TIGR²ESS

Transforming India's Green Revolution by Research and Empowerment for Sustainable food Supplies

Transforming India's Green Revolution by Research and Empowerment for Sustainable Food Supplies

A synthesis of research outputs and forward thinking with the TIGR²ESS GCRF programme consortium

June 2022

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Transforming India's Green Revolution by Research and Empowerment for Sustainable food Supplies

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The TIGR²ESS Programme: Context, Vision and Legacy

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Since the 1960s, intensive agriculture in India's Green Revolution has led to multiple inequalities and unsustainable pressure on natural resources. As the climate changes, there is an urgent need for a more sustainable, resilient, and equitable food and water system for the world's fastest growing population.

'A wonderful collaboration where complementary skills have brought about new knowledge.'

Prof Usha Vijay Raghavan

Context for the Programme

The father of India's original Green Revolution, M.S. Swaminathan, has warned the nation that yields are threatened by increasing temperatures and drought. The vulnerable sectors of societies were highlighted at being most at risk and likely to be facing malnutrition once more.

Vision of the TIGR²ESS Programme

Through the GCRF Grow Call, we aimed to future-proof food-system processes across contrasting agroclimatic zones in India. The consortium initiated a network of interdisciplinary collaborations across science, engineering and social science researchers. The programme incorporated regular dialogues, training and engagement programmes with a focus on equal opportunities and female empowerment.

Fundamental research activities ranged from the molecular basis of crop improvement, to the evaluation of water conservation and delivery of alternative cropping systems. These were coupled with novel interventions to improve education, health, nutrition and promote financial independence and resilience for rural communities.

TIGR²ESS Delivery and Outcomes

In this summative brochure of case studies, we celebrate high impact outputs which have arisen across relevant fundamental science and societal research questions. Our understanding of crop diversity and varietal traits has been advanced for intensively irrigated and semi-arid dryland staples (wheat, millets, sorghum) across India's agroclimatic zones, informed by archaeological and contemporary methods for best practices in managing common water resources.

Across the programme's six Flagship Projects, researchers established novel technologies and approaches, which were translated through community engagement activities and workshops. Outputs from their research have led directly to: policies being adopted to promote water conservation, marketing diversification, female entrepreneurship, and education for food and nutritional security in the communities most vulnerable to climate change.

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1. Advanced Crop Breeding for climatic resilience

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1.1 Smart water-use sorghum and pearl millet lines for dryland systems

Research at ICRISAT measured and compared crop traits (phenotypes) to identify climate-smart lines from global diversity collections of sorghum and pearl millet. This method yields precise data on water-consumption related to crop yields and provides information on traits (here transpiration efficiency) that contribute to yield increase. Climate smart-lines were identified for inclusion in breeding programs to develop cultivars adapted to drought conditions.

The climatic challenge for high-yielding varieties: drought

The 1960s Green Revolution saw accelerated breeding programmes develop high-yielding (elite) cereal crop varieties which provided food for a rapidly growing global population. The introduction of and dependence on water-thirsty varieties harvested twice annually across arid regions of India has reached tipping point, with a reported 60% decline in agricultural productivity of sorghum and pearl millet, caused by drought stress and land-use change.

Automated phenotyping monitors water use

Researchers at ICRISAT developed an automated crop monitoring facility including lysimeters, which weigh weekly water use by individual elite varieties of Sorghum and pearl millet. Allowing rapid identification of drought tolerant phenotypes to enable climate-smart lines to be selected from global diversity collections. This method yields precise data on water-consumption in relation to crop yields and information on the genetic links that combine water use efficiency with yield increase.

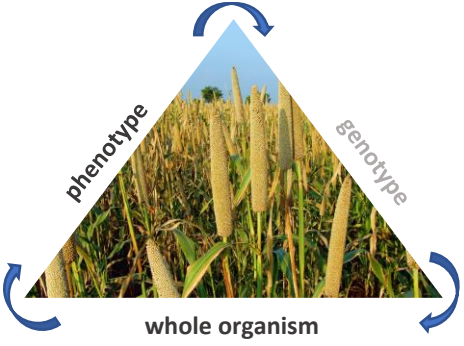
Climate smart lines were identified for inclusion in breeding programs to develop more resilient varietal lines adapted to drought conditions.

A citizen science approach with tribal small holder farmers

In collaboration with the Centre for Collective Development, Utnoor, the ICRISAT team introduced small-holder farmers from tribal regions in Telangana, to the water-efficient varieties of Sorghum for comparison with traditionally preferred varieties.

Participatory engagement processes explored farmers' needs and varietal preferences, as well as suitability for local growing conditions. Researchers discovered that the tribal farming communities valued grain quality, taste and resilience to drought and disease over high-yielding varieties.

Working closely with farmers in the early stages of the research-planning process enabled researchers to demonstrate the benefits of drought-adapted varieties to farming communities in water-limited regions.



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TITLE:	Transforming India's Green Revolution by Research and Empowerment for Sustainable food Supplies (TIGR²ESS)
GRANT NO:	BB/P027970/1
LEAD INVESTIGATOR & CO-INVESTIGATORS	Sivasakthi,K, Srikanth Bollam, Tharanya, Santosh P Deshpande, Rakesh K Srivastava, Damaris A Odeny, Jana Kholova and Rajeev Gupta ICRISAT, Essex, NIPGR

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INTERNATIONAL CROPS RESEARCH INSTITUTE FOR THE SEMI-ARID TROPICS

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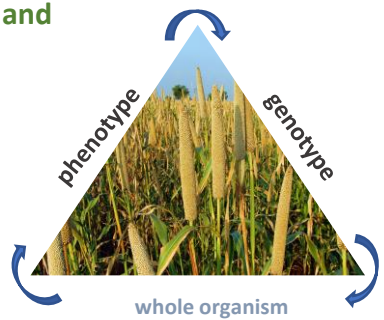
1.2 Elucidation of genetic basis of water use efficiency in sorghum and pearl millet through genome-wide association studies and transcriptome profiling.

*TIGR2ESS research partnerships shed new light on genetic basis of **Water Use Efficiency (WUE)** in sorghum and pearl millet which links phenotypes to drought resilience and yield enhancement. Detecting the principal genes responsible for increasing a plant's tolerance to extreme conditions requires advanced biotechnological tools to ensure that we understand the basis to drought resilience and can breed crops for the future*



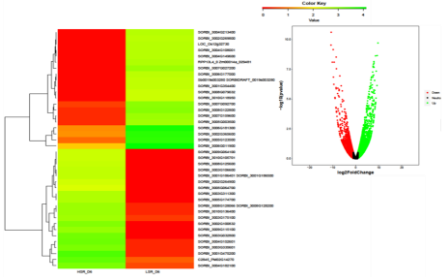
Collaborating phenotyping and molecular breeding teams at ICRISAT investigated genetic variation in sorghum and pearl millet with the aim of identifying tolerance traits which will keep pace with predicted climate change. Integrated genomic approaches which include Genome Wide Association Studies (GWAS) and transcriptome analyses across contrasting lines or individuals were used to pin-point alleles, candidate genes and gene networks that couple with improved WUE.

Global diversity panels, analysed over two seasons by ICRISAT's phenotyping team, included all basic and intermediate races of Sorghum and represented the genetic diversity of pearl millet across 27 countries. Once phenotyped, marker trait associations (MTAs) were established using GWAS for data generated under well-watered and water-stressed conditions. These MTAs were annotated to identify putative candidate genes involved in drought adaptation and WUE in sorghum and pearl millet.

Sorghum and pearl millet lines with natural resilience to drought were selected based on phenotypic data. Genome-wide transcriptome analysis by deep sequencing was done for contrasting lines in order to identify differentially expressed genes (DEGs) and gene networks associated with WUE and physiological and developmental traits.

The research identified promising sorghum and pearl millet lines for WUE associated traits. The promising lines will be exploited to serve as valuable QTL donors for improving trait using MABC/FB. GWAS and transcriptome profiling facilitated the identification of candidate genes and QTLs related to drought adaptation and water use efficiency in sorghum and pearl millet.

This study was directly linked with the analysis of stomatal and other molecular physiology studies at the University of Essex, allowing a fully integrated investigation of promising lines for future breeding programmes.



Transcriptome analysis for root samples of contrasting sorghum genotypes under water stressed conditions

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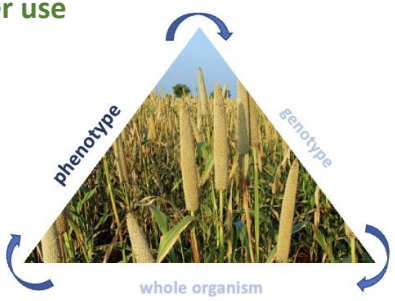
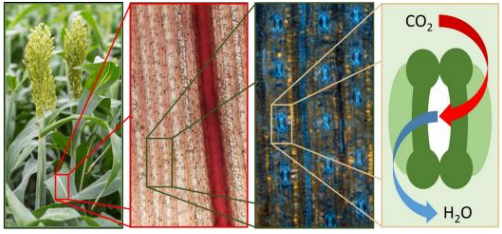
1.3 Advanced methodologies identify the basis to plant water use and drought



Exploiting the physiological controls on leaf water loss in Sorghum and Millet

Photosynthetic CO_2 uptake is critical for plant growth and crop yield, but around 1000 water molecules are lost for every CO_2 assimilated. Hundreds of tiny pores, called stomata, are found in each mm^2 of leaf surface. They act as variable valves, controlling the supply of CO2 whilst sensing the evaporative cost in terms of water through transpiration. TIGR2ESS researchers are investigating how this relates to crop resilience to drought, in varieties of sorghum, millet (and wheat) which possess stomata that are more sensitive to dry environments, potentially allowing these plants to respond more rapidly to future climate change.

Evaluating crop water use efficiency is technically demanding High throughput screens are needed to evaluate genetic variations in water use traits which can relate to water-use efficiency. Variations can be quantified by measuring the ratio of water loss per unit carbon gain, defined as water use efficiency (WUE). Relative to photosynthesis, stomata are an order of magnitude slower in responding to transient changes in environmental conditions. Measurements are time- consuming and require elaborate gas exchange equipment. The latest technology uses infra-red thermography allowing leaf temperature to indicate the extent of evaporative cooling (and transpiration rate) in contrasting crop lineages.



Stomata are tiny pores on the leaf surface which allow CO_2 in and water out

Speedy stomata can enhance photosynthesis and improve water use

Measurements of stomatal sensitivity are providing a mechanistic basis to whole plant phenotypic screens.

Researchers at the University of Essex investigated traits linking photosynthesis to water use in a range of Sorghum and Millet in landraces, traditional cultivars, breeding material and elite varieties identified by TIGR2ESS partners based at ICRISAT. This has led to varieties being ranked on the basis of stomatal density and WUE.

The studies have identified the most suitable lines for international crop breeding programmes which will be resilient and adaptable to more extreme climatic conditions in the future. In addition, selected lines were measured in detail to evaluate the amplitude and speed of stomatal movements for maximising assimilation of carbon at the lowest cost of water (high WUE), as well as developing online resources and protocols to support a broader international community phenotyping during Covid lockdowns

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LEAD INVESTIGATOR, CO-INVESTIGATORS & PARTNERS:	Tracy Lawson, Martin Battle, Silvere Vialet-Chabrand (University of Essex) and partners at ICRISAT

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University of Essex

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1.4 Re-creating Wheat: Enhancing genetic diversity to deliver drought tolerance

Major research at Punjab Agricultural University (PAU) aims to increase the genetic diversity of wheat by incorporating genes from early grass progenitors into the modern 'hexaploid' wheat genome. These are being selected to increase drought tolerance and lower demand for water overall. The key approaches at PAU allow modern genetic approaches to be allied with traditional breeding and evaluation under field conditions for more rapid development of wheat varieties which are resilient under the extreme heat and drought conditions more frequently being encountered due to climate change.

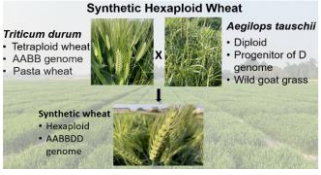
Modifying wheat using traditional breeding approaches is challenging and time consuming

Wheat breeding is complicated because traits are carried by genes across six sets of chromosomes. There are also distinct regional requirements: the growing season in India demands fast-maturing varieties, in contrast to the UK.

Pioneering researchers at PAU are using at least three contrasting approaches to increase genetic diversity and screen drought tolerance traits within advanced wheat varieties, which can then be delivered direct to farmers:

- **Synthetic wheats**
- **Chromosomal segmentation substitution**
- **Mapping populations**

Group	Pedigree/Combination	No. of Synthetics
Group-1	PBW114-*Aegilops tauschii* 14102	23
Group-2	PBW114-*Aegilops tauschii* 14128	63
Group-3	PBW114-*Aegilops tauschii* 14170	29
Group-4	PBW114-*Aegilops tauschii* 9809	18
Group-5	PBW114-*Aegilops tauschii* 9810	32
Group-6	PBW114-*Aegilops tauschii* 3761	8
Group-7	PBW114-*Aegilops tauschii* 14328	69
Group-8	PBW114-*Aegilops tauschii* 14576	7
Group-9	PDW233-*Aegilops tauschii* 9796	1
Group-10	PDW233-*Aegilops tauschii* 14135	4



Screening of synthetic hexaploid wheat under drought stress

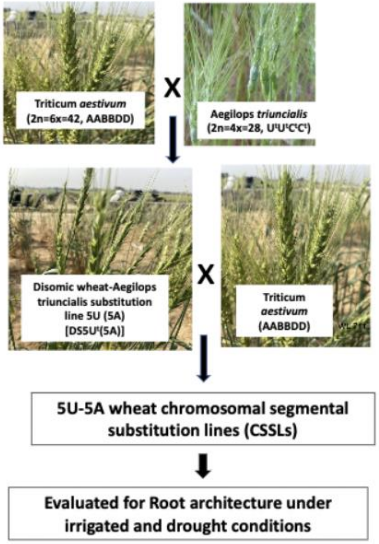
Selecting for Previously Neglected Root Traits

Root characteristics are substantially connected to drought stress. Studies on synthetic wheats (recrossing durum wheat and with wild goat grass lines) have opened up tremendous opportunities to understand the complex architecture of drought tolerance mechanisms.

An initial synthetic wheat population, was screened for phenotypic plasticity for drought tolerance using hydroponic solutions. Traits being selected included longer roots, increased root growth and biomass. The outputs provided a unique example of success using wild relatives in mainstream breeding at a large scale.

Using an alternative approach, the chromosome segmentation substitution lines initially incorporate copies of chromosomes from a wild grass relative (*Aegilops triuncalis*), with genes then crossed into elite wheat varieties. Lines were identified which had longer, thinner roots with a higher biomass, greater ability to seek out water and sustain productivity under drought.

Development of Chromosomal Segmental Substitution lines (CSSLs)



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LEAD INVESTIGATOR, CO-INVESTIGATORS & PARTNERS:	Achla Sharma, Parveen Chhuneja, Satinder Kaur, Raveneet Kaur, Himanshu Sharma. NIAB and Rothamsted Research

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1.5 Sustaining wheat yields under drought and heat stress and recovery

Wheat and Climate Change

TIGR2ESS research teams based in India and UK focused on sustaining wheat yield under climate extremes, identifying wheat genotypes that are tolerant of heat and drought. The identified genes and metabolites specific to the tolerant genotype revealed specific metabolic pathways, genes and traits that can now be targeted for breeding and for in-depth analysis.

The Challenge: Heat and Drought Resilience in Wheat

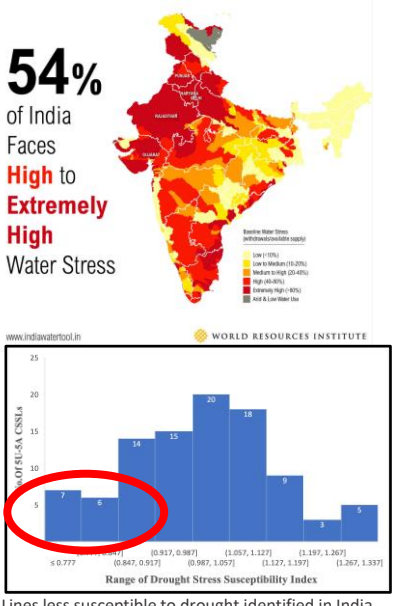
Wheat forms 20% of human calorie consumption and it is a highly valued commodity in India with a value of ₹1.29 trillion India (£12.5 billion) and £2.5 billion in the UK (2019). Predicted effects of climate change on the production of wheat are significant, with forecasts of up to a 23% production gap in India by 2050. To address this deficit in wheat supplies, it is crucial that knowledge and tools become rapidly available for resilience-breeding programmes.

Wheat genotypes were assembled and shared between partners and screened (i) under field conditions during multiple seasons by PAU (ii) during vegetative heat stress at Rothamsted Research, (iii) under drought conditions at NIAB. A wheat diverse panel were additionally monitored for performance using the field-system phenotyping platform developed by partners at ICRISAT.

Phenotyping studies identified stress-tolerant line which produced larger yields compared to current commercial varieties under both stress and non-stressed conditions. Additionally, analysis of the identified heat tolerant genotypes revealed novel mechanisms of tolerance which will be targeted for future studies. Wheat lines with increased drought tolerance are currently being introduced into breeding programs and will be made available internationally.

The Future

Drought is episodic, with more than one period of little rainfall followed by irrigation. Crop recovery and achieving productive yields after extended periods of drought is as important as pure crop tolerance to these conditions. TIGR²ESS interdisciplinary collaborations continue to focus on trait combination for better resilience to multiple climate factors and episodic drought conditions. The research will ensure future sustainable production of wheat crops across global climatic regions.



Lines less susceptible to drought identified in India

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LEAD INVESTIGATOR, CO-INVESTIGATORS & PARTNERS:	Robert Jackson (NIAB), Alison Bentley (CIMMYT, Lead), Phil Davey (University of Essex), Tess Dilks (Rothamsted), Sigrid Heuer (NIAB/Rothamsted, Lead), Tracy Lawson (University of Essex), Eric Ober (NIAB), Ravneet Rai (PAU), Achla Sharma (PAU, Lead), Himanshu Sharma (PAU).

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1.6 TIGR2ESS: FieldCAM-Quant (FCQ)

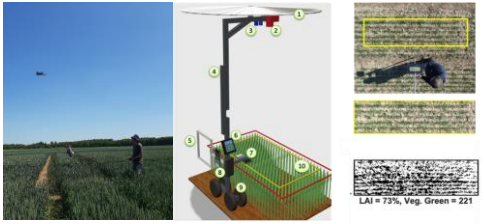
Climate change negatively impacts food production requiring an urgent need to speed up and scale up the search for resilient crop varieties. TIGR²ESS researchers developed the FieldCAM-Quant (FCQ), a low-cost, open-source and mobile in-field device for rapid assessments of crop lines, with wider implications for global food security.

The challenges: Bringing a new crop variety to market demands labour-intensive processes requiring multiple measurements, ranging from height and biomass to flowering-times, to be made throughout the year. Drone technologies can perform rapid assessments in the field but they are costly and require a high level of technical expertise.

Travel restrictions during the COVID-19 pandemic saw a reduction in the availability of labour for agricultural fieldwork studies in India. TIGR²ESS researchers were faced with a stark choice between assessing fewer plant traits or assessing fewer varieties. The first choice gives a less accurate assessment, potentially resulting in the selection of poorer varieties. The second approach runs the risk of missing a high performing variety.

Developing accessible technologies: To address these scenarios, researchers at NIAB developed prototype FieldCAM-Quant (FCQ); a cheap, mobile tool that is easy to construct. Once assembled, image acquisition is a simple process using cameras controlled using a smartphone. Basic analysis can be carried out on the smartphone, giving instant readouts or enabling images to be stored and later analysed.

Precision and impact: While most visual measurements performed by humans are subjective the FCQ technology provides consistent measurements. Due to its low cost, open-source nature, the FCQ can be deployed in any location by someone with minimal training. A single worker will be able to assess more varieties in a day for more traits, increasing the capacity of those using the device and compensating for labour shortages.



Design of FIeldCAM-Quant with example of conversion of original image into an image to be analysed and final output as a Leaf Area Index.

TIGR²ESS provided the opportunity for the NIAB team to develop and construct a prototype, which will be tested throughout 2022. It is envisaged that the FCQ will be constantly developed over the next 5-10 years by NIAB to meet the changing needs of agricultural research and development.

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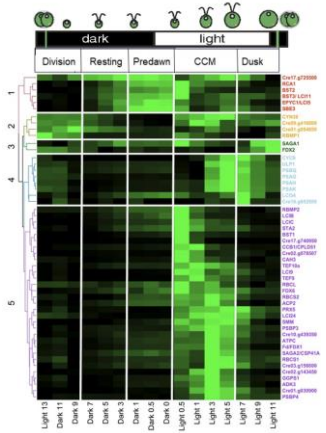
1.7 Understanding Genetic Regulation of Photosynthetic Mechanisms to Enhance Plant Productivity



GRAPH EMBEDDING THE DYNAMIC LANDSCAPES OF CCM GENE OPERATION

"Recommendations to funders and policy makers: support for individuals is crucial in order to conduct high quality research, and to train upcoming generations that are the future researchers in a developing country"

Prof Nyovani Madise
Director of Research for Sustainable Development Policies AFIDEP

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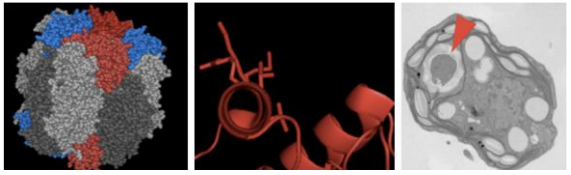
Measuring and monitoring gene expression provides fundamental insights for plant photosynthesis *Food security for a burgeoning global population, facing the threat of a changing climate, will require a paradigm shift in crop production and stress resilience. Major efforts are being directed at understanding how we might turbocharge crop productivity; perhaps by augmenting photosynthesis with a carbon concentrating mechanism (CCM). Current approaches range from incorporating elements of maize photosynthesis into rice, but in a collaboration between Cambridge and NIPGR, New Delhi, we have defined novel highly productive algal traits prior to transfer into higher plants.*

The Microbial Carbon Concentration Mechanism could enhance Agricultural Production The key enzyme driving carbon uptake by plants (RubisCO) is slow and rather inefficient. Algae have evolved a CCM which helps to turbocharge photosynthesis. Using the model green alga, *Chlamydomonas reinhardtii,* a partnership between Cambridge and NIPGR has been investigating the molecular basis of the mechanism which allows RubisCO to aggregate within a subcellular microcompartment, the **pyrenoid**. We have been characterising how a specific protein, EPYC1, acts as a molecular glue to facilitate pyrenoid assembly, and using outputs from the GRN analysis to identify key molecular factors which co-ordinate CCM operation. In future, these carbon capture mechanisms (CCMs) could be transferred to higher crops to increase photosynthetic efficiency and resilience to environmental stress.



Revolutionising genomics though modelling and empirical studies Tremendous advances in the availability of high throughput Omics- datasets demand new analytical protocols for sifting and sorting genes related to specific traits. Colleagues at NIPGR are pioneering new algorithms and computational methods to find the proverbial needle (key regulators) in the haystack of hundreds of millions of transcriptional reads. Spatio-temporal mapping of changing relationships between genes allows key regulatory hubs to be identified at important stages of plant or algal development, using Gene Regulatory Networks (GRN) and graph embedding methods for transforming nodes and edges into numerical representations.

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Department of BioTechnology, Government of India

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2. Millets:
local and regional opportunities for crop diversity and acceptability

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2.1 Odisha Millets Mission: Improving Nutrition and Farm Incomes

Rice, maize and wheat account for 60% of plant-based calories consumed world-wide. Dependence on these crops, bred for yield rather than resilience, is part of the reason for India's current agricultural and nutritional crisis. Millets, a nutritious and climate-resilient crop, championed by the Odisha Millets Mission, could be an important part of the solution.

The Odisha Millets Mission (OMM) was launched in 2017 to improve nutrition through the revival of millets on the farms and plates of tribal communities in Odisha. The program has successfully introduced millets in the Public Distribution System and other State nutrition schemes.

The project includes partners from academia, regional government and civil society; breaking down conventional silos to come together to combine traditional knowledge and cutting-edge science to open up new possibilities and improve the food system, from diets to farm incomes. To address a gap between producers and consumers, the programme has worked across four vertical themes: production, processing, marketing and consumption.

The first-year outcome, compared to a baseline, led to a doubling of output and trebling of additional value, paving the way for the Programme's expansion from 30 blocks (a block is subdivision of a rural administrative district) across seven districts in year one (2017-18) to 84 blocks across 15 districts by year five (2021-22). The Programme expanded from 8,030 farmers cultivating millets in 3,399 hectares in year one to 1,18,561 farmers cultivating millets in 54,496 hectares in year five. and, in 2022-23, the planned expansion is 81,700 hectares in 142 blocks across 19 districts.

The intervention shows great promise in addressing nutritional deprivation in Odisha particularly in the tribal population.

The World Food Programme has entered into an agreement with the Government of Odisha to document, provide technical support and share what has been learnt from the Mission in a global platform in line with the UN General Assembly's designation of2023 as International Year of Millets.

The Government of India has set up a task force to understand the framework of the Odisha Millets Mission and revise the National sub mission on millets based on the learnings of the OMM.

CMO Odisha
@CMO_Odisha

#Odisha Govt's #MilletMission is boosting consumption of nutrition-rich millets across the state. The mainstreaming of millet is also contributing to the nutrition security and strengthening of livelihoods of small farmers, including women.

> **United Nations in India** @UNinIndia · 30 Mar
> Subasa Mohanta is no stranger to hunger. Even after 16 long hours of back-breaking work as a farmhand, she didn't know where her next meal would come from.
>
> Then, in 2018, a small bag of seeds, 250 grams to be precise, helped her bid farewell to uncertainties around food & more.
> Show this thread

3:23 pm · 30 Mar 2022 · Twitter Web App

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LEAD INVESTIGATOR & PARTNERS:	Prof Srijit Mishra Government of Odisha, Odisha Millets Mission, Watershed Support Services and Activities Network (WASSAN), Nabakrushna Choudhury Centre for Development Studies (NCDS), and Indira Gandhi Institute of Development Research (IGIDR).
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Transforming India's Green Revolution by Research and Empowerment for Sustainable food Supplies

2.2 Millets: Closing the Circle on Production and Consumption for a Healthy, Resilient, yet Neglected Crop

Millets include a range of hard-grained cereals which are nutritionally rich in key micronutrients, with growth also resilient to heat and drought. However, widespread use is limited in part by cultural associations, with millets often considered to be inappropriate as an indicator of status, and difficulties in flour preparation with a short shelf life. Research undertaken through the TIGR²ESS and MillNETi programmes across contrasting agroclimatic zones and rural communities in India and sub Saharan Africa demonstrate how millets could make a major contribution to healthier diets and provide an economic opportunity for supply to rural and urban communities.

Challenges and opportunities for millet cultivation
Researchers identified major challenges both in terms of consumption and production for millets. With the more widespread availability and aspirations for the larger, starchy grains in wheat and rice, millets have been increasingly considered to be appropriate for impoverished communities or animal foodstuffs. In addition, there are challenges in terms of both processing and production.

Millets are laborious to process, and the flour has a shelf life limited to a few weeks. The lack of demand within rural communities, and absence of a supply chain network, limits the economic returns on such crops, even though they remain productive under more extreme climatic conditions.

The aims of the research were to engage with rural communities to promote the benefits of millets in terms of health and cropping diversity, and develop marketing opportunities for millets as smart foods in urban populations.

Local engagement was key to promote millet production and consumption. The researchers found that millets had once been widely grown and consumed across India, but had become an 'orphan' crop, with the cultural traditions displaced over recent decades.

The team included social scientists, economists and public administrators to tackle the challenges in production and processing. In Odisha, they used local languages and local recipes to restore pride and a positive appreciation of the nutritional benefits of millets for mothers and infants. On the production side, they helped farmers improve crop diversity, mechanise processing and develop marketing opportunities

Markets in urban communities could improve the supply chain and add value. Biofortified millets (produced by ICRISAT and HarvestPlus) could enhance novel millet food products. Overall, impact arose from improved nutrition, incomes and livelihoods, and enhanced self esteem for females, leading to resilience in the value chain for production and consumption of millets.

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GRANT NO:	BB/P027970/1
LEAD INVESTIGATOR & PARTNERS	Prof Shailaja Fennell Panjab University, ICRISAT, IIT Bombay, NCDS

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2.3 Promoting healthy diets and improving nutrition: Gender transformative behaviour change in Telangana, India

Despite substantial improvement in health and well-being since Indian independence, malnutrition remains a silent emergency in the country. TIGR²ESS researchers from ICRISAT found that even in areas where diverse crops are cultivated and there is access to government food security and nutrition programs, levels of stunting and wasting amongst children remain high.

The study focused on two tribal locations in Telangana where, for example, 57% of adolescent girls are underweight. Starting from the premise that what is on the plate is what matters for nutrition, they asked why plates in the area studied did not contain the kind of diversity essential to better nutritional outcomes.

Using participatory action research methods, the researchers collaborated with the communities to identify the issues involved, engaging with people of all ages, genders and walks of life, to take into account their particular needs.

Photo credits: NIN, India and R Padmaja, ICRISAT

Pictures show recommended "Healthy Plate" vs "My Plate" in rural and tribal areas.

Together with frontline workers they then developed a series of nutrition education sessions, covering nine focus topics, tailored to the needs of each section of the community.

Knowledge exchange and constant interaction were important elements; learning what was available in communities and understanding local food know-how, rather than imposing outside ideas.

The study found that enhancing the nutrition knowledge, attitudes and practices of the target population led to better food awareness. For example, families were enabled to allocate resources (scarce due to the Pandemic) according to need and thereby improve the nutrition of all.

The team are now working on scaling this up and developing digital tools/apps in the local language for use by front-line workers and communities as a whole.

The overall goal is the adoption of these practices as a regional policy, in particular using knowledge exchange to improve self-help and dietary expertise for females within rural communities.

Photo credits: R Padmaja, ICRISAT

Nutrition messaging on balanced diet for adolescent girls in Telangana.

"Working with the communities and co-designing nutrition education sessions will lead to transforming community attitudes towards healthy diets, food and nutrition alongside enhancing agency of women, men and frontline workers to challenge traditional norms and cultures around healthy eating."

Dr R Padmaja, ICRISAT

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LEAD INVESTIGATOR, CO-INVESTIGATOR & PARTNERS:	Professor Nitya Rao, University of East Anglia. Dr R Padmaja, ICRISAT. International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), MSSRF, Punjab University, NNEDPro

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2.4 International & Inter-programme Co-operation: Addressing Iron Deficiency by Enhancing the Presence and Bioavailability of Iron in Millets from Farm to Plate in India, Ethiopia and The Gambia

MillNETi

Funded by the BBSRC Food and Nutrition programme, Millets and Nutritional Enhancement Traits for iron bioavailability (MillNETi) programme investigated approaches to enhancing nutrition in The Gambia and Ethiopia by increasing the amount of iron in millets, and improving the bioavailability of this iron through food preparation practices. In The Gambia the focus was on the effects of biofortified pearl millet previously developed by ICRISAT. In Ethiopia (where finger millet is consumed presently) the potential to introduce pearl millet, and the biofortification of finger millet, was investigated.

Approaches to enhancing the amount of iron in millets through crop breeding and shifts in farming methods were explored. ICRISAT evaluated the effects of agronomy and landscape on micronutrients in millets, and NIAB characterised pearl millet biofortification for translation to other millets.

University of Cambridge researchers investigated the traditions and hierarchies of millet consumption in communities in The Gambia and Ethiopia. Work focused on Identifying Nutrition Sensitive Pathways in both countries alongside a qualitative investigation to develop a sustainable strategy for healthy diets across communities in The Gambia.

Nutrition researchers at Kings College London and Bahir Dar University conducted in vitro (lab-based) experiments to investigate the effects of fermentation and other traditional and contemporary Ethiopian cooking practices on making iron in pearl and finger millets bioavailable and bio accessible to human digestive cells. Researchers at the MRC Unit in The Gambia conducted an in vivo study to assess the iron bioavailability of biofortified Dana Shakti pearl millet in people.

Millets Festival in The Gambia

Cooking demonstrations in Ethiopia

The new Bio Lab in Ethiopia

Knowledge Exchange and Capacity Development: During the COVID-19 pandemic restrictions, resources were pivoted towards equipping a biolab at Bahir Dar University, including a laminar flow cabinet, CO2 incubator, microplate reader, microscope and cell culture consumables for iron bioassays. Researchers at Kings College London developed training videos in tissue culture bioassay methods and assisted the Ethiopian team online during micronutrient bioavailability assays.

Outreach and Impact: In The Gambia engagement with local communities was based on household surveys on food use and preparation. Research insights and findings were presented to communities through a Millets Festival run by MRC Unit in The Gambia. In Ethiopia a programme to enable last-mile research and innovation with smallholder farmers called 'Innovation Communities' was established by the Centre for Global Equality, an Ethiopian community development organisation JeCCDO and Bahir Dar University. Community members shared their food preparation methods with researchers, and researchers conducted nutrition workshops for communities.

Visits to India by Ethiopian researchers to attend TIGR²ESS events catalysed the development of new finger millet food products. Inspired by additional work on Millets in India, MillNETi researchers collaborated with local industry to develop nutritious cookies and cakes for the urban market in Ethiopia.

"**Recommendations to funders and policy makers:** increase in equitable partnerships; involve and engage communities. This leads to co-creation of ideas and co-authorship of research papers. Crucially it encourages scientifically excellent research, driven by the needs of research users and policymakers in LMICs." - **Prof Nyovani Madise**, Director of Research for Sustainable Development Policies, AFIDEP

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2.5 Millets and Sustainable Agriculture: Study conducted by Vertiver and IORA Ecological Solutions to support research under the TIGR2ESS programme

In India, arid and semi-arid regions account for more than 60% of the cultivated area under millets, providing around 40% of the food produced. These regions are characterized by long dry seasons and inadequate and unpredictable rainfall. In the past few decades, recurrent droughts and frequent dry spells have led to further land degradation and desertification. In arid and semi-arid conditions millets provide a viable and sustainable solution.

Millets once made up more than 40% of cultivated grains in India. Since the Green Revolution in the 1960s millet production has declined by 35%, due to the emergence of rice and wheat as preferred substitutes.

TIGR²ESS commissioned a socio-economic survey in five states (Andhra Pradesh (AP), Tamil Nadu (TN), Odisha, Rajasthan and Karnataka) to identify the challenges of millet farming, to mainstream research and policy actions. Farmer behaviour, practices and needs regarding millets were surveyed.

English	Hindi	Telugu	Kannada	Tamil	Oriya
Pearl Millet	Bajra	Sajjalu	Sajje	Kambu	Bajra
Finger Millet	Nachani, Mundua, Mandika, Marwah	Ragula, Ragi, Chodi	Ragi	Kezhvargu	Mandia
Foxtail Millet	Kangni, Kakum, Rala	Korra	Navane	Thinnai	Kanghu, Kangam, Kora
Kodo Millet	Koden, Kodra	Arikelu, Arika	Harka	Varagu	Kodua
Little Millet	Kutki, Shavan	Sama, Samalu	Saame, Save	Saamai	Suan
Barnyard Millet	Jhangora, Sanwa	Udalu, Kodisama	Oodalu	Kuthravali	Khira
Sorghum	Jowar	Jonna	Jola	Chola	Juara

Regional names of different millets across survey States

Key findings:

- Income from millets as ratio of total farming related income ranged from 10-50%, highest in Karnataka (52%)
- Key needs included access to agri-inputs, post-harvest processing facilities and technical guidance
- Farmers in all states, except in AP, were unaware of MSP for millets
- Most farmers in AP, TN and Odisha preferred traditional seeds for millet cultivation, in contrast to Karnataka and Rajasthan
- Most farmers noted changes in cropping patterns, decline in rainfall, increased pests and diseases over last couple of decades.

This survey was conducted by Vertiver and IORA Ecological Solutions, New Delhi– organisations with expertise in forestry, biodiversity, sustainable agriculture and climate change

Enhancing millet production could hold the key to greater food and farmer security in India. Policies to change perceptions of millets, improve extension support for cropping systems and post-harvesting processing are some of the major challenges to be addressed.

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Vertiver enabling sustainability
IORA Ecological Solutions

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3. Rural Engagement: Employment, Welfare and Health

3.1 Designing Climate Resilient Agricultural Systems with Digital

Climate risk is a major and growing challenge faced by farmers and agricultural industries. The burden of that risk falls disproportionately on the poor and small-holder farmers. Although there are national and state level plans for climate change, local implementation of adaptation at village, district or panchayat level are absent in most states. Rural development remains a community-driven imperative.

Stake-holders, policy-makers and institutions need to come together to redesign farm systems, taking into account historical and future climate analyses, resilience and market opportunities, to enhance adaptive capacity.

Climate knowledge is key. Incorporating it into context-specific advice for farmers remains a challenge. TIGR2ESS researchers from CRIDA, ICRISAT, IITM and IMD have crafted an advisory system, NextGen Agro-met to be a one-stop shop that combines data from multiple sources, visualising and integrating it into one-easy-to-read dashboard data, making it easier for extension services and the private sector to design climate-smart options.

The system sends out tailored advice in the form of text messages. A farmer or extension officer can also dial up information for their block to understand where they are in history and where forecasts are indicating specific actions. The system has spun off into a number of apps developed with partners all over India.

TIGR2ESS researchers in northern Telangana also worked with stakeholders on a multi-criteria analysis to develop an index for northern Telangana that listed all of the climate smart agricultural practices as well as the sources of capital, machinery, policy etc that would be needed to support them.

They designed mapping to visualise current cropping systems (see below) and how they might be changed for the future. This analysis and mapping could be replicated in other states of India to guide local policy on climate-smart agriculture.

'The soul of India lives in its villages.'
Mahatma Gandhi.

Picture: Mr P.Vijay Kumar, ICRISAT

Farmer using Plantix app on his phone.

'Digital is a game changer: information on climate, markets, regulation, inputs, credit, insurance, etc. combined are bringing risk down for the smallholder.'

Anthony Whitbread, ILRI

FUNDING CALL:

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Co-funded by the Earth System Science Organization, Ministry of Earth Sciences, Government of India (IITM/MM-II/ICRISAT/2018/IND-11 and IITM/MM-II/CRIDA-ICRISAT-IIPR /2018/IND-9) and the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) with support from the CGIAR Trust Fund (for details, visit https://ccafs.cgiar.org/donors).

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3.2 Work and labour in Indian agriculture: Insights for socially just & sustainable agriculture systems

Climate change not only jeopardises crops, it also threatens the socio-economic status and wellbeing of rural populations, potentially destabilising societies and ultimately compromising food security for all.

Agricultural stakeholders experience the challenges that climate change brings in different ways. A few relatively well-off stakeholders may even benefit from shifts in land use, while others bear the brunt of the decreasing productivity of land for crop cultivation, leading them to abandon or reduce cultivation and increase dependence on non-agricultural sources of income.

Researchers from MSSRF and the University of Cambridge have developed new perspectives on policies for sustainable agriculture that address issues of inequality and destabilisation in rural communities. Their research asks whose sustainability is considered when developing policies for sustainable agriculture?

One of the areas they have looked at is environmental, including land, degradation. Environmental degradation increases the amount of time women spend collecting water, reducing their time for other activities, such as paid work, increasing their drudgery so that their well-being and that of their households suffers. It also constitutes one of the factors increasing male out-migration and off-farm work, but the effects of this on households can vary considerably.

PICTURE: TIGR2ESS

Without any concerted state effort to either restore the land or to alleviate widespread agrarian distress, land degradation develops into a continuously evolving downward spiral, where there will still be some winners (in terms of individual incomes) but many losers, creating long-term instability and an overall decline in production.

Policies are needed that look not just at productivity and diversity of cropping systems, but also employment guarantees and social protections in order to ensure that 'sustainable' agriculture is sustainable for all.

Political will is needed to work in favour of the most marginalised; they face the brunt of unsustainable policies and environmental challenges.

'Political will and farmers' skill are two major determinants of future of agricultural progress.'

Prof M S Swaminathan

PICTURE: TIGR2ESS

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3.3 Fostering Female Empowerment: Entrepreneurship Training for Rural Women

Vulnerable sectors of societies are often the first to suffer consequences when water and food is scarce and the lack of resilience of these groups to climate change will exacerbate these societal inequalities further. Interdisciplinary teams across TIGR²ESS undertook a series of trial community interventions with the primary aim of empowering rural women to take on sustainable business opportunities, ensuring health and nutrition for them and their communities.

Fostering Entrepreneurship Amongst Rural Women

A first step towards developing entrepreneurial skills in women living in rural regions was to understand the current knowledge baseline and attitude of these communities towards entrepreneurship and gauge their awareness of government initiatives. The Panjab University team found cultural idealisms impacted rural women's decisions on business ventures, with over 90% of respondents unfamiliar with concepts of entrepreneurship and unaware of supportive government schemes. Interdisciplinary expertise was required to design products and train women in technical skills, entrepreneurship and social media marketing strategies.

Sewing Techniques, Sustainable Product Designing and Production & Entrepreneurship Development

Training units were set up in two villages of Punjab - Pandwala and Bagh Sikandar. Workshops ran in conjunction to teach business and marketing-related skills, with progress evaluation on skill development and improvement in self-esteem recorded at regular intervals.

Participants were able to exhibit and sell their sustainable products at village events enabling cultural and experience sharing sessions. Participants developed skills to design and sew products and were able to generate income from the local community and beyond.

Bank linked Self-Help Groups (SHG) were formed in both villages; profits are distributed among the members after covering costs and keeping some reserve. This made them economically self-reliant; they acquired self-confidence and improved their status in society. The model was self-perpetuating, with the aid of the SHG cooperative, working towards bringing more women from other villages into the fold, thereby serving the wider rural community.

'With this training our routines have changed significantly. Now we are excited about going for our sewing sessions and quickly finish off the morning household chores. We get to learn something new every day. Our lives are more meaningful as we are doing something. This also provides an economic opportunity…we can start this home-based work …improve our economic condition and become financially independent'.

Sonia, President, Pandwalian SHG, Village Pandwala, Punjab

Engaging and training women with sewing skills and entrepreneurship for community and self-sufficient business ventures.

Going forward training will be extended to ensuring business skills such as book-keeping, leadership and decision making within the SHG are sufficiently supported for long-term sustainability of entrepreneurial initiatives.

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LEAD INVESTIGATOR, CO-INVESTIGATOR & PARTNERS:	Prof. Ramanjit K. Johal (PI, Panjab University), Prof. Monika Aggarwal, Dr. Prabhdip Brar, Dr. Rita Kant, Ms. Harpreet Kaur, Ms. Ginni Singh, Ms. Divya Chauhan, Ms. Khushboo Aggarwal, Dr. Amanjot Kaur and Ms. Malika Kukreja Pandwalian Self Help Group, Shaheed Bhagat Singh Youth Club & Panchayat, Village Pandwala. Baags SHG, Youth Club & Panchayat, Village Bagh Sikandar

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3.4 Crop diversification: Knowledge sharing with rural communities in Punjab (India)

'Crop diversifications is dependent on both consumers and producers. Both must be committed to the aspects of sustainability and nutrition.'
Professor Ramanjit K. Johal, Panjab University

High-input cropping systems dominate agricultural landscapes in Punjab State, with 90% of farm land currently supporting wheat and rice. Crop diversification equates to only 10% of agriculture in this region, yet diversifying reduces rural communities' reliance on cereal production, ensuring food security at times when grain yields are affected by drought. An interdisciplinary team of social scientists, nutritionists and agricultural management experts explored barriers in crop diversification from three stakeholder groups' perspectives. Unravelling influential factors which require state intervention, incentives and political to encourage uptake.

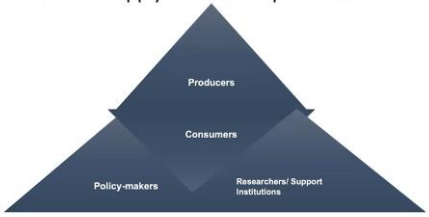
Consumer stakeholders

TIGR²ESS researchers led by Punjab University engaged with consumer groups, comprised of community members (individuals and collectives) and organisations (schools, food and hospitality industries and skills training centres). Basic nutrition workshops and training sessions were conducted for each stakeholder group, exchanging knowledge on the benefits of crop diversification, nutritional aspects of fruit and vegetables and providing students with first-hand experience of growing food plants. The study highlighted that educating consumers on the nutritional benefits of a varied diet increased the demand for farmers to produce and supply diverse crops.

Supplier stakeholders

The team engaged with farmers and farmer associations and found when producers grew food for their own consumption, they were highly attuned to the benefits of crop diversification. In contrast, commercial grown crops were selected according to market trends and cultivated for high economic returns, often using intensive farming methods (fertilisers and pesticides). Further, the team identified factors such as seasonality and farm location correlated to crop diversification. To support diversification, farmers were requesting institutional support for training in cultivation techniques and access to equipment for harvesting and processing.

Demand-Supply Chain in Crop Diversification



Various stakeholders in the demand-supply chain of crop diversification

Institutional support for Crop Diversity

Crop diversification requires institutional support to fulfil the needs of consumers and farmers. However, a current problem is that extension services are short staffed and while NGOs are active, they have limited capacity for outreach.
TIGR²ESS researchers identified the need for government support to incentivise farmers to grow new crops for profit and generate consumer demand for these crops through formal training programmes on nutritional benefits of diverse crop production systems.

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3.5 Policy Interventions in Food Supply Chains: Role of Farmer Producer Organisations and Digital Platforms on Bargaining Power and Equity

Climate stability, social and political interactions are key factors that can influence food production and distribution, with instability in these creating uncertainties at points throughout the entire agricultural supply chain market. Evidence for this occurred in 2021, when newly implemented Farm Bills in India provoked disputes between India's farmers and the federal government.

Competing and Coexisting Policies: The Context

Competing and Coexisting Policies (CACP) are increasingly common in international supply chains as well as Indian federal structures that operate across multiple states. In recent years, coinciding federal policies and state interventions, designed to increase supply chain dynamics in India's food systems have raised concerns on the different impacts on small farmers, specifically in terms of equity and bargaining power, and their ability to have fair access to markets, potentially accentuating social inequalities. Previous research has typically focused on the impact of a single policy intervention.

Alternative Supply Netting and Pooling Configurations in Indian Agriculture

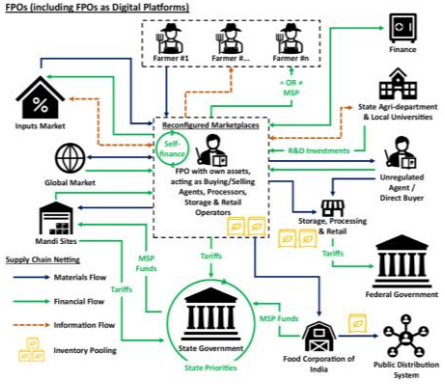
To understand how multiple policies applied to the food system interact at the market level, TIGR²ESS researchers based at the University of Cambridge, Punjab Agricultural University, and the University of Boston, applied novel supply chain netting analyses to map material, financial and information flows, along with inventory pooling, to determine imbalance indicators across different market scenarios, and identify where federal and state policies conflict in these systems.

TIGR²ESS Research Leads to State Policies for FPO Development

Stakeholder-led discussions which included representatives from Farmer Producer Organisations (FPO), state agriculture administrators, and finance bodies provided insights on how actors in the supply chain are affected by new and interacting policy implementations. Digital Platforms were explored as a means of enabling FPOs to be self-regulating, through reconfiguring market places and providing a means for self-financing, buying, selling, processing, storage, and retail. The approach harnesses the benefits of scale, leveraging the network effects of digital platforms, and facilitating engagement with international markets.

The interdisciplinary research demonstrated how policy interventions aimed at modernising food production and distribution, can lead to significant supply chain reconfigurations and consequent changes to bargaining power and equity between state/nation and federal/supranational entities, as well as between farmers, intermediaries, and retailers. The supply netting analysis and integrated modelling approach in this CACP context shows the shifts in bargaining power and their implications for welfare economics and food security.

TIGR²ESS investigations contributed to a Punjab Policy Notification (2021) with future modelling work aimed at identifying the ideal size for FPOs, across different market scenarios in India.



"We're seeing actionable outcomes that will really make a difference in changing people's lives and saving lives"

Lord Karan Bilimoria, Chair TIGR²ESS IAB

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3.6 Congruity of Crop Diversification and Dietary Diversity: Study of Akole Block in Maharashtra.

A study conducted by TIGR²ESS researchers from IIT Bombay offers insights into making agriculture more economically viable, accessible and diverse as well as increasing regional dietary diversity.

The research looked at four tribal communities in upland and lowland settings in Akole block, Maharashtra, the second most populated state in India. It compared socio-economic conditions, adoption of new technologies, dietary diversity and market access. A **School Nutrition Awareness Programme** analysed the socio-demographic background, anthropometry, diet and activity, eating behaviours of seventh grade students in the area studied.

Upland region: Hilly, densely forested with sparse population and low productivity, subsistence agriculture. Small land holdings. Multiple cropping requires intensive manual labour. Self-sufficient in food crops; rice, wheat and millets are staples. Agriculture is primarily rain fed and organic. Cattle farming is least developed. The area has poor transport, communication network and healthcare facilities.

Lowland region: 100% of the net sown area is irrigated. Crops are varied: pomegranate, onion, vegetables and flowers. Market trends dictate the cropping pattern and farmers use modern farm implements. Hence productivity is quite high. Dairy is a major subsidiary occupation. The area has good accessibility, infrastructure, healthcare, transport and communication networks.

School Nutrition Awareness Programme

The study found that information dissemination and overall income have an influence on dietary diversity. Child nutrition status is not clearly linked to general dietary diversity. State government should prioritise creation of FPOs, better water management, market and financial accessibility, credit affordability, and efficient pricing mechanisms. Such a holistic approach would offer vulnerable households opportunities to increase their income, improve their standard of living and reduce distress migration.

TIGR²ESS has given us an opportunity to identify the drivers of dietary diversity in a transitional agriculture scenario moving gradually from subsistence toward commercial production.

'Integrated and complementary actions and interventions are needed to tap the exhaustive knowledge of diverse and nutrient rich indigenous food sources to reduce the "triple burden" of malnutrition.'

Prof. K. Narayanan,
Lead Investigator, IIT Bombay

The challenges identified include:

- improving market access for upland farmers to improve their economic prosperity and nutrition; scaling local markets up to FPO would benefit villagers,
- tapping the potential of eco-tourism as an alternate source of income in the uplands,
- adopting an integrated approach of ground water resource development to improve agriculture in lowland villages and,
- educating parents, teachers, healthcare workers and children on the significance of a diversified diet to improve nutrition, whilst emphasizing the need for balance or proportion of foods as well as variety.

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LEAD INVESTIGATOR	Prof. K. Narayanan
FUNDER:	UKRI GCRF

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3.7 Creating value from waste – opportunities and challenges from the valorisation of rice straw

In India, rice straw stubble burning is commonly practised by farmers to clear fields for the next crop. Harmful pollutants are released with detrimental effects on health and the environment. Rice straw valorisation is seen as a solution for sustainable rice straw management providing economic, environmental, and social benefits.

Waste generated by a growing population, the rise in consumerisation particularly within the middle-classes, and the current linear "make-consume-dispose" supply model is unsustainable.

The re-use of agricultural by-products such as waste straw stubble, as an input feedstock in industrial value chains offers opportunities for local value-adding processes, local material supply security and pollution prevention. However, whilst such reuse of waste materials can support circular supply chains, and sustainable economic growth, the evaluation of technical and commercial feasibility is complex. Furthermore, the multi-entity partnerships (farmers, industrial partners, public sector bodies) requires public-private coalition building.

A TIGR²ESS research team led by the University of Cambridge, explored the potential of straw-stubble waste valorisation. By mapping alternative 'waste' valorisation production processing routes, the team identified industrially scalable economical solutions and collaborations to address the rice straw burning challenge.

Identifying products and partnerships

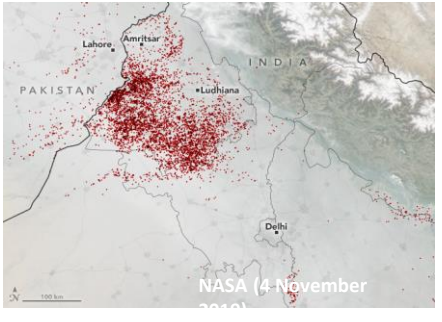
Two pathways were selected for further exploration for their potential for scalable valorisation, namely *straw pellets* and *furniture panels*. Discussions with supply and demand-side actors (e.g. farmers, MNEs, start-ups), production processing equipment providers and institutional bodies provided supply network design inputs regarding local feedstock collection, production process technologies, and multi-entity contractual partnership options.

The research demonstrated how supply chain configuration analysis can be used to explore scalable solutions for the reuse of 'waste'/by-products of agriculture. It provides practitioners and policy makers with a methodology for the design and evaluation of valorisation options for local 'waste'/by-products, including the partnering arrangements between public and private entities. Moreover, it highlights the importance of organisational intermediaries required for the creation of circular supply chains where both public and private inputs are needed.

Going forward

The valorisation of straw waste products has been shown to be a viable option for use in the furniture industry, with products currently being tested by partners at IIT Ropar. Researchers will continue to validate the principles established through the TIGR2ESS programme by exploring opportunities with other waste by-products.

Farmers clearing the fields



Fire locations from NASA satellites

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TITLE:	Transforming India's Green Revolution by Research and Empowerment for Sustainable food Supplies (TIGR²ESS)
GRANT NO:	BB/P027970/1
LEAD INVESTIGATOR & CO-INVESTIGATORS:	Lisa Arianna Rossi (University of Cambridge) Jagjit Singh Srai (University of Cambridge)
PARTNERS:	IIT Ropar

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4. Sustainable Water use and management of water resources

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4.1 UK Research Excellence Framework Impact Case Study: Sustainable farming and food security in China and India

Insights from historical archaeology inform today's food security agenda *Research in the Department of Archaeology at the University of Cambridge has shown the importance of past agricultural practices, especially cultivation of hardy, adaptable millets and use of sustainable water management practices, in semi-arid regions of Asia. The work in China demonstrated how millets could contribute to rural population nutrition, food security and generate income. Inclusion as a Case Study in the 2021 REF submission represents a major recognition for these research outputs and formed a vital element in the success of the University's submission*

Field research activities identified archaeological remnants of water storage systems for restoration "In India, the work supported in part by the TIGR²ESS programme, the researchers have particularly focussed on how rural populations adapted their farming practices to survive in variable and changing environments. This diversity appears to have been resilient to short-term crises and enabled long-term sustainability.

In collaboration with partners in India, the project is encouraging the importance of millet as a drought-resistant crop and promoting efficient water management, like the renovation of historic ponds, to enhance the sustainability of farming practices that are today on the edge of crisis due to depletion of groundwater from aquifers.

"The insights… from the Cambridge visit encouraged me to organise a workshop on village ponds and water bodies… [which] served to introduce these new insights into India's recent and deeper past to civil servants, policymakers, and stakeholders… who will now be able to work together to identify strategies for renovating village ponds across Punjab, so that they produce a sustainable and manageable water source."

Chief Principal Secretary of the Chief Minister of Punjab (and TIGR2ESS Policy Fellow)

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TITLE:	Transforming India's Green Revolution by Research and Empowerment for Sustainable food Supplies (TIGR²ESS)
GRANT NO:	BB/P027970/1
LEAD INVESTIGATOR & CO-INVESTIGATORS:	Adam Green (University of Cambridge), Cameron Petrie (University of Cambridge) Martin Jones (University of Cambridge)
PARTNERS:	TwoRains Programme (ERC funded) Banaras Hindu University (BHU), Varanasi

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4.2 A Policy Framework for Water Conservation Management informed by Archaeology

South Asia's unique combination of semi-arid and monsoonal environments has historically given rise to diverse cropping systems and water management strategies. TIGR²ESS researchers have shown that urbanisation in early cultures developed in association with a range of successful agricultural interventions. Importantly, understanding how water was stored and distributed from reservoir systems in the past can and has informed new policies for water management in the contrasting agroclimatic regions of Punjab, Haryana and Telangana.

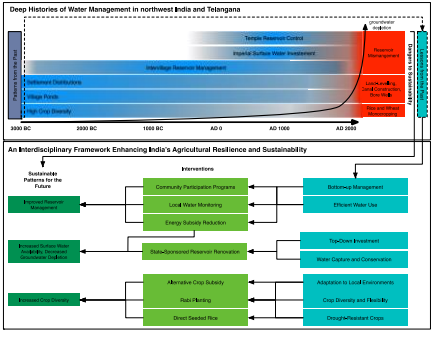
Semi-arid conditions favour diverse agricultural landscapes rather than monocultures

A rich and dynamic agricultural heritage emerged in northwest India over 5000 years in the past. Archaeological evidence indicates that past communities employed many combinations of cropping and water management strategies. An analysis of small water bodies ('village ponds') and irrigation in historical maps indicates that such systems endured until the more recent advance of intensive cropping strategies. One policy challenge is to attract investment for re-establishing elements of these heritage infrastructures, together with more diverse cropping systems, while ensuring that farmer income is protected.

Diversification scenarios require top down investment and buy-in from rural communities

TIGR²ESS researchers have found legacy data preserved on historical maps reveals key patterns in the distribution of ponds, tanks and wells prior to the Green Revolutions. Studies have identified a 75% reduction in the area dedicated to surface water storage in some of the most agriculturally productive parts of Punjab. Restoration and integration of some village ponds for use in agriculture could make a significant contribution to the groundwater deficit in these States.

Studies by researchers based at ICRISAT in Telangana have also identified evidence of massive reservoirs and irrigation systems that were constructed by the Kakatiya Dynasty 100 years ago. TIGR²ESS researchers have been wrking with communities to determine the role they could play in increasing water availability in the area, near Warangal, today. Together with the work in Punjab and Haryana, these TIGR²ESS studies have led to the development of a major interdisciplinary framework for sustainable production patterns, which is being adopted as Policy by State legislatures.



An interdisciplinary research team combined studies, developing a policy framework building on lessons from the past (Green et al., *Environ. Res. Lett.* **15** (2020) 105021)

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LEAD INVESTIGATOR & CO-INVESTIGATORS:	Adam Green, Cameron Petrie, Kamal Vatta, Sandeep Dixit, KK Garg, NR Sandya, Anthony Whitbread
PARTNERS:	CIPT, ICRISAT
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CENTERS FOR INTERNATIONAL PROJECT TRUST CIPT
ICRISAT INTERNATIONAL CROPS RESEARCH INSTITUTE FOR THE SEMI-ARID TROPICS

4.3 Groundwater Management to Build Climate Resilience: Lessons from Dryland Agriculture in India

Groundwater provides the essential irrigation support required to mitigate climate risks in dryland farming. However, managing groundwater is challenging because it is a common pool resource and its use unregulated. The lack of effective resource governance leads to its over-extraction.

The situation is compounded by increasing climate risks, in particular variability in rainfall, rising temperatures and desertification, so that traditionally rainfed dryland agricultural livelihoods have become more vulnerable. In the absence of effective groundwater water management, water table levels are likely to drop, this can cause crop failure and reduce or even eliminate sources of drinking water.

TIGR²ESS researchers evaluated the impact of strategies to manage groundwater in semi-arid dryland agricultural regions which cover nearly two-thirds of cultivated land in India. Their research focussed on a water budgeting tool's potential to build local capacity (at village level) for groundwater management.

The tool is a visual aid displayed in a public space in the village, keeping track of monthly rainfall, the consequent recharge in the groundwater levels, and an appropriate selection of crops for the water-balance.

Local champions are trained to measure and record rainfall received and the resulting recharge. If the recharge levels are low, the tool suggests farmers cultivate low irrigation demanding crops. In a year of good rainfall they may revise their crop choices. The crops suggestions are the recommended by local agricultural extension agencies.

The tool informed a seasonal intensification or de-intensification plan subject to groundwater availability, reducing both the risks to farmers' income and of overexploiting groundwater.

Crop diversification is the dominant cropping pattern. Farmers endowed with more wells include a high value horticultural crop along with dryland commercial crops in their crop choice. Amongst farmers with high to medium irrigation needs, 31-42% perceived the tool as useful in planning the irrigation requirements.

This research shows the importance of local institutions, such as agricultural extension agencies, to groundwater governance. It highlights the need for dynamic interaction between governance systems and resource users, and for government policies to favour such strategies so that effective groundwater management is possible in the future.

"The demand for the development intervention should arise from the community"

Senior officer, Agricultural Extension Office.

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GRANT NO:	BB/P027970/1
LEAD INVESTIGATOR:	Prof Shailaja Fennell,
PARTNERS:	WOTR (Watershed Organisation Trust)

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4.4 Soil Moisture Digital Monitoring: Major Savings in Groundwater Use and Energy Demand

Breaking the circle: intensive agriculture makes unsustainable demands on water and energy resources

Annual dual cropping of wheat and the use of rice paddy systems emerged from the original green revolution as highly productive practices, but these create substantial pressure on limited water resources in arid regions of India. TIGR²ESS *researchers used direct engagement with farmers and policy makers in the Punjab State, to introduce new technologies and provide evidence for good-practice, saving over 80 billion litres of water in this region alone.*

Changing farmer behaviour to conserve or diversify

The Indo-Gangetic plain groundwater is falling at a rate of 0.25-1 m per year. Currently the Punjab State Government subsidises energy requirements for pumping water for irrigation use. Reducing water by one third, would slow groundwater depletion and save around 2300 CR (0.23 billion GBP) in energy subsidies and emissions.

TIGR²ESS project partners at CIPT used a number of interventions to promote water efficient technologies and practices (WETP) and these activities were demonstrated and promoted through farmer communities and Farmer Producer Organisations. The value of these innovations guided policy recommendations formulated with Regional Government stakeholders.

"The Food Policy in India is required to be reoriented and redirected to assure quality food to all at all places at all times by transforming the existing systems, structures, and processes that increase agriculture, water, and energy productivity. The efforts of CIPT that include developing and piloting new models, technologies, and practices for effective water and energy management, fully reflect on these long-cherished goals".

Mr Suresh Kumar* TIGR²ESS *Policy Fellow, Former CPSCM

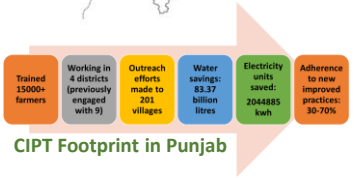
Benefits of soil meters outweigh initial infrastructure costs

The current bunded paddy system relies on flood irrigation staged 3 -5 times during the growing seasons, largely irrespective of actual crop water demand.

The CIPT team worked with farmers across 4 major districts Punjab State, trialling 2000 digital soil moisture sensors, each linked to a mobile phone app that indicates soil moisture status and irrigation requirements. The benefits in terms of reduced water use and energy demand translate into reduced subsidised expenditure, and ultimately, in yields and farmer income.

The plan is to expand this and other advances, including monitoring precipitation and pump water flows and encouraging uptake of a water credit voucher system, across many districts in the Punjab with the support of State government. The goal is to reduce 1,200 billion litres of water loss over 100,000 acres in two years bringing benefits to this region that can be translated across farming communities in India.

Proposed Program Districts



CIPT Footprint in Punjab

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GRANT NO:	BB/P027970/1
LEAD INVESTIGATOR& CO-INVESTIGATORS:	Cameron Petrie Sandeep Dixit, Kritika Gulati, Ranjodh Singh
PARTNERS:	Dept. of Agriculture & Farmer Welfare, Dept. of Cooperation, Govt. of Punjab

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4.5 Sub-surface Drip Irrigation and Potential for Diversification in Cropping Systems

Targeted irrigation and crop diversification could maintain farmer incomes and meet consumer demand

Despite the immediate challenges of reducing water used in the dual cropping wheat and rice paddy system, there is a need to sustain farmer incomes and meet consumer demand. Research being undertaken at PAU under the programme has identified alternative cropping systems which could meet the expectations for increased profitability and reduced water use.

Evaluating the impact of diverse cropping systems for farmers and State Policy makers

Research led by the Punjab Agricultural University and the University of Cambridge combined empirical field studies and agricultural economic modelling to compare input demands for differing drip irrigation strategies and seasonal crop combinations. Alternative crop combinations and irrigation strategies were identified for transitioning towards more sustainable agricultural supply chains. Outputs from these studies were benchmarked against paddy rice production in terms of subsurface irrigation water demand, yield, and overall financial return.

Additionally, outputs were projected against future market demand, given societal changes in consumption patterns, to advise on policies for more sustainable cropping systems. The research results strengthen agricultural resiliency in terms of reduced resource inputs and alternative product supply chains. In addition, export opportunities and replacement of imports were considered, along with the ease of cultivation and opportunities for mechanisation.

Seasonal Crop Combinations Plan for Diversification Scenarios

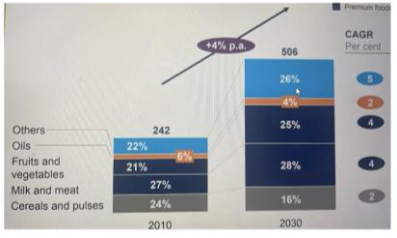
Cropping combinations included rice, potato and spring maize, or cotton and canola. These were tested under three irrigation regimes, including conventional flood irrigation and the installation of a sub-surface pipe network for drip irrigation.

Key findings indicated that nearly all cropping combinations produce equivalence to paddy rice in terms of standardised yield, with scenarios producing markedly increased financial returns. All cropping systems benefitted from sub-surface drip irrigation, which reduced groundwater water demand by between 34 and 46%.

Researchers concluded that diversification could meet demands for milk, oils, fruit, and vegetables and reduce the extent of wheat and traditional paddy rice, that dominate agricultural production. Alternative crop variants, e.g. basmati rice (lower water requirements, higher returns) as well as maize, cotton, and canola were considered. Other attractive cropping possibilities included pulses and dairy production.

"Ultimately, we need water conservation as a mainstream agenda for public policy in Punjab, and through various interventions, (crop diversification, conservation technologies), and a very strong extension system, develop an extensive dialogue with the farmers" ***Anirudh Tewari, Chief Secretary, Govt of Punjab, TIGR2ESS Policy Fellow***

Surface drip irrigation at Level 2



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LEAD INVESTIGATOR & CO-INVESTIGATORS:	Sandeep Kapur (Punjab Agricultural University), Ajmar Brar ((Punjab Agricultural University), Jagjit Singh Srai (University of Cambridge), Naoum Tsolakis (University of Cambridge)

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5. Female Education, Nutrition, Livelihoods & Intersectionality

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5.1 Building Equitable and Sustainable Food Systems: a Gender Perspective

Climate change has disproportionately affected poor, marginalised smallholder farmers in India. Tribal/local practices continue to be devalued and commonly excluded from formal institutions. India was ranked in the bottom five countries (of 156) in terms of health and survival in the 2021 Global Gender Gap Report.

As part of the TIGR²ESS programme, a portfolio of qualitative studies, spanning three flagship projects FP1,FP5 and FP6, tackled these issues; exploring societal needs as a means of balancing the conflict between economic performance and other development goals, including gender equality and social solidarity.

Adopting a gender lens, the researchers used a Participatory Action Research methodology to engage with diverse people and groups. **Areas of focus**, highlighted in their findings, included: Growing vulnerabilities of farming systems to climate change/variability; male migration and the feminisation of agriculture; lack of access to technology, information and resources (especially for women farmers) including in farmer-producer organisation (FPO)-type arrangements.

Action interventions and training initiatives with various groups included:

- Children - using local food stories to illustrate food-related topics in the curriculum
- Youth - participatory film-making and development of creative tools, focussing on local food practices and nutrition issues
- Women's self-help groups - harnessing local knowledge on dietary diversity and recipes
- Front-line workers - translating knowledge into practice, adapting to locally available resources.

A key finding has been **the importance of transdisciplinarity** in research and the need to work in partnership. For example:

- Many FPO-type commodity-based initiatives aim to counter exclusion, but women farmers continue to be marginalised, with just 3% of FPO-type arrangements being female-led.
- Gender research - involving women farmers - provided unique insights on how emerging FPO arrangements in India might play a central role in shaping equity and inclusivity, particularly in rural areas, at different stages of development.

In conclusion

Food security and nutrition are often at odds with people's aspirations for better livelihoods.

Innovative thinking about existing tensions is needed, to save time and reduce drudgery (particularly for women), and expand access to knowledge, so that a critical consciousness can be generated, contributing to the development of equitable social institutions.

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LEAD INVESTIGATOR, CO-INVESTIGATORS & PARTNERS	Prof Nitya Rao, Tomás Harrington, Shuvajit Chakraborty, Nivedita Narain, Astha Upadhyay, R. Rengalakshmi, Reetu Sogani University of East Anglia, PRADAN, MSSRF

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5.2 Education for Sustainable Development: An Open Access On-line Course to Improve Community Wellbeing and Inform Policy-makers.

Despite India's rapid socio-economic growth, large numbers of Indians continue to experience food insecurity and nutritional vulnerability. This problem is compounded at policy level by poor understanding of contextual constraints and local nutritional know-how, as well as the inability to communicate in ways responsive to local needs, aspirations and cultures.

Two-way knowledge-exchange between government and local communities is needed so that both policy-makers and local people can make better informed choices, improving health outcomes and the sustainability of diets.

To facilitate this, TIGR2ESS and related GRTA project partners in India and the UK created a free Massive Open Online Course, called '**Communication and extension for sustainable development**' for Indira Gandhi National Open University the world's largest university. Hosted by the Swayam platform of the Indian government's Ministry of Human Resources Development, the course launched in September 2021.

Aimed at a broad range of learners, from postgraduate students to frontline workers in NGOs and government organisations, the 15-week course uses contextual examples from recent TIGR2ESS research to explain key theoretical concepts in simple language.

Through 20 hours of video material, case studies, and written text, the aim is to empower and improve the wellbeing of rural (and urban) communities, especially indigenous groups, women and children.

Photograph: Atul Purty, PRADAN

Organised in four blocks, the course seeks to educate participants in the latest creative tools in extension, communication for development, training and advocacy, and key elements of creating and nurturing sustainable food systems and community resources.

At its launch in English over 500 learners enrolled. To reach a larger audience, especially frontline and extension workers, a Hindi version of the course launched in July 2022. The course can be accessed at: https://onlinecourses.swayam2.ac.in/nou21_ge38/preview

'What is unique about the course is the ability to bring together theoretical frameworks on various topics of communication and collaboration, with practical approaches/solutions for sustainable development.'

Ayesha Pattnaik, current student.

'The Course is already benefitting online students, including community health workers, social change makers, teachers and those interested in welfare and development. Efforts to develop the Course in Hindi are under-way and after its launch, frontline health workers in the communities who are well versed in Hindi will be hugely benefitted.'

Dr Umesh Pandey,
IGNOU Regional Director, Bhopal

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LEAD INVESTIGATOR, CO-INVESTIGATORS & PARTNERS	Prof Nitya Rao, Nivedita Narain, R. Padmaja,R. Rengalakshmi, Sanchita Banerji, Heena Bijli, Arundhita Bhanjdeo, Imran Amin, Chandni Khanduja, Anuprita Shukla,Kavitha Kasala, Shubhashree Shankar, Raj Kumar, Bharti Goel, Sumedha Singh,Jorgen Johnson, Sumantra Ray, Luke Buckner, Shane McAuliffe, Wanja Nyaga, Helena Trigueiro,Kai Kargbo, Sehjo Singh, Reetu Sogani UEA, PRADAN, ICRISAT, MSSRF, IGNOU, KISS, PU, NnedPro, Lok Chetna Manch
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5.3 THE MOBILE TEACHING KITCHEN MODEL: Innovative solutions to Malnutrition and Diet-Related Challenges

'I was always a cook but now I have learnt to prepare a balanced diet and about nutritional values for the first time'

Anumati Sarkar, MTK Champion

Malnutrition, which includes undernutrition, obesity, and micronutrient deficiencies, is a leading risk factor for ill health, affecting about 30% of the world's population and an even greater percentage in India. In response, TIGR²ESS researchers at NNEdPro Global Centre for Nutrition and Health have developed the 'Mobile Teaching Kitchen' (MTK) Initiative.

This is an award-winning scalable micro-model launched in February 2018 in two urban slums in Kolkata, India. The MTK trains marginalised women to become microentrepreneurs and culinary health educators, with the potential to improve nutrition-related Knowledge, Attitudes and Practices (KAP) across multiple sectors of society. By training just 12 women, approximately 4000 people are being impacted on a monthly basis, getting nutritious food and nutrition advice which they can further disseminate to their communities.

The idea is simple: Local volunteers trained in healthy cooking transfer core principles through cooking demonstrations of sustainable, nutritional, and affordable meals. They follow a 'See One, Do One, Teach One' model to transfer knowledge to their peers. This model aims to create a sustainable solution that will enable the rural-urban slum dwellers across regions of the world to challenge food insecurity and malnutrition.

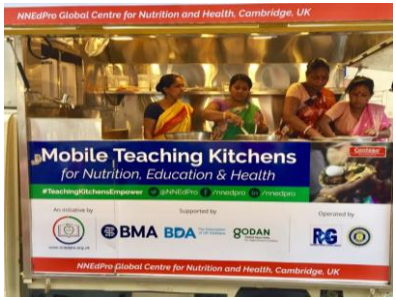
MTKs have a really big reach. Each mobile unit is staffed by 5-6 champions, and serves about 100 meals a day, and therefore has the potential to reach 24,000 people a year.

The project has a positive impact on the health and nutritional status of the wider community and potentially creates livelihood opportunities by empowering women with catering skills.

After successful impacts in India, the Mobile Teaching Kitchen model has been proposed to eight other existing regional NNEdPro networks: Australia and New Zealand, Brazil, Italy, Mexico, Morocco, Switzerland, the USA, and the UK.

'This project has transformed groups of untrained women into MTK Champions, who can be advocates in their local communities. Similarly, the TIGR²ESS project has been producing exemplary outputs that involve many partners and stakeholders. I strongly support and recommend the continuation of this great work done by TIGR²ESS partners'

Lord Diljit Rana,
Honorary Joint President of NNEdPro



Picture: Debashis Chakraborty (NNEdPro)

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LEAD INVESTIGATOR, CO-INVESTIGATORS & PARTNERS	Prof Sumantra Ray, Dr Luke Buckner, Prof Ianthi Tsimpli, Dr Marjorie Lima do Vale, Jorgen Johnsen, Jodie Webber, Wanja Nyaga, Sucheta Mitra. NNEdPro

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5.4 Success Story of a Basic Nutrition Curriculum Intervention for Skill Trainees (Men and Women)

Good health is closely associated with nutritious food intake and healthy eating habits; this awareness and practice makes for a healthy work force. A Basic Nutrition Course was designed and run for young men and women at two locations in Punjab; Meher Baba Charitable Trust, Fategarh Sahib and Punjab Skill Development Mission, Ludhiana. The ten sessions curriculum was developed and tested as a participatory action research intervention. (Figure 1)

TIGR²ESS researchers led by PAU conducted Knowledge, Attitude, Practices (KAP) based pre- and post- surveys, to assess nutrition and food awareness, consumption habits and basic health parameters (Figure 2). Training sessions included undertaking anthropometric measurements, one to one counselling, live demonstrations and group activities. Opportunities in the nutrition food sphere were also highlighted to participants.

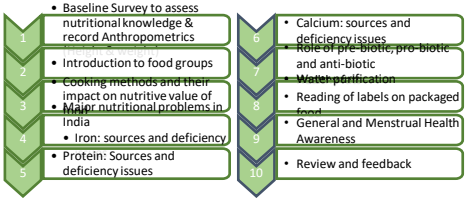

Figure 1: 10 sessions curriculum

Knowledge	Attitude	Practice
• Enhanced knowledge about basic nutrition food groups, the food platter etc. • Increased awareness about causes and symptoms of nutrition related deficiencies and appropriate foods to overcome them. • Knowledge sharing with peer group and family members was observed.	• Consciousness of being healthy eaters noted. • Mindfulness of cooking practices • Discarded assumptions based on social beliefs; for example, non consumption of certain foods by young women. • Enhanced confidence to discuss their health problems with the family, especially in case of female trainees.	• Notable changes in daily eating habits – eating at the right time, appropriate water consumption, including different food sources • Use of appropriate quantity of cooking oil • Motivations influenced interest: some male trainees focusing on body building relied on protein rich diet; whereas female trainees focused on home-based remedies for beauty care.

Figure 2: KAP

Participants demonstrated an increased awareness of causes and symptoms of nutrition related deficiencies and appropriate foods to overcome them. Behavioral changes were also observed in terms of healthy and regular eating, daily water consumption and mindfulness of cooking materials and practices. Importantly, the nutrition training raised the perceived value of 'domesticated' kitchen activities.

Knowledge exchange through recipe sharing, discussions on health and nutritional advice occurred amongst participants peer groups and family members.

Interactive training and demonstrations with trainees at MBCT and PSDM

Future Steps

The aim is to advocate 'Basic Nutrition Curriculum' as a compulsory component in all Skill Development Programmes, under the Punjab Skill Development Mission.

Researchers are actively working to develop the programme with stakeholders' support, and to extend this intervention to schools and women in rural areas. The goals of nutritional empowerment of women and youth, a low disease burden and enhancing the productive human capital of the nation would be well served.

FUNDING CALL	Growing Research Capacity: UKRI GCRF
COUNTRY:	India
TITLE:	Transforming India's Green Revolution by Research and Empowerment for Sustainable food Supplies (TIGR2ESS)
GRANT NO:	BB/P027970/1
LEAD INVESTIGATOR, CO-INVESTIGATORS & PARTNERS	Prof. Ramanjit K. Johal (PI), Dr. Amanjot Kaur (PDRA), Bharti Goel (Project JRF), Malika Kukreja, Nimret (Research Fellows) Panjab University Punjab Skill Development Mission, Meher Baba Charitable Trust
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5.5 Holistic solutions for on-farm sustainability in Punjab, India

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Since the introduction of Green Revolution technologies, the state of Punjab has become the Granary of India. This has come at a price, with farmers entrapped in a cycle of unsustainable production systems, bringing socio-economic instability, leading to agrarian distress across the region. TIGR²ESS researchers developed and piloted innovative intervention models with rural communities, which consider a suite of economic, environmental and social factors. These innovations provide promising solutions for securing sustainable farming systems.

Researchers at Panjab University captured an overview of farm-level sustainability by integrating economic, environmental and social sustainability indicators using the stock-and-flow framework to propose a **Comprehensive Farm Assessment Index**.

Dynamic early-career researchers facilitated stakeholder engagement which included field surveys, interviews, focus group discussions, and workshops. Immersive engagement with the farmers enabled researchers to map constraint-based creative solutions for more sustainable agriculture practises.

Farmers' innovations ranged from adopting experimental farming systems, improvising agricultural machinery/implements, processes, water conservation, storage and preservation, and using mobile phone applications.

Although innovations were designed to be locally applicable, most solutions have wider applicability and replicability.

"TIGR²ESS at PU has fleshed out the cross sectionalities in the sustainable *agriculture, nutrition and skill development realms and used this understanding to liase with stakeholders across the board to come on the same page vis-a-vis sustainability. This is a work in progress; the innovative and entrepreneurial farmer – the 'x' factor – is there; what is required to drive diversification and sustainability in effect is reasonable infrastructural support, especially for processing and marketing".*

Prof Ramanjit Kaur Johal, Panjab University

Farm innovations clockwise from top left: Planting to attract pollinators; Drip Irrigation; Agri-voltaics through solar panels; Fruit netting bags; **right**: Multi-tier zero energy storage

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LEAD INVESTIGATOR, CO-INVESTIGATORS & PARTNERS:
Prof. Ramanjit K. Johal (PI, Panjab University); Prof. Suveera Gill, Dr. Bharati Garg (CoIs, Panjab University), Dr. Amanjot Kaur (PDRA) Maitri Sharma (Project JRF), Malika Kukreja, Sheena Chadha (Research Interns)
Bagh Sikandar and Pandwala Village Panchayats and Government Schools; Horticulture Department, Punjab; Krishi Vigyan Kendras; Participant farmers and students.

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5.6 Nutrition-oriented practices in Punjab, India

Images: Engaging youth and women with the cultivation of Nutrition Gardens

Engaging & empowering youth and women through farming enterprise

In a focused study on 'Nutrition Kitchen Gardens,' locally known as 'Poshan Vatika', TIGR²ESS researchers established that agriculture normally identifies as a male domain in this region. In contrast, kitchen gardens close to residential areas provided women with greater control over what they grow and use for cooking.

The study cultivated 32 new kitchen gardens with connections to rural households and government schools. Knowledge sharing activities engaged participants in aspects of food groups, nutritional value of vegetables, healthy cooking and preservation practices, cultivation and commercial value for income generation. The women who were in control of their kitchen gardens felt more empowered to make decisions on growing nutritional crops.

Proactive discussions on the economic potential of the cultivated produce were recorded during the study.

The 'Poshan Vatika' model can be effectively implemented through Government schemes, with NGOs and development researchers bridging the gap between local communities.

The research demonstrated the benefits received by target groups and shows that adding practical components of agricultural methods and nutrition to the existing school curriculum related to Agriculture and Science would improve learning outcomes, develop skills and ingrain nutrition consciousness.

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5.7 A new digital approach to dietary data collection: GIBSONIFY

Understanding dietary diversity and levels of nutrition in varied settings and communities has been an important part of TIGR²ESS research. However, there is limited quantitative dietary intake data to support evidence-based decision making, in part because collecting and processing quantitative data is so time consuming and expensive.

Currently, quantitative dietary intake data is collected on paper forms that have to be digitised prior to analysis. This process is time and resource intensive, and risks introducing errors. Proprietary software to digitise the data collection process exists, but is too expensive for most researchers in low- and middle-income countries.

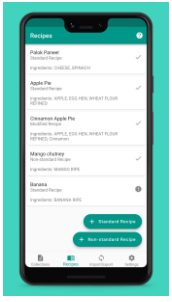
To address this challenge, TIGR²ESS researchers from ICRISAT and the Centre for Global Equality (CGE) teamed up with engineers from the University of Cambridge to develop an open-source, free-to-use digital dietary surveying app called Gibsonify.

The app uses the 24-hour dietary recall method developed by Gibson and Ferguson (2008) to evaluate the adequacy of macro- and micro-nutrient intake in people's diets. The survey approach of the Gibson method relies on multiple passes of questions to enhance the accuracy of the information captured.

http://gibsonify.org

The Gibsonify app provides a user-friendly interface to collect information about local recipes and nutrient intake, replicating the tested 24h-recall methodology. Data is collected locally and is managed using existing data collection protocols. It can be used on any smartphone, tablet or computer and works off-line, enabling surveys in remote areas.

The interface is currently being tested with users. This will be followed by iterative cycles of trial data collection, feedback and continued app development to enable effective processing and management of the data.



"Gibsonify will help us collect better data, faster, for less cost: we can't wait to start using it!"
Kavitha Kasala

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GRANT NO:	BB/P027970/1
LEAD INVESTIGATOR, CO-INVESTIGATORS & PARTNERS:	Shazril Suhail, Adam Sroka, Kavitha Kasala, Alexandre Kabla, Lara Allen, Padmaja Ravula. International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) Centre for Global Equality

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Centre for Global Equality

ICRISAT
INTERNATIONAL CROPS RESEARCH INSTITUTE FOR THE SEMI-ARID TROPICS

5.8 Nutrition Kitchen Pilot conducted by Vertiver and NNEdPro

Vertiver and NNEdPro initiated a Nutrition Education Kitchen Pilot in East Delhi, integrated with Vertiver's existing project on waste management. This pilot was part of a new cradle to cradle model as best practice for policy makers to provide subsidies and other incentives to promote longer term impact in the management of both waste and nutrition.

This pilot was implemented with women in East Delhi communities, predominantly from low-income backgrounds. The area is surrounded by street vendors and hawkers selling cheap, adulterated and unhygienic food. The aim was to change food habits in the local community.

The nutrition kitchen was set up by the women as part of an ongoing pilot, the key idea of which was to create a Circular Economy model in which organic waste is turned to fuel (biogas).

An initiation See-One Do-One Teach-One (SODOTO) training was held for 15 women as a first step in this initiative. This will be an ongoing process to enhance the women's understanding of nutrition, and support them in their entrepreneurial journey in establishing a nutrition kitchen.

Key objectives:

- Generate awareness of nutrition and health thrugh healthy, coarse grain nutrient snacks made with biogas
- Build capacity of women to make nutritious food/snacks as part of livelihood generation
- Repurpose organic waste into biogas providing free access to fuel and contribute to waste management.
- Introduce consumption of healthy snacks in a community where there are no healthy alternatives available
- Encourage creation of SHG (Self-Help Groups) as an institutional model for female self- sufficiency
- Collect data and evaluate potential of the NNEdPro SODOTO model to impact nutrition Knowledge, Attitudes and Practices (KAP) as well as establishing microenterprise and health awareness

Future Plans:

- Develop train-the-trainer modules to equip women trained in the pilot to become nutrition champions and spread awareness in their community
- Build awareness in students in EDMC schools across East Delhi on nutrition and waste management

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Since 2019 Vertiver has been the implementation partner of the Su-Dhara program under the Principal Scientific Advisor (PSA) to the Govt of India's Waste to Wealth mission, working with East Delhi communities and Municipal Corporation of Delhi on creating behaviour change models for waste management.

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6. Conclusions and Summation of Outputs

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6.1 Delivering the Grow Call:
Training and Outreach for Capacity Building- how NIPGR enhanced Data Skills & Female Empowerment

The TIGR²ESS ResearchFish submission reported over 400 engagement activities which had been facilitated during the programme. In order to provide a snapshot of the diverse levels and extent of engagement, this Case Study highlights the activities co-ordinated primarily by Dr Gitanjali Yadav, through National Institute for Plant Genome Research (NIPGR). In addition to these activities, the programme celebrated a major launch with the University of Cambridge Vice Chancellor (New Delhi 2018), a General Assembly held at ICRISAT (Hyderabad) early in 2019, as well as three major summative workshops in January – February 2022 and four scheduled reporting sessions to our International Advisory Board

MAJOR WORKSHOPS & SYMPOSIA

- #R4R: Workshop on R for Genomics and Data Mining (New Delhi Feb 2018)
- Workshop on Quantitative Social Science Study Design (New Delhi Feb 2018)
- Science Camp for High School Students (New Delhi, Sep 2019)
- Introductory Workshop on AI and Deep Learning (ICRISAT Feb 2020)
- We-VIDYA: Women Enabled for Virtual Induction as Data Youth and AI Professionals (Dec 2020)
- Workshop on Complex Networks for Biologists (April 2021)
- "Protocols From Home" Series: Free Computational Skills Trainings during Pandemic (2020-2021)
- India-U.K Crop Sciences Research Event (March 2022)

POLICY INTERVENTIONS & CAPACITY BUILDING

- Women in Leadership Panel Discussion (New Delhi Oct 2018)
- ASPB Plantae Steering Committee for Plant Biologists (2021)
- Ex-Co Membership of Asia Pacific Bioinformatics Network (APBioNet) 2020-2022
- Launch of the Cambridge-India Research Foundation (CIRF) in Jan 2019
- Panel on Equality, Diversity & Unconscious Bias (New Delhi Jan 2019)
- Fostering Entrepreneurial & Innovation Activities (Jan 2019)
- Internships: 10 Four Week Internships (With KARYA, Govt of Rajasthan); 10 Two Month Summer Internships (With Indian Academies of Science); 8 Six Month Internships (With NIPGR and Cambridge University)

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NIPGR

Department of BioTechnology, Government of India

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6.2 Delivering the Grow Call: Capacity Building Destinations, Exchanges and Translation into Policy

In order to deliver the capacity building challenge inherent to the GCRF Grow Call, the TIGR2ESS programme has facilitated the careers of over 33 directly employed Early Career researchers, across more than 20 institutions in UK and India, with many additional places being made available at workshops, conventions and through academic exchanges. The summary table (pictured right) taken from the 2022 UK ResearchFish submission for the programme demonstrates the magnitude of cumulative research activities, outputs, engagements and overall impact.

Onward Destinations
At the time of collating the ResearchFish submission, some 37 next destinations had been reported for research and administrative staff associated with the programme. These included:

PDRA to PI: 7 Early Career Researchers (ECR) were elected to lectureships or research fellowships in UK, Greece and India;
PDRA to PDRA: 10 ECRs moved on to additional PDRA positions, including two in Industry;
PDRA to NGO/ Administration: 7 ECR positions;
Admin Team: 5 moved to permanent positions, 3 on fixed term contracts

Capacity building Exchanges and Summer Students: Despite the pandemic, a total of 37 exchanges were undertaken, both to the UK and to India. Notably these included a number of undergraduates and postgraduates who went on to obtain either PhD or PDRA positions, or industrial startups, after training with TIGR2ESS ECRs

Policy Fellows
Key advisors from national and regional government organisations participated either in extended visits to Cambridge or virtual engagements to address questions relevant to their portfolios. Fellows included:

Dr Arabinda Mitra (Scientific Secretary, PSA Office, Govt of India)
Mr Suresh Kumar (Former Chief Principal Secretary to Chief Minister, Punjab)
Mr Anirudh Tewari (Chief Secretary, Government of Punjab)
Mr Vijay Kumar Advisor for Agriculture and Cooperation, Government of Andhra Pradesh
Mrs Juthika Patankar (Principal Secretary to the Governor of Uttar Pradesh)

Joint Policy Workshop: Organised between Prof Ambuj Sagar (IIT New Delhi) and Dr Rob Doubleday (CSaP, Univ. Cambridge) to promote mechanisms of policy engagement.

Publications	240
Collaborations & Partnerships	34
Further Funding	14
Next Destination	37
Engagement Activities	400
Influence on Policy, Practice, Patients & the Public	32
Research Tools & Methods	37
Research Datasets, Databases & Models	14
Intellectual Property & Licensing	1
Medical Products, Interventions & Clinical Trials	0
Artistic & Creative Products	11
Software & Technical Products	2
Spin Outs	0
Awards & Recognition	51
Other Outputs/Outcomes	19
Use of Facilities & Resources	15

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6.3 Collaboration Award for Research Impact and Engagement, 2021

Notable achievements of the programme in its final phase:

240 publications; 400 engagement activities including fieldwork training exercises and Mobile Teaching Kitchen workshops: PDRA skills-training workshops & presentations, academic exchanges (UK-India), invited symposia presentations, on-line open communications (blogs and newsletters) and five policy fellowship exchanges.

Further, the programme has established a new open dissemination tool (MOOC, English & Hindi) for farmer engagement to enable front-line workers to access equitable and sustainable food systems, saved 58 billion litres of water across two growing seasons through development of new technologies, instigating policy notifications (Punjab state), one of which will support Farmer Producer Organisations (FPOs) and benefit agri-businesses.

The judges said: "The impact of this programme is truly epic in scale and importance. The projects have had a huge influence on people and communities in the developing world. This was demonstrated through the exemplary, and very large scale of engagement that has been undertaken, working in close collaboration with partners."

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Acknowledgements

TIGR²ESS is an India-UK partnership programme designed to scope and build a network of transdisciplinary stakeholders, with objectives to develop, adopt and promote new strategies and future pathways for sustainable farming, water use management and open channels for equitable and fair access to common-use resources.

The research programme was funded through a grant awarded by UKRI, through GCRF and BBSRC open calls and additionally supported by DBT (India). The logos presented below represent many of the key institutes who participated through providing leadership, expertise and time throughout the duration of the programme. In no simple way can all small charitable organisations, community groups and individuals who contributed be represented here, yet we acknowledge the programme would not have been a success without their contributions and dedication.

For more information about TiGR²ESS partners, please see:
https://tigr2ess.globalfood.cam.ac.uk/partners