach. Gerhard.Saalbach@jic.ac.uk

Molecular Genetics
High throughput capabilities where work carried is carried out in 96 well plate format. The team can help with large scale PCR and sanger sequencing, as well as screening of gene edited lines
https://www.jic.ac.uk/research-impact/technology-research-platforms/molecular-genetics/

Platform Manager Saleha Bakht - Saleha.Bakht@jic.ac.uk