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REVIEW

An introduction to conducting responsible and reproducible agricultural research

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Abstract

This article aims to provide researchers with introductory guidance to good practices in the design, conduct and reporting of agricultural research. This narrative review considers issues related to research co-design, ethics and integrity, equity, diversity and inclusion, reproducibility and (meta)data reporting. Aspects for researchers to consider are highlighted, and relevant resources are identified, including academic papers and research funder guidance.

Keywords: collaborative research, research integrity and ethics, FAIR data, equity diversity and inclusion, open access, reproducibility of results, agriculture

Background

Agriculture is a major economic lever for improving livelihoods of many of the world's population; it accounts for only 4% of global gross domestic product (GDP) but for more than 25% of GDP in many low-income countries (FAO *et al*., 2024). Improving agriculture can help reduce poverty, raise incomes, and improve food security. While crop production is the mainstay of many agricultural systems, livestock also contribute to food security by supplying essential macro- and micro-nutrients, providing manure and draught power, as a household asset, and for generating income (Mottet *et al*., 2017). Globally, agriculture occupies nearly 40% of the Earth's land area, accounts for 70% of global water use and directly contributes to around 11% of global greenhouse gas emissions (IPCC, 2014). However, agricultural productivity is limited by diverse constraints, both biotic (growth and production) and abiotic (environmental) (Temesgen, 2020). According to the Organization for Economic Co-operation and Development (OECD, 2019), feeding a growing population, providing a livelihood for farmers, and protecting the environment are the three major challenges facing agriculture that need to be tackled globally to make sustainable progress. The need for agricultural improvement has become even more pressing due to climate change and regional conflicts.

Agricultural Research and Development (R&D) and innovation play an important role in improving global food security, livelihoods and environmental outcomes, and large increases in agricultural R&D investment are required to support achievement of Sustainable Development Goal 2 (to end hunger by 2030) and the Paris Agreement (to limit the increase in global average temperature to well below 2°C above pre-industrial levels) (Rosegrant *et al*., 2022). Furthermore, a supportive research environment is required to enable impactful R&D investments. Gallacher and Webster (2024) – reflecting on challenges facing the biomedical research community – propose a model for achieving and sustaining a high-quality research environment in which value-based and user-led innovation underlie research collaboration, data access and trustworthiness. The model is applicable to other research fields, and this article considers its application in agriculture research, including practical steps that researchers can take to contribute to ensure the research process and outputs contribute to a high-quality research environment.

There are multiple potential benefits to adopting good research practices in agriculture. From the researcher's perspective, demonstrating good research practices increases the chances of obtaining funding, the impact of outputs, the productivity and sustainability of partnerships (including with study participants and communities), and improved institutional reputation. From the perspective of participants, good research practices can increase empowerment and promote positive experiences of participating in research, and make research more valuable to addressing their

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needs. Other benefits include better value for money for research R&D investment and improved trust and reputation in the research sector.

The objective of this article is to provide agriculture researchers with an introduction to designing and implementing responsible and reproducible agricultural research, drawing on resources developed for the agriculture community, and more widely from biomedical and non-discipline-specific resources. This framework explicitly focuses on critical issues of research co-design and co-production, research integrity, ethics, equity-diversity-inclusion and data management. The overview intends to be broadly relevant across multiple domains of agricultural research, including soil and crop surveys, designed crop and livestock experiments, and experimental work involving human participants. Potential users of this framework include scientists from research institutes, academic institutions, government agencies and non-governmental organisations (NGOs). The article may be particularly valuable as a guide for early career researchers or those with limited professional development or training opportunities in research integrity and related topics.

Review methodology

A narrative review was conducted based on the authors' direct experience of establishing and conducting various agricultural research studies, including multi-partner collaborations involving universities, research institutes and national agricultural research departments. This was supplemented by a review of UK Research and Innovation (UKRI) policies and guidelines on good research practices, and cross-learnings from other research domains, primarily biomedical sciences and public health. Additionally, the USDA National Agricultural Library's SEARCH tool and Web of Science were searched using the following terms: 'Review' AND ('Integrity' OR 'Ethic*' OR 'Participat*) AND 'Agricultur*'. Review articles were used to further identify original studies.

Partnerships, co-production and stakeholder engagement

Integrated multidisciplinary and multisectoral teams are required to tackle many global development challenges, including agricultural research in support of healthy and sustainable food systems (Dangour *et al*., 2012; McDermott *et al*., 2015). Co-development and co-creation of research is an important component of equitable partnership, whereby the research question and proposal are jointly developed by multiple stakeholders, including non-academic actors, representatives of the study communities and study participants. The involvement of communities in framing research needs and co-creating the research objectives, interventions and methods can help to address power imbalances in the research process, empower often-marginalised communities and voices, and ensure maximum relevance of the research for locally-defined needs. This contributes to decolonising the research process (Yanou *et al*., 2023). Furthermore, by drawing on multiple, diverse sources of knowledge and expertise and lived experience, co-production approaches can lead to more innovative thinking with strengthened research outputs and impacts, including through increased acceptability and community buy-in. The use of co-production processes is much-needed and increasingly widely adopted in agriculture-related research (Howarth & Monasterolo, 2017), including to orient research needs (Blue Bird Jernigan *et al*., 2012), to inform study design and delivery (Christine *et al*., 2019; Harris-Fry *et al*., 2020a; Chiutsi-Phiri *et al*., 2021), and to enable scale up (Lu *et al*., 2022; Nkomo *et al*., 2023).

The term 'co-production' covers a wide range of approaches and activities, but Shaw *et al*. (2024) identify four 'shared principles' of co-production drawing on recent UKRI-funded Transforming UK Food Systems research projects – relationships, knowledge, power and inclusivity – and they provide a set of recommendations to support the effective use of co-production in research and practice. Maughan and Anderson (2023) provide a framework to guide practical decisions on the use of co-production in the early-stages of agro-ecology study design, while Ingram *et al*. (2020) consider adaptive co-innovation approaches in which stakeholders are engaged in framing and designing research such that outputs are more effective and useable. Cerf *et al*. (2012) explore methods for participatory co-design of agronomy decision support tools. Meanwhile, the FIT4FOOD2030 project (Baungaard *et al*., 2021) has developed a wide range of tools to support research co-design, innovation, stakeholder engagement and cross-learning in the agriculture-food systems space.

Agricultural research is often conducted in partnership between different researchers and research organisations. Partnerships can enable multi-disciplinary research, collaborations with practitioners and policy actors, and international teams. The process of developing and undertaking research collaborations raises several potential equity issues, which may relate to existing power imbalances including post-colonial structures. The issue of 'helicopter' or 'parachute research' in soil science has been highlighted as widespread and problematic (Giller, 2020; Minasny *et al*., 2020), whereby partners from high-income countries control funds, design research projects, and lead on publications, while partners from low-income countries conduct fieldwork and are often not included in project governance roles, proposal development and written publications. There is increasing awareness of the role of establishing and maintaining equitable partnerships to challenge and address power imbalances. Haelewaters *et al*. (2021) provide 'Ten simple rules for Global North researchers to stop perpetuating helicopter research in the Global South', while there are several resources to guide the process of developing equitable partnerships, including the EquiPar tool (LSHTM, 2023) and the TRUST Global Code of Conduct for Equitable Research Partnerships (TRUST, 2018).

Communicating research objectives and findings beyond the project partners is an important component of research integrity. For example, at the start of a project, a project inception or awareness meeting can be organised with representatives from relevant government departments, other organisations, local or community leaders and other researchers. During this meeting, the investigators should prepare presentations orienting stakeholders to the study scope, objectives, and anticipated outputs and outcomes. Towards the end of a project, findings should be communicated with stakeholders, including study participants or their representatives, the media, community groups, relevant policy and program staff, and the wider research community. Researchers may co-design the format of research outputs with intended user groups, to support appropriate interpretation and use in subsequent decisions (Chagumaira *et al*., 2020; Chagumaira *et al*., 2022).

Strengthening institutional capacity to administer grants and manage research funds is an important component of enabling equitable partnerships between research institutions (Posthumus *et al*., 2012; Marjanovic *et al*., 2017; Van der Veken *et al*., 2017). In terms of process, most research partnerships will require a Collaboration Agreement, which is a contract involving legal representatives that should be signed by all the institutions involved. It covers the focus of the collaboration or scope of work (the overall goal), collaboration duration, institutional budgets, confidentiality, ownership of intellectual property, warranties, termination, collaborator contributions, reporting requirements and other relevant terms between the collaborating parties. Usually, one institution will manage the project funding and distribute funds to each partner. Site/collaborator budgets are based on estimates stipulated during the grant writing phase, hence partners should be involved in budget development to ensure activities are appropriately costed. Often, recruitment and research activities cannot begin until the collaboration agreement is signed (and for many partners, particularly in low-income countries, research activities cannot begin until funds are received), so projects should factor in time to complete this process.

In addition to the collaboration agreement, partners or institutions involved in multisectoral research must, as appropriate, develop and sign data sharing or material transfer agreements (MTA). Data sharing agreements will specify the purpose of the data sharing, the management and analysis of the data at each stage (considering ownership and license conditions), and the roles and responsibilities of each partner (ICO, 2022). Similarly, an MTA describes the type of material/sample to be collected and the reason for the transfer. It is very important where materials (germplasm or other samples) for research will be transferred from one place/country to another. Project collaborators should check the requirements and rules concerning data and material transfers between countries early in the proposal development process. Some types of data and samples are not allowed for export/import by some jurisdictions, and the rules can change with time. The MTA should be signed by an institution or country representative where samples will be collected and by the receiving institution. In the case of germplasm, international agreements such as the Nagoya Protocol may apply and should be adhered to (CBD, 2010). Co-developed publication and authorship policies should be encouraged, with the Project CRediT taxonomy and International Committee of Medical Journal Editors (ICJME) policies providing useful guiding resources (Brand *et al*., 2015; ICMJ, 2024).

Research integrity and ethics

Agricultural scientists engaged in research through surveys, laboratory analysis, or experiments under controlled conditions or field trials need to ensure the integrity of their research. Research integrity refers to the way in which conducted research follows the professional research standards expected (UKRI, 2018). It refers to both, the scientific integrity of conducted research and the professional integrity of researchers. This involves conducting research in a way that allows others to have trust and confidence in the methods used and the results found (Davis *et al*., 2007).

Research integrity includes five major commitments to be followed by researchers (UKRI, 2018): (1) Upholding the highest standards of rigour and integrity in all aspects of research, (2) ensuring that research is conducted according to appropriate ethical, legal and professional frameworks, obligations and standards, (3) supporting a research environment that is underpinned by a culture of integrity and based on good governance, best practice, and support for the development of researchers, (4) using transparent, timely, robust and fair processes to deal with allegations of research misconduct that may arise and (5) working together to strengthen the integrity of research and to review progress regularly and openly. The UK Research and Integrity Office (UKRIO, https://ukrio.org/resources, accessed 29 October 2024) provides a range of resources to guide institutional policies and processes and researcher practices in support of research integrity.

Research integrity principles need to be followed during all stages of a research project, from design through to results communication. Relatedly, research should be guided by a set of ethical principles and frameworks. In many disciplinary fields, applied ethical research frameworks are derived from Euro-Western paradigms, although researchers may draw on indigenous ethical principles (Kara, 2018). International frameworks and guidelines have been developed to support ethical research conduct, including the Singapore Statement on Research Integrity (Available at: https://www.wcrif.org/guidance/singapore-statement, accessed 29 October 2024).

In its applied form, research ethics is well established in biomedical, clinical and social science fields. Agriculture research studies that directly involve participants can draw experience from these fields, including the core ethical principles of 'beneficence' (i.e. the duty to act in the interests of research participants, including people and animals), 'non-maleficence' (i.e. the duty to do no harm), 'autonomy' (i.e. right to self-determination) and 'justice' (i.e. to treat people equally). In studies involving human participants, major ethical concerns lie in the relationship between researchers and research participants, participant welfare and wellbeing, and risk-benefit of research to individual participants, participant communities and wider society (Iphofen, 2020). These principles can guide researchers as they consider the ethical justification and scientific validity of the research considering important issues such as vulnerability of individuals, groups, communities, and populations involved in the research, equity regarding expected burdens and benefits, fair selection of subjects, confidentiality, respect for the potential or enrolled subjects, voluntarily informed participation and including the right to withdraw (Ofsted, 2019). This includes studies using surveys, interviews and focus groups. Furthermore, participatory, community-based research provides its own particular set of ethical research challenges, including tensions between research rigour and flexibility to accommodate participant inputs (Wilson *et al*., 2018).

Studies involving human tissue sampling or analysis, and secondary use of participant data also raise important ethical issues that require careful consideration and independent review. Where personal data are collected, for example in some farmer surveys, appropriate data management is a legal requirement under the General Data Protection Regulation (GDPR). Guidance for research organisations and researchers for processing personal data for research purposes is available via the Information Commissioner's Office (available at: https://ico.org.uk/for-organisations/uk-gdpr-guidance-and-resources/the-research-provisions/, accessed 29 October 2024) and UKRI (Available at: UKRI-020920-GDPR-FAQs.pdf, accessed 29 October 2024).

There is growing use of randomised, controlled trials to test the efficacy and effectiveness of agriculture-led interventions to improve human nutrition and health outcomes (Bird *et al*., 2019). Trials involve the prospective assignment of participants to one or more treatment groups, and there are specific guidelines for their conduct. For example, the MRC Guidelines for the Management of Global Health Trials (MRC, 2022) provides comprehensive guidance on aspects such as ethics, research governance and management, and oversight. The principles of these guidelines apply to any trial with a health-related outcome, including 'low risk' interventions in the agriculture domain, such as agronomic interventions (Joy *et al*., 2022) and participatory nutrition-sensitive agriculture training (Kadiyala *et al*., 2021). The active engagement of study participants in trial delivery including identifying and managing trade-offs or unintended consequences, particularly in community-based trials, can support ethical research conduct (Matandika *et al*., 2022).

Ethical principles are also applicable at the societal level, with relevance to multiple agriculture-related research fields including biotechnology, conservation and economics. The wider impacts of research on society are considered under 'responsible research and innovation' (RRI) in UKRI parlance, in which the benefits of advancing knowledge and understanding are weighed against potential unintended consequences, risks and ethical dilemmas. UKRI has developed a framework for RRI using the 'Anticipate, reflect, engage, act (AREA)' approach, which can be used by researchers to identify and respond to the wider impacts of their research on society and inform strategies to maximise benefits and minimise risks or harms (Available at: https://www.ukri.org/who-we-are/epsrc/our-policies-and-standards/framework-for-responsible-innovation/, accessed 29 October 2024). Adopting an RRI lens can foster responsible and inclusive development of agricultural innovations and technologies (Fielke *et al*., 2022; Jakku *et al*., 2022), including the growing use of Artificial Intelligence tools (Rose and Chilvers, 2018; Craigon *et al*., 2023).

The specific case of research involving animals (e.g. livestock), for example under the Animals (Scientific Procedures) Act (ASPA) regulations (Animals (Scientific Procedures) Act 1986), requires the implementation of the principles of replacement, reduction and refinement (the 3Rs) in research projects (Fenwick *et al*., 2009). A harm–benefit analysis of the program of work is required to assess whether the harm that would be caused to protected animals in terms of suffering, pain and distress is justified by the expected outcome, taking into account ethical considerations and the expected benefit to human beings, animals or the environment (UKRI, 1986). Examples of country-specific legislations regarding the use of animals in research include the ASPA in the UK (Animals (Scientific Procedures) Act 1986), Directive 2010/63/EU of the European Parliament and of the Council in the European Union (2010), the Animal Welfare Act in the US (AWA, 1966) or Law #11.794 for scientific use of animals in Brazil (Marques *et al*., 2009). As with research ethics pertaining to human participants, researchers should consider alternative framings that draw on indigenous knowledge and beliefs, depending on the study context (Stewart & Birdsall, 2024).

Prior to any planned or proposed research, researchers should evaluate the ethical considerations of the project using a decision tree, such as the following provided by the ENERI network (Available at: https://eneri.eu/decision-tree/, accessed 29 October 2024). Decision trees can also be used to triage requirements for Research Ethics Committee (REC) review, in line with institutional policies, for example for studies relating to human participation, tissue samples or data (Fig. 1). Similar decision trees can inform the need for ethical review of studies involving animals, or other areas of potential 'ethical concern' such as genetic modification. Appropriate ethical review is increasingly a requirement of funders. Researchers should ensure that before the research is initiated, the proposed work and implementation protocol is reviewed by an appropriate committee and given a favourable opinion. Relevant committees could be the Institution's ethical review committee or animal welfare body, or a Government (REC; Posthumus *et al*., 2012). Some projects may require review by multiple committees, including those 'local' to the study location.

Not all research requires an independent ethical review. Examples are crop experiments in laboratory, on-station or glasshouse settings, as well as literature reviews or the analysis of secondary data fully in the public domain. Nevertheless, it may be appropriate

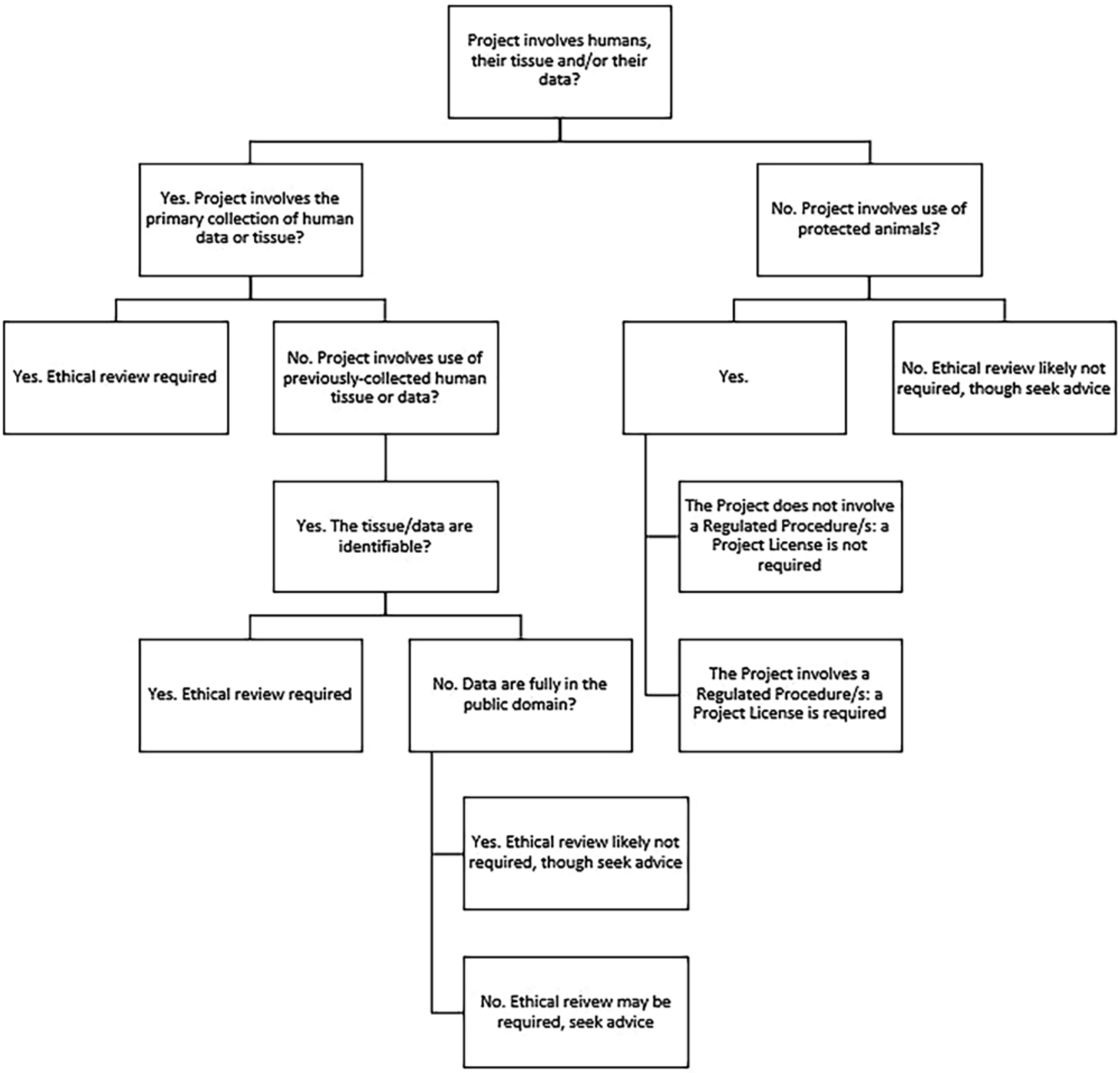

Fig. 1. Decision tree for planning the need for independent ethical review.

to seek independent advice on the requirement for ethical review, and this may be provided, for example, by the chair of an institutional ethics committee.

An independent REC should review the study protocol, including the data management plan. A data management plan needs to specify how the researchers will collect, store, analyse and share sensitive and personal data. In addition, as a part of the protocol, the researcher should develop the participant information sheet and consent form to be given to, read, and signed by the participants or their guardians, although in some cases verbal approval may be more appropriate. The participant information sheet should have information about the project (goals and objectives), what participation would involve, details on participant compensation, options for withdrawal, how data or samples would be managed, stored and used, and the format of results communication. Translation of the information sheet into local languages is important, and participants should be given time to consider their involvement. Furthermore, researchers may consider arranging community awareness activities, including with the support of relevant stakeholders (such as agriculture extension agents), to ensure a wider understanding and acceptability of the research activities. Many organisations provide tools and guidance for research ethics review purposes, aimed at researchers and research institutions, including UKRIO (Available at: https://ukrio.org/resources/, accessed 29 October 2024).

The TRUST code (Trust, 2018) provides guidance to support research integrity and ethical partnerships, including avoidance of 'ethics dumping', where researchers choose to conduct ethically dubious research in a low-income setting with limited regulatory oversight and where participants are particularly vulnerable to coercion and exploitation due to poverty and lack of power. The process of 'ethics dumping' is particularly problematic in an era of globalised research. Strengthening ethical review capacity in agriculture-development and agriculture-health research is a key challenge facing the global research community (Carter and Williams, 2019; Bain *et al*., 2022).

Protocols and reproducibility

A research study protocol will typically define a research aim, specific objectives and outcomes, and provide a detailed methodology for achieving these (Giraldo *et al*., 2018). In clinical studies – and therefore of relevance for studies of agriculture interventions with health outcomes – a study protocol is also expected to provide a statistical analysis plan, data management plan and information on managing ethical issues, and the SPIRIT group provides guidance and templates (Available at: https://spirit-statement.org/, accessed 29 October 2024). Study protocols are key for planning, performing and publishing research, especially in relation to the reporting of materials and methods used, and for ensuring reproducibility (Giraldo *et al*., 2017). However, inadequate protocols remain a major issue hindering scientific transparency and reproducibility, in biomedical sciences (Freedman *et al*., 2020) and in agricultural sciences (Kool *et al*., 2020).

A study protocol may include a set of standard operating procedures (SOPs), which are step-by-step instructions compiled by researchers for routine operations. SOPs aim to achieve efficiency while delivering robust, consistent and reproducible findings, thus reducing measurement error and risk or observer bias, and allowing comparison of findings between studies conducted at different locations and/or timepoints (Casadevall and Fang, 2010). SOPs are also helpful when there is a need to standardise laboratory methods to ensure successful replication of results by other laboratories (Selwyn, 1996), and they help to promote consistency across field and laboratory activities by delivering accurate and clear adaptable sets of procedures and data elements. A well-produced and adapted experimental protocol will make it easier for reviewers and editors to measure the quality of submitted manuscripts against a set of established criteria. Furthermore, accurate and comprehensive documentation of activities is critical for patenting and in cases of potential scientific misconduct.

Several aspects of study design are important to support reproducibility, and for designed experiments, these include replication, random allocation of treatments, and blocking. Crucially, the design of the experiment must match the statistical analysis methodology (Webster and Lark, 2018). Relatedly, researchers must ensure that studies are adequately powered to detect the outcomes of interest. Given logistical and financial constraints, in designed experiments, this may often mean reducing number of treatments and increasing replicates to attain sufficient statistical power (Botoman *et al*., 2020, 2022; Lark *et al*., 2020). Festing and Altman (2002) and Smith *et al*. (2018) provide useful guidance for the design of experiments with laboratory animals.

Publication and pre-registration of study protocols can improve transparency and reproducibility. The approach is common practice in human health research, with specialist protocol registries (e.g. https://www.isrctn.com/, accessed 10 July 2023 and https://clinicaltrials.gov/ct2/home, accessed 10 July 2023) as well as journals specialising in the publication of trial protocols e.g. BMC Trials. Many health-related journals will not publish trial findings if the protocol was not registered before study recruitment began. The practice of registering protocols is gaining traction in other research domains, including biology and agriculture, for example you can now submit Registered Reports in the journal "Plant Direct", however, there remains a need for improved research infrastructure and incentivisation of protocol registration for agricultural sciences.

Other advantages of publishing and pre-registering study protocols include the provision of an opportunity for independent review of proposed methods, reducing the potential for duplication of effort, and helping with finding data (some of which may not be published). A further advantage is reducing the risk of publication bias, since authors are 'committed' to reporting findings using pre-specified methods. Publication bias occurs when the outcome of an experiment influences whether or not the findings are published. Typically, this occurs because researchers are more likely to report 'positive' or 'significant' research outcomes, and these are more likely to be favourably received and reviewed by journals. Publication bias presents a major challenge for systematic reviews and meta-analyses, although there are methods and guidance to support researchers in identifying and addressing this issue (Lin and Chu, 2018; Boutron *et al*., 2022). Koutsos *et al*. (2019) report a framework and guidelines for conducting systematic reviews in agricultural sciences.

Transparency in reporting of findings is another issue that requires attention. In the health sciences, the Equator Network (Enhancing the QUAlity and Transparency Of health Research) provides a set of guidelines and templates for reporting of various study types including randomised trials (Schulz *et al*., 2010) observational studies (von Elm *et al*., 2007), systematic reviews (Page *et al*., 2021) and study protocols (Chan *et al*., 2013). Large portions of these guidelines and templates are relevant and adaptable for the reporting of agriculture studies, and can greatly improve consistency and transparency of reporting.

Findable, accessible, interoperable, and reusable (FAIR) data management principles

Digital data generated by agricultural research has grown exponentially in volume, particularly by remote sensing, image analysis, and mobile and web-based applications specific to agricultural management (Ali and Dahlhaus, 2022). Agricultural data digitalisation aims to support a resilient and sustainable global food system (Top *et al*., 2022). Although the amount of potentially useful research data is growing rapidly, its (re)use is still limited (Top *et al*., 2022). To attain data usability and add value to investment in research, researchers and research institutions conducting agricultural research should adopt FAIR (i.e., findability, accessibility, interoperability, and reusability) data management principles. These guidelines were established by a consortium of scientists and published to promote the reusability of research data and digital assets (Mons, 2018; Top *et al*., 2022). FAIR is a set of principles applied to all digital datasets, software and code to increase their value and reuse potential, with a specific emphasis on the ability of machines to automatically find and use data or metadata (Mons, 2018; Top *et al*., 2022).

One of the challenges in open science is encouraging researchers and database owners to share their data. As a response, research funding agencies, institutions, journals and publishers encourage data sharing as part of their policies (Colavizza *et al*., 2020). The measures to promote data sharing go from simple statements regarding data availability recommendations (e.g. data available upon request) to mandated data policies (e.g. compulsory data archiving). However, data are still mostly available upon request or findable in the supplementary information, which often provides raw data in a non-open and non-reusable format (e.g. pdf or Word) or even as a data summary (Gareth *et al*., 2023). Thus, although data 'findability' has improved as an effect of the inclusion of data availability statements (Vines *et al*., 2013), many researchers are still unable or reluctant to share data using data repositories (or data archiving), even when their use is considered best practice in data management recommendations (Colavizza *et al*., 2020).

Data repositories have several advantages including long-term data archiving, and the provision of digital object identifiers (DOIs) to datasets, protocols and metadata (i.e., data about the data). DOIs increase the findability, accessibility and reusability of datasets by providing a persistent online identifier that resolves to rich metadata to describe the dataset, and which should include a data license to describe how data can be reused (Ali and Dahlhaus, 2022). Multiple options exist for data preservation/archiving, including public and open access archives, for instance, Zenodo (available at: https://zenodo.org/, accessed 15 August 2023), Figshare (available at: https://figshare.com, accessed 15 August 2023) or data DRYAD (available at: https://datadryad.org/stash, accessed 15 August 2023), controlled access repositories such as The European Genome-phenome Archive (available at: https://ega-archive.org/, accessed 15 August 2023) and the database of Genotypes and Phenotypes (available at: https://www.ncbi.nlm.nih.gov/gap/, accessed August 2023), and Institutional data archives. An example of the latter is the electronic Rothamsted Archive (e-RA), which provides a platform for long-term experiments and meteorological data generated by Rothamsted Research (Perryman *et al*., 2018). The invaluable information from long-term experiments and their importance in the knowledge of agricultural systems and their future challenges require data to be FAIR (Ostler *et al*., 2023). e-RA provides data stewardship, data supply and delivery upon request. For example, yield and analytical data are available from the Long Term Experiments (available at: https://www.era.rothamsted.ac.uk/index.php, accessed 15 August 2023) and at the same time, those data may be associated with archived samples (available at: https://www.rothamsted.ac.uk/facilities-and-resources/rothamsted-sample-archive, accessed 15 August 2023), Rychlik *et al*., (2018) provide guidance on issues surrounding the provision of accurate food chemistry results and FAIR data in multi-centre studies.

Lack of data 'interoperability' across the domain due to the non-use of standards and accepted definitions is another challenge in agricultural research (Strömert *et al*., 2022). For example, researchers may refer to the same term using different words or even different units of measure for the same variable, making it difficult to compare studies or perform analyses combining datasets if data are not harmonised. Ontologies and standards provide specific descriptions for data, information and knowledge about any area of expertise, and make the digitised data interoperable and understandable by machines and humans. If we use a standard vocabulary from the start of data generation and through research workflows, it will allow our data to be FAIR (FORCE11 Consortium, 2020). Specific ontologies have been elaborated for use in agricultural science, for example, the Agronomy Ontology (AgrO, available at: https://www.ebi.ac.uk/ols/ontologies/agro, accessed 18 August 2023) and the Crop Ontology (CO, Available at: https://cropontology.org, accessed 18 August 2023) (Matteis *et al*., 2013). Other ontologies are multi-disciplinary, for example, the n.d. Environment Ontology for Livestock (EOL, available at: https://www.ebi.ac.uk/ols/ontologies/eol, accessed 15 August 2023), are multi-disciplinary, e.g. the Environment Ontology (ENVO, available at: https://www.ebi.ac.uk/ols/ontologies/eol, accessed 18 August 2023) (Buttigieg *et al*., 2016) and the Compositional Dietary Nutrition Ontology (CDNO, available at: www.cdno.info, accessed 18 August 2023) (Andrés-Hernández *et al*., 2022), or are concerned with the standardisation of units of measures, e.g., the Ontology of units of Measures (available at: https://www.ebi.ac.uk/ols/ontologies/om, accessed 18 August 2023) (Rijgersberg *et al*., 2013). Using common standards will increase the data quality and make them machine readable, enabling secondary uses.

Data archiving or storing data already used (Whitlock, 2011) aims to save data for posteriority, preserve data in a (re)usable form, describe data to avoid misinterpretations, and offer guidelines for (re)use. Providing these guidelines in human and machine-readable metadata allows us to understand the criteria for data (re)use (Ali and Dahlhaus, 2022), being conscious that data reuse may vary from the original data collection purpose and the metadata may have a new version, including new information. Thus, describing data (re)use conditions is indispensable. Data 'reusability' is possible through the provision of a clear usage license and conditions of reuse with accurate information on its provenance. The Creative Commons license family is mostly used for dataset publishing. To summarise, the FAIR Data Principles provide a data management framework to help researchers manage their data assets and reuse the repository of metadata. The final objective of the FAIR principles is the data (re)use and thereby the data reproducibility, which will enhance data quality, transparency and credibility.

Open, responsible, and reproducible (meta)data publication

Although FAIR is not a synonym for open access data, making data FAIR will imply research will be 'open' to be repeatable, replicable and reproducible. In the current 'reproducibility crisis' the non-access to protocols, raw data and research materials are some of the factors contributing to the lack of reproducibility (ATCC, 2022). Open access to structural (e.g. experimental design, sampling methods, analytical methods, data transformation and data dictionary), descriptive (e.g. dataset overview) and technical (e.g. data organisation, cleaning, and process) metadata plays an important role in the research transparency in agriculture (e.g. Bello and Renter, 2018; Sileshi, 2023). Thus, well-described metadata should be open even when data is not open access in the first instance. The Global Long-Term Agricultural Experiment Network (GLTEN) (available at: https://glten.org, accessed 18 August 2023) is a clear example of how metadata is relevant in data access. GLTEN is a collaborative platform to discover over 300 Long-Term agricultural experiments from five continents (Ostler and Castells-Brooke, 2023). This platform provides access to open metadata to describe key characteristics of a long-term experiment, including environment, cropping and treatment factors, using a standardised metadata schema. The GLTEN schema uses existing ontologies such as PECO (available at: https://bioportal.bioontology.org/ontologies/PECO, accessed 18 August 2023), ENVO and AgrO (available at: https://www.ebi.ac.uk/ols/ontologies/eol, accessed 18 August 2023) to annotate captured metadata.

A critical point in responsible (meta) data publication is when research is associated with personal information that may be sensitive, posing an increasing concern regarding privacy, which must be addressed (Jiang *et al*., 2022). Thus, one of the first steps in data management plans (DMPs) should be to define the type of data generated and how it will be managed and shared. DMPs should provide details on the types of data that will be generated, data standards and metadata, provision for secondary use, methods for data sharing and methods for handling of personal and sensitive data. Templates and guidance are available via UKRI (available at: https://www.ukri.org/who-we-are/mrc/our-policies-and-standards/research/data-management-and-sharing/ and https://www.ukri.org/councils/bbsrc/guidance-for-applicants/what-to-include-in-your-application/data-management-plan/, accessed 29 October 2024).

Responsible data publication is highly relevant when the information comes from and belongs to vulnerable communities (e.g., indigenous populations, migrant farmers and women with precarious land rights). For example, in the current open science movement, indigenous people have reclaimed control of their data, data narratives, data science and data ecosystems (Ostler and Castells-Brooke, 2023) . Indigenous data consider information about resources and the environment, social, health, economic information about individuals and cultural information (Carroll *et al*., 2020). Global Indigenous Data Alliance 2022 (Carroll *et al*., 2022) also includes data generated by governments and institutions (Carroll *et al*., 2020). Thus, in response to the FAIR principles, the CARE principles for indigenous data governance emerged because of the lack of engagement with Indigenous People's rights and interests. The CARE principles are referred to obtain 'collective benefit' and 'authority to control' recognition, 'responsibility' when working with indigenous data, and 'ethic' in the data (re)use (Carroll *et al*., 2020). They also aim to protect data access from large multinational companies and transnational corporations which may incur data misuse and misunderstanding and take control of data royalties; at the same time, they avoid data inequities (Carroll *et al*., 2020).

In addition to the privacy of sensitive data, equity in data access, and data use by vulnerable communities are also challenges in responsible data publication. A clear example of inequity in data access is documented in African indigenous farmer communities where agricultural data digitalisation is covered by a 'governance data framework' focused on data privacy, neglecting the rights and interests of their own data from these communities (Ferris and Rahman, 2017). In agriculture, data access inequities may also be given by socio-economic differences at a small scale, for example, within the same community with differences in social networking (Hoang *et al*., 2006) or at a large scale among members of the same economic activity; for example, differences in financial means to buy data. Data access inequity increases as data complexity grows (e.g. precision agriculture data and remote sensing data; Responsible Data in Agriculture, Sishodia *et al*., 2020), for example, due to the lack of technical skills and data understanding (Ferris and Rahman, 2017). Thus, even when smallholder farmers are considered a primary source of data in agriculture, they may be unable to access their information (Quisumbing *et al*., 1995) and these differences increase many times over for subsistence farming households. Historically, equity in access to resources and human capital improved the economy and life quality of vulnerable communities (Johnson *et al*., 2016).

Equity, diversity and inclusion

Designing research proposals and research projects that accommodate the needs and desires of a wide variety of people according to Equality/Equity, Diversity and Inclusion (EDI) concepts has become an emergent priority (Jones *et al*., 2022; ANH, 2024). Equity refers to fairness and justice and is distinguished from equality which means providing the same to all, without considering age, race or sex (Jones *et al*., 2022). Diversity is the condition of having or being composed of differing elements, including differences relating to race, gender, religion, sexual orientation, ethnicity, nationality, socioeconomic status, language, ability, age or political perspective (Van den Bold *et al*., 2015). Inclusion is when different people come or work together, comfortably, and confidently in a way that suits them to achieve an intended goal (NACE, 2024).

Achieving equitable distribution of power, influence and resources in a project can be successfully achieved in research through inclusive processes of project planning, decision making and implementation of activities. Inclusion also takes gender equality issues into consideration. Achieving gender equality requires equal rights, conditions and opportunities, and contributes effectively to the development of a project (UNFP, 2005). Researchers should carefully deal with barriers to gender equality for the success of the research project. Some common barriers to gender equality include gender stereotypes, cultural norms, societal expectations regarding gender roles and lack of flexible participation among women and children.

EDI concepts and policies are important in achieving a healthy research culture that is inclusive and creates a sense of belonging for marginalised and under-represented groups (Wolbring and Nguyen, 2023). Advancing EDI of teams and sectors can empower diverse talent to contribute and share their different experiences and perspectives, leading to improved productivity and creativity (Cooke and Kemeny, 2017). Meanwhile, there is increasing awareness that projects that accommodate the needs and desires of a wide variety of people according to EDI concepts yield stronger teams and provide more effective results. EDI concepts seek to prevent inequities from systemic, institutional and individual levels to exist, which limits the baseline opportunities for minority groups. Despite evidence that diverse teams enable more creative problem solving, yield greater innovation and improved project outputs and outcomes, most agriculture research teams/projects and other related professionals conduct research without considering EDI requirements (Dixon-Fyle *et al*., 2020). Exclusion of minority views and voices leads to loss of valuable ideas and contributions, creating inefficient and biased research results. The lack of diversity among research participants has serious ethical and research consequences (UKRI, 2023). Consequently, incorporating EDI concepts in research proposals/projects has become a priority consideration by most funders and/or research granters, ensuring fair treatment and opportunity for all. Researchers should therefore design and implement agricultural research programs that encompass all the three principles of EDI to create a research environment and belonging, that engages the full potential of individuals where innovation thrives and views, beliefs and values of all participants and collaborators regardless of age, race and gender are integrated. The belonging that emerges from appropriate EDI integration is now a major requirement by the research funders, including UKRI (UKRI, 2023).

EDI is important to consider from a variety of perspectives, including the role of funders, research institution policies and practices, research teams recruitment and management, conducting research, research participation, analysing and publishing findings, and research dissemination (Guyan and Oloyede, 2019; Wedekind *et al*., 2021; ANH, 2024). EDI and its components are also topics or lenses of study in their own right, for example studies and methods that focus on the importance of gender and household power dynamics in agriculture and agriculture-nutrition linkages (van den Bold *et al*., 2015; Johnson *et al*., 2018; Harris-Fry *et al*., 2020b), and consideration of the role of agricultural development projects in empowering women. In recent years, there has been an upward trend in the number of studies looking at aspects of equity in agriculture-nutrition in low- and middle-income countries (Harris *et al*., 2022). Generally, however, few studies have considered the intersection between different dimensions of equity, and relatively few studies have considered structural determinants of inequity.

Several resources are available to support researchers to integrate EDI into agriculture projects. These include the Women's

Empowerment in Agriculture Index (available at: https://weai.ifpri.info/, accessed 15 August 2023; Alkire *et al*., 2013) and the Reach-Benefit-Empower-Transform framework (available at: https://gender.cgiar.org/tools-methods-manuals/reach-benefit-empower-transform-rbet-framework, accessed 29 October 2024; Quisumbing *et al*., 2019). The National Institute of Health Research (NIHR) provides an EDI Toolkit to better understand how to embed EDI in research design (available at: https://www.rssleicesterresources.org.uk/edi-toolkit, accessed 29 October 2024) while the UKRIO has collated a set of Equality, Equity, Diversity and Inclusion Resources (available at: https://ukrio.org/ukrio-resources/equality-diversity-and-inclusion/, accessed 29 October 2024).

Conclusions

Agriculture underpins global food security, yet the sector is facing multiple, compounding challenges. Climate change, depleted resources, soil erosion, economic volatility and conflict are among the pressing issues that negatively impact the agricultural sector. Robust research is required to successfully combat these global threats to achieve sustainable agricultural production and support improved livelihoods, wellbeing, environmental outcomes and health.

This article provides guidance to researchers on how to conduct responsible and reproducible research, recognising wider structural issues that need to be addressed, including existing power and knowledge imbalances and the need to decolonise research processes. Consideration is given to the design of the study, its conduct and reporting. The review draws on the combined experience and observations of the authors, principally from the fields of agriculture and nutrition. Good/best practices are highlighted, as are deficiencies or shortcomings of current common practices, particularly where there is potential to learn from other research domains. Pre-registration of study protocols and adoption of standard guidelines for study reporting are two such examples. This review aims to support the adoption of good practices in agricultural research, including among groups without ready access to institutional training or other forms of support, by providing introductory guidance and pointing to further resources.

CONFLICT OF INTEREST

The authors have no conflicts of interest to declare.

AUTHOR CONTRIBUTIONS

ISL, SPM, SMH, MGMK and MRB contributed in conceptualisation; ISL, SPM, SMH, MGMK, EJMJ and MRB contributed in methodology; ISL contributed in writing—original draft preparation; EJMJ, ISL, SPM, SMH, MGMK, MRB, LP, MJR and MWD contributed in writing—review and editing; SPM, SMH, MGMK and MRB supervised the study; SPM contributed in project administration and funding acquisition. All authors have read and agreed to the published version of the manuscript.

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