Responsible Agri-Food Research: A Behavioural Perspective

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Abstract. The agri-food system experiences pressures for a socially-desirable and sustainable transformation. The Responsible Research and Innovation (RRI) approach can arguably contribute towards a transition to more sustainable agri-food systems. However, its successful implementation in the agri-food context remains challenging. This study examines if and how agri-food researchers enact the RRI principles – particularly inclusion and anticipation – and identifies influencing factors at the individual level. Findings indicate that inclusive behaviours, such as stakeholder engagement, are more common than anticipatory behaviours. A cluster analysis reveals two behavioural patterns: 'Anticipatory Collaborators' and 'Non-anticipative Collaborators' both engaging stakeholders in their agri-food research but the latter show less anticipatory behaviours. Supporting agri-food researchers in improving their skills and creating conducive organisational environments could enhance their engagement in responsible research behaviours. By introducing a behavioural lens to RRI, this study enhances the understanding of its enactment and underscores the role of individual researchers in advancing a responsible agri-food transition.

1 Introduction

The agri-food sector encompasses challenges in economic, environmental, and societal dimensions (e.g., climate change, population growth, reduction in arable land) (Bodirsky et al., 2020; Fedoroff, 2015; Food and Agriculture Organization of the United Nations, 2023; Leclère et al., 2020). The sector is under pressure for radical transformations. Hereby, it is important that the profound transformations in the agri-food sector are implemented in a socially-desirable way by considering societal needs and by contributing to solving current challenges without creating new ones.

Following the Responsible Research and Innovation (RRI) principles was argued to contribute towards a responsible digital 'Agri-food 4.0' transition (in reference to 'Industry 4.0') (Klerkx & Rose, 2020) and enhance the positive impacts while proactively addressing emerging challenges (Rose et al., 2021). In the author's view, RRI could support not only the digital transformation but also other aspects of agri-food system transformation. Moreover, in context of system change, the need for innovative and collaborative solutions to ensure robust and resilient agri-food systems in the future is evident (Herrero et al., 2020; Lezoche et al., 2020; Preiss et al., 2022), emphasising the need to incorporate the four guiding principles of the RRI framework in the agri-food sector (Castilla-Polo & Sánchez-Hernández, 2022; Mangelkramer, 2024).

Therefore, the study focuses on the enactment of RRI principles in agri-food research practice, with a particular focus on inclusion and anticipation. Recognising that the enactment of RRI principles remains challenging, the study examines how researchers' skills, motivation, and organisational environment enable or hinder researchers' engagement in responsible behaviours. Accordingly, it addresses the following research question: *Whether and how are the principles of inclusion and anticipation enacted in agri-food research, and what factors enable or inhibit their enactment?* A survey among agri-food researchers in Germany was conducted to answer this question. The study emphasises the central role of individual researchers in driving a responsible agri-food transition. Its novelty lies in applying a behavioural lens to RRI by using the COM-B behavioural model to explore the behavioural dimensions underlying the enactment of RRI. Since this is the first attempt to take a behavioural perspective on RRI in the agri-food context, the research follows an exploratory approach, providing a foundation for future studies.

The paper is structured as follows: Section 2 introduces the RRI framework in the agri-food context and reviews current literature on the implementation of the inclusion and anticipation principles, identifying key drivers and introducing a behavioural lens to RRI. Section 3 outlines the methodology, while Section 4 presents the findings, which are discussed along with the study's limitations in Section 5. Section 6 concludes the paper.

2 Theoretical Background

RRI is a process-orientated framework developed to ensure that research and innovation are conducted in an ethical and socially-responsible manner (Owen et al., 2013; von Schomberg, 2011; Stilgoe et al., 2013). It involves engaging with society to guide the research and innovation processes and considering their broader impacts (Owen et al., 2013). RRI is defined as 'a transparent, interactive process by which societal actors and innovators become mutually responsive to each other with a view to the (ethical) acceptability, sustainability and societal desirability of the innovation process and its

marketable products […]' (von Schomberg, 2011, p. 50). It incorporates research and innovation practices that are aligned with four guiding principles: (1) *inclusion* which involves actively engaging with multiple stakeholders to ensure that a variety of values, needs, and concerns are taken into account; (2) *anticipation* which involves considering the potential short and long-term consequences of research and innovation, both positive and negative, with the aim to mitigate negative impacts; (3) *reflexivity* which refers to reflecting on own values, interests, and potential biases and how they might affect the alignment of the research and innovation with societal values and ethical considerations; and (4) *responsiveness* which involves making active efforts to respond to the insights gained through inclusion, anticipation, and reflexivity by adapting the research and innovation trajectory accordingly (Owen et al., 2013; Stilgoe et al., 2013).

It is argued that RRI has the potential to drive just and sustainable transformative change (Purvis et al., 2023; Rose et al., 2021) by broadening the scope of the 'techno-centric' agri-food sector (Jakku et al., 2023; Psarikidou, 2023). Thus, RRI can play a crucial role in facilitating a responsible agri-food transition (Klerkx & Rose, 2020).

There is substantial literature on RRI in agri-food. The review by Sabio and Lehoux (2024) reveals that the interpretation and application of RRI varies widely, although the majority of reviewed articles based on von Schomberg's (2011) definition. The studies evaluate the significance of individual RRI principles differently where some authors highlight the principle of including multiple stakeholders, others set their emphasis on anticipation of potential impacts (Sabio & Lehoux, 2024).

This study examines the inclusion and anticipation principles, in line with previous research that has adopted a selective focus (Fleming et al., 2021; Sabio & Lehoux, 2024). While the four RRI principles are closely interconnected and ideally addressed as a whole, a targeted investigation allows for a more in-depth and methodologically coherent analysis. Specifically, inclusion and anticipation are the most directly operationalisable within the chosen explorative, quantitative study design. The intention is not to diminish the importance of the reflexivity and responsiveness principles, which remain central to RRI. Reflexivity and responsiveness are often more effectively examined as subsequent or complementary dimensions that build upon prior inclusive and anticipatory activities. For instance, responsiveness can steer research and innovation towards desired trajectories, especially when grounded in inclusive, anticipatory, and reflexive considerations (Owen et al., 2013; Stilgoe et al., 2013). Concentrating on the latter two principles therefore strengthens the methodological validity and analytical depth of this study.

2.1 Inclusion in Agri-Food Research

Looking at negative examples in the agri-food sector, the importance of inclusion immediately becomes apparent. The involvement of farmers in seed innovations in Canada declined due to the prioritisation of high-yield harvests, the shift to lab-based plant breeding, seed commercialisation, and the rising influence of agri-food industry (Bronson, 2015). This exclusion is problematic as it has led to farmer dependence on chemicals, the loss of traditional agricultural knowledge, environmental harm including reduced crop diversity, and food safety concerns (Bronson, 2015). However, inclusion is often neglected in the quite 'techno-scientific' focused agri-food sector (Psarikidou, 2023). Hence, certain stakeholder groups and their expertise are excluded, despite being essential for overcoming hierarchical knowledge production in the bio-economy (Psarikidou, 2023) and ensuring a more diverse and inclusive range of perspectives. For instance, inclusion has been shown to be crucial for re-evaluating plant breeding and seed systems to address the rapid changes and ensure a sustainable and resilient future (Lopes, 2023), for identifying stakeholder needs in the development of a digital platform in the sweet potato industry (Grieger et al., 2022), for broadening discussions on agricultural robotics to enhance reflections on sustainability and justice of food production systems (Ayris et al., 2024). Inclusion helps to understand stakeholder perceptions and challenges in shaping responsible nanotechnology in the agri-food sector (Grieger et al., 2021), strengthen responsible protein transitions (Amoneit et al., 2024), and ensure economically viable, environmentally sustainable, and socially-desirable solutions in precision agriculture (Gardezi et al., 2024; Gardezi et al., 2022). An effective collaboration among diverse stakeholders through inclusive and multidisciplinary dialogue can also shed light on potential tensions within and among stakeholder groups in dairy farming (Henchion et al., 2022).

However, caution is needed, as inclusion is often narrowly interpreted as multidisciplinary research or assumed to be achieved simply by involving end-users (Jakku et al., 2022). Inclusion goes beyond knowledge exchange between scientific disciplines and especially involve stakeholder groups hard to reach (Rose et al., 2023).

The question therefore arises how inclusion can be facilitated in research and innovation processes in order to contribute to developing socially-acceptable, sustainable, and effective agri-food technologies and innovations (Henchion et al., 2022; Lopes, 2023) while fostering a joint understanding of challenges and needs to find most promising solutions for the agri-food sector (Jakku et al., 2022). Previous studies have addressed this issue by focusing either on the system-level and policy measures to make agri-food research more responsible (Klerkx & Rose, 2020; Lopes, 2023; Regan, 2019) or on the organisation and structure of research networks and projects (Jakku et al., 2022; Psarikidou, 2023; Regan, 2021). Some authors investigated different levels covering individual researchers, organisational structures (e.g., research programmes and

projects), and the socio-political context including policy measures (Jakku et al., 2023; Kuzma, 2022; Merck et al., 2022). Besides the emphasised need for structural and institutional changes to enhance stakeholder engagement in agri-food research (Jakku et al., 2022; Psarikidou, 2023; Regan, 2021), enabling individual researchers is also considered (Grieger et al., 2021; Jakku et al., 2022; Jakku et al., 2023; Kuzma, 2022; Kuzma & Cummings, 2021; Regan, 2021).

2.2 Anticipation in Agri-Food Research

The enactment of the principle of anticipation entails that researchers and innovators identify potential future impacts of their research and innovation activities before such technologies are brought into use and diffused widely (Regan, 2019; Strand et al., 2022). Anticipatory practices have been shown to deepen the understanding of possible consequences of using insects as salmon feed, including concerns about food and feed safety, fish health, pollution and waste efficiency, allowing ethical and environmental considerations to be integrated early in the research process (Strand et al., 2022). Additionally, recognising both the positive (e.g., improvements in decision-making through data availability) and negative (e.g., concerns about data sharing and ethics) impacts of introducing smart farming technologies, can help to address societal concerns at an early stage and exemplified the adoption of an RRI approach (Regan, 2019). Anticipating different future options for digital agriculture can aid to identify opportunities for improved decision-making and the consequences of different transition pathways while underscoring the need for collaboration among researchers and policymakers to shape more desirable outcomes for the digital future of agriculture (Fleming et al., 2021). Anticipation contributed towards a comprehensive view of ‘Agriculture 4.0’ and its potential impacts on livestock farming (Eastwood et al., 2021). In alignment, potential impacts should be taken into account in their embedded agri-food system instead of anticipating consequences isolated for each agri-food innovation (Klerkx & Rose, 2020). Anticipating potential positive and negative impacts meant to be incorporated along the whole research and innovation processes to contribute to responsible agri-food transitions (Klerkx & Rose, 2020) and to socially-desirable and sustainable agri-food transition pathways in the future (Mangelkramer, 2024).

However, anticipating potential impacts of digital transformation in agriculture is often limited to risk assessment and impact identification with minimal consideration of unintended consequences or broader stakeholder effects (Jakku et al., 2022). Although concerns such as data security are recognised, the focus remains on positive outcomes, neglecting potential challenges posed by future uncertainties, such as regulatory changes (Jakku et al., 2022). Therefore, special attention needs to be taken to anticipatory behaviours encompassing impacts at various scales including all potential affected stakeholders even if it might be difficult (Rose & Chilvers, 2018). However, responsible innovation means to stakeholders in the field of nanotechnology in agri-food

research considering environmental, health, and safety impacts as well as increasing product efficacy and efficiency (Grieger et al., 2021; Kokotovich et al., 2021), whereas project leaders in digital agri-food projects refer rather to management tasks (Jakku et al., 2022).

Consequently, there is a lack of understanding on how to facilitate anticipatory activities on the individual researcher level. Several studies focus on identifying and assessing potential positive and negative impacts of agri-food research applying various methods (e.g., foresight workshop, interviews, sociotechnical imaginaries) (Fleming et al., 2021; Jakku et al., 2022; Regan, 2019; Strand et al., 2022). Some authors argue that an inclusive and collaborative environment is required to engage in anticipatory activities (Jakku et al., 2022; Klerkx & Rose, 2020). Moreover, envisaged positive impacts are more inclined to be achieved and negative impacts of the research are more likely to be reduced when agri-food research is better aligned with societal values and needs (Jakku et al., 2022). However, the role of individual skills, motivators, and organisational factors is only given little attention in the literature.

2.3 Drivers of Responsible Agri-Food Research

Agri-food researchers require specific skills (e.g., systems thinking, communication) and training in order to research and innovate responsibly in agri-food (Cummings et al., 2021; Jakku et al., 2022). Scholars mostly refer to methods and tools (e.g., design thinking methods, vale-sensitive design) researchers should apply (Jakku et al., 2022; Jakku et al., 2023) whereas others highlight the role of social scientists being primarily in charge as experts to (better) align research and innovation with societal values and needs (Jakku et al., 2022).

Incentives and rewards can increase researchers' motivations towards more responsible agri-food research (Jakku et al., 2023; Kuzma, 2022; Merck et al., 2022). Drivers to pursue responsible innovation in nanotechnology encompass a range of societal, environmental, ethical, and industry-related considerations which not reflect the breadth of RRI (Kokotovich et al., 2021). In some occasions, RRI resonates with the researchers' academic values highlighting its alignment with their disciplines' missions, such as sustainability in environmental engineering or research integrity and ethics (Kokotovich et al., 2021). Some agri-food researchers emphasise that stakeholder engagement is part of their professional role and responsibility (Kokotovich et al., 2021) whereas others believe that basic research is not suitable for enacting RRI (Roberts et al., 2020).

It is suggested that agri-food researchers regularly discuss the meaning of responsible innovation creating 'an opportunity to reflect upon their own research and innovation in a broader societal context' (Grieger et al., 2021, p. 10). Reflecting on the research individually or with others can aid to consider potential research impacts (Jakku et al., 2022). Guidance provided by the organisation (e.g., code of conduct) and evaluation

systems (Jakku et al., 2023; Merck et al., 2022) can also facilitate conducting agri-food research responsibly. Funding agencies can promote responsible agri-food research by providing sufficient resources including time (Kuzma, 2022; Regan, 2021), designing 'funding and project management' more flexible (Jakku et al., 2023; Roberts et al., 2020), and setting requirements for anticipatory activities (Merck et al., 2022). Institutional barriers need to be reduced and a supportive organisational environment (e.g., 'formalised mechanisms for anticipation exercises') should be established to facilitate responsible agri-food research (Jakku et al., 2022; Jakku et al., 2023; Kuzma, 2022; Regan, 2021).

In summary, facilitating the RRI principles inclusion and anticipation can be achieved through multiple individual levers in order to support responsible agri-food research. Researchers' skills, motivational aspects, and organisational and funding environment play an important role. A better understanding of the role of individual agri-food researchers is needed to increase the enactment of inclusion and anticipation. This can help to shed light on the behavioural dimension of RRI – which appears as a current 'black box' – and can contribute to responsible agri-food research.

2.4 A Behavioural Perspective on Inclusion and Anticipation

The study takes a behavioural perspective on RRI and examines whether and how inclusion and anticipation are enacted in agri-food research by assessing the types of stakeholder groups engaged, impacts of their research and innovation anticipated, and frequency of such behaviours. Potential influencing factors are investigated by applying the behavioural COM-B model by Michie et al. (2011). It helps to dive deeper into what enables and hinders agri-food researchers to show inclusive and anticipatory behaviours. While numerous behavioural models exist that might be suitable to apply to RRI behaviours, none have yet been linked to the concept of RRI. However, a behavioural model was sought that (a) is not specialised for particular fields of applications or disciplines (e.g., HAPA model by Schwarzer (1992)) and (b) considers internal and external factors that influence behaviour. On that basis, it was decided to proceed with the behavioural change COM-B model which is applicable to behaviours across all domains and at various levels ranging from individuals, groups to entire populations (Michie et al., 2014). It enjoys a wide range of application (e.g., researchers' publishing behaviours (Weckowska et al., 2017), hand hygiene behaviours (Lambe et al., 2020)). The COM-B model consists of three components, namely capability, opportunity, and motivation, that lead to the target behaviour (Michie et al., 2005; Michie et al., 2011). *Capability* is defined as the 'individual's psychological and physical capacity to engage in the activity concerned. It includes having the necessary knowledge and skills.' (Michie et al., 2011, p. 4). *Opportunity* covers 'all the factors that lie outside the individual that make the behaviour possible or prompt it' (Michie et al., 2011, p. 4) whereas *motivation* includes 'all those brain processes that energize and direct behaviour, not just goals and

conscious decision-making' (Michie et al., 2011, p. 4). The COM-B model helps to better understand the target behaviour and its determinants while considering behaviour as part of a system related to other behaviours, not occurring in isolation (Michie et al., 2014; Michie et al., 2011). Hence, the behavioural COM-B model provide a valuable lens for examining researchers' inclusive and anticipatory behaviours and their underlying influences.

3 Methods

The study is part of the research project food4future, funded by the former German Federal Ministry of Education and Research's funding line 'Agricultural Systems of the Future' (Grant number: 031B0730H). It is based on an online survey conducted between April, 11 2022 and April, 13 2023. The results presented in this paper are drawn directly from this survey, which targeted agri-food researchers in Germany. The survey was distributed via email invitations to researchers in the food4future project as well as to researchers in similar research fields, who were identified through a comprehensive web search.

3.1 Sample

A total of 41 participants fully completed the survey and are included in the data analysis. The researchers are primarily from the fields of natural sciences (51.2%), agricultural sciences (22.0%), and social sciences (12.2%). 20 participants identify as male, 19 as female and two did not disclose their gender. In terms of career stage, 14 participants (34.1%) indicate being fully independent researchers, twelve participants being PhD researchers (29.3%), ten participants being mid-career researchers (24.4%), four participants being early-career researchers (9.8%), and one participant did not indicate their career stage (2.4%).

3.2 Measurements

The measurement of whether and how inclusion and anticipation are enacted by agri-food researchers was guided by van de Poel's (2020) suggested two-step procedure for operationalising RRI, which was originally aimed to assess RRI performance. This approach was considered appropriate for the present study, as it addresses the same methodological challenge of lacking operationalisation and available measurements. Similar to the aims of operationalising RRI performance (van de Poel, 2020) or moral values (Kroes & van de Poel, 2015), this study strived to operationalise inclusive and anticipatory behaviours and their influencing factors to make them measurable. The first step was to identify the key dimensions of inclusion and anticipation which may not be directly measurable. Second, these dimensions were translated into measurable items

which served as proxies to assess whether and how inclusion and anticipation are enacted in agri-food research. It was differentiated between anticipation of environmental and social impacts in line with previous studies (Grieger et al., 2021; Kuzma & Cummings, 2021). The focus laid both on assessing the frequency of inclusive and anticipatory behaviours during a twelve-month period and on specific characteristics of inclusive and anticipatory behaviours (e.g., stakeholder groups engaged, types of environmental and social impacts considered).

As said before, the behavioural COM-B model by Michie et al. (2011) was applied. Each of the three components – capability, opportunity, and motivation – can be subdivided into sub-components (Michie et al., 2014; Michie et al., 2011) and expanded into 14 domains by using the Theoretical Domains Framework (TDF) (Cane et al., 2012; Michie et al., 2014). Following recommendations to select domains relevant to a specific behavioural context, the focus laid on seven TDF domains, which were perceived having the potential to explain RRI behaviours. The items developed surveying the influencing factors were based on previous studies using the COM-B model and its TDF extension (Cane et al., 2012; Huijg et al., 2014; Keyworth et al., 2020; Michie et al., 2014) (see Table 1).

COM-B Component	TDF domain	Items[1]
Capability	Skills	I have the skills needed to engage non-academic stakeholders in my research.
		I have the skills needed to anticipate the environmental/ social impacts of agri-food innovations.
Opportunity	Social influences	My colleagues want me to engage non-academic stakeholders in my research.
		My colleagues want me to anticipate the environmental/ social impacts of agri-food innovations.
	Environmental context and resources	With my current workload, I have enough time to engage non-academic stakeholders in my research.
		With my current workload, I have enough time to anticipate the environmental/ social impacts of agri-food innovations.
Motivation	Professional role	Engaging non-academic stakeholders in research is part of my professional role.
		Anticipating the environmental/ social impacts of agri-food innovations is part of my professional role.
	Optimism	I am enthusiastic about engaging non-academic stakeholders in my research.
		I am enthusiastic about anticipating the environmental/ social impacts of agri-food innovations.
	Beliefs about consequences	Engagement of non-academic stakeholders in research helps to build sustainable agri-food systems of the future.
		I believe that anticipating the environmental/ social impacts of agri-food innovations helps to build sustainable future food systems.
	Intentions	In the next twelve months, I intend to engage non-academic stakeholders in my research.
		In the next twelve months, I intend to anticipate the environmental/ social impacts of agri-food innovations.

Table 1. COM-B items for Responsible Research and Innovation (RRI) behaviours (inclusion, anticipation)

[1] Items were measured on self-assessment basis on a six-point Likert-scale (strongly agree to strongly disagree). The environmental and social impacts were surveyed separately and are presented together here for reasons of readability.

3.3 Procedure

Two versions of the survey were used: one version for researchers within the food4future project and one for researchers in similar fields outside the project. The only difference was that 'food4future sub-project' replaced 'your selected research project'. Both questionnaires began with participant information, consent, and data protection, followed by questions on demographic (gender), disciplinary background, and career stage. Followed by three blocks with questions addressing researchers' behaviours: (1) engaging non-academic stakeholders (inclusion), (2) anticipating environmental impacts, and (3) anticipating social impacts. Each block had the same structure, including questions on behaviours, their frequency, and COM-factors influencing the corresponding RRI behaviour.

3.4 Data Analysis

The study applied the COM-B model to individual RRI behaviours using an exploratory approach. Data were analysed in IBM SPSS Statistics (Version 28) (IBM Corp.). 36 cases were excluded due to missing values or lack of consent. Given the ordinal nature and skewed distribution of the Likert-scaled data, median (middle value in a set of ordered data) and mode (most frequently occurring value in data) were used for descriptive statistics, as the mean value may misrepresent the 'central tendency' (Jamieson, 2004; Sullivan & Artino, 2013). In line, non-parametric statistical methods were employed, as the data did not meet normality assumptions, supporting this analytical choice despite the debate over the use of parametric tests for Likert-scaled data (Carifio & Perla, 2008; Norman, 2010; Sullivan & Artino, 2013).

Additionally, a cluster analysis was conducted to explore behavioural patterns. Following recommendations for ordinal data, Ward's method with squared Euclidean distance was applied in a hierarchical cluster analysis to determine the number of clusters (Žiberna et al., 2004). In a second step, the k-means algorithm was employed to refine and further explore the cluster structure identified in the first step.

4 Results

In the following, the study's results are presented structured by whether (frequency assessments) and how (which stakeholder groups are engaged and impacts are anticipated) inclusion and anticipation are enacted by agri-food researchers followed by the findings of the cluster analysis. Supplementary information, including sample characteristics, frequencies of study variables, dendrogram from the cluster analysis, and results of post-hoc Mann-Whitney U tests, is available from the author upon request.

4.1 Responsible Agri-Food Research

Non-academic stakeholders were engaged (inclusion) at a median level of Mdn = 3.00 (three or four times in a twelve-month period), with a mode of Mode = 2.00 (once or twice) (multiple modes exist, the smallest value is reported). Environmental impacts were considered (anticipation of environmental impacts) at a median frequency of Mdn = 2.00 (once or twice) and the mode was Mode = 1.00 (never). The anticipation of social impacts had a median of Mdn = 1.00 (never) and a mode of Mode = 1.00 (never). The findings indicated that researchers in agri-food research most frequently involved non-academic stakeholders in their research, less frequently anticipated environmental impacts and rarely anticipated social impacts. **Fig. 1** displays the frequency distribution. To obtain an overall picture of inclusive and anticipatory behaviours, specific characteristics of each behaviour were assessed, as presented in the following.

Inclusion. The researchers primarily involved 'established commercial companies' (n=20, 48.8%), followed by 'early adopters of innovation (e.g., consumers, users)' (n=15, 36.6%), and 'government agencies' (n=14, 34.1%) (multiple answers were possible). Potential future adopters (n=12, 29.3%) and civil society organisations (n=11, 26.8%) were included less frequently. Five researchers (12.2%) indicated that they did not engage any non-academic stakeholders in the last twelve months and were thus not included in the further analysis. Non-academic stakeholders were involved in particular by being informed about the research topic and the research process (n=27, 75.0%), by providing information needed for their research (n=19, 52.8%), and by giving feedback on the research process or the planned innovation (n=13, 36.1%) (multiple answers are possible).

Anticipation of environmental impacts. The majority of researchers (n=25, 61.0%) stated that they considered environmental impacts in their research during the last twelve months whereby 16 researchers (39.0%) indicated that they did not investigate any environmental impacts. Among the researchers who have considered environmental impacts, water consumption (n=17, 68.0%), land use (n=17, 68.0%), greenhouse gases emissions (n=13, 52.0%), and energy consumption (n=13, 52.0%) were the most frequently investigated environmental impacts. The most frequent practices to anticipate

environmental impacts were that the researchers clearly identified the environmental problems which can be addressed by agri-food innovations (n=16, 64.0%), they conducted pilot studies to evaluate different environmental impact scenarios (n=9, 36.0%), and technology assessment (e.g., cost-benefit analysis, life cycle analysis, etc.) (n=9, 36.0%).

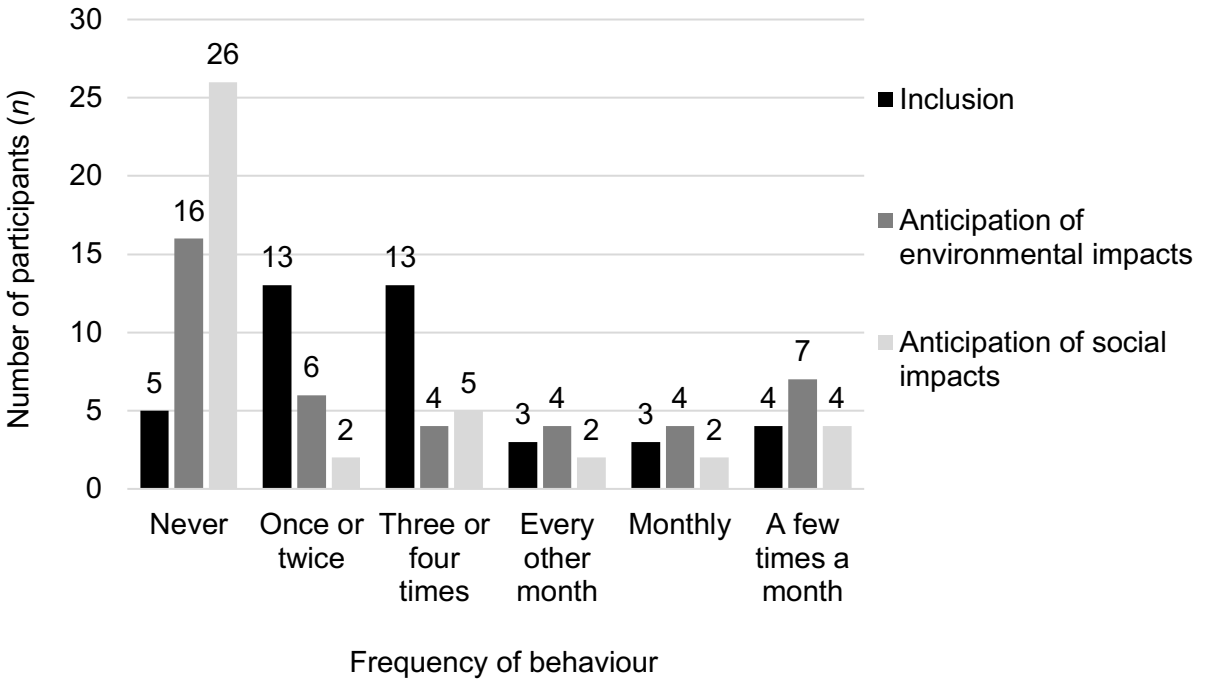

Figure 5.: Frequency of RRI behaviours (inclusion, anticipation) referring to the last twelve months.

Anticipation of social impacts. The majority of researchers (n=26, 63.4%) indicated that they did not investigate any social impacts in their research projects during the last twelve months. 15 participants (36.6%) stated that they considered social impacts – most frequently impacts on consumers (n=11, 73.3%), especially consumers' health and safety (n=8), followed by impacts on workers in the value chain (n=9, 60.0%), especially the creation and elimination of employment opportunities in the agri-food system (n=6). The most frequently practices to anticipate social impacts were that they clearly identified the social needs which can be addressed by agri-food innovations (n=10, 66.7%), employing exercise in which they tried to imagine the worst-case scenario of misuse/ misemployment/ evil use of agri-food innovations to explore potential risks (n=5, 33.3%), and they conducted technology assessment (e.g., social life cycle analysis) (n=4, 26.7%).

4.2 Drivers of Inclusion and Anticipation

A two-step cluster analysis was conducted to identify behavioural patterns of agri-food researchers along the frequency of their inclusive and anticipatory behaviours. The hierarchical cluster analysis using Ward's method and squared Euclidean distance suggested an optimal solution of two clusters, determined based on the agglomeration

schedule and dendrogram inspection. To validate this two-cluster structure, the k-means clustering algorithm was applied and confirmed the classification. The iteration history indicated convergence after four iterations. The distance between the final cluster centres was 4.39, suggesting clear separation between the two clusters. The clusters varied in size with Cluster 1 consisting of 13 (31.7%) and Cluster 2 of 28 participants (68.3%). The post-hoc Mann-Whitney U-tests showed that the two clusters did not differ in the frequency of inclusive behaviours (U = 149.50, Z = -.943, p = -.357) but in anticipatory behaviours of environmental impacts (U = 11.00, Z = -4.967, p < .001) and social impacts (U = 42.00, Z = -4.552, p < .001), whereas for the latter only the distributions differed significantly (Kolmogorov-Smirnov p < .05) (see **Fig. 2**).

The two cluster groups were labelled ‘Anticipative Collaborators’ and ‘Non-anticipative Collaborators’, as they mainly differed in the level of anticipatory behaviours. Furthermore, the two clusters differed between disciplinary backgrounds based on the Fisher's exact test (p = .016). The ‘Anticipative Collaborators’ had disciplinary backgrounds in agricultural science (n=5, 12.5%), social sciences (n=4, 10.0%), natural sciences (n=3, 7.5%), and engineering and technologies (n=1, 2.5%) whereas the ‘Non-Anticipative Collaborators’ mostly had a natural sciences background (n=18, 45.0%), followed by agricultural sciences (n=4, 10.0%), engineering and technologies (n=2, 5.0%), and social sciences, humanities and medical sciences (n=1, 2.5% each). Differences between the two clusters in gender and career stage had not been found. Overall, the cluster analysis revealed meaningful behavioural patterns among agri-food researchers, offering insights into the differences in the frequency of their anticipatory behaviours and researchers’ disciplinary backgrounds.

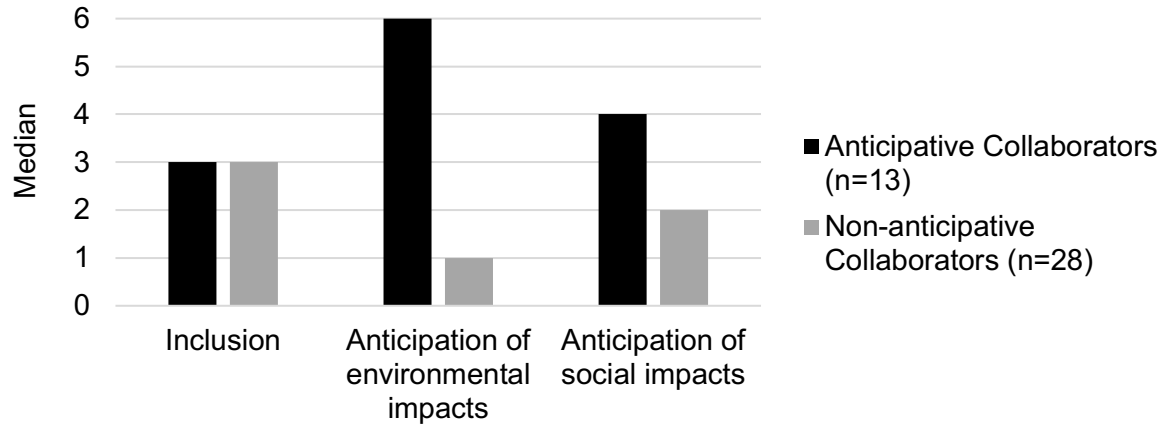

Figure 6.: Two-step cluster analysis – median differences in the frequency of inclusive and anticipatory behaviours. Note: Frequency was measured on a six-point ordinal scale and related to a twelve-month period (1 = never, 2 = once or twice, 3 = three or four times, 4 = every other month, 5 = monthly, 6 = a few times a month).

In order to investigate the influencing factors, the differences in capability, opportunity, and motivation between the two clusters were further examined. The differences were examined using post-hoc Mann-Whitney U-tests with the ‘Anticipative Collaborators’

cluster consistently exhibited higher medians. In the following only the significant results are reported.

Capability. The ‘Anticipative Collaborators’ perceived their skills to anticipate social impacts as significantly higher than the ‘Non-Anticipative Collaborators’ ($U = 81.50$, $Z = -2.907$, $p < .001$), whereas the skills for inclusion and anticipation of environmental impacts did not differ significantly.

Opportunity. The ‘Anticipative Collaborators’ reported the social pressure in their professional environment to engage stakeholders, to anticipate environmental and social impacts of their research as significantly higher than the ‘Non-Anticipative Collaborators’ (inclusion: $U = 104.00$, $Z = -2.236$, $p < .05$; anticipation of environmental impacts: $U = 94.00$, $Z = -2.518$, $p < .05$; anticipation of social impacts: $U = 63.00$, $Z = -3.418$, $p < .001$). The environmental context and resources did not play a significant role in the differences between the two clusters.

Motivation. The ‘Anticipative Collaborators’ perceived the anticipation of environmental and social impacts as part of their professional role as significantly higher than the ‘Non-Anticipative Collaborators’ (anticipation of environmental impacts: $U = 79.50$, $Z = -2.923$, $p < .001$; anticipation of social impacts: $U = 75.00$, $Z = -3.048$, $p < .001$). The ‘Anticipative Collaborators’ were significantly more optimistic to anticipate (anticipation of environmental impacts: $U = 77.50$, $Z = -3.022$, $p < .001$; anticipation of social impacts: $U = 109.50$, $Z = -2.084$, $p < .05$), and showed stronger intention to anticipate environmental as well as social impacts of their research (anticipation of environmental impacts: $U = 90.00$, $Z = -2.633$, $p < .001$; anticipation of social impacts: $U = 79.50$, $Z = -2.926$, $p < .001$). The ‘Anticipative Collaborators’ were significantly more convinced that anticipating environmental impacts contributes to sustainable agri-food innovations in the future ($U = 98.50$, $Z = -2.517$, $p < .05$). In contracts to the above results for anticipatory behaviours, the motivational aspects for inclusive behaviours showed no significant differences between the two clusters.

In summary, the ‘Anticipative Collaborators’ tended to have higher capabilities, especially in anticipating social impacts of their research and innovation, tended to have a social environment (opportunities) conducive to inclusion and anticipation, and stronger motivations for anticipatory behaviours compared to the ‘Non-Anticipative Collaborators’.

5 Discussion

The German agri-food sector faces economic, environmental, and societal challenges (Food and Agriculture Organization of the United Nations, 2023). The multifaceted transformation of the agri-food sector should arguably be socially-desirable and responsible. The four process principles of RRI (inclusion, anticipation, reflexivity, and

responsiveness) can serve as guidance in navigating the research and innovation processes (Klerkx & Rose, 2020). This study focused on inclusion and anticipation.

A survey was conducted assessing whether and how inclusion and anticipation principles are enacted in agri-food research and what factors influence the researchers' enactment in practice, based on the behavioural COM-B model. The study's findings showed that inclusive behaviours such as engaging stakeholders in research and innovation processes were more frequent than anticipatory behaviours among agri-food researchers in Germany. The growing expectations for inter- and transdisciplinary research – particularly in funding announcements – might lead to increased stakeholder engagement (Owen et al., 2021; van Rijnsoever & Hessels, 2011). The strong involvement of stakeholder groups such as commercial companies and early adopters in this study may also suggest that commercialisation efforts play a key role in driving stakeholder engagement rather than the ambition to understand society's needs and values to adapt the research and innovation activities in a responsive manner. Regarding anticipation of environmental and social impacts, environmental impacts of research and innovation were considered more frequently than potential social impacts which is in line with previous studies that environmental, health, and safety considerations are more often associated with responsible innovation, than societal concerns (Grieger et al., 2021).

5.1 Drivers of Responsible Agri-Food Research

The results of the two-step cluster analysis revealed two behavioural patterns: the 'Anticipative Collaborators' and the 'Non-anticipative Collaborators'. Both groups of agri-food researchers engaged with non-academic stakeholders but differed in considering environmental and social impacts of their research and innovation. The 'Anticipative Collaborators' tended to have higher *capabilities*, especially in anticipating social impacts of their research. This finding is in line with previous studies observing that socio-ethical considerations are neglected in anticipatory activities in dairy farming (Eastwood et al., 2019), which could be due to a lack of specialised skills required for enacting RRI principles (Cummings et al., 2021; Jakku et al., 2022; Jakku et al., 2023). However, educational and training programmes could foster the acquisition of necessary skills and thus facilitate the enactment of RRI (Merck et al., 2022).

The 'Anticipative Collaborators' tended to have greater perceived social *opportunities*. In line with previous research, the pressure to take responsibility into account in food system research is identified as one of four key drivers for integrating RRI (Sabio & Lehoux, 2024). Cultural constraints and discipline-specific resistance can serve as barriers to stakeholder engagement in the field of digital agriculture and synthetic biology (Regan, 2021; Roberts et al., 2020). Therefore, it requires support to develop norms aligned with RRI within academia that foster researchers' willingness and commitment to RRI behaviours (Regan, 2021). Although the study did not find significant differences in

anticipatory behaviours related to environmental context, organisational factors including lack of time and resources were perceived as important barriers to implement RRI in the literature (Ayris et al., 2024; Regan, 2021; Roberts et al., 2020; Taylor et al., 2023). A supportive environment (social and physical) is needed for shaping the agri-food transition responsibly (Jakku et al., 2023).

The 'Anticipative Collaborators' tended to have stronger *motivations* for anticipatory behaviours. In order to encourage agri-food researchers in general to anticipate potential environmental and social impacts of their research and innovation, incentives and reward systems could be implemented (Jakku et al., 2023; Kuzma, 2022; Merck et al., 2022). Motivating researchers to take new roles and responsibilities to conduct agri-food research responsibly might be helpful (Regan, 2021) whereas some researchers already perceive RRI in line with their disciplines' mission (Kokotovich et al., 2021).

According to the study's findings, important levers seem to lie in interpersonal dimensions including social influence, norms and organisational culture, and motivational dimensions. Differences in disciplinary backgrounds should also be taken into account. However, social scientists should not bear sole responsibility for considering social impacts of agri-food research as inter- and transdisciplinary research highlights the risk of researchers' multiple roles and possible tensions between roles (Bulten et al., 2021; Wittmayer & Schäpke, 2014). Instead, all agri-food researchers should be empowered to contribute, ensuring a responsible agri-food transition.

5.2 Limitations and Future Research

Some limitations of the study should be noted. First, by focusing on inclusion and anticipation, not all four RRI principles were investigated. This focus was based on the assumption that inclusion can provide the foundation of anticipatory consideration (Rose & Chilvers, 2018) and that critical self-reflection and responsive re-orientation of research and innovation are likely to be more impactful when inclusive and anticipatory activities take place as a first step. Nevertheless, future research is required to take a more holistic approach by investigating the enactment and its influencing factors of all four principles. Second, the study's findings should be viewed with caution, as this first attempt to apply a behavioural lens to RRI followed an exploratory approach with a small sample size of 41 participants, which may limit the robustness of the results. Nonetheless, the study provides important initial empirical findings into the enactment of RRI principles in agri-food research, which warrant further research. Third, the frequency of individual enactment of RRI was assessed over a period of twelve months, whereas, as noted by Repo and Matschoss (2019), RRI adoption (e.g., citizen participation) ideally occurs throughout the entire research and innovation process. Future research is needed to investigate RRI behaviours beyond the twelve-month period. Fourth, post-hoc tests after cluster analysis are used (Gere, 2023), but are not necessarily typical as the clusters to be compared are assigned rather randomly. For this reason, the post-hoc tests' findings

should be treated carefully. Future research might use further statistical methods to better understand the relationship between RRI behaviours and its influencing factors (capability, opportunity, and motivation). Notably, the COM-B model and TDF can be investigated with both quantitative and qualitative methods (Cane et al., 2012; Lambe et al., 2020). Fifth, the study surveyed agri-food researchers in Germany which limits its generalisability. Therefore, future research might consider other fields of application and further stakeholder groups across different countries.

6 Conclusions

This study makes several contributions to understanding the enactment of RRI principles in agri-food research. First, it is the first attempt to introduce a behavioural lens to RRI by applying the COM-B model to investigate factors influencing the enactment of inclusion and anticipation. Second, it provides initial empirical insights into the behavioural dimension of RRI, enhancing understanding of inclusive and anticipatory behaviours and their drivers. These insights can inform strategies to promote inclusive and anticipatory behaviours, foster reflexivity and responsiveness in research and innovation, and support socially desirable and sustainable agri-food transition pathways. Third, the study highlights the pivotal role of individual researchers as key actors in driving responsible agri-food transitions, in line with previous scholarship (Felt et al., 2018; Shelley-Egan et al., 2018).

From a practical perspective, the findings suggest that enhancing RRI enactment requires facilitating the development of relevant skills particularly for anticipating social impacts, creating social and organisational environments supportive of RRI, and strengthening individual motivation to anticipate both environmental and social impacts. As an exploratory study, it serves as a foundation for future research to further unpack researchers' responsible behaviours and the factors enabling them.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used ChatGPT-5 mini and ChatGPT-4 in order to improve readability and language of the work. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

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Declaration of competing interest

The author declares that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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