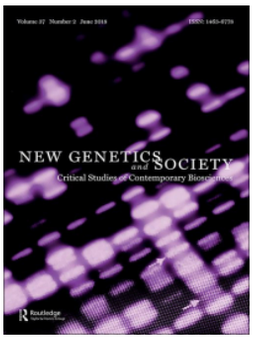

Routledge
Taylor & Francis Group

New Genetics and Society

Critical Studies of Contemporary Biosciences

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/cngs20

Siloed discourses: a year-long study of twitter engagement on the use of CRISPR in food and agriculture

Lauren Crossland-Marr, Alexandru Giurca, Maya Tsingos, Matthew A. Schnurr, Adrian Ely, Dominic Glover, Glenn Davis Stone & Klara Fischer

To cite this article: Lauren Crossland-Marr, Alexandru Giurca, Maya Tsingos, Matthew A. Schnurr, Adrian Ely, Dominic Glover, Glenn Davis Stone & Klara Fischer (2023) Siloed discourses: a year-long study of twitter engagement on the use of CRISPR in food and agriculture, New Genetics and Society, 42:1, e2248363, DOI: 10.1080/14636778.2023.2248363

To link to this article: https://doi.org/10.1080/14636778.2023.2248363

Published online: 22 Aug 2023.

NEW GENETICS AND SOCIETY
2023, VOL. 42, NO. 1, e2248363 (20 pages)
https://doi.org/10.1080/14636778.2023.2248363

Routledge
Taylor & Francis Group

Siloed discourses: a year-long study of twitter engagement on the use of CRISPR in food and agriculture

Lauren Crossland-Marr [a], Alexandru Giurca[bc], Maya Tsingos[d], Matthew A. Schnurr [a], Adrian Ely [e], Dominic Glover [f], Glenn Davis Stone [g] and Klara Fischer [h*]

[a]*Dalhousie University, Halifax, Canada;* [b]*Heidelberg Center for the Environment (HCE), Heidelberg University, Heidelberg, Germany;* [c]*European Forest Institute, Bonn, Germany;* [d]*Washington University, St. Louis, MO, USA;* [e]*University of Sussex, Brighton, UK;* [f]*Institute of Development Studies, Brighton, UK;* [g]*Sweet Briar College, VA, USA;* [h]*Department of Urban and Rural Development, Swedish University of Agricultural Sciences, Uppsala, Sweden*

(*Received 8 November 2022; final version received 10 August 2023*)

Gene editing technologies are emerging as powerful tools for agricultural development, spurring both hopes and concerns in society. To understand emerging discourses and coalitions around the role of CRISPR gene editing in food and agriculture we map the main actors and themes emerging from English-speaking Twitter networks over the course of one year (2021). Scientific actors are the most active and best networked in the debate. They promote a positive image of CRISPR gene editing and actively work to strengthen their network. A smaller but equally distinct group comprises civil society actors, who voice skepticism towards the technology and sometimes questions scientists' claims, but without eliciting responses from the scientists. We conclude that emerging discourse coalitions forming around the topic of CRISPR in food and agriculture on Twitter are siloed, with limited interaction between contrasting perspectives.

Keywords: genome editing; GMO; biotechnology; network analysis; social media

1. Introduction

In 2020, Jennifer Doudna and Emmanuelle Charpentier were awarded the Nobel Prize in Chemistry for their work, first published in 2012, demonstrating the use of the Cas9 protein associated with Clustered Regularly Interspaced Short Palindromic Repeats (henceforth CRISPR) in gene editing (Jinek *et al*. 2012). This technology's ability to edit and turn off genes has created new, potentially

*Corresponding author. Email: Klara.fischer@slu.se

life-changing, possibilities to eradicate inheritable diseases and adapt crops to climate change (Caplan *et al*. 2015; Gates 2018; Kaiser 2021; Ledford 2015). As CRISPR technology is potentially cheaper to use and less invasive than earlier genetic modification (GM) methods that relied on introducing foreign DNA, there are also hopes that it will be more easily accepted by the public and more accessible to a wider group of stakeholders (Caplan *et al*. 2015). Alongside these hopes are concerns about potential environmental and health risks (Ledford 2015), ethical issues (Gyngell 2017; Ledford 2015) as well as indications that the hopes of a more openly accessible technology will not materialize (Jasanoff, Hurlbut, and Saha 2015; Rock *et al*. 2023).

In this paper, we focus specifically on the emerging public debate regarding the use of CRISPR in food and agriculture. As of 2021, media reporting and public debate on CRISPR have mainly concerned scientific advances, particularly in medical applications, as well as ethical and legal issues (Calabrese *et al*. 2020; Ji *et al*. 2022; Müller *et al*. 2020; Ni *et al*. 2022). While food and agriculture had received limited attention, there are indications of an emerging debate on this domain (Tabei *et al*. 2020; Walker and Malson 2020). Previous controversies about GM crops (Fischer, Wennström, and Ågren 2019) suggest that applications of CRISPR to food and agriculture might well spur controversies and debate in the developing public discourse.

Acknowledging that public debate will also play out on other arenas, our analysis focuses on the debate emerging on the micro-blogging social media platform Twitter (http://twitter.com). Making use of social network analysis techniques and analyzing emerging networks and discussions through Hajer's (1995) conceptualization of discourse coalitions and storylines, we examine the most circulated tweets about CRISPR in food and agriculture over the course of one calendar year (January–December 2021). We identify how actors build coalitions around common interests, and how storylines about CRISPR technology begin to emerge. The next section (1.1) summarizes some key events in the public debate on GMOs and describes what is known about the emerging public debate on CRISPR in food and agriculture. Section 2 describes the study design, including the analytical framework and data collection. Section 3 outlines key findings about the emerging actor coalitions and the topics that dominated the debate amongst English-speaking actors on Twitter around CRISPR in food and agriculture during 2021. In section 4 we discuss what these early findings suggest about the emergent debate about CRISPR in food and agriculture and outline some potential avenues for future research.

1.1. *Public Debates on GMO and CRISPR*

CRISPR and other gene editing technologies constitute the most prominent current wave of technical development in the field of modern biotechnology. We can expect that the emerging debate on CRISPR in food and agriculture will be

shaped and influenced by earlier debates about GM organisms (GMOs). Indeed, connections are repeatedly made in the public debate, between the previous generation of "classical" GMOs and new gene editing techniques (Greenpeace 2021; Ribero 2020; Walker and Malson 2020).

GM technology emerged on the public radar during the 1980s, but media reporting during this period has been described as rather limited. Early reporting focused mainly on scientific breakthroughs, medical applications, safety, and ethical and regulatory issues (Bauer 2002). When GM crops first appeared in the mid-1990s the public debate intensified, particularly in Europe (Bauer 2002; Frewer, Miles, and Marsh 2002; Levidow 1999). This coincided with an increase in negative media reporting and negative public perceptions which followed several controversial events surrounding the technology, including the cloning of the sheep Dolly, the import of unlabeled GM soy into the European Union, public awareness campaigns about GM foods, and scientific reports on unforeseen effects of genetic modification in food and agriculture (Fischer, Wennström, and Ågren 2019). The British outbreak of so-called Mad Cow Disease in humans (variant Creutzfeldt Jacob's Disease, vCJD), and the way this outbreak was handled by public authorities, has been identified as a game-changer in the GMO debate,[1] shifting British and wider European publics to much more negative views of GMOs in food and agriculture in the late 1990s (Stephan 2012). The presence and desirability of GMOs in food and agriculture remain controversial today, whereas medical applications of GM technology have gone largely unnoticed in public debate (Fischer, Wennström, and Ågren 2019).

An important difference between the context of the former GMO debate and the unfolding debate on CRISPR is in the media landscape. GM crops arrived during the infancy of the worldwide web and before the takeoff of social media platforms, so that the public debate largely unfolded via traditional media (newspapers, television and radio) (Bauer 2002; Cook, Robbins, and Pieri 2006). Today, much public debate occurs on social media platforms, such as Facebook, Weibo and Twitter. Thus, studies of the media debate on gene editing have mainly focused on social media (two exceptions are Dawson *et al*. 2022 and Stapleton and Torres Yabar 2022). These studies indicate that the early debate has been dominated by reporting of scientific advances and their medical applications, technical discussions about the technology itself, as well as ethical and legal issues (Calabrese *et al*. 2020; Ji *et al*. 2022; Müller *et al*. 2020; Ni *et al*. 2022). In these respects, there are clear similarities with early media reporting about GMOs in the 1980s.

A large share of the literature on media discourse about gene editing (Calabrese *et al*. 2020; Ji *et al*. 2022; Müller *et al*. 2020; Ni *et al*. 2022; Stapleton and Torres Yabar 2022; Zhang, Chen, and Zhang 2021) focuses on the "CRISPR babies experiment" (Dickenson and Darnovsky 2019), in which the Chinese scientist Jiankui He revealed that his research laboratory had edited human genes to

confer resistance to the human immunodeficiency virus (HIV). Jiankui He was imprisoned amid uproar in the scientific community and heated discussions about ethics and regulation (Dickenson and Darnovsky 2019). Studies of how this event was reported and commented on in social media indicated that it stimulated increased public debate on CRISPR (Calabrese *et al*. 2020; Ji *et al*. 2022; Zhang, Chen, and Zhang 2021), with some studies finding indications that attitudes became more critical towards CRISPR technology than before the event (Müller *et al*. 2020; Zhang, Chen, and Zhang 2021).

The CRISPR babies experiment was announced in 2018 and most published studies on the media debate about CRISPR focus on a short period following the announcement (Calabrese *et al*. 2020; Ji *et al*. 2022; Ni *et al*. 2022; Stapleton and Torres Yabar 2022; Tabei *et al*. 2020; Zhang, Chen, and Zhang 2021). One of few studies spanning over a somewhat longer period is by Müller *et al*. (2020), who explored all tweets in the English language that included the term CRISPR over a period of 6.5 years starting in 2013 (January 1, 2013 to May 31, 2019). The authors found the dominant topics to be technical discussions about gene editing and medical applications of the technology, with tweets being predominantly positive (52.3%) or neutral (40.3%) in sentiment. However, negative sentiment increased after 2017, with more spikes in negative sentiment as well as more negative sentiments overall (although tweets were more commonly positive than negative over the whole time period).

Most studies mapping the CRISPR debate on social media focus solely on mapping the topics discussed, and do not analyze the actors engaged in the discussion. One exception is Zhang, Chen, and Zhang (2021) who mapped the debate on the Chinese social media platform Weibo during 2018, before and after the babies experiment. They grouped actors deductively into government, science professionals, general journalists, and laypeople, and showed that laypeople actively engaged in the debate during that period.

Overall, published studies of the debate show that applications of CRISPR in food and agriculture have been present, but remain marginal (Calabrese *et al*. 2020; Ji *et al*. 2022; Müller *et al*. 2020; Ni *et al*. 2022). Walker and Malson (2020) focused specifically on agricultural and environmental gene editing. They performed a frequency and thematic analysis of Facebook comments made between 2015 and 2019 on news items posted by eleven US-based media outlets. They showed that much of the debate concerned the science and technology of gene editing in general, encompassing moral and religious perspectives, hopes and risks, rather than the pros and cons of specific applications. Comments repeatedly drew parallels between gene editing and earlier GM technologies (Walker and Malson 2020). Our study on the emerging debate on CRISPR on Twitter aims to contribute to the extant literature by mapping the debate in 2021, focusing specifically on the comparatively understudied topic of CRISPR in food and agriculture.

2. Materials and methods

2.1 *Data selection*

We used the Twitter API to capture all tweets in the English language (lang: en) that mentioned CRISPR (case insensitive, including hashtagged versions) from 1 January 2021 to 31 December 2021, resulting in a corpus of 375,776 tweets (134,993 from January to June and 240,783 from June to December). We subsequently ran a JavaScript Object Notation (JSON) script (called Tweet sorter) to separate out tweets containing food and agriculture related keywords (known as keyterms in the Twitter Sorter). The final search was designed as follows: ((agriculture OR ag OR food OR crop OR plant) AND ((edit) AND (genome OR gene))). We ran the Tweet Sorter program to separate the food and agriculture tweets from the original dataset of 375,776 tweets, using the keyterm search. This generated 16,792 tweets related to CRISPR in food and agriculture, including original tweets (i.e. those with original content) as well as modified tweets, for example retweets. Modified tweets were identified by JSON script, and removed. This gave us a dataset with 5,374 original tweets about CRISPR in food and agriculture. We sorted the tweets by most retweets to identify the most retweeted accounts (referred to here as actors). If not otherwise stated, the subsequent analysis focused on a set comprised of the top 50 original tweets (i.e. the most retweeted tweets) on CRISPR in food and agriculture.

2.2. *Analytical framework*

We structured our analysis around Hajer's (1995) approach to discourse analysis. To facilitate conceptualization of how actors both use and are shaped by discourses, Hajer introduced the concept of storylines. Storylines are punchlines or condensed messages that play a crucial role in both reproducing and transforming wider discourses. Actors who unite around the same storyline can be understood as "discourse coalitions" (Hajer 1995, 65). In our analysis, we draw on a combination of a network analysis (2.3) to identify actor coalitions, and a qualitative analysis of tweets and associated media (section 2.4) to identify emerging storylines that subsequently were connected with identified actor coalitions.

2.3 *Network analysis*

We began with categorizing all accounts behind the top 50 tweets into actor groups (Table 1), based on information in the biography connected to the Twitter account, or linked websites. We identified seven actor groups in the material and one group containing "others" who did not logically fit into any larger grouping.

To identify how actors (accounts) and actor groups interacted, and how information flowed between them, we ran a series of network analysis measures. Two quantitative social network analysis techniques were used studying (i) the overall structural features of the network (i.e. density, centralization); and (ii)

Table 1. Actor categories

Category	# of Actors
Scientist	18
Scientific publication	7
NGO	6
Networking organization	5
Other	5
Popular news	4
Policy	3
University	2
Company	0

actor-level measures detailing the positions and roles of specific actors within a network (i.e. betweenness and community clustering) (Scott 2012). The betweenness centrality measure is especially useful for gathering information flows and information brokers in a Twitter network (Britt *et al*. 2021; Riddell *et al*. 2017). It measures the extent to which a node (in this case a top tweet by an account) acts as a bridge-builder or broker connecting what would otherwise be disconnected segments of a network (Freeman 1977; Wasserman and Faust 1994).

Additionally, we ran measures to identify *communities*, defined as pockets of densely connected nodes that are only sparsely connected to other pockets (Newman and Girvan 2004). Several different network clustering (also known as community detection) algorithms exist to create organic clusters based solely on network ties, which help find subgroups of highly inter-connected nodes. Different algorithms or layouts provide different insights into the network (Hansen, Shneiderman, and Smith 2019); we used the Clauset-Newmann-Moore algorithm (Wakita and Tsurumi 2007) with which the researcher does not predetermine the number of clusters, but rather lets the algorithm dynamically determine clusters (Hansen, Shneiderman, and Smith 2019). The data were organized in the NodeXL Excel Template (https://nodexl.codeplex.com/) where the network statistical analysis was run, and the network maps visualized.

2.4 *Qualitative analysis*

Tweets frequently share and comment on articles and other media produced by traditional media outlets (Marchetti and Ceccobelli 2016). Therefore, it makes sense to also analyze these linked media sources when analyzing emerging debates. Doing so also gives access to longer arguments, which makes it easier to analyze the wider stories that tweets are part of and may build upon or contest. For all the original tweets we identified any original sources that the tweet referred to, such as news articles, press releases, academic papers, podcasts, and screenshots from academic presentations. Of the 50 top tweets, 49 linked to original

sources. All tweets and original sources were uploaded to NVivo software for qualitative analysis. Through repeated readings of original tweets and linked text sources the first and last author identified three storylines that presented coherent reasoning on certain topics with regard to CRISPR in food and agriculture. By studying which accounts were connected to emerging storylines, we analyzed how storylines connected with the actor coalitions identified in the network analysis (2.3). We also studied differences in tweeting styles across coalitions.

3. Results

3.1 *Twitter news cycles*

Studying the whole dataset (not limited to CRISPR in food and agriculture), there were many more tweets on CRISPR in the second half of the year (240,783 tweets between June and December) than in the first half of the year (134,993 tweets between January and June). Some of the top tweets in our sample were up to two years old. The most circulated tweet was created in February 2019 but was still being circulated in the timespan of our capture in 2021 and listed the innovations to look forward to in the decade of the 2020s. A tweet from the account @NobelPrize announcing that Jennifer Doudna and Emmanuelle Charpentier won the 2020 Nobel Prize in Chemistry was the second most circulated tweet in our timespan. The original tweet was posted on October 7, 2020 and was thus already a few months old at the beginning of our data capture, January 2021.

Tweets about CRISPR in food and agriculture (including both original tweets and modified content or retweets) only amounted to 6% of the total amount of tweets (16,792) in the dataset. Like for the entire dataset, tweets about CRISPR in food and agriculture also increased over the study period (5,688 tweets in the first 6 months and 11,104 tweets in the last 6 months of the year).

3.2 *Actor coalitions*

We now narrow in on the top 50 original tweets about CRISPR in food and agriculture. The actor groups we identified as authors of the top 50 original tweets (Table 1) are depicted by the different colors of the nodes in Figure 1 and Figure 2. The most common actor group was Scientists (18/50), the majority being plant scientists (15), two working on medical applications, and one having expertise in sustainability studies (see Table 1). Interestingly, there were no companies that tweeted in the top 50.

The network of the top 50 tweets is made up of 1,619 nodes (one tweet made by one actor) connected by 1,863 unique (undirected) edges (Figure 1). The size of each node in Figure 1 corresponds to more re-tweeted tweets. As seen to the right in Figure 1, Scientists are the most present and active actor group in the network and they are closely connected with the groups Universities and Scientific publications, who mainly re-share the information published by scientists. In other

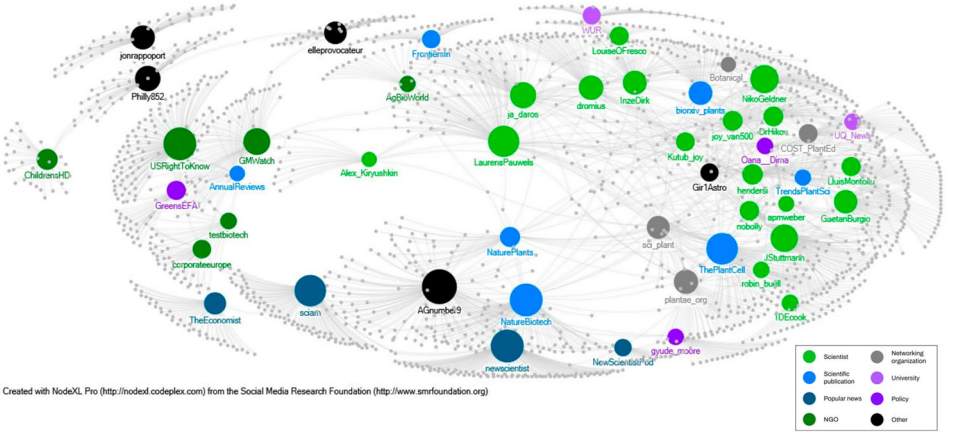

Figure 1. The CRISPR agriculture Twitter network map depicting the most re-tweeted tweets between January–December 2021. The color of the nodes represent the different actor groups identified by the authors. The size of each node corresponds to its degree centrality

words, our results suggest that there is an emerging coalition of scientists and academic institutions, which constitutes the most active and visible coalition on Twitter in the debate around CRISPR in food and agriculture. This conclusion is also supported by the community-detection algorithm employed here, identifying

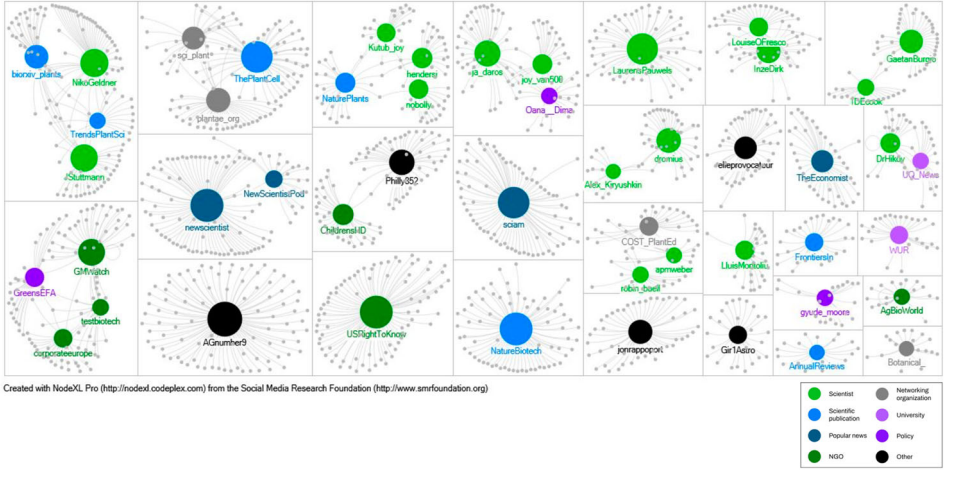

Figure 2. Community clusters for the top 50 original, unique tweets. Actor groups illustrate that the "scientist" accounts (green nodes) are both the most present and the best connected (for example see NikoGeldner). Popular news (teel nodes) on the other hand, are not being retweeted by the top 50 accounts – at the moment it is primarily scientific information and breakthroughs that are being circulated to and from scientists and scientific publications (dark blue nodes)

the Scientist coalition as the group that is most active and most connected (Figure 2).

Another emerging coalition, smaller and less active than the Scientist coalition, consists of NGOs and a membership group within the European Parliament @GreensEFA (referred to here as the NGO coalition). As seen in Figure 2, @corporateeurope, @GMwatch, @Testbiotech and @GreensEFA together formed a distinct information-sharing cluster. Looking to the left in Figure 1, it is clear that @USRightToKnow, the most influential NGO in the network (indicated by the size of the circle), also interacts with this distinct cluster. The NGO coalition has its own information-sharing dynamic, largely separate from the Scientist coalition. Popular news media, located along the bottom of Figure 1, are weakly connected with both of these coalitions, and are located in the periphery of the network.

3.3 *Storylines*

3.3.1 *CRISPR is a powerful and precise tool*

Looking at the top 50 tweets, one storyline we identified concerns CRISPR as a powerful and precise tool. The actors behind tweets in this storyline are mainly found in the Scientist coalition, and many tweets are about ongoing experiments and new publications.

We found that scientific findings were often framed within a wider argument about the power and precision of CRISPR. For example, one tweet highlighted that the application of CRISPR in apples could also be useful to modify pears, affirming the power of CRISPR techniques to modify genomes across species: "*the CRISPR-Cas9 gene editing system has proved popular and cost efficient in many organisms. Research published in @FrontPlantSci shows improved transformation efficiency in the Gala apple cultivar and extends the methodology to pear*".

A tweet from @plantae_org, a platform hosted by the American Society of Plant Biologists, provided a screenshot of an online summary of a peer reviewed paper by Gaillochet, Develtere, and Jacobs (2021) entitled "*Crispr Screen in Plants: Approaches Guidelines, and Future Prospects*" that commented "*We don't need to remind you of the tremendous positive impact that CRISPR-based technologies have on the life sciences through enabling any gene to be edited precisely*".

Another tweet circulated by plantae_org highlighted a paper that described how "*recent advances in genome editing technologies, mainly the CRISPR-Cas system, make the targeted and precise genetic manipulation of crops more feasible and accelerate the transition toward precision breeding*" (Ahmad *et al*. 2021, 8309).

Actors in the Scientist coalition frequently connected the precision of gene editing with possibilities for speeding up plant breeding and achieving broad impacts on basic science. For example, COST PlantEd, the twitter account of an EU funded research and networking project led by the department of plant

breeding at the Swedish University of Agricultural Sciences, tweeted "*CRISPR-Cas9 Based Genome Editing in wheat @JohnInnesCentre @MarkSmedley15 @SadiyeHayta @wileyplantsci*" and linked to a study which stated that "*[t]he development and application of high precision genome editing tools such as programmable nucleases are set to revolutionize crop breeding and are already having a major impact on fundamental science*" (Smedley *et al*. 2021, 1). As exemplified in the quote, connections were frequently made between CRISPR and positive values, for example, "*cost effective*", "*advances*", "*tremendous positive impact*" and "*revolutionize crop breeding*".

In a similar vein, a scientist tweeted about an article titled: "*Combined fluorescent seed selection and multiplex CRISPR/Cas9 assembly for fast generation of multiple Arabidopsis mutants*" (Ursache *et al*. 2021). The article called attention to the impact "*precise editing*" would have, because it provides information on "*gene function, production of new plant traits and developing new plant breeding strategies*" (Ursache *et al*. 2021, 2).

The technological optimism of the "*powerful and precise*" storyline was a defining feature of the tweets in the Scientist coalition overall. The NGO coalition however made efforts to challenge the way this storyline framed the technology. For example, Corporate Europe Observatory, an actor in the NGO coalition, circulated a report that questioned the inference of safety that some attributed to CRISPR's supposed precision. The report read: "[*the] narrative equating precision = control = safety is not supported by the scientific evidence*" (The GREENS/EFA 2021, 1). No tweets from the Scientist coalition in the top 50 picked up on this and challenged the claim.

3.3.2 *CRISPR will solve global food security and climate change*

While many of the tweets circulating within the Scientist coalition were clearly addressed towards scientifically literate readers, there were also tweets circulated by this coalition that were more public facing, for example, sharing press releases from universities. In these tweets and linked media, CRISPR was framed as a technology that would solve big contemporary societal issues, in particular, global food security and climate change. As one scientist tweeted: "*CRISPR will have a critical role in addressing the climate change. I personally believe that the potential impact of CRISPR on agriculture will affect many more people in a short time frame compared to the medicine field*".

The connection between CRISPR, climate change, and food security was also highlighted in discussions that surrounded Wageningen University's decision to make their CRISPR patents publicly available. The Scientist coalition intensively circulated this news. A press release published on Wageningen University's website, shared in the Scientist coalition, made explicit connections between the decision and the possibility to reduce hunger and improve resilience to climate change: "*Two billion people face inadequate nutrition around the world in*

2020. Nearly all of them are also vulnerable to the effects of climate change". One scientist posted: "*Free IP licenses to use @WUR CRISPR gene editing technology will be provided for non-profit crop-improvement applications. This is a great step towards changing the CRISPR IP landscape, leading to benefit for farmers and consumers in low-income countries*." Another scientist wrote: "*License CRISPR patents for free to share gene editing globally: the follow-up in a @nature editorial of our announcement @wur last week that we will provide licenses for free for non-profit purposes in food security*" A linked online news piece claimed that the decision would advance the global transformation to a sustainable food system: "*CRISPR technology and other biosciences could accelerate a shift into more sustainable, affordable and resilient food systems that could drastically reduce hunger and malnutrition*" (Noltemeyer 2021).

Yet another example of the circulation of this storyline is a journal publication from Theoretical and Applied Genetics entitled "*Hotter, drier, CRISPR: the latest edit on climate change*" (Massel *et al*. 2021, 1691). The article was widely circulated in the Scientist coalition. University of Queensland News (UQ_News) tweeted "*Hotter, drier, CRISPR: editing for climate change. #UQResearch on gene editing technology for future crops from @QAAFI*" and shared the article. One of the authors to the article tweeted "*Conceptual model of a futuristic breeding program that integrates lab-free genome editing, speed breeding & genomic selection to fast-track climate resilient inbred crops*" and linked to a press release from University of Queensland where the lead author, Massel, was interviewed about the publication. In the interview Massel described how

> [i]t's a race between a changing climate and plant breeders' ability to produce crops with genetic resilience that grow well in adverse conditions and have enriched nutritional qualities. […] The problem is that it takes too long for breeders to detect and make that genetic diversity available to farmers, with a breeding cycle averaging about 15 years for cereal crops.

Although consensus within the Scientist coalition on this storyline was strong, it received some pushback from the NGO coalition. This constituted a rare example of where some contestation occurred, although critiques remained isolated to the NGO coalition. One example of this contestation was how GreensEFA, a policy group connected with the NGO coalition, shared a report widely circulated in the NGO coalition (see also 3.3.1), which voiced a strong critique of the way the European Academies Science and Advisory Council "*ignores the growing recognition among experts that the root causes of hunger are related to social and economic issues (conflict, poverty, exclusion, etc.) more than to crop yield*" and emphasized that "*There is no record of GMO interventions increasing crop yields as such, or indeed reducing hunger*" (The GREENS/EFA 2021, 2). Notably, this kind of opposition to the storyline of how CRISPR will solve food security and climate change did not attract any attention from the Scientist coalition.

3.3.3 *Tomatoes pave the way*

In October 2021, the GABA tomato released onto the Japanese market, was the first CRISPR food product to go on sale anywhere in the world. The tomato, developed by Sanatech Seed, was biofortified using CRISPR to express higher than usual amounts of Gamma Aminobutyric Acid (GABA), a neurotransmitter that is said to have relaxing effects and is aimed at lowering blood pressure. The news value attracted to this novel food product seems to have driven many tweets into the top 50.

A typical example is a tweet by Nature Biotech, which stated: "*GABA-enriched tomato is first CRISPR-edited food to enter market*". Within the linked media, hopes were evident that the GABA tomato foreshadowed greater acceptance of CRISPR technology in the global food system. The tomato was framed as a vehicle that would promote broader public acceptance and eventually lead to deregulation. An article in Nature Biotechnology highlighted that the GABA tomato was "*a smart marketing strategy for genome-edited fruit and vegetables, especially those with boutique traits*" (Waltz 2022, 10). Another article pointed out that the GABA tomato might soon be available elsewhere as regulations on CRISPR-edited foods are changing: "*Sanatech Seed has previously said it is 'keeping a close eye' on regulations in the UK*" (Le Page 2021, 2). A podcast run by the NewScientist also highlighted the new technology. A tweet, linking to the podcast, read: "*A 'super tomato' has been created by a startup in Japan. @rowhoop and @PennySarchet explain why CRISPR is less controversial than past methods of gene-editing*".

Again, the argument that CRISPR is less controversial than other methods of gene editing and previous types of GMOs is validated within the Scientist coalition, but not within the NGO coalition. This leads us towards our next insight, regarding the limited extent of debate between actors in different discourse coalitions. In particular, the Scientist coalition seems to have been reluctant to engage in debating alternative and critical perspectives.

3.3.4 *Siloed discourses reveal limited debate between perspectives*

The Scientist coalition and the NGO coalition voice clearly different sentiments on CRISPR in food and agriculture. In the preceding sub-sections of this paper, we have noted that actors within the NGO coalition challenged the Scientist coalition's storylines of the technology. Despite this, our analysis did not capture any explicit conflicts between coalitions. In fact, tweets within the top 50 did not appear to cross coalitions. While NGOs made efforts to oppose positive framings of CRISPR technology advanced by the Scientist coalition, their critiques were left uncommented upon by scientists. Overall, our analysis of the top 50 tweets suggests that participants belonging to the Scientist coalition focused mainly on building their own coalition and supporting one another, and ignored rather than engaged with challenges to their preferred storylines about

CRISPR in food and agriculture. When we look at the wider dataset, not only the top 50 tweets, open contestation is still limited. The use of scientific jargon in the Scientist coalition as well as the fact that the most commonly shared media form by actors in the Scientist coalition were academic journal articles, gives further support to the conclusion that the actors in the Scientist coalition were mainly focused on talking with each other. In the next sub-section, we dig deeper into this phenomenon by looking at contrasting tweeting styles.

3.3.5 *Different actor groups employ different tweeting styles*

A major feature of discussions on Twitter about CRISPR is the way certain actors use hashtags and "at" symbols. Scientists commonly used "at" symbols to tag collaborators and publications. One example of this use of the "at" symbol is the COST PlantEd tweet mentioned in section 3.3.1: "*CRISPR-Cas9 Based Genome Editing in Wheat @JohnInnesCentre @MarkSmedley15 @SadiyeHayta @wiley-plantsci*". All tagged actors in this tweet are scientists, research centers or scientific journals. This practice of tagging collaborators serves to further strengthen the Scientist coalition.

The Scientist coalition overall employed the "at" symbol far more than any hashtag. This structure differed from how the NGO coalition constructed tweets. NGOs frequently used hashtags, but rarely tagged other actors using the "at" symbol. The hashtags #newGMO and #GMO were used particularly frequently, indicating strong efforts to connect newer gene editing technologies with longer-established GMO technologies. For example, one tweet from an NGO read: "*For a tech that's being sold by the seed giants as #nonGMO, it's hard to see any difference from their old #GMO playbook. #CRISPR #BigFood"*. Like most tweets in the NGO coalition, and in contrast to the Scientist coalition, the tweet did not employ the "at" symbol to identify who #BigFood represents. In fact, the NGO coalition rarely highlighted the actors involved in the issues they were tweeting about. This strategy might serve to avoid direct confrontation with those critiqued which avoids acts to challenge the storyline. However, not targeting particular actors also has the effect of generalizing critique (Mahé 2019; Rundblad 2007).

4. Discussion and conclusions

Previous studies on CRISPR reporting in social media have shown that scientific advances and general discussions about the technology's capability persist over time as the dominant themes (Calabrese *et al*. 2020; Ji *et al*. 2022; Müller *et al*. 2020; Ni *et al*. 2022). Our study confirms that this continued to be the case in 2021. Both in the whole dataset capturing all tweets on CRISPR (375,776 tweets), and in the dataset focused on CRISPR in food and agriculture (16,792 tweets) the dominant focus was reporting on scientific advances. Our study also

shows that agricultural topics are only mentioned in a minority of tweets about CRISPR, only 6% of all tweets about CRISPR related to food and agriculture. Another finding is that Twitter debates are not necessarily so short-lived as previously indicated (Vosoughi, Roy, and Aral 2018). A handful of tweets in the top 50 continued to circulate for up to two years following the original posts, indicating a similarity between how news circulates on social media with how it circulates in traditional news media (Cook, Robbins, and Pieri 2006; Fischer and Hess 2022).

At the same time, our study shows that the CRISPR babies experiment from 2018 did not dominate Twitter discussions in 2021, suggesting that it had not had any obvious long-term effect on the debate that was visible at the time we collected our data. The leading theme of the debate – relating to both CRISPR in general and with regard to CRISPR in food and agriculture – continues to be characterized by rather positive or neutral reports about scientific and technical developments, which suggests to us that the CRISPR babies experiment has not been the game-changer that studies reporting on trends from 2018 to 2019 assumed (Calabrese *et al*. 2020; Ji *et al*. 2022; Ni *et al*. 2022; Stapleton and Torres Yabar 2022; Tabei *et al*. 2020; Zhang, Chen, and Zhang 2021). At the time of writing, we do not perceive strong indications that this situation has changed since 2021.

Most previously published work has focused on mapping dominant debates around CRISPR, without attending to the roles of different actors involved in those debates (Calabrese *et al*. 2020; Ji *et al*. 2022; Müller *et al*. 2020; Ni *et al*. 2022; Walker and Malson 2020). Our network analysis of the actors posting about CRISPR in food and agriculture on Twitter reveals that clusters of actor coalitions had emerged and coalesced around shared interests, which framed hopes and concerns about CRISPR in similar ways. Scientists (notably molecular biologists and other lab-based researchers) and scientific institutions formed the largest and most tightly networked coalition. This Scientist coalition was strengthened as scientists supported one another by retweeting each other's articles and tagging one another in tweets. The coalition coalesced around storylines of technical novelty and technological progress. The Scientist coalition was also successful in gaining traction for these storylines. Our analysis did not identify any dominant storylines about CRISPR in food and agriculture which united more critical perspectives to the technology. Challenges to the dominant storylines on Twitter have not been taken up by the Scientist coalition.

The other emerging coalition was dominated by civil society actors, who united around negative sentiments towards CRISPR technology. Our quantitative and qualitative data lends support to a previous study by Helliwell *et al*. (2017, 2091), who applied frame analysis to focus group data and showed that NGOs "*expressed an alternative framing of agricultural biotechnology that was sceptical of the dominant problem and solution framing*" and articulated their own "*motivations for rejecting agricultural biotechnologies*". Within the NGO coalition,

discursive connections were made between older GMOs and newer CRISPR-derived organisms (a finding supported by other studies, e.g. Walker and Malson 2020), and stories of scientific advances and progress were questioned – but while civil society actors referred to scientific publications, news and events, they avoided direct confrontation with actors in the Scientist coalition. Simultaneously, scientists did not make any explicit efforts to counter claims made by the NGO coalition. Overall, findings from the network analysis and discourse analysis both give support to the conclusion that conversations about CRISPR occurred within their respective coalitions with limited evidence of wider impacts across coalitions and that efforts to spread more critical perspectives as of yet have had limited success.

Interestingly, the scientist and NGO coalitions identified in our study appear to be largely the same groups that have been previously identified as key adversaries in debates about an earlier generation of GMOs (Agre *et al*. 2016; Tosun and Schaub 2017). Their rival discourses demonstrate the persistence of divergent perspectives in the agricultural biotechnology sphere (Berkhout 2002; Macnaghten and Habets 2020). The fact that scientists and academic institutions dominated English-language Twitter postings in 2021, and that open debate between contrasting perspectives is limited, is reminiscent of early debates about GMOs in the 1970s and 1980s, which were similarly dominated by scientists' perspectives, and chiefly concerned medical applications (Bud 1993).

Private-sector entities became prominently involved in shaping public debates about GMOs during the 1990s (Glover 2010). At present, the private sector is conspicuously absent from the Twitter debate about CRISPR in food and agriculture, at least up front. Why is this? Negative experiences of their previous engagements in contentious public debates about GMOs in food and agriculture may well have led private-sector organizations to avoid engaging directly and openly in debates about gene editing. This does not necessarily mean that the private sector is not engaged in the background of these debates. Providing support to allies, who have independent standing in public debates, is a well-established public relations strategy employed by the biotechnology industry. For instance, corporate influence on GMO debates was exposed in 2015, when The New York Times revealed that Monsanto had funded third-party scientists to act as spokespeople on behalf of GM technologies, and to publish material ghost-written by Monsanto staff (Lipton 2015). A more recent similar example of a biotech company pushing its agenda through the publications of seemingly independent scientists is outlined in detail by Glenna and Bruce (2021). Thus, the fact that our study did not identify actors from the private sector in any of the dominant coalitions, does not mean that they are not influencing the emerging coalitions and storylines that we see in our data. Further research and other forms of data and methods would be needed to answer the question about if and how the private sector is currently engaged in the debate on CRISPR in food and agriculture.

Several studies have shown that social media is serving as an increasingly important medium for science communication (Anderson *et al*. 2021: Ji *et al*. 2022; Wang and Guo 2018). This study has provided some early findings about how stakeholders attempted to shape debates on Twitter about CRISPR in food and agriculture. The view presented here is essentially a snapshot of the debate amongst English-speaking actors in 2021 on one social media platform (Twitter). Bearing in mind that the role of Twitter as a platform for public debate is not static, and that the platform is only one of many where public debate on CRISPR occurs, our study still indicates some interesting trends in emerging public discourse which will be valuable to continue exploring in future research moving beyond Twitter. Three key conclusions are that (1) the respective coalitions in support of and critical of CRISPR are largely similar to those that previously supported and criticized the previous generation of GMOs; (2) scientists currently have most influence over how the role of CRISPR in food and agriculture is portrayed on Twitter, and (3) there is as of yet there is limited interaction between actors with contrasting perspectives and as a result limited debate.

Note

1. Note that the disease outbreak technically was unrelated to GMOs.

Acknowledgements

The authors would like to thank Riccardo Bommarco for suggesting the title of the paper to us, Alanna Taylor, Alejandra Figueredo, Brent Uramoto and Paige Lockwood for their research assistance, and the editor and anonymous reviewers at New Genetics and Society for their robust feedback.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This article is supported by the Jean Monnet Network "Genome Editing and Agricultural Policy, Practice and Public Perceptions', with the support of the Erasmus + programme of the European Union (Agreement number: 611150-EPP-1-2019-1- CA-EPPJMO-NETWORK – 2019-1887).

ORCID

Lauren Crossland-Marr http://orcid.org/0000-0002-7253-3506
Matthew A. Schnurr http://orcid.org/0000-0001-7560-3437
Adrian Ely http://orcid.org/0000-0002-3242-839X
Dominic Glover http://orcid.org/0000-0003-2055-1996
Glenn Davis Stone http://orcid.org/0000-0001-6265-6396
Klara Fischer http://orcid.org/0000-0001-6590-4025

References

Agre, P., et al. 2016. "Laureates Letter Supporting Precision Agriculture (GMOs)." *Support Precision Agriculture*, June 29. Accessed 31 January 2023. https://www.supportprecisionagriculture.org/nobel-laureate-gmo-letter_rjr.html.

Ahmad, S., L. Tang, R. Shahzad, A. Mawia, G. Rao, S. Jamil, and C. Wei. 2021. "CRISPR-Based Crop Improvements: A Way Forward to Achieve Zero Hunger." *Journal of Agricultural and Food Chemistry* 69 (30): 8307–8323. https://doi.org/10.1021/acs.jafc.1c02653.

Anderson, J. T., E. Howell, M. A. Xenos, D. Scheufele, and D. Brossard. 2021. ""Learning without Seeking?" Incidental Exposure to Science News on Social Media & Knowledge of Gene Editing." *Journal of Science Communication* 20 (4): A01. https://doi.org/10.22323/2.20040201.

Bauer, M. W. 2002. "Controversial Medical and Agri-Food Biotechnology: A Cultivation Analysis." *Public Understanding of Science* 11 (2): 93–111. https://doi.org/10.1088/0963-6625/11/2/301.

Berkhout, F. 2002. "Novel Foods, Traditional Debates: Framing Biotechnology Sustainability." *New Genetics and Society* 21 (2): 131–148. https://doi.org/10.1080/1463677022000006989.

Britt, B. C., J. L. Hayes, A. Musaev, P. Sheinidashtegol, S. Parrott, and D. L. Albright. 2021. "Using Targeted Betweenness Centrality to Identify Bridges to Neglected Users in the Twitter Conversation on Veteran Suicide." *Social Network Analysis and Mining* 11 (40): 1–15. https://doi.org/10.1007/s13278-021-00747-x.

Bud, R. 1993. *The Uses of Life. A History of Biotechnology*. Cambridge: Cambridge University Press.

Calabrese, C., J. Ding, B. Millam, and G. A. Barnett. 2020. "The Uproar Over Gene-Edited Babies: A Semantic Network Analysis of CRISPR on Twitter." *Environmental Communication* 14 (7): 954–970. https://doi.org/10.1080/17524032.2019.1699135.

Caplan, A. L., B. Parent, M. Shen, and C. Plunkett. 2015. "No Time to Waste—The Ethical Challenges Created by CRISPR: CRISPR/Cas, Being an Efficient, Simple, and Cheap Technology to Edit the Genome of Any Organism, Raises Many Ethical and Regulatory Issues beyond the Use to Manipulate Human Germ Line Cells." *EMBO Reports* 16 (11): 1421–1426. https://doi.org/10.15252/embr.201541337.

Cook, G., P. T. Robbins, and E. Pieri. 2006. ""Words of Mass Destruction": British Newspaper Coverage of the Genetically Modified Food Debate, Expert and Non-Expert Reactions." *Public Understanding of Science* 15 (1): 5–29. https://doi.org/10.1177/0963662506058756.

Dawson, W., A. Paintsil, J. Bingaman, and P. R. Brewer. 2022. "CRISPR Images: Media Use and Public Opinion About Gene Editing." *Bulletin of Science, Technology & Society* 42 (1-2): 11–18. https://doi.org/10.1177/02704676221080919.

Dickenson, D., and M. Darnovsky. 2019. "Did a Permissive Scientific Culture Encourage the 'CRISPR babies' Experiment?" *Nature Biotechnology* 37 (4): 355–357. https://doi.org/10.1038/s41587-019-0077-3.

Fischer, K., and S. Hess. 2022. "The Swedish Media Debate on GMO Between 1994 and 2018: What Attention was Given to Farmers' Perspectives?" *Environmental Communication* 16 (1): 43–62. https://doi.org/10.1080/17524032.2021.1960406.

Fischer, K., P. Wennström, and M. Ågren. 2019. "*The Swedish Media Debate on GMO 1994-2017*." Future Food Reports 10. Swedish University of Agricultural Sciences.

Freeman, L. C. 1977. "A Set of Measures of Centrality Based on Betweenness." *Sociometry* 40 (1): 35–41. https://doi.org/10.2307/3033543.

Frewer, L. J., S. Miles, and R. Marsh. 2002. "The Media and Genetically Modified Foods: Evidence in Support of Social Amplification of Risk." *Risk Analysis: An International Journal* 22 (4): 701–711. https://doi.org/10.1111/0272-4332.00062.

Gaillochet, C., W. Develtere, and T. B. Jacobs. 2021. "CRISPR Screens in Plants: Approaches, Guidelines, and Future Prospects." *The Plant Cell* 33 (4): 794–813. https://doi.org/10.1093/plcell/koab099.

Gates, B. 2018. "Gene Editing for Good: How CRISPR Could Transform Global Development." *Foreign Affairs* 97 (3): 166. https://www.foreignaffairs.com/articles/2018-04-10/gene-editing-good.

Glenna, L., and A. Bruce. 2021. "Suborning Science for Profit: Monsanto, Glyphosate, and Private Science Research Misconduct." *Research Policy* 50 (7): 104290. https://doi.org/10.1016/j.respol.2021.104290.

Glover, D. 2010. "The Corporate Shaping of GM Crops as a Technology for the Poor." *The Journal of Peasant Studies* 37 (1): 67–90. https://doi.org/10.1080/03066150903498754.

Greenpeace. 2021. "Danger Ahead: Why Gene Editing is not the Answer to the EU's Environmental Challenges." *Greenpeace*. Accessed 23 January 2023. https://www.greenpeace.org/static/planet4-eu-unit-stateless/2021/04/20210331-Greenpeace-gene-editing-position-paper-EN.pdf.

The Greens/EFA. 2021. Scientific Critique of Leopoldina and EASAC Statements on Genome Edited Plants in the EU: Executive Summary of a Study by Ensser and CSS.

Gyngell, C. 2017. "Gene Editing and the Health of Future Generations." *Journal of the Royal Society of Medicine* 110 (7): 276–279. https://doi.org/10.1177/0141076817705616.

Hajer, M. A. 1995. *The Politics of Environmental Discourse: Ecological Modernization and the Policy Process*. New York, NY: Oxford University Press. https://doi.org/10.1093/019829333X.001.0001.

Hansen, D. L., B. Shneiderman, and M. Smith. 2019. *Analyzing Social Media Networks with NodeXL: Insights from a Connected World*. 2nd ed. Burlington, MA: Morgan Kaufmann.

Helliwell, R., S. Hartley, W. Pearce, and L. O'Neill. 2017. "Why are NGOs Sceptical of Genome Editing? NGOs' Opposition to Agricultural Biotechnologies is Rooted in Scepticism about the Framing of Problems and Solutions, rather than Just Emotion and Dogma." *EMBO Reports* 18 (12): 2090–2093. https://doi.org/10.15252/embr.201744385.

Jasanoff, S., J. B. Hurlbut, and K. Saha. 2015. "CRISPR Democracy: Gene Editing and the Need for Inclusive Deliberation." *Issues in Science and Technology* 32 (1): 25–32. https://issues.org/crispr-democracy-gene-editing-inclusive-deliberation/.

Ji, J., M. Robbins, J. D. Featherstone, C. Calabrese, and G. A. Barnett. 2022. "Comparison of Public Discussions of Gene Editing on Social Media Between the United States and China." *PLoS One* 17 (5): e0267406. https://doi.org/10.1371/journal.pone.0267406.

Jinek, M., K. Chylinski, I. Fonfara, M. Hauer, J. A. Doudna, and E. Charpentier. 2012. "A Programmable Dual-RNA–Guided DNA Endonuclease in Adaptive Bacterial Immunity." *Science* 337 (6096): 816–821. https://doi.org/10.1126/science.1225829.

Kaiser, J. 2021. "CRISPR Injected Into the Blood Treats a Genetic Disease for First Time." *Science*, June 26. https://www.science.org/content/article/crispr-injected-blood-treats-genetic-disease-first-time.

Le Page, M. 2021. "Tomato Is First CRISPR-Edited Food to Go on Sale in the World." *New Scientist*, September 24, 2021. https://www.newscientist.com/article/2291194-tomato-is-first-crispr-edited-food-to-go-on-sale-in-the-world/.

Ledford, H. 2015. "CRISPR, the Disruptor." *Nature* 522 (7554): 20–24. https://doi.org/10.1038/522020a.

Levidow, L. 1999. "Britain's Biotechnology Controversy: Elusive Science, Contested Expertise." *New Genetics and Society* 18 (1): 47–64. https://doi.org/10.1080/14636779908656889.

Lipton, E. 2015. "Food Industry Enlisted Academics in G.M.O. Lobbying War, Emails Show." *The New York Times*, September 5.

Macnaghten, P., and M. G. J. L. Habets. 2020. "Breaking the Impasse: Towards a Forward-Looking Governance Framework for Gene Editing with Plants." *Plants, People, Planet* 2: 353–365. https://doi.org/10.1002/ppp3.10107.

Mahé, A.-L. 2019. "Aligning Epistemology and Writing: A Literary Analysis of Qualitative Research." *International Studies Perspectives* 20 (3): 226–245. https://doi.org/10.1093/isp/ekz004.

Marchetti, R., and D. Ceccobelli. 2016. "Twitter and Television in a Hybrid Media System: The 2013 Italian Election Campaign." *Journalism Practice* 10 (5): 626–644. https://doi.org/10.1080/17512786.2015.1040051.

Massel, K., Y. Lam, A. C. S. Wong, L. T. Hickey, A. K. Borrell, and I. D. Godwin. 2021. "Hotter, Drier, CRISPR: The Latest Edit on Climate Change." *Theoretical and Applied Genetics* 134 (6): 1691–1709. https://doi.org/10.1007/s00122-020-03764-0.

Müller, M., M. Schneider, M. Salathé, and E. Vayena. 2020. "Assessing Public Opinion on CRISPR-Cas9: Combining Crowdsourcing and Deep Learning." *Journal of Medical Internet Research* 22 (8): e17830. https://doi.org/10.2196/17830.

Newman, M. E. J., and M. Girvan. 2004. "Finding and Evaluating Community Structure in Networks." *Physical Review* 69 (2): 026113. https://doi.org/10.1103/PhysRevE.69.026113.

Ni, C., Z. Wan, C. Yan, Y. Liu, E. W. Clayton, B. Malin, and Z. Yin. 2022. "The Public Perception of the# GeneEditedBabies Event across Multiple Social Media Platforms: Observational Study." *Journal of Medical Internet Research* 24 (3): e31687. https://doi.org/10.2196/31687.

Noltemeyer, M. 2021. "Plant Genetics Patents Shared with Research Partners." *World Grain*, September 8, 2021. https://www.world-grain.com/articles/15804-plant-genetics-patents-shared-with-research-partners.

Ribero, S. 2020. "Nobel Prize for a Gene Bomb." *The Ecologist*, October 22. https://theecologist.org/2020/oct/22/nobel-prize-gene-bomb.

Riddell, J., A. Brown, I. Kovic, and J. Jauregui. 2017. "Who Are the Most Influential Emergency Physicians on Twitter?" *Western Journal of Emergency Medicine* 18 (2): 281–287. https://doi.org/10.5811/westjem.2016.11.31299.

Rock, J. S., M. A. Schnurr, A. Kingiri, D. Glover, G. D. Stone, A. Ely, and K. Fischer. 2023. "Beyond the Genome: Genetically Modified Crops in Africa and the Implications for Genome Editing." *Development and Change* 54 (1): 117–142. https://doi.org/10.1111/dech.12750.

Rundblad, G. 2007. "Impersonal, general, and social: The use of metonymy versus passive voice in medical discourse." *Written Communication* 24 (3): 250–277. https://doi.org/10.1177/07410883073029.

Scott, J. 2012. *Social Network Analysis*. 3rd ed. Los Angeles: SAGE Publications Ltd.

Smedley, M. A., S. Hayta, M. Clarke, and W. A. Harwood. 2021. "CRISPR-Cas9 Based Genome Editing in Wheat." *Current Protocols* 1 (3): e65. https://doi.org/10.1002/cpz1.65.

Stapleton, P., and A. Torres Yabar. 2022. "Playing God? Media Coverage of CRISPR in the United States." *Public Understanding of Science*, https://doi.org/10.1177/09636625221138953.

Stephan, H. R. 2012. "Revisiting the Transatlantic Divergence Over GMOs: Toward a Cultural-Political Analysis." *Global Environmental Politics* 12 (4): 104–124. https://doi.org/10.1162/GLEP_a_00142.

Tabei, Y., S. Shimura, Y. Kwon, S. Itaka, and N. Fukino. 2020. "Analyzing Twitter Conversation on Genome-Edited Foods and Their Labeling in Japan." *Frontiers in Plant Science* 11: 1–10. https://doi.org/10.3389/fpls.2020.535764.

Tosun, J., and S. Schaub. 2017. "Mobilization in the European Public Sphere: The Struggle Over Genetically Modified Organisms." *Review of Policy Research* 34 (3): 310–330. https://doi.org/10.1111/ropr.12235.

Ursache, R., S. Fujita, V. Dénervaud Tendon, and N. Geldner. 2021. "Combined Fluorescent Seed Selection and Multiplex CRISPR/Cas9 Assembly for Fast Generation of Multiple Arabidopsis Mutants." *Plant Methods* 17 (1): 111. https://doi.org/10.1186/s13007-021-00811-9.

Vosoughi, S., D. Roy, and S. Aral. 2018. "The Spread of True and False News Online." *Science* 359 (6380): 1146–1151. https://doi.org/10.1126/science.aap9559.

Wakita, K., and T. Tsurumi. 2007. "Finding Community Structure in Mega-Scale Social Networks." In *Proceedings of the 16th International Conference on World Wide Web (WWW '07)*, Banff, AB, Canada, May 8–12. New York, NY: Association for Computing Machinery.

Walker, B., and J. Malson. 2020. "Science, God, and Nature: A Textual and Frequency Analysis of Facebook Comments on News Articles About Agricultural and Environmental Gene Editing." *Environmental Communication* 14 (7): 1004–1016. https://doi.org/10.1080/17524032.2020.1761853.

Waltz, E. 2022. "GABA-Enriched Tomato Is First CRISPR-Edited Food to Enter Market." *Nature Biotechnology* 40 (1): 9–11. https://doi.org/10.1038/d41587-021-00026-2.

Wang, W., and L. Guo. 2018. "Framing Genetically Modified Mosquitoes in the Online News and Twitter: Intermedia Frame Setting in the Issue-Attention Cycle." *Public Understanding of Science* 27 (8): 937–951. https://doi.org/10.1177/0963662518799564.

Wasserman, S., and K. Faust. 1994. *Social Network Analysis: Methods and Applications. Structural Analysis in the Social Sciences*. Cambridge: Cambridge University Press. https://doi.org/10.1017/CBO9780511815478.

Zhang, X., A. Chen, and W. Zhang. 2021. "Before and After the Chinese Gene-Edited Human Babies: Multiple Discourses of Gene Editing on Social Media." *Public Understanding of Science* 30 (5): 570–587. https://doi.org/10.1177/0963662520987754.