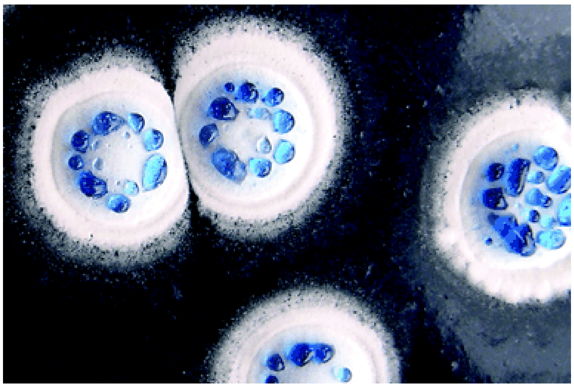
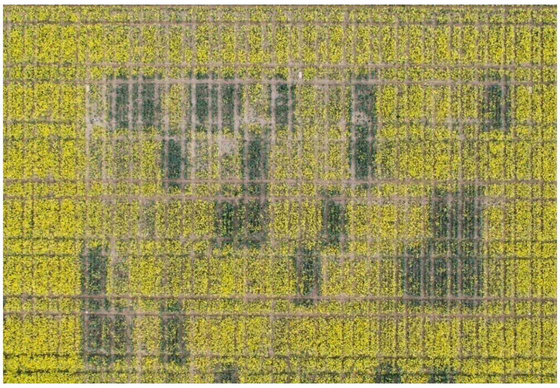
Impact of the John Innes Centre 2022





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Contents

Cover Images: Clockwise from top left – At work in the brassica glasshouse, wrinkled beas, wheat transformation, in the lab, oilseed rape trials at church farm, *streptomyces. Credit: Phil Robinson, John Innes Centre*

Executive Summary

Brookdale Consulting was commissioned by the John Innes Centre (JIC) to produce an updated socio-economic impact assessment of the Institute, the last one being in 2018.

JIC is one of eight institutes strategically aligned to BBSRC. These institutes focus on long-term world class strategic bioscience research with the aims of contributing to UK and global socio-economic growth, sustainable food supply and improved health outcomes; as well as positioning the UK as a leader in science, knowledge and innovation.

JIC continues to invest in fundamental research to support new discoveries, with a particular focus on agri-tech for food security, health and wellbeing as well as innovation in natural and new-to-nature chemicals. The focus of this report is on the early commercialisation of JIC's emerging impacts through a series of case studies. JIC is in the top 10 of Nature journal's institutions ranked by patent influence (https://www.nature.com/nature-index/supplements/nature-index-2022-innovation/tables/overall). All the case studies considered are within JIC's patent portfolio.

On-going Impacts

JIC's operating impact (from staff and supplier spending) supports 881 jobs and generates £42.5m of Gross Value Added (GVA) across the UK economy per year.

JIC's extensive training activities including visiting workers, PhDs, MSc and post-doctoral training which are estimated to contribute £89m to the UK over the next 10 years and a further £49m internationally.

Research Impacts[1]

A sample of JIC's research has been assessed for impacts. This report identifies research impacts of £1.578bn at the UK level over 10 years and a return on investment (RoI) of £15.29 per £1 invested. This is based on the sample of commercialisation projects reviewed and the research costs they represent (just under a third of JIC operating costs). An assessment of attribution to JIC is included along with conservative assumptions to assess potential impacts. This compares to the previous report (2018) which had a RoI of £14.22 per £1 invested.

[1] See Appendix 1 for assumptions.

Total impacts	NPV - 10 yrs	NPV - 15 yrs	NPV - 25 yrs
UK (excludes operating spend)	1,578,911,892	3,159,605,521	5,951,968,683
Rest of the world	11,177,193,783	24,255,375,166	48,034,075,834
Total	12,756,105,675	27,414,980,687	53,986,044,517

Operational cost attributable	NPV - 10 yrs	NPV - 15 yrs	NPV - 25 yrs
Direct costs	103,292,238	143,046,243	204,700,411

RoI (GVA leverage)	NPV - 10 yrs	NPV - 15 yrs	NPV - 25 yrs
UK	15.29	22.09	29.08
Rest of the world	108.21	169.56	234.66
Total	123.50	191.65	263.73

A summary of the results in more detail shows the split of impacts by type and at UK and global level.

Economic benefits to the UK	NPV - 10 yrs	NPV - 15 yrs	NPV - 25 yrs
Education and training impacts	89,689,010	114,879,612	115,678,707
Productivity impacts	415,667,146	766,820,822	1,405,844,448
Health impacts	1,059,602,710	2,256,298,767	4,394,529,279
Environmental Impacts	13,680,677	21,221,393	35,345,361
Total impact on the UK economy	**1,578,639,543**	**3,159,220,594**	**5,951,397,795**

Economic benefits rest of the world	NPV - 10 yrs	NPV - 15 yrs	NPV - 25 yrs
Education and training impacts	49,847,298	63,690,669	64,126,766
Productivity impacts	5,904,401,074	12,306,255,323	24,159,156,610
Health impacts	5,222,945,412	11,885,429,173	23,810,792,458
Environmental Impacts	-	-	-
Total impact rest of the world	**11,177,193,783**	**24,255,375,166**	**48,034,075,834**

Total economic benefits	NPV - 10 yrs	NPV - 15 yrs	NPV - 25 yrs
Operating spend	103,292,238	143,046,243	204,700,411
Visitor spend - in UK economy	272,349	384,927	570,887
Education and training impacts	139,536,307	178,570,281	179,805,474
Application of research outcomes	6,320,068,220	13,073,076,145	25,565,001,058
Health impacts	6,282,548,121	14,141,727,941	28,205,321,737
Environmental Impacts	13,680,677	21,221,393	35,345,361
Total impact on the global economy	**12,859,397,913**	**27,558,026,930**	**54,190,744,928**

1. Introduction

Brookdale Consulting was commissioned by the John Innes Centre (JIC) to produce an updated impact assessment of the Institute for 2022. The previous report was produced by Brookdale in 2018.

This report highlights a range of impacts generated by the ongoing research of JIC. JIC receives three quarters of its revenue from BBSRC and supports BBSRC's vision to 'advance the frontiers of biology and drive towards a healthy, prosperous and sustainable future' through:

- **Food security** - feeding nine billion people by 2050. *Work to improve wheat and oilseed rape yields, and alleviate the impact of vernalisation in brassicas are examples of JIC contributions here.*
- **Staying healthier for longer** - through fundamental bioscience, particularly as the proportion of UK society living beyond 65 continues to increase dramatically. *Resistant starch, antibiotics and other high value compounds are examples here.*
- **Developing renewable 'low carbon' energy and chemicals through bioscience** - *The potential to make new high value products from plants such as adjuvants or drugs, to improve sustainability of extraction or to increase oil content in oilseed rape are examples*.

JIC's HP^3 Healthy Plants, Healthy People, Healthy Planet vision, in partnership with The Sainsbury Laboratory outlines a revolution in plant and microbial sciences to address these challenges and position the UK as a global leader in plant and microbial science.

JIC is in the top 10 of Nature journal's institutions ranked by patent influence (https://www.nature.com/nature-index/supplements/nature-index-2022-innovation/tables/overall). All the case studies considered in this report are within JIC's patent portfolio. The structure of the rest of the document is as follows:

- Section 2 - sets out the operating impact of JIC
- Section 3 - presents the impact of JIC's research through a series of case studies
- Section 4 - summarises the findings of the report
- Annexes contain supporting material and data.

Brookdale Consulting acknowledges the significant contribution of JIC staff in working with the team to produce this final report.

2. Operating Impact of JIC

The operating impact of JIC relates to the on-site running of the Institute, such as expenditure incurred and staff employed, plus the knock-on effects as these expenditures ripple through the UK economy and support further activities. The total economic impact of operating JIC therefore encompasses three distinct elements:

1. Direct impact: output generated and persons employed in the day-to-day operation of the Institute in Norwich;

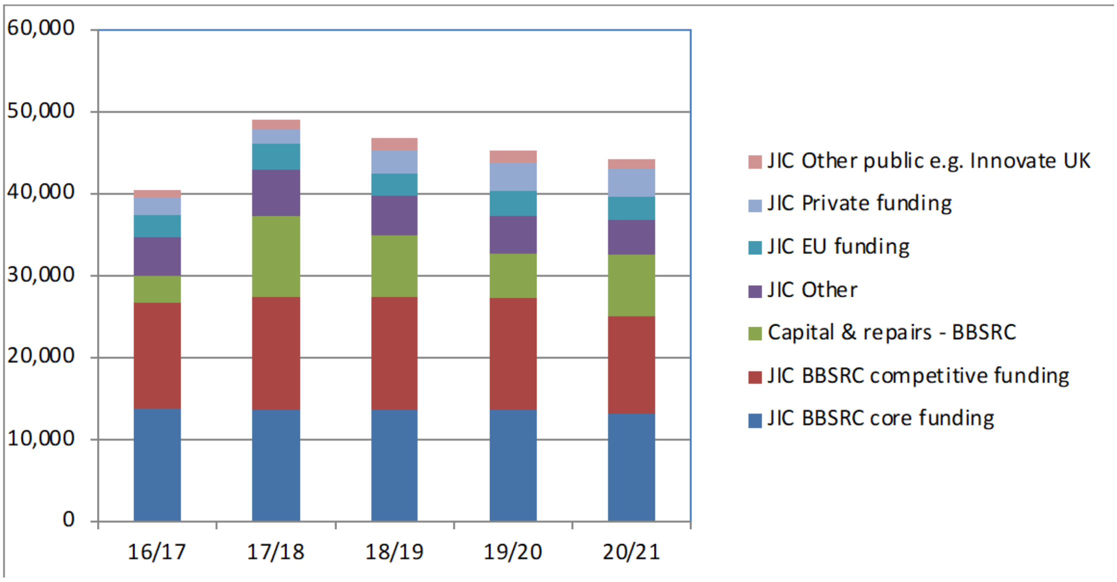
2. Indirect impact: output and employment created in the businesses which supply the inputs or materials used by the Institute; and

3. Induced impact: output and employment created when workers employed directly or indirectly spend their income in the local economy.

2.1 Direct Impact

JIC's income in 2020/21 was £44.3m. Figure 2.1 illustrates JIC income by source over the last 5 years. Income has steadily reduced over the last 3 years, largely due to reduced capital expenditure since 2017/18. BBSRC core and competitive funding has been fairly stable as have other sources of income.

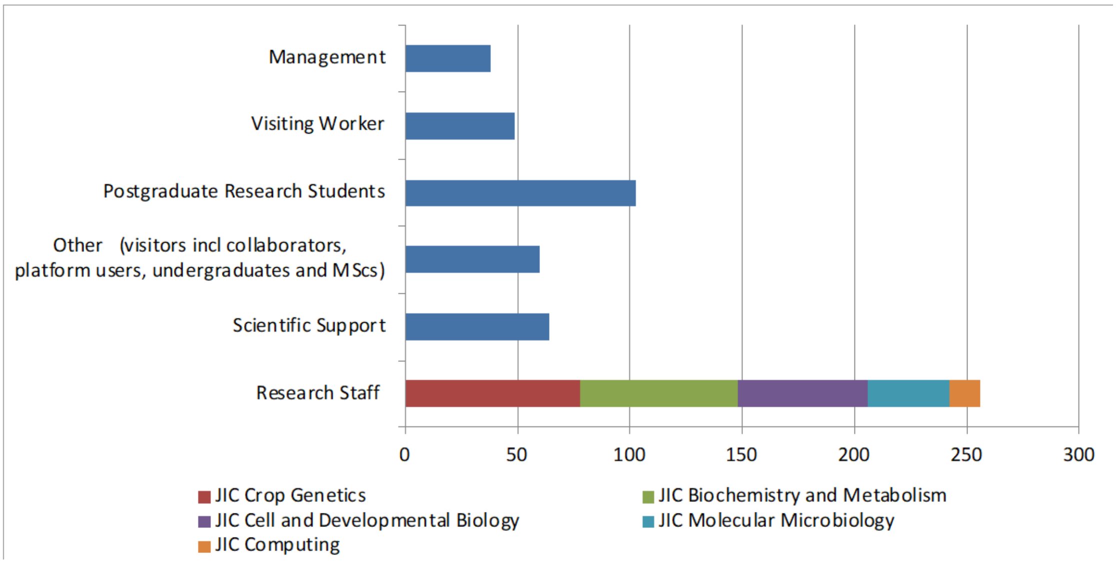
Figure 2.1 Sources of JIC Income (£000's)



Source: JIC Management Accounts

JIC directly employs 358 FTE staff comprising 256 in research, 64 in scientific support and 38 in management. JIC also has 103 postgraduate research students, an additional 60 other students and 49 visiting scientists in June 2022. The students receive a stipend that varies according to the sponsor. Visiting scientists are supported by their host institutions, or grant funding for training purposes – see Figure 2.2.

Figure 2.2 Staffing at JIC June 2022



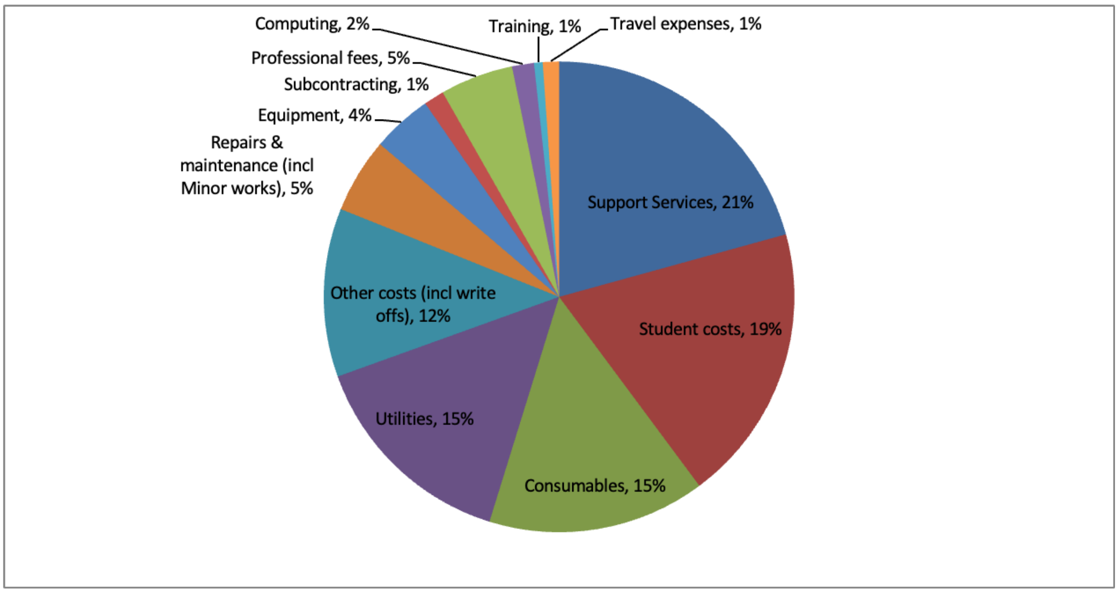
Source: JIC

Administrative support is provided to JIC via NBI, a shared services organisation used by all institutes on the Norwich Research Park.

2.2 Indirect Impact

JIC spent £22.6m with suppliers in 2020/21, of which £21.5m was with UK based suppliers. A further £9.2m was spent on capital improvements. This supplier expenditure forms the inputs for calculating the indirect operating impact of JIC. Figure 2.3 illustrates the supplier expenditure by type.

Figure 2.3: JIC Expenditure by Type



Source: JIC Management Accounts

In 2020/21 support services was a major element of the expenditure, student costs, consumables and utilities were also high.

This profile of supplier expenditure supports output and employment amongst supplier industries, and their suppliers in turn. The extent of this impact can be estimated using the UK National Accounts published by ONS, estimating the level of expenditure required to support a FTE job in each supplier, and their knock-on expenditure.

In total for 2020/21, JIC's supplier expenditure is estimated to **generate a total of £53.1m output for UK industries, supporting 359 jobs**. This comprises 238 FTEs in those UK companies directly supplying JIC, and a further 121 employed through further supply chain effects (i.e. as JIC's suppliers purchase inputs in-turn from their suppliers, which are still attributable to JIC's initial demand).

2.3 Induced Impact

Total salaries and associated costs paid to JIC staff amounted to £17.1m for 2020/21. There was a further £4.3m of student costs. The salaries paid to staff working within the JIC supply chain are estimated at £8.6m. In total, this £30m of direct and indirect salaries accrues to households to be spent on a profile of consumer goods and services, generating further economic activity in the UK. This forms the basis for JIC's induced impact.

Modelling this household income using an average consumer profile, indicates that the direct and indirect salaries will lead to increased spending of £9.4m and will support a further 61 jobs across the UK economy. While these induced impacts can be attributed to JIC, they will largely occur in sectors in consumer industries such as retail and recreational services.

2.4 Summary of Operating Impacts

Figure 2.4 summarises the direct, indirect and induced impacts of JIC highlighting the 881 jobs and £42.5m of Gross Value Added (GVA) across the UK economy.

Figure 2.4 Summary of JIC Operating Impacts

	Output (£m)	Employment (jobs)	GVA (£m)
Direct	46.6	461	17.1
Indirect	53.1	359	23.5
Induced	9.4	61	1.9
Total	109.1	881	42.5

3. Impact of JIC Research

This section sets out the calculation of actual and potential impacts arising from JIC research through a series of case studies under the following headings:

- Global Food Security – covering JIC's work in wheat and brassicas
- Bio-engineering – making useful chemicals from plants
- Antibiotic resistance – identifying potentially new antibiotics to counter resistance
- Global nutrition and health – natural fortification of food and increase in nutrients
- Environment and Biodiversity – focusing on Xylella

Alongside the case studies there is an economic model that calculates the impacts arising from the research in a consistent manner – see Appendix 2 for the methodology.

3.1 Global Food Security

Growing world populations, the threat of climate change, new pests and diseases and the withdrawal of certain crop protection products mean that there is an ever more pressing need for more productive food crops. Recognising this need, the UK has developed the Designing Future Wheat Programme with JIC having the leading role alongside other partners. This Programme is being followed up with the Delivering Sustainable Wheat Programme.

While wheat's average annual genetic gain has been estimated at around 1% per year, demand has been increasing by 1.7% and forecast to reach 1 billion tons by 2050[2].

In 2020, arable crops suffered from two contrasting periods of weather leading to a drastic reduction in yield and area. Heavy rainfall during the winter planting season caused waterlogging and compaction, followed by spring drought which affected the establishment of spring sown crops. We have therefore used figures for 2019 where the UK average wheat yields were 8.9 tonnes per hectare leading to a wheat harvest of 16.2m tonnes and UK farm gate turnover of £2.43bn[3], up from £2.11bn in 2018. With 1,816,000 hectares grown, wheat is by far the largest UK cereal crop by value and area. Uses include milling to

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[2] Tadesse W, Sanchez-Garcia M, Assefa SG, Amri A, Bishaw Z, Ogbonnaya FC, Baum M. Genetic Gains in Wheat Breeding and Its Role in Feeding the World. Crop Breed Genet Genom. 2019;1:e190005.
https://doi.org/10.20900/cbgg20190005

[3] All Defra references in this section are from the publication 'Agriculture in the United Kingdom 2020'

produce flour for baking, animal feed and distilling. Diseases such as Yellow Rust can impact on crop yields in the UK by 5-30%[4]. Finding long term resistance will reduce yield losses and as chemical treatments available become fewer, finding robust resistant varieties is increasingly a priority.

At an International level, the Food and Agriculture Organisation (FAO) estimates global wheat production (2020) at almost 761m tonnes almost 30% of total global cereal production with the global market value in 2020 worth £1.9bn, making the average price £249 per tonne. Since this figure is exceptionally high, the impact estimates are based on £150 per tonne.

3.1.1 Improving Wheat Productivity

JIC's historic discoveries in wheat are well documented and included in previous impact reports. **In 2018, the gross value of these benefits globally was estimated to be £4.9bn**.

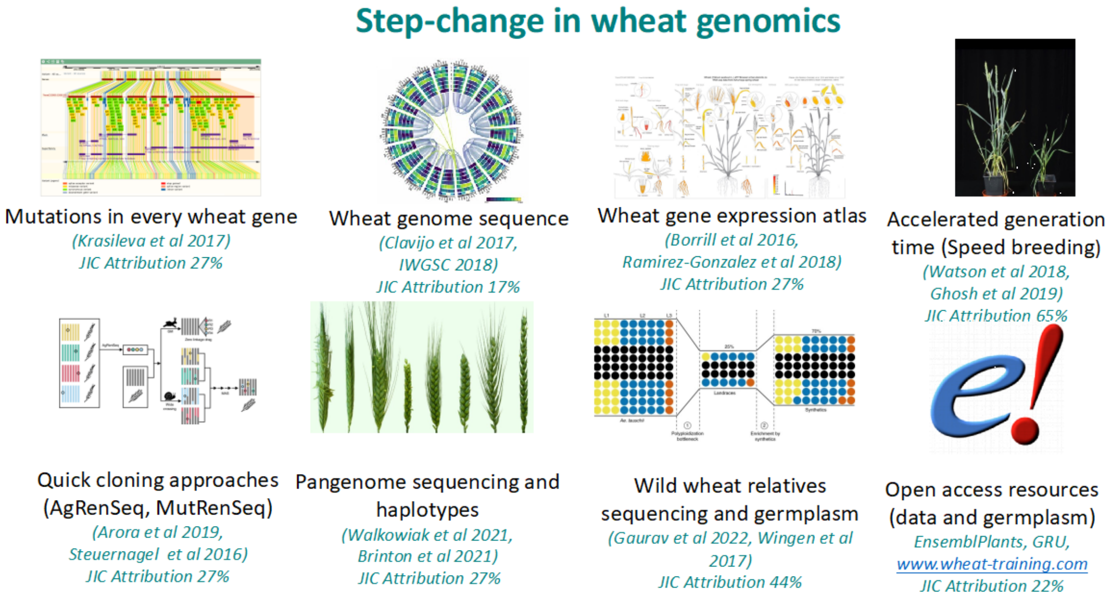
JIC is one of eight institutions in the Designing Future Wheat (DFW) Programme[5], the UK's National Wheat Research Programme. DFW aims to develop new germplasm with the traits needed by plant breeders to develop new wheat varieties.

In addition to co-ordinating the whole programme, JIC is leading two of four work packages in DFW: 'Added Value & Resilience' and 'Germplasm - development for trait dissection' as well as contributing to the remaining two work packages[6]. This programme is likely to lead to productivity enhancements for UK wheat.

Alongside DFW, JIC's research collaborations are global and wide ranging. Figure 3.1 summarises eight specific developments that when taken together are delivering substantial improvements to global wheat breeding efforts. JIC's contribution is estimated based on its proportion of journal article authorship as shown in Figure 3.1.

[4] Bayer Crop Science UK – 30% being the most susceptible varieties growing in coastal regions
[5] Other partners are Rothamsted, NIAB, EBI (the European Bioinformatics Institute), Earlham Institute and the Universities of Bristol and Nottingham.
[6] WP1 'Increased efficiency and sustainability' and WP4 'Data Access and Analysis'.

Figure 3.1 JIC involvement in Wheat research



Two examples from the new techniques developed include:

Speed breeding in collaboration with Queensland, JIC had an important role in developing the technique which allows six generations of wheat to be grown in one year compared to two with traditional methods. This allows new higher performance crop varieties to be delivered more quickly.

AgRenSeq, patented by JIC, enables researchers to rapidly search for resistance genes in wild relatives of modern crops. These genes can then be transferred into domestic crops to confer protection against pathogens and pests such as rusts, powdery mildew and Hessian fly. This will improve yields and reduce pesticide use.

Two examples of techniques that are likely to have future impact include:

Hybrid wheat and barley. As self-pollinating crops, cost-effective production of hybrid seed on a large scale is virtually impossible. Through genetic modification, JIC scientists have found a way to generate a conditional male-sterile phenotype in these crops, which makes crossing of different varieties easy. This will allow production of superior crop varieties, with major economic implications and potential to contribute to global food security.

Tools to accelerate genetic improvement of wheat
JIC has improved the Cas nuclease genome editing tools available. This technology will enable researchers to make key modifications in wheat to increase yield, resilience and quality.

As the plant breeding industry is constantly introducing new lines, and JIC and the DFW Programme have close links to industry, the research is feeding through to have an impact in three ways:

- Improving wheat productivity (this may be in terms of reduced inputs to achieve the same yield or increased yield from the same inputs). We assume an increase of 1% per year[7].
- Improving crop health (valued in terms of yield that would otherwise be lost). We assume the potential to reduce the severity of major disease outbreaks by 10% in Years 10 and 17.
- Improved crop quality (for example in the longer term improving the viability of growing bread making wheat in the UK). We assume this provides for a transformational uplift in wheat value of 10% in the long term (from year 10).

Impacts of JIC research can be attributed amongst the research partners and the plant breeding industry that will implement the findings. As a major partner in DFW and in consultation with JIC we assume 30% attribution for JIC. On this basis, and assuming 40% adoption, **for every 1% increase in yield achieved, the JIC share of impact will be £9.7m at the UK level. With the other impacts, over 25 years we estimate the total impact of JIC on UK wheat at £496m.**

Given the significance of this work and the international nature of plant breeding, it is likely that yield improvements resulting will also influence the rest of the world. **Assuming 40% adoption in the rest of the world, we estimate the impact of JIC on global wheat production at £21bn over 25 years.**

3.1.2 High Performance Brassicas

JIC has found a way to switch off the response of brassicas to vernalisation. Vernalisation is a prolonged period of cold temperatures necessary for the plant to flower. JIC has identified the genetic combinations to provide the necessary characteristics, finally patenting its technology in April 2018.

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[7] Tadesse W, Sanchez-Garcia M, Assefa SG, Amri A, Bishaw Z, Ogbonnaya FC, Baum M. Genetic Gains in Wheat Breeding and Its Role in Feeding the World. Crop Breed Genet Genom. 2019;1:e190005. https://doi.org/10.20900/cbgg20190005

JIC has formed an industrial consortium of 9 partners from farm to retail. JIC's technology has potential application to a wide number of crops but the initial targets are stem broccoli and cauliflower. At the moment, broccoli and cauliflower tend to be grown outdoors in the UK and harvested in the autumn with 18,000 hectares producing 171,000 tonnes in 2021 worth £146m at the farmgate[8]. Out of season requirements are imported with 2021 seeing 103,000 tonnes imported (the lowest level in a decade) worth £151m[9].

It is anticipated that new commercial varieties could be available within 2 years. JIC will license use of the technology producing royalty income. More importantly, the technology will vastly improve quality and productivity of brassica production. With no need to wait for vernalisation, growing single stem broccoli in glasshouses will allow up to 4 crops per year in polytunnels or 5-6 crops in glasshouses. The more uniform plants resulting will permit automated harvesting instead of multiple-pass hand harvesting thus saving cost and reducing waste. Stem vegetables are also worth four times the value of field grown crops.

Another benefit will be to plant breeders as the technology shortens generation time, and in some instances will remove the biannual nature of seed production allowing 2-3 seed crops per year. This will enable breeders to create new varieties much more quickly. There is also the potential future application of the technology to oilseed rape in the next 15-30 years.

A summary of the benefits (Table 3.1) has been calculated as part of the project drawing on expert input. This shows that application of JIC's technology to the current crop in the UK could add £30-34m if fully adopted. A high level of adoption is likely as brassica growers tend to be large and specialist. It is likely that the technology would displace imports to the UK and could support new forms of robotic indoor farming close to major population centres. It would also reduce the dependence of farmers on migrant labour which is in increasing shortage. With 50% attribution to JIC we estimate this could be worth £167m to the UK over 25 years.

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[8] Defra Horticultural Statistics 2021.

[9] HMRC Trade Statistics Code 0704 Cabbages, cauliflowers, kohlrabi, kale and similar edible brassicas 165,500 worth £172.6m. Defra import statistics suggest 103,000 tonnes cauliflower and broccoli which is 84% of volume is, the target crops here.

Table 3.1 Summary of benefits of JIC's technology in broccoli and cauliflower at UK level

Crop	2021 area (ha)	Extra yield value (£per ha)	Automated harvest saving (£per ha)	Retail waste reduction (based on 2.5% of farm gate value)	Total additional value
Field Broccoli	8,217	£740-£1,224	£107.50	£2.075m	£9m-£13m
Field Cauliflower	9,794	£1,120	£160	£1m	£14.1m
Stem Broccoli	2,000[10]	£561	£2,808	£0.24m	£6.52m
Total					£29.6m-£33.6m

Source: Defra horticulture statistics, AHDB Project FV368 and NIPPY project grower base data

The technology would also benefit European production of 117,450ha in 2020 (FAOSTAT) at £136m based on mid-point savings for field production (the level of stem broccoli is not disclosed in the statistics). Assuming 75% adoption in the EU and 50% attribution to JIC this could be worth £547m over 25 years.

3.1.3 Oilseed Rape

JIC's research into yield instability of oilseed rape has highlighted the importance of vernalization in early winter (late Nov-Dec) for a high yield. By researching historic temperatures and yield data from long term trials, the research has found a one-degree temperature rise in early winter costs UK rapeseed growers £16m at harvest with losses of up to £160m in the UK rapeseed harvest – about 25% of the total value. Genetic analysis shows that the trait of yield stability is not correlated with that of yield. This means it should be possible to breed for yield stability and high yields together without having to sacrifice one for the other. In establishing a clear link between temperature and productivity, the study raises the hope that future rapeseed crops can be bred so that they are less temperature-sensitive, offering breeders the prospect of more stable and productive yields.

[10] Industry estimate.

We assume that new OSR varieties will take 5 years to reach the UK market and that the 25% saving will apply every 5 years on average with 30% attribution to JIC. We also assume the EU will take up the benefit on the same frequency but at a lower level of 15% to reflect likely lower price effects. **This could potentially deliver £72m GVA to the UK and £530m to the rest of the world over the next 25 years.**

3.2 Bio-engineering

JIC is investigating the vast diversity of natural products made by plants and microbes. Alongside foods, these include drugs, therapeutics and antibiotics, and raw materials for sustainable manufacturing of a host of industrial products. Research on plant and microbial genomes shows that these organisms can make a vast array of as-yet undiscovered products. By unlocking this untapped resource, JIC's research will underpin development of new products and processes of economic and societal benefit, such as new therapeutics and antibiotics, and sustainable ways to improve crop yields.

JIC's research is being used to design and engineer new molecules and produce organisms that can accelerate advances in health, medicine, sustainable manufacturing, and sustainable agriculture. A selection of these is set out below.

3.2.1 QS-21

QS-21 is a plant saponin extracted from tree bark of *Quillaja saponaria*, the Chilean Soapbark Tree. QS-21 is a potent adjuvant; it can significantly improve the efficacy of prophylactic vaccines and is being investigated for use in therapeutic vaccines for diseases such as cancer. It works by stimulating the body's response to fighting infections and has been found to be more effective than many other adjuvants.

In 2017, GSK's vaccine for shingles (Shingrix) was the first vaccine approved in the USA and Canada that utilises QS-21 as a key adjuvant. The vaccine has been found to be very effective and its first quarter sales were £110m, well ahead of analyst expectations of £35m[11]. QS-21 Stimulon is also currently being evaluated in numerous GSK vaccine development candidates for both therapeutic and prophylactic applications. The AS01 adjuvant containing QS-

[11] Reuters.

21 is also licenced in vaccine formulations for malaria (Mosquirix) and is a promising vaccine candidate for tuberculosis from GSK[12].

As use of QS-21 increases, an emerging challenge is that current extraction methods are of variable quality and not sustainable. JIC is working on an engineered, alternative plant-production system for triterpenes such as QS-21. JIC has already identified and reconstructed the first part of the production pathway. QS-21 provides an ideal proof of concept for JIC's technology as it has recently come off patent. Success with QS-21 is likely to open up the possibility of producing other valuable plant triterpene products such as Bardoxolone with promise for treating lung disease.

The vaccine adjuvants market alone is anticipated to be worth 1.26bn in 2021[13]. While it is anticipated it will be at least 5 years until commercialisation, JIC's technique could gain substantial market share and bring manufacturing production of QS-21 to the UK from abroad. In discussion with JIC scientists, **we estimate a 20% market share as a conservative figure given there are other competing production systems alongside natural growing systems. With attribution of 50% to JIC this equates to £126m per year and gives the UK a leading position in this growing area.** In the meantime, JIC is developing a database of enzymes that can modify triterpene scaffolds. Once the capabilities of the enzymes, and the pathways they derive from are fully understood, JIC will be able to make a whole host of valuable plant products, including new to nature molecules, with the potential to be new drugs or modifications to known drug molecules that have greater potency or fewer side effects.

[12] https://www.gsk.com/en-gb/media/press-releases/gsk-candidate-vaccine-demonstrates-sustained-level-of-protection-against-active-pulmonary-tuberculosis/
[13] https://www.marketsandmarkets.com/PressReleases/vaccine-adjuvants.asp $1.5bn in 2022 up from $769.4m in 2018. Converted to £1.26bn at $1.19/£1.

3.2.2 Antibiotic Resistance

There is considerable future potential to find new useful natural products with antibiotic activity that can counter antibiotic resistance. Growing antimicrobial resistance and the lack of financial incentive for commercial development of new antibiotics necessitates an ongoing need for public sector investment in antibiotic discovery and development.

The increasing incidence of antimicrobial resistance (AMR) is a significant global threat and development of new antibiotics is vital. As many synthetic antibiotics have failed to progress through clinical trials, there has been a renewed interest in natural products.[14] By studying the microbiome of leaf-cutter ants, JIC scientists have discovered formicamycins, a new structural class of antibiotics that kill MRSA and vancomycin-resistant enterococci (VRE). They have a very high barriers for the selection of resistance. JIC's work on formicamycins has led to discovery of several new mechanisms by which antibiotic biosynthesis is regulated. This will be useful to researchers around the world trying to discover and develop new antibiotics.

As well as formicamycins, JIC is also researching compounds that target the bacterial enzymes DNA gyrase and DNA topoisomerase IV (which are essential to survival of harmful bacterial). These enzymes are well-documented targets for antimicrobial therapy, especially by fluoroquinolones that are renowned for inhibiting both enzymes simultaneously. JIC has used computational modelling to design new compounds targeting DNA gyrase and DNA topoisomerase IV, providing an important step towards creating new antibiotics.

The 2022 Global Research on Antimicrobial Resistance (GRAM) report[15] estimates deaths linked to 23 pathogens and 88 pathogen-drug combinations in 204 countries and territories in 2019. The research estimates disease burden in two ways: deaths caused directly by AMR (i.e. deaths that would not have occurred had the infections been drug-susceptible and therefore more treatable), and deaths associated with AMR (i.e. where a drug-resistant infection was implicated in deaths, but resistance itself may or may not have been the direct cause). It is the first comprehensive analysis of the global impact of antimicrobial resistance (AMR) and the report estimates resistance itself

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[14] Devine, R. et al (2021) *Re-wiring the regulation of the formicamycin biosynthetic gene cluster to enable the development of promising antibacterial compounds* Cell Chemical Biology, 28 (4) pp515-523, 15 April 2021

[15] Antimicrobial Resistance Collaborators (2022) *Global burden of bacterial antimicrobial resistance in 2019: a systematic analysis* The Lancet 299 (10325) pp629-655, 12 February 2022

caused 1.27 million deaths in 2019 - more deaths than HIV/AIDS or malaria - and that antimicrobial-resistant infections played a role in 4.95 million deaths.

Taking MRSA as one example, the report estimates that in 2019, more than 120,000 deaths were attributable to MRSA and a further 470,000 were associated with MRSA. These deaths could be avoided if new antibiotics that kill MRSA were developed.

JIC research on new antibiotics will support researchers in discovery and development of new antibiotic products. The global antibiotics market is estimated at £31.7bn in 2021.[16] **However, the cost of MRSA deaths in the UK alone is estimated at £10.2bn. JIC's discoveries have significant potential to reduce this cost substantially so if we assume a reduction of 25% in the UK this would save £2.5bn plus a 10% reduction in the rest of the world would save £17.6bn per year. Given the need for pharmaceutical company involvement and clinical trials, a low attribution to JIC of 10% is assumed with impacts from Year 6.**

[16] Fortune Business Insights Jan 2022 $38.08bn in 2021 converted to £31.7bn at $1.2/£1.

3.3 Global Nutrition and Health

JIC and its partners on the Norwich Research Park are working to advance our understanding of plant-based nutrition from crop to clinic, addressing diet-related illness which costs billions globally.

Plant-based foods are critical in tackling chronic illness such as cancers, diabetes and cardiovascular disease. The loss of plant-based, unrefined foods from the human diet means more people are burdened with nutritional insecurity and associated chronic illnesses. Understanding how plant-based foods promote and protect health will underpin effective future dietary recommendations, food choices and food production. JIC is working on nutritional trait development focused on improving the diet and health of consumers.

3.3.1 Resistant starch

JIC has developed a genetic screening method for determining if a pea variety or a product derived from that pea variety has improved digestion properties due to the presence of a form of resistant starch. Wrinkled pea seeds (*Pisum sativum*) and wrinkled pea flour are derived from a null mutant in the SBEI (starch branching enzyme I) gene and differ primarily in the type of starch accumulated. When eaten, the cell structure and starch morphology associated with the SBEI null mutation correlate with lower glucose availability in the small intestine. This results in acutely lower postprandial glucose (PPG) and promotion of changes in the gut bacterial composition associated with long-term metabolic health improvements.

Compared to eating smooth peas, wrinkled peas prevent 'sugar spikes' – where blood sugar levels rise sharply after a meal. The same effect is seen when consuming flour made from wrinkled peas incorporated in a mixed meal. This could be important, as frequent, large sugar spikes are thought to increase the risk of diabetes. Flour from these 'super peas' could potentially be used in commonly consumed processed foods, preventing these sugar spikes.

It could become policy to include resistant starch in foods in the longer term. There are precedents for this kind of intervention, such as iron being added to bread to tackle anaemia. This could tackle type 2 diabetes and other metabolic illnesses.

Incorporating the peas into foods in the form of whole pea seeds or flour may help tackle the global type 2 diabetes epidemic. The International Diabetes

Federation[17] estimates that in 2021, **diabetes caused at least US$966bn (£805bn) in health expenditure, equivalent to 9% of total spending on adults**. Expenditure in the UK is estimated at $23.4bn (£19.5bn), Europe $165.6bn (excl. UK £138bn) and ROW $777bn (excl. Europe £647.5bn). The global pea flour market is estimated at £456bn in 2020.[18] The likelihood is that any new pea products would displace existing ones within this market.

The England Department of Health and Social Care has developed a model to quantify the benefits of reduced calorie intake. This model simulates a "control" group of would-be overweight and obese adult population, compared with an "intervention" group. The "intervention" group has a lower average BMI, as calculated from the reduced daily calorie intake. The simulation is over 25 years.

The average BMI determines the likelihood of the following five conditions associated with obesity, which in turn have a fatality rate and a reduced quality of life: diabetes, coronary heart disease, stroke, colorectal cancer, and breast cancer. The savings to the NHS are calculated from the reduced treatment of each disease. Reductions in mortality are used to calculate the impact on economic output from an increased workforce. The costs of social care savings are calculated due to a reduced proportion of overweight, obese, and morbidly obese individuals and hence fewer people needing social care in the treatment scenario.

A study by Giles et al (2019)[19] found that consumption of resistant starches leads to absorption of 25% fewer calories. Various studies[20] by Piecyk (2019), Birt et al (2013) suggest that 10-15% of starch intake needs to be resistant starch to have health benefits. If we assume the average carbohydrate content in a 2,000 kcal/day diet is 200g and 15% (30g) is required to be Resistant Starch then this would generate a daily calorie saving of (30g x 4 kcal/g) – (30g x 3 kcal/g) = 30 kcal/day. If we assume 30% effectiveness of the policy, we would end up with a calorie reduction of (30% x 30 kcal/day) = 9 kcal/day reduction. **Based on the DHSC model this would generate NPV Health benefits to the UK of £5.4bn, plus NHS savings of £510m and social care savings of £566m over 25 years. Attribution to JIC is estimated at 10% taking account of the role of plant breeders, farmers, manufacturers and retailers.**

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[17] International Diabetes Federation *IDF Diabetes Atlas Tenth Edition 2021* https://diabetesatlas.org/
[18] Global Industry Analysts April 2021 US$547bn converted to £456bn at $1.2/£1.
[19] The In Vivo Net Energy Content of Resistant Starch and Its Effect on Macronutrient Oxidation in Healthy Adults
[20] Journal of Functional Foods June 2022 – Health benefits of resistant starch: A review of the literature. Bojarczuk et al

3.3.2 Vitamin D

Poor vitamin D status is a global health problem; insufficiency underpins higher risk of viral infection, cancer, neurocognitive decline and all-cause mortality. Most foods contain little vitamin D and plants are generally very poor sources. In looking to solve this problem, JIC has engineered the accumulation of provitamin D3 in tomato fruit and leaves by gene editing, modifying a section of phytosterol biosynthesis that has been duplicated in Solanaceous plants, to provide a biofortified food.

Previous research estimates that the **costs to the NHS in treating vitamin D deficiency are in the order of £100m per year**[21]**.** Similarly a study assessing the impact on health resource utilisation for patients clinically diagnosed with vitamin D deficiency estimated that prescribing vitamin D therapy could save £1.1m in health costs per Clinical Commissioning Group (CCG), which would equate to over £110m in health cost savings in England alone.[22] On top of this, a 2015 study in the UK highlighted additional benefits of routinely treating the older population with Vitamin D in terms of fewer falls, reduced care needs and reduced deaths. **This study found a net benefit of £420m over 5 years using costly supplements**[23].

The global vitamin D ingredients market is estimated at £1.17bn in 2021[24] and projected to rise to £1.32bn by 2025[25]. However, JIC hopes that its enhanced tomatoes could be used by food manufacturers to produce a healthier tomato paste/puree packed with Vitamin D. This could become an ingredient for ready meals, which are popular with the elderly, and also sold in its own right. British consumers spend £921m on fresh tomatoes annually, with around £190m of this on British grown tomatoes.[26] In addition, cooking sauces, pickles and canned tomato products account for £1.2bn of GB retail grocery sales[27]. There is potential to grow UK market share of fortified tomatoes and to help address the UK's Vitamin D deficiency. **If this can be done in combination with food manufacturers, it could substantially reduce the costs of prescribing Vitamin D and the costs associated with Vitamin D deficiency, especially**

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[21] https://www.gponline.com/treating-vitamin-d-deficiency-cost-100m-year-2013/nutrition/nutrition/article/1116651

[22] https://www.gmjournal.co.uk/substantial-cost-savings-could-be-made-with-appropriate-vitamin-d-prescribing

[23] Poole CD, Smith J, Davies JS Cost-effectiveness and budget impact of Empirical vitamin D therapy on unintentional falls in older adults in the UK *BMJ Open* 2015;**5:**e007910. doi: 10.1136/bmjopen-2015-007910

[24] Zion Market Research July 2022 $1.40bn converted to £1.17bn at $1.2/£1.

[25] https://www.businesswire.com/news/home/20200806005640/en/Global-Vitamin-D-Market-2020-to-2025---Increase-in-Demand-for-Feed-Fortification-Presents-Opportunities---ResearchAndMarkets.com

[26] British Tomato Growers Association https://www.britishtomatoes.co.uk/tomato-facts

[27] Kantar Worldpanel

in the aged. The UK Government is conducting a review to examine whether food and drink should be fortified with vitamin D to address health inequalities. **Assuming a 25% reduction in prescribing and a 25% increase in net benefit amongst older people would be worth £46m per year. Attribution to JIC is estimated at 30% taking account of the role of food manufacturers and health providers.**

JIC has also discovered that the enhanced tomato leaves are rich in provitamin D3 thus providing a potential new feedstock for the manufacture of vitamin D3 supplements or food fortification, which would be suitable for vegans. Since tomato leaves are currently a waste product, this potential biorenewable source of vitamin D3 could support the UK in developing a circular economy.

3.3.3 High-iron Peas

Iron is an essential micronutrient for the human diet. Iron deficiency (ID) is a global health problem with some 2bn people affected, particularly children in Africa[28]. Recent research suggests ID may be more prevalent in Africa than thought when defined using the WHO guidelines. This is because tests for iron levels can be altered by inflammation and infections such as malaria[29].

Within the UK, ID prevalence is 2-5% among men and older women and 14% in younger non-pregnant women rising to 23% in pregnant women[30].

Causes of ID include poor diets low in iron, bowel disease, high infection rates and demographic characteristics of the population[31]. Alongside diet, the use of supplements such as ferrous sulphate can increase iron levels. However whilst ferrous sulphate is cheap, its uptake efficiency is low ranging from 5-28% when fasting or as low as 2-13% when taken with food[32]. It also causes side effects such as gastrointestinal pain, nausea, and constipation. Unabsorbed iron may disrupt gut bacteria, enhancing growth of unwanted bugs and causing gut

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[28] Kassebaum NJ, Jasrasaria R, Naghavi M, Wulf SK, Johns N, Lozano R, et al. A systematic analysis of global anaemia burden from 1990 to 2010. Blood J. 2014;123:615–25. GBD-2016-Disease-and-Injury-Incidence-and-Prevalence-Collaborators. Global, regional, and national incidence, prevalence, and years lived with disability for 328 diseases and injuries for 195 countries, 1990–2016: A systematic analysis for the Global Burden of Disease Study 2016. Lancet. 2017;390:1211–59

[29] Muriuki, J.M., Mentzer, A.J., Webb, E.L. *et al.* Estimating the burden of iron deficiency among African children. *BMC Med* **18**, 31 (2020). https://doi.org/10.1186/s12916-020-1502-7

[30] NICE evidence on anaemia – iron deficiency

[31] Mwangi M, Mzembe G, Moya E, Verhoef, H Iron deficiency anaemia in sub-Saharan Africa: a review of current evidence and primary care recommendations for high-risk groups. The Lancet, Published: September 02, 2021DOI:https://doi.org/10.1016/S2352-3026(21)00193-9

[32] Cook, JD (2005) Diagnosis and management of iron-deficiency anaemia Best Pract. Res. Clin. Haematol., 18 (2) pp. 319-332

inflammation[33]. Up to a third of people experience an adverse reaction to iron supplements[34].

JIC's research has focused on pea mutants discovered more than 30 years ago. It has identified the mutations responsible for high iron content in peas giving a 10-fold accumulation from normal[35]. High-iron pea plants can be used to make concentrated ferritin extracts which are highly bioavailable. The leaves of these high iron peas can form an important new feedstock for the manufacture of iron supplements or for food fortification.

Importantly, it has been found that while bioavailability of iron in the peas and leaves is high, the purified pea ferritin does not negatively affect gut flora. This opens the potential for much more effective iron supplement treatments with lower adverse reactions. JIC's technology is likely to take significant market share and to improve the cost effectiveness of iron treatments.

Analysis of ID treatment in the UK showed a 72% rise in hospital admissions between 2012/13 and 2017/18 with an average day-case cost of £449 and £1,676 for non-elective admission[36]. Per 100,000 of population, non-elective admissions have increased from 11-55 in 2012/13 to 18-118 in 2017/18. Adverse reactions are a major driver of non-elective admission. **Within the UK there is significant potential to reduce these costs through improved iron delivery supported by JIC's research. Whilst elective admissions would continue, the potential to reduce non-elective admissions back to the 2012/13 level through JIC research would save £43.7m per year[37] Attribution to JIC is estimated at 30% taking account of the role of food manufacturers and health providers.**

3.4 Environment and Biodiversity

Plants make up 80% of the food we eat, and produce 98% of the oxygen we breathe. However, this natural capital is under threat due to environmental

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33 D. Paganini, M.B. Zimmermann (2017) The effects of iron fortification and supplementation on the gut microbiome and diarrhea in infants and children: a review Am. J. Clin. Nutr., 106 (Suppl. 6) pp. 1688S-1693S

34 Culeddu, G, Su, L, Cheng, Y, et al. Novel oral iron therapy for iron deficiency anaemia: How to value safety in a new drug? *Br J Clin Pharmacol*. 2022; 88(3): 1347- 1357. doi:10.1111/bcp.15078

35 Sophie A. Harrington and Janneke Balk (2022) The genetic basis of iron-accumulating mutants dgl and brz in pea, Pisum sativum L. Awaiting Publication

36 Brookes MJ, Farr A, Phillips CJ*, et al* Management of iron deficiency anaemia in secondary care across England between 2012 and 2018: a real-world analysis of Hospital Episode Statistics *Frontline Gastroenterology* 2021;**12:**363-369.

37 Reduction with range of 7-63 admissions, take midpoint of 35 per 100,000. UK population of 67.1m (ONS) so 671*35=23.485*£1,676=£39.36m in 2018 *1.11 to convert from nominal into 2022 prices = £43.69m

pollution and climate change. New and emerging plant pathogens threaten crop production, forestry, horticulture, as well as woodlands and broader biodiversity.

By working on solutions to improve plant health, research at JIC is helping to decarbonise agriculture, and maintain the natural diversity of plants and microbes, paving the way for a low carbon, sustainable future for agriculture, medicines and food.

3.4.1 Xylella

Xylella fastidiosa is a bacterial infection of the xylem vessels of plants, transmitted by insects. The bacteria block the xylem tubes and prevent the plant from transporting nutrients to where they are needed. *Xylella* can infect more nearly 600 plant species causing leaf scorch (browning), wilt, die-back and even plant death. There is no known cure. Insects which feed from the xylem can acquire *Xylella* and transmit it to other plants. To date, *Xylella fastidiosa* has not been discovered in the UK. However, there is real concern about the possibility of a disease outbreak in the UK along with significant damage to the horticultural trade and wider environment. Currently it is a notifiable (quarantine) bacterial plant disease in the UK.

The BRIGIT consortium[38], led by JIC is a collaborative international research project to raise awareness of *Xylella fastidiosa*, addresses knowledge gaps to minimise the risk of its introduction, and improve early detection and control. This work has facilitated the UK to respond to interceptions and outbreaks, and to mitigate the impact of the disease should it become established.

There have been *Xylella* outbreaks in France, Italy, and Spain. In 2019, the UK Government stated that *Xylella fastidiosa*'s damage to olive trees alone had caused a loss of €390 million over three years in Italy.[39] Portugal confirmed its first case in 2019, in lavender.

In 2022, Defra published a plant health response plan for *Xylella fastidiosa*[40] The plan notes that the pathogen and its vectors have an exceptionally large host range, making it hard to predict which UK plant host species are potentially susceptible to infection. The UK conducts annual surveys for symptoms of infection.

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[38] Funded by UKRI, BBSRC with support from NERC, Defra and Scottish Government.

[39] https://lordslibrary.parliament.uk/uk-import-restrictions-controlling-the-spread-of-xylella/

[40] Defra (2022) *Pest specific plant health response plan: Xylella fastidiosa,* Crown copyright 2022

A potential pathway for *Xylella* to enter and spread in the UK is in the horticulture supply chain, possibly via import of infected plants. Defra has identified nine *Xylella* high risk hosts in the UK (https://www.rhs.org.uk/disease/xylella-fastidiosa). BRIGIT has modelled potential *Xylella* spread via insect vectors and in the UK trade network, including nurseries, growers, retailers and the UK landscape. The modelling highlights the UK locations that are potentially most at risk as East, South East and South West England.[41]

Any outbreak in the UK would likely lead to destruction of plants and trees, restricted movement of horticultural products and the use of pesticides to control the insects which spread the disease.[42] *Xylella fastidiosa* sub species multiplex is of most concern to the UK as it is able to survive in cooler climates and affect a wide range of hosts, including many native broadleaved trees such as oak, elm and maple.[43]

Oak is the second most common broadleaf tree in woodland and the most common tree species amongst open grown trees in Great Britain. The social and environmental value of oak is estimated at £320m per year and elm a further £21m giving a total value of £341m.[44]

The BRIGIT research consortium has improved the UK's preparedness and ability to mitigate the impact of Xylella outbreaks if they were to occur by:

- enhancing the diagnostic capabilities for *X. fastidiosa* and standardising these among UK laboratories.
- generating a better understanding of geographic distributions of the *X. fastidiosa* insect vectors in the UK, as well as their host plant preferences, migration behaviours, and population structures.
- developing *X. fastidiosa* epidemiology models for the UK horticultural trade and landscape. The models enable scenario testing of how *X. fastidiosa* may spread into the UK if introduced, as well as the efficacy of surveillance and control strategies.
- developing recommendations for education and awareness, and regulation and good practice, to minimise both the risk and potential impact of *Xylella* infection.
- improving information exchange and general awareness of the *Xylella* threat.

[41] https://www.jic.ac.uk/brigit/brigit-databases-and-resources/new-xylella-data-for-uk-risk-assessment-policy/
[42] https://www.gov.uk/government/news/public-urged-not-to-bring-plant-pests-and-disease-into-the-uk
[43] https://planthealthportal.defra.gov.uk/pests-and-diseases/high-profile-pests-and-diseases/xylella/
[44] Tree health resilience strategy (publishing.service.gov.uk) p 56

- enabling implementation of BRIGIT findings by policymakers, government and industry stakeholders (including horticultural trade), charities and membership networks and the general public.

If an outbreak were detected in the UK, all host plants within 100m of the infected plants would have to be destroyed and host plant movement restrictions would be brought in for a 5km buffer zone. This would be potentially devastating for nurseries and garden centres. The Horticulture industry contributes £5bn to the UK economy every year.[45] In addition, the social and environmental value attached to affected woodland oak and elm trees of £341m would also be at risk.

The latest population estimates from Office of National Statistics (ONS) show that the area's most at risk represent 32% of the UK population, while ONS standard area measurements suggest the three high-risk regions account for 27% of the GB land area. Assuming that not all the horticultural industry or woodland area will be at risk, these estimates can be used to provide an indication of *Xylella* impact if no action is taken. The estimates do not take account of the actual distribution of industry and trees across the UK so might be considered as maximum values. The costs of the control strategy are also unknown.

These estimates would suggest that preventing losses through disease and business restrictions in the high-risk areas of the UK (East, South East and South West of England) in the horticulture market could be worth as much as £1.6bn per year while maintaining the social and environmental value of one of the main risk species (oak trees) in these regions could be worth a further £92m per year. We assume the policy could be 50% effective with attribution to JIC of 10%.

3.5 Education and Training

JIC runs an extensive programme of training and engagement across the entire school and university spectrum aimed at inspiring and developing the next generation of scientists. This continuum of training has impacts from raising awareness or changing the perception of science as a career, attracting young people into bioscience through to increasing the capability and productivity of staff including helping them take the next step in their career.

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[45] Charted Institute of Horticulture estimate of business, production and food in the UK horticulture industry as cited in House of Lords Report – *The UK's horticulture sector* published 25 March 2022 [The UK's horticultural sector - House of Lords Library (parliament.uk)]

In terms of higher skills training, JIC trains postgraduates through its Plant Genetics MSc as well as hosting PhDs and postdoctoral workers. A summary of this training is set out below.

Schools

- JIC continues to run the **Youth STEMM award**, challenging young people aged 11-19 to consider STEMM careers. This involves working with schools and colleges across the region.
- JIC also hosts the **Teacher Scientist Network** which supports JIC staff and students in linking with local schools to encourage uptake of science subjects.

Undergraduates

- JIC hosts an **Undergraduate summer school** with around 16 participants split 50:50 UK and international
- **Year in Industry students** – An opportunity for 4 undergraduates to have a year-long research project placement as part of their degree

Postgraduates

- **MSc** – JIC typically has 14-15 MSc students on its Plant Genetics and Crop Improvement course though this number dropped during COVID.
- **PhD** – There are more than 110-120 PhDs at JIC at any one time. As well as its own PhD students, JIC leads the **Norwich Research Park Biosciences Doctoral Training Programme** with 20-30 of these students hosted at JIC (included in the number above). Moreover, included in the above, JIC has started the **EDESIA programme** which is a unique cross-disciplinary PhD programme that aims to advance understanding of plant-based nutrition from crop to clinic. The programme is a collaboration between the University of East Anglia (UEA), the John Innes Centre, Quadram Institute and Earlham Institute. In addition, the JIC PhD student pool includes PhD students on the prestigious **John Innes Foundation (JIF) student rotation programme,** involving 5-6 students per year.

Postdoctoral

- **Postdoctoral researchers** are a feature of JIC staff with 135 in the latest year contributing to JIC research projects and developing their own research areas.
- **Entrepreneurial Training:** JIC postdocs can participate in the 2Blades Masterclass aimed at providing entrepreneurial training to postdocs

within JIC and TSL. JIC has so far participated once with support of the UKRI National Productivity Investment Fund (NPIF); in 2021/22, 4 postdocs from JIC joined the course.

Other training

- **Designing Future Wheat training course**, open to external participants and aimed at aimed at anyone with an interest in cereals research and crop breeding; JIC trains 15-20 participants per year from both UK and non-UK.
- **Flexible Talent Mobility Award (FTMA) Scheme:** in the last few years JIC has been able to offer training to PhD students, postdocs and research and support staff through the Flexible Talent Mobility Award (FTMA) Scheme that promotes the movement of researchers and technicians either from or to the John Innes Centre. The aim is to allow skills to be transferred between two working environments, so that the participants can gain valuable new work experience. The programme is supported by BBSRC and has so far been able to offer between 8-14 placements per year. Moreover, the FTMA scheme has allowed for **Personal Development Training**; in this specific training programme 15-16 research and support staff have participated per year.

JIC undertakes a considerable amount of staff training in computing, health and safety, leadership and management, post graduate specific training and professional development and wellbeing. In the latest year, over 6,600 participants were trained (many would receive training in multiple topics).
For Scientific & Technical Training there were 691 participants in the latest year, while for Scientific Computing there were 327 participants. This type of training improves science productivity amongst staff.

The impacts of the training on UK productivity are assessed as part of the impact modelling of JIC and included in the return on investment.

3.6 Spin Outs and Spin Ins

JIC has created nearly 20 spin outs in the past 20 years with three new ones created since 2020. As early stage companies, these have received investment funding including equity stakes from JIC and have employed an estimated 15 staff over the period. Some of the newest companies are:

- MVPea Ltd – aims to produce pea products with improved dietary characteristics

- PfBio Limited – is developing bioactive products for crop protection as an alternative to synthetic pesticides.

The bioscience cluster on the Norwich Research Park has also attracted investment in the form of spin ins with two examples set out below:

Tropic Biosciences - an innovative start-up company formed in 2016 to develop new high yielding coffee and banana varieties. Originally based in Israel and the USA, it chose the Norwich location for its supply of highly trained researchers, the facilities and equipment available on-site and the supportive environment for growth. It has grown from 17 staff in 2018/19 to 95 staff and has totally equity of £16.5m.

Colorifix – was formed in 2016 by two biologists who were developing sensors to monitor heavy metal contamination in Nepal. Having seen the impact of the dyeing industry on water and human health they decided to develop safe natural pigments for the dyeing industry using microbes and a fermentation process to produce the colour in commercial quantities. The company is pre-commercial but has grown to employ 39 staff.

4. Summary of Impacts

A summary of JIC's impact, based on the selected case studies, is set out below with assumptions set out in Appendix 1.

JIC's impact is considered under four headings highlighting the global impact of its research:

- Global Food Security
- Bio-engineering
- Global Nutrition and Health and
- Environment and Biodiversity

In terms of **global food security**, JIC continues to be a major contributor to the **UK's Designing Future Wheat** programme as well as undertaking other extensive ongoing research in wheat. A new **Delivering Sustainable Wheat** Programme is getting underway. JIC's work is estimated to contribute £496m GVA to the UK and £21.4bn to the rest of the world through improved wheat productivity over the next 25 years.

JIC's research in reducing the need for vernalisation in **high performance brassicas** could make a major contribution to UK production with new higher yielding varieties. These are estimated to potentially deliver £167m GVA to the UK and £547m to the rest of the world over the next 25 years. By supporting development of less temperature sensitive **oilseed rape** JIC could support impact of an estimated £72m GVA to the UK and £530m to the rest of the world over the next 25 years. Improving productivity of brassica crops will also encourage farmers to include such crops in rotations thus improving soil quality.

JIC's work in **bio-engineering** has potential to deliver new more sustainable novel plant products. The vaccine adjuvants market has grown rapidly and JIC's technique for producing QS-21 could generate substantial market share delivering £56m GVA to the UK and 1.6bn to the rest of the world over the next 25 years.

Antibiotics continues to be a research area for JIC with new discoveries having the potential to reduce MRSA as one example of potential impact albeit a relatively low level of attribution to JIC. Reducing fatalities and health care costs could be equivalent to £3.4bn GVA in the UK and £24bn in the rest of the world over the next 25 years.

JIC is delivering solutions contributing to **global nutrition and health**. JIC's research in resistant starch could deliver major public health benefits if it is implemented into UK diets with potential savings to the UK healthcare system and improved productivity worth £661m over 25 years. Vitamin D and iron enrichment are further areas of public health interest with substantial potential, especially amongst the elderly and potentially worth £287m over the next 25 years based on attribution to JIC of 30%.

The final area of JIC impact considered is **environment and biodiversity** where JIC's work in Xylella preparedness is helping to safeguard the UK from the threat of incursion. The value of this attributable to JIC is estimated at £650m to the UK over 25 years.

JIC's ongoing training of PhD, Postdoc, Masters and undergraduate students provides an estimated £116m of GVA at the UK level and £64m to the rest of the world over 25 years.

JIC and its research partners on the Norwich Research Park are an important cluster that is drawing in investment from around the world as well as creating new spin outs.

JIC's operating impact (from staff and supplier spending) supports 881 jobs and generates £42.5m of Gross Value Added (GVA) across the UK economy per year.

Alongside the case studies an economic model has been developed to capture and estimate the impacts of JIC. This model assesses the actual and potential impacts of JIC using reasonable assumptions developed in consultation with JIC and industry.

All impacts are expressed as Gross Value Added (GVA) the Government's preferred method of economic activity.

A summary of the combined impacts is set out below over the next 10, 15 and 25 years at both UK and Global levels. The Return on Investment (RoI) of JIC's science is also estimated.

This report identifies research impacts of £1.578bn at the UK level over 10 years and a return on investment (RoI) of £15.29 per £1 invested. This rises to almost £6bn over 25 years. This is based on the sample of commercialisation projects reviewed and the research costs they represent (around a third of JIC operating costs).

An assessment of attribution to JIC is included along with conservative assumptions to assess potential impacts. This compares to the previous report (2018) which had a RoI of £14.22 per £1 invested.

Table 6.1 Summary of JIC Impacts from the case studies

Total impacts	NPV - 10 yrs	NPV - 15 yrs	NPV - 25 yrs
UK (excludes operating spend)	1,578,911,892	3,159,605,521	5,951,968,683
Rest of the world	11,177,193,783	24,255,375,166	48,034,075,834
Total	12,756,105,675	27,414,980,687	53,986,044,517

Operational cost attributable	NPV - 10 yrs	NPV - 15 yrs	NPV - 25 yrs
Direct costs	103,292,238	143,046,243	204,700,411

RoI (GVA leverage)	NPV - 10 yrs	NPV - 15 yrs	NPV - 25 yrs
UK	15.29	22.09	29.08
Rest of the world	108.21	169.56	234.66
Total	123.50	191.65	263.73

A summary of the results in more detail shows the split of impacts by type and at UK and global level.

Economic benefits to the UK	NPV - 10 yrs	NPV - 15 yrs	NPV - 25 yrs
Education and training impacts	89,689,010	114,879,612	115,678,707
Productivity impacts	415,667,146	766,820,822	1,405,844,448
Health impacts	1,059,602,710	2,256,298,767	4,394,529,279
Environmental Impacts	13,680,677	21,221,393	35,345,361
Total impact on the UK economy	**1,578,639,543**	**3,159,220,594**	**5,951,397,795**

Economic benefits rest of the world	NPV - 10 yrs	NPV - 15 yrs	NPV - 25 yrs
Education and training impacts	49,847,298	63,690,669	64,126,766
Productivity impacts	5,904,401,074	12,306,255,323	24,159,156,610
Health impacts	5,222,945,412	11,885,429,173	23,810,792,458
Environmental Impacts	-	-	-
Total impact rest of the world	**11,177,193,783**	**24,255,375,166**	**48,034,075,834**

Total economic benefits	NPV - 10 yrs	NPV - 15 yrs	NPV - 25 yrs
Operating spend	103,292,238	143,046,243	204,700,411
Visitor spend - in UK economy	272,349	384,927	570,887
Education and training impacts	139,536,307	178,570,281	179,805,474
Application of research outcomes	6,320,068,220	13,073,076,145	25,565,001,058
Health impacts	6,282,548,121	14,141,727,941	28,205,321,737
Environmental Impacts	13,680,677	21,221,393	35,345,361
Total impact on the global economy	**12,859,397,913**	**27,558,026,930**	**54,190,744,928**

5. Appendix 1 Methodology

In order to measure impact, each area of JIC science was reviewed and routes to impact assessed. Four broad headings for JIC's areas of impact were selected. Under these four headings, nine areas were chosen as case studies in consultation with JIC. The areas were chosen to give the best representation of current research effort, taking into account previous impact reports and the evolution of JIC's research over time.

In each case, the impacts were explored by modelling socio-economic outcomes of the research such as improved health, improved productivity, and environmental benefits. Impacts are quantified at the UK level, and in most cases, estimates made for global impacts as much of JIC research has global application. The Green Book does not normally include non-UK benefits, however, to not include these would be to significantly underestimate the value of JIC's research. Softer impacts such as academic, collaboration and human capital are also highlighted. Findings were shared back to scientists for comment and amendment.

The report contains a mixture of actual and potential impacts, as the fundamental nature of JIC's research has often not yet fed through to final impacts. In all cases, estimates or examples have been used of actual and potential impacts based on available evidence with conservative assumptions relative to a counterfactual where no improvement takes place. The impacts are assumed to be net additional at the UK level – much of JIC's work is displacing activity from overseas or improving UK potential.

Attribution of the results to JIC is calculated based on the consultations and the scale of JIC's role relative to other actors. This varies for each area with rates of 30% or 10% being examples. The attribution is a simple way of ensuring that JIC's net impact is not overstated but it is not an exact science.

Estimates of the rate of adoption of the research/technologies are also included along with a build-up of impacts so that net impacts are measured over a 10, 15 and 25 year period (base year 2022) by way of a net present value (NPV) and discount rates in line with HM Treasury Green book. The 10, 15 and 25 year NPVs presented can be considered the net contribution to the UK economy. The value for money or return on investment (ROI) for JIC's research can then be measured by dividing the net economic impacts by the research costs. The ROI compares the case study impacts, excluding operating and training impacts with a proportion of the annual costs of running JIC, this proportion being agreed with JIC to represent the case studies (around £12m per year – JIC's total income in the latest year was £44m). This methodology provides a reasonable basis for estimating a proportion of JIC impact and the ROI associated with it. By its nature, the case study approach cannot cover every aspect of JIC's work.

6. Appendix 2 Case Study Assumptions

The following assumptions have been used to generate impacts in the model. These assumptions are based on consultations with JIC, industry consultees, market data and official sources. Where no information has been available, reasonable assumptions have been made by Brookdale. The economic model has been designed in accordance with HM Treasury Green Book principles and uses a 25 year appraisal period.

Wheat

- Based on official data for UK and global wheat production (Defra and FAO).
- Assume 1% productivity increase per year from year 1 to reflect JIC historic research and based on the literature – see reference in report. The increase is capped at 5% cumulative figure in Year 5 and from then on till Year 25.
- Adopted by 40% of UK wheat production and 20% of global.
- Periodic disease outbreaks e.g. yellow rust have 10% less impact than otherwise in years 10 and 17.
- Disruptive productivity improvement implemented from year 10 giving a 10% uplift to the improved crop at the adoption rates above.
- Any price changes of wheat are ignored.
- Attribution of 30% to JIC.

High Performance Brassicas

- Based on official data for broccoli and cauliflower production (Defra) and industry estimates of savings per ha.
- For indoor production, assume extra yield of £561 per ha and reduced harvesting costs of £2,808 per ha and reduced retail waste of 2.5% of farm gate price from year 4 building up from 500 to 2,000 hectares over 4 years from Year 5.
- For field varieties, building up over years 7-10. For broccoli the mid-point of savings is used and for cauliflower, £1,120 plus £160 harvesting saving per hectare.
- For the rest of the world, EU production figures are used with the same assumptions for field production only with adoption from 25% in Year 7 to 75% in Year 9 and remaining at that level.
- Any price changes of product are ignored.
- Attribution to JIC 50%.

Oilseed Rape – Vernalisation

- Based on official data from Defra, JIC estimates of vernalisation yield benefit (25%) are applied to latest UK production data and a 15% increase to EU data which gives £121m and £893m respectively in terms of the value of additional OSR ignoring any price elasticity effects.
- This is built up from Year 6 to Year 8 from 25% to 75% adoption with the vernalisation benefit happening every 5 years from Year 6 (Yrs 11, 16, 21).
- Attribution of 30% to JIC.

QS-21

- Market size data of £1.26bn from industry sources.
- Assume 20% market share achieved with build up from years 6-9 from 25% to 90%.
- Benefits split pro rata between UK and rest of world on the basis of population size/health spend giving £8.37m per year UK and £244m per year rest of the world, the UK being 3% of global health spending.
- This 3% could also represent a royalty to the UK for the new technology as it is not clear if production will actually happen in the UK.
- The market has grown very rapidly from $796m in 2018 to $1.5bn in 2022 so likely the impact of this technology could be substantial.
- Attribution to JIC 50%.

Antibiotic Resistance

- MRSA is used as an example with 5,120 deaths annually UK and 294k rest of the world.
- This is based on journal data on number of global cases and official UK government data on value of fatalities avoided.[46]
- GRAM report estimates 121,000 deaths attributable to MRSA globally in 2019 with a further 473,000 deaths associated with MRSA.
- Total deaths split pro rata between UK and rest of world on the basis of population size giving 5,120 per year UK and 294,440 per year rest of the world.
- Assume reduced mortality rate due to new antibiotics of 25% in UK and 10% in rest of world. Build up from years 6-9 from 25% to 90% in line with new antibiotic product market assumptions above.
- Attribution to JIC 10%.

[46] The UK Treasury currently uses £2m as the value of a single prevented fatality (VPF) in economic appraisal (HM Treasury 2018). This figure is used by the Department for Transport (DfT) among other government bodies and is based on research conducted on behalf of DfT on the internal willingness-to-pay valuations of individuals to avoid mortality risk.

Resistant starch – Peas

- Global health expenditure caused by diabetes in 2021 of £805bn. Expenditure split into £19.5bn UK, £138bn Europe and £647.5bn ROW based on IDF report data.
- Assume 10% cost reduction achieved in UK, 5% in EU and 0.5% ROW, with build up from years 3-6 (25-90%).
- Pea flour market size data of £456bn from industry sources but assume this is all displacement so not included.
- Estimate a calorie reduction due to incorporation of resistant starch in the diet.
- Due to uncertainty, this focuses on the UK only where the Department for Health and Social Care (DHSC) model can be used to quantify the benefits of a small calorie reduction across the population.
- Assume 30kcal reduction achieved with 30% effectiveness gives 9kcal per day and this generates savings of £5.4bn plus NHS savings of £510m and social care savings of £566m.
- Attribution to JIC is estimated at 10%.

Vitamin D Production

- Cost of £100m per year to NHS from treating vitamin D deficiency. Assume 25% cost reduction achieved with build up from years 6-9 (from 50-90%) in UK only.
- In addition, given the potential to increase dietary Vitamin D, we assume that the net health benefits (reduced falls and deaths) increase by 25% or £21m with same build up as above.
- Total annual benefit is £46m.
- Attribution to JIC 30%.

High-Iron Peas

- Costs of Iron Deficiency (ID) have been rising. Iron Sulphate is poorly tolerated. JIC pea mutants have high iron content with good bioavailability and no adverse reactions.
- ID treatment in UK has seen a 72% increase in hospital admissions 2012-2017/18
- In particular non-elective visits are expensive and disruptive. Increasing peas in diet or as food supplements instead of iron sulphate will reduce the problems.
- Reduction with range of 7-63 admissions, take midpoint of 35 per 100,000.
- UK population of 67.1m (ONS) so 671*35=23.485*£1,676=£39.36m in 2018 *1.11 to convert from nominal into 2022 prices = £43.69m.

- Assume half of this is achieved so £21.8m.
- Build up from Years 5-9 (25% to 90%) with 30% attribution to JIC.
- UK only benefits due to uncertainty about rest of the world. But could be further global benefits.

Xylella

- Horticulture industry worth £5bn p.a. from industry sources.
- Assume 50% prevention of losses to 32% of industry achieved with two assumed outbreaks peaking in years 10-11 and 20-21 informed by BRIGIT research on likely rate of spread, thus having less impact.
- Social and environmental value of oak and elm trees of £341m p.a. from industry sources.
- Assume 50% prevention of losses to species in 27% of land area with build up from years 1-10 as above.
- Benefits concentrated in UK.
- Attribution to JIC 10%.

Training

- Modest salary uplifts are attached to the level of training (DFW, MSc, PhD and Post doc) in line with the UK literature on the impact of training on salaries.
- Salaries are then converted to GVA.
- Impacts tail off over 10 years.

Research Cost assumptions

- In discussion with JIC, it has been agreed that the case studies considered represent around a third of JIC's activity.
- On this basis, the cost benefit analysis takes £12m of JIC annual running costs on the cost side of the calculations.
- This, combined with attribution levels in each case study based on the number of actors involved allows net impacts and return on investment to be calculated.