Journal of Applied Communications

Volume 108 | Issue 2 Article 1

An Enthusiastic but Uncertain Welcome: Coverage of Risks, Benefits, and Social Contexts of CRISPR Technology in U.S. Agricultural News 2012-2022

Lindsey Middleton
University of Wisconsin Madison

Anqi Shao
University of Wisconsin Madison

Ashley Cate
University of Wisconsin Madison

See next page for additional authors

Recommended Citation

Middleton, Lindsey; Shao, Anqi; Cate, Ashley; Haugen, Jade; and Li, Nan () "An Enthusiastic but Uncertain Welcome: Coverage of Risks, Benefits, and Social Contexts of CRISPR Technology in U.S. Agricultural News 2012-2022," *Journal of Applied Communications*: Vol. 108: Iss. 2. https://doi.org/10.4148/1051-0834.2532

An Enthusiastic but Uncertain Welcome: Coverage of Risks, Benefits, and Social Contexts of CRISPR Technology in U.S. Agricultural News 2012-2022

Abstract

To foster the responsible development and governance of CRISPR, it is important to understand how agricultural communities perceive and discuss this technology. This study conducted a content analysis of 529 articles from 53 diverse agricultural news publications across sectors and U.S. regions between 2012 and 2022. We analyzed how CRISPR technology is depicted in terms of risk, benefit, social/policy context, quoted experts, and the mentioning of other biotechnologies. Our findings show that from the time that CRISPR was developed for agriculture over a decade ago, agricultural news has consistently reflected a pro-innovation stance, frequently describing its benefits as well as advantages over longer-standing biotechnologies. Industry representatives were quoted most frequently, followed by university scientists and political representatives, while producers and non-governmental groups were quoted least frequently. Technology-related risks (off-target effects, financial risks) were notably lacking, but CRISPR's social context was covered more extensively, including uncertainties in regulation and consumer acceptance. We discussed the implications for agricultural news professionals, communicators, and future researchers, emphasizing the importance of fostering a more balanced discourse and ensuring informed decision-making within the agricultural sector.

Keywords

CRISPR gene editing, newspapers, content analysis, food, agriculture

Cover Page Footnote/Acknowledgements

Funding for this research was provided through the USDA Hatch formula grant program.

Authors

Lindsey Middleton, Anqi Shao, Ashley Cate, Jade Haugen, and Nan Li

Gene editing technologies like Clustered Regularly Interspaced Short Palindromic Repeats (CRISPR) have emerged as a relatively new genetic tool that precisely modifies the genetic material of living organisms like plants and animals (Gasiunas et al., 2012; Jinek et al., 2012). CRISPR has been praised in comparison to previous technologies, which often involve "randomly" inserting genetic materials, for working only on a specific and pre-determined gene location (Zhang et al., 2021, p. 208). CRISPR is being applied toward improving crop nutrition value (Ku & Ha, 2020), plant disease resistance (Ahmad et al., 2020), food appeal (Gao et al., 2020), and many other applications. However, the technology also carries risks, such as unintended mutations and off-target effects (e.g., per Sturme et al., 2022). Thus, policymakers, scientists, and others debate the risks and ethics of CRISPR (e.g., Brokowski & Adli, 2019), the likelihood of public acceptance (Müller et al., 2020), and how to best regulate the technology (e.g., Gould et al., 2022). CRISPR-edited foods have begun to enter global markets (e.g., Waltz, 2022), making the discourse around innovation and adoption more timely.

While existing CRISPR communication research extensively explores public opinion, knowledge, risk perceptions, and engagement (e.g., Baik et al., 2022; Baum et al., 2023; Montenegro de Wit, 2020; Müller et al., 2020; Scheufele et al., 2021; Wirz et al., 2020), as well as media representations concerning CRISPR technology (e.g., Crossland-Marr et al., 2023; Dahlstrom et al., 2022; Marcon et al., 2019), there remains a noticeable gap in applying theories that would examine risk management. This study is guided by two models of risk and technology management to understand agricultural news discourses surrounding CRISPR: the Social Arena of risk (Renn et al., 1992) and the Responsible Research and Innovation (RRI) framework (Owen et al., 2012; Stilgoe et al., 2013).

Social Arena of risk theory conceptualizes new risk topics, like emerging technologies, as existing in an "arena" where various "actors" (e.g., policymakers or experts) and "social groups" (e.g., activists, interest groups, or lobbyists) compete for the attention of political institutions and the general public, with "issue amplifiers" (e.g., journalists, thought leaders) selectively sharing and promoting certain ideas over others (Renn et al., 1992). On the topic of CRISPR and similar technologies like GM, news media may have agenda setting effects for the public, due to a long-term trend of news outlets publishing more *positive* stories about medical applications and more *negative* stories about agricultural applications (Marks et al., 2007), but they also influence policy in an agenda-setting manner, such as when news coverage of a GM labeling policy proposal in California led to decreased political support for the measure (McCluskey et al., 2016). Social Arena theory hence not only facilitates identifying key actors and social groups, but also enables an examination of the narratives propagated by issue amplifiers and the ways these narratives may influence other actors' opinions and decisions.

Building on this theoretical framework, this study also integrates RRI framework for governing science. The framework has four components for managing innovations: anticipation of societal impacts, reflexivity and recognition of the values and goals that shape science decisions, inclusion of impacted stakeholders, and responsiveness to societal challenges (Foley et al., 2016; Stilgoe et al., 2013). In the case of biotechnologies like CRISPR, RRI entails not only assessing technological risks but also addressing social and ethical concerns held by experts in broader disciplines, as well as producers, the public, and civil society organizations (Hartley et al., 2016). This aligns with risk literature overall finding that "expert" risk assessments rarely align with non-experts (e.g., Alaszewski, 2005). Thus, using this framework enables us to delve beyond the mere depiction of risks and benefits in news discourse, facilitating an examination of responsible CRISPR development that includes producers and others further along the chain.

Since other work has examined public facing CRISPR news (e.g., Dahlstrom et al., 2022), this study focuses on agricultural news publications to better understand how CRISPR is presented to agricultural audiences, a critical issue group for the adoption of CRISPR technology. Agricultural news is an important source of information for producers: as many as 92% of farm owners, operators, and managers use traditional media, such as ag magazines and newspapers, at least monthly to stay informed about new advancements in agriculture (Ag Media Council, 2018). In addition, digital news publications were chosen due to their growing popularity, with approximately 60% of farm and ranch owners, operators, and managers visiting agricultural news sites at least weekly (Iowa NAMA, 2022). In this study, we analyzed CRISPR-related agricultural news articles targeted at producers across diverse agricultural sectors and geographical regions in the U.S. We compiled a list of 53 digital agricultural news outlets and collected 529 articles that contained the word "CRISPR" between 2012 and 2022.

Drawing from Social Arena theory, our analysis examined coverage of both risks and benefits of CRISPR (Baum et al., 2023). We also analyzed which actors and social groups were prominently featured through direct quotes, including policymakers, academics, and others. Additionally, in line with the RRI framework, we analyzed broader social and regulatory concerns, such as policy debates and public sentiment. Furthermore, given the frequent juxtaposition of CRISPR with more publicly familiar concepts like GM and CRISPR for human applications like medical treatments, we also coded for mentions of GM and non-agricultural CRISPR applications to better understand how associations with similar, potentially risky technological applications might influence risk perceptions. The findings offer insights into the RRI of CRISPR and present implications for communication researchers and practitioners.

Literature Review

CRISPR Debate as a Social Arena

CRISPR is a transformative gene editing tool capable of making precise changes in the genetic material of living organisms. Its applications extends from human therapeutics to agricultural enhancement (European Medicines Agency, 2023; Vilela, 2021). However, the regulatory landscape regarding CRISPR has been complex since its introduction in 2012, marked by mixed support from producers and trade organizations (Bickell, 2023). Moreover, alongside regulatory ambiguities, concerns persist regarding technological risks, like off-target effects and unintended mutations (Kawall et al., 2020).

This has led to myriad academic and political debates around how CRISPR should be defined, regulated, and utilized (e.g., Brokowski & Adli, 2019; Feeney et al., 2021; Gould et al., 2022; Martin, 2018). For instance, the U.S. Department of Agriculture recently opened the biotechnology rule governing CRISPR for public comment and updated their definition of which applications are exempted from regulation (Hoffman, 2021), making it easier to receive exemption status. In response, scholars presented concerns that the U.S. might not be as able to trade with nations holding more stringent regulations and expressed concern that developers of gene edited crops were "reconstituting the same conditions that led to public rejection and mistrust of the first generation of GM foods" (Kuzma & Grieger, 2020, p. 916). These concerns show that developers, academics in different fields, and regulating bodies hold different priorities and have assigned different levels of capitol and resources toward managing the technological and social risks around CRISPR.

These complexities and uncertainties render CRISPR in agriculture a complex topic for effective debate and discussion. While scientific input is crucial in assessing CRISPR risks, a comprehensive RRI approach necessitates broader stakeholder involvement (Wickson & Wynne, 2012). However, despite growing calls for public and stakeholder engagement in CRISPR deliberations (e.g., Kuiken et al., 2021), existing institutions often lack the long-term capacity to facilitate meaningful participation (Scheufele et al., 2021). In other words, the idealized frameworks of RRI and risk management may not be actualized in the case of CRISPR and similar technologies, when this type of framework may facilitate financially and ethically desirable outcomes for more of the parties involved, including consumers and producers.

Given the intricate interplay of political, public, and academic discourses surrounding CRISPR, especially concerning food production, it becomes imperative to elevate the CRISPR risk discourse into a more inclusive RRI standard. This entails fostering a Social Arena where diverse stakeholders actively participate in shaping the trajectory of CRISPR innovation while ensuring alignment with their social values and ethical concerns.

Risks and Benefits of CRISPR and its Agricultural Applications

Despite the precision of techniques like CRISPR (Gasiunas et al., 2012; Jinek et al., 2012), there may be risks of unintended effects at the micro scale (Kawall et al., 2020). Specifically, off-target effects occur when the Cas9 protein misses its intended target, which could have unpredictable outcomes (Guo et al., 2023). Even when acting at the intended target, Cas9 can still induce unexpected deletions, inversions, or insertions (Lee & Kim, 2018). Furthermore, research is underway to determine how and in which circumstances CRISPR genes are integrated into future generations for both plants through traditional reproduction (e.g., Michno et al., 2020) and animals, typically through cloning (e.g., Carlson et al., 2016). This uncertainty has led to some speculation about the risks involved with breeding gene-edited organisms, such as unforeseen epigenetic mutations and broader-scale genetic integration than intended (Kawall et al., 2020).

There have also been concerns about broad-scale impacts of gene editing technologies. These include gene drives, in which genes spread rapidly, either intentionally or perhaps accidentally, through a natural population (Brossard et al., 2019). Others point to security risks associated with the production of intentional or unintentional biological hazards and biological weapons (Watters et al., 2021). More broadly, the debate surrounding CRISPR-edited food can intertwine with discussions on ethics, human embryos, and human applications (Brokowski & Adli, 2019). Sentiment surrounding the technology has shown a negative trend in some online spaces, such as Twitter (Müller et al., 2020). As an understanding of CRISPR's adverse effects remains incomplete (e.g., as summarized for plants by Sturme et al., 2022), it is not yet possible to fully characterize its risks to the environment, animals, and humans.

When weighing risks and benefits, individuals are often more likely to support gene editing technology if the benefits outweigh risks (Frewer, 2017). Benefits associated with CRISPR technology include addressing malnutrition problems (Brokowski & Adli, 2019) and reducing food waste (Hemalatha et al., 2023). It can also potentially improve crops by increasing yields (Huang et al., 2021), enhancing nutritional quality (Arora & Narula, 2017; Ku & Ha, 2020), controlling fruit ripening (Martín-Pizarro & Posé, 2018), and providing resistances to damaging pests and stressors (Ahmad et al., 2020; Borrelli et al., 2018; Zafar et al., 2020). Moreover, there may be improvements to food aesthetics like taste and quality (e.g., Corte et al., 2019; Guo et al., 2023; Naves et al., 2019; Wang et al., 2019). Considering the importance of contrasting risks with benefits, we raise a research question on how these aspects are covered in agricultural news publications as the technology evolves over time:

RQ1: How do agricultural news publications portray the risks and benefits of CRISPR technology over time?

Social Context Surrounding CRISPR-Edited Foods

The social context also influences risk perceptions and management decisions (Alaszewski, 2005), which is why RRI framework calls for consideration of these contexts (Foley et al., 2016). In terms of regulatory decisions, the U.S. has different regulations for CRISPR depending on the application. In 2018, the U.S. Department of Agriculture (USDA) decided to exempt most CRISPR crops from regulation, particularly those with genetic material that might arise from conventional breeding practices (final rule: USDA-APHIS, 2020). The leniency of USDA's approach caused backlash, such as when the agency had exempted a non-browning CRISPR-edited mushroom in 2016 (Waltz, 2016). Additionally, in response to USDA rules that largely exempt CRISPR food crops from regulation (USDA-APHIS, 2020), trade organizations like the National Feed and Grain Organization have criticized the rules for their overly broad approach, while groups like the National Farm Bureau Federation, a lobbying organization, have praised the ruling as a path toward rapid innovation (Bickell, 2023).

In contrast to the more lenient regulations for plants, the regulation of CRISPR-edited animals, feed, and drugs given to animals by the Food and Drug Administration (FDA) follows a more thorough process akin to the regulation of conventional drugs (National Academies of Sciences et al., 2017). Despite the rigor of this approach, the FDA granted approval for the use of CRISPR-edited beef cattle in meat production in 2022 (FDA, 2022).

To characterize broader debates and disagreements, there are still concerns about how to classify CRISPR. Regulatory bodies around the world have long debated whether to govern the entire *process* of biotechnology, or the end *products*, such as genetically edited crops (Gould et al., 2022; McHughen, 2016). Process-based regulation operates under the premise that gene editing technology carries inherent risks (Van der Meer et al., 2023). This "precautionary principle" has long been the foundation of genetic technology regulation in the European Union (McHughen, 2016), although the European Commission has since proposed a governmental reevaluation of this stringent approach (Stokstad, 2023). Countries like the U.S. and Canada trend more toward product-based regulation (Gould et al., 2022), with exceptions: although the U.S. currently regulates crops according to the product resembling conventional breeding, earlier drafts of the rule were triggered by the presence of plant pests (agrobacterium) involved in the process of delivering CRISPR to plant cells, which is a process-based regulation (Bickell, 2023).

With these policy uncertainties and fluctuations, variation remains in determining which applications warrant regulation (McHughen, 2016). This nuanced decision-making process reflects the complexities of biotechnology and the necessity to adapt regulations as the technology evolves. These decisions, and the sharing of information by, for example, the USDA or FDA in their rules, also influence the way issue advocates like agricultural news publications discuss the risk.

Within risk communication literature, this broader social context plays an important role in helping people determine risk levels (Alaszewski, 2005). This has also been termed a "social concept of risk" (Zinn, 2005). When determining risk levels, people look to compare direct risks and benefit outcomes, but they also look at the social context such as disagreement and debate among legislators or the public (Plough & Krimsky, 1987). The social and regulatory context of

DOI: 10.4148/1051-0834.2532

CRISPR is therefore also important to risk communication about CRISPR. This led us to ask how the broader social and regulatory context was characterized in agricultural publications:

RQ2: How do agricultural news publications depict social and regulatory contexts surrounding CRISPR technology over time?

Related to this, some actors and social groups (per Social Arena theory) are more vocally involved in the process of understanding risk. For example, politicians and interest groups often shape the regulatory framework and define technological risks, whereas scientists and technical experts may play a role in quantifying such risks and informing policy (Clarke, 1988). These individuals and groups can provide feedback and input on regulations, aiming to gain support or ensure that public concerns are considered (Renn et al., 1992). These social groups can amplify and enforce issues in this Social Arena and together contribute to the discourses disseminated to the agricultural sector (Renn et al., 1992). For example, recent studies have shown that popular news sources frequently cite *academics* when discussing CRISPR food, while *industry* social groups are cited less frequently (Dahlstrom et al., 2022). Interestingly, it has been reported that European popular news articles tend to cite policymakers more often than their U.S. counterparts on these topics (Dahlstrom et al., 2022). This might in turn indicate that U.S. popular news articles tend to cite industry more frequently.

The type of social group quoted may also have an impact on decisions about whether to adopt new technology. In Hungary and the UK, for example, analysis of interviews with 82 farmers found that farmers had adapted their practices after seeing news and information from influencers and other farmers, but they were less likely to adopt technologies and practices recommended by academic scientists or governmental institutions – the study inferred that farmers had “had enough” of these types of traditionally recognized experts (Rust et al., 2022). This might echo sentiments in other parts of the world, as well, although there is more research to be done on whether traditional experts are trusted more frequently in different formats, like online news, or on different subjects, like certain types of technologies. Therefore, it will be important to know the affiliations, such as academia or industry (termed “actors” and “social groups” in Social Arena theory), of people quoted with information about CRISPR technology, a topic that could be expanded on in future research. To learn more about social groups quoted in agricultural publications, we asked:

RQ3: Which actors and social groups are cited most frequently in U.S. agricultural news publications regarding CRISPR technology?

Comparing CRISPR-Edited Food With GM and Non-Agricultural Applications

CRISPR-edited foods are often compared with GM. Notably, CRISPR technology offers an advantage over GM as it does not usually involve the insertion of outside DNA such as DNA from another type of organism (Cohen et al., 1973; Klug, 2010; Joung & Sander, 2013). Support for CRISPR may arise from the perception that it is more precise, efficient, and “natural” than other technologies (Bartkowski et al., 2018; Meyer, 2001; Marette et al., 2021).

The public may have difficulty forming opinions about new technology without more extensive information. There may be potential for a “spillover effect” in which judgments about a new technology are shaped by perceptions of a more familiar topic (Akin et al., 2019). Concerns regarding the risks and benefits associated with GM have been found to strongly correlate with perceptions of the risks and benefits of the less well-known nanotechnology (Akin et al., 2019). Similarly, public opinions about GM might map onto CRISPR opinions.

Conversely, if the public successfully distinguishes CRISPR and GM and even favors CRISPR, there may be further backlash against GM (Doxzen & Henderson, 2020). Given that the U.S. agricultural industry currently utilizes both technologies, it will be useful to understand how agricultural publications characterize the difference. CRISPR-edited foods and GM are more often contrasted than equated in mass media (Dahlstrom et al., 2022), but there is yet no evidence on how agricultural news publications portray the comparison between CRISPR-edited food and GM. We hence raise the fourth research question:

RQ4: How do agricultural news publications compare CRISPR-edited foods with GM?

Furthermore, CRISPR technology has extensive applications in the field of human health (Doudna & Charpentier, 2014). CRISPR presents potential to simplify and improve the efficiency of existing gene therapy techniques, which hold promise for treating a wide range of diseases (Uddin et al., 2020), including neurological conditions such as Parkinson's (e.g., Safari et al., 2020) and Alzheimer's (e.g., Giau et al., 2018). Despite these benefits, controversial incidents such as the birth of CRISPR-edited babies in 2018 caused global outcry and may raise concerns when the technology is applied for food (Normile, 2019). The spillover effect from descriptions of either benefits or controversies surrounding human gene editing can hence influence the perception of CRISPR food technologies. Acknowledging the significant implications of CRISPR in human health, we thus propose the last research question as:

RQ5: How do agricultural news publications cover non-agricultural applications of CRISPR?

Notably, any articles that mentioned human applications, but did not mention agriculture, were excluded. We only analyzed the mention of human applications when agricultural applications were also mentioned, due to the possibility of spillover effects to opinions about agricultural CRISPR.

Methods

Content Analysis

For this content analysis, we selected agricultural news stories from a list of online publications to make them easily searchable. While content of online and offline sources may differ, online news is becoming more readily available. In Iowa, a 2022 Media Channel Study by the Iowa National Agri-Marketing Association (Iowa NAMA, 2022) reported that 97% of owners, operators, and managers of farms or ranches ($n=957$, sampling method not clear) had visited websites for agricultural news and information in the last month, and 18% said these websites were one of their top two sources of agricultural news and information. Additionally, 82% either "somewhat" or "completely" agreed that they would be more likely to click on agricultural advertisements within agricultural news sites compared to other sites, which, while less relevant to the study here, might imply some level of conferred trust or credibility for content found within online agricultural news, including content intentionally designed to persuade. Therefore, despite producers' reliance on a diverse set of media sources, the significance of online agricultural news articles warrant attention, particularly considering their relatively under-studied status in current research.

Our coding and analysis procedures adhered to the principles of quantitative content analysis. We adopted an approach that hinges on the premise that statistically analyzing units of meaning within textual data can unveil trends that may elude both news media creators and readers alike (Gerbner, 1958). This method also allows us to delve into potential underlying factors shaping the selection of news stories or the manner in which topics are presented. In addition, we followed established content analysis methodologies, including the preparation of a codebook and the testing of inter-coder reliability, to enhance the validity and consistency of our findings (Krippendorff, 2004).

Sample and Data

To identify the most relevant agricultural news publications, we focused on those that are targeted specifically to the agricultural industry, excluding hobby farming and lifestyle publications. To compile our list, we initially consulted AgEdNet's compilation of agricultural publications, which included six publishers, five equipment and input product guides, seven general farm publications, 12 livestock and dairy publications, three special interest publications, and five specialized crop publications (AgEdNet, 2022). This list was compared with other lists highlighting the most popular agricultural news publications (e.g., Mercier, 2018; Shelton, 2021). We thoroughly reviewed each source and identified a total of 53 publications that provide codable data and can be extracted from their websites.

In total, we collected 639 articles published between January 1, 2012, and December 31, 2022, that mentioned 'CRISPR' from the websites of all the identified publications (see Table 1). To ensure the relevance of the collected articles to agricultural applications, we only included articles that discussed CRISPR in the context of agriculture and filtered out articles exclusively addressing CRISPR in relation to human gene editing or lacking any reference to agricultural applications (91 articles). Additionally, we excluded 11 duplicated articles and 3 articles that consisted solely of lists of links to other articles without any substantial content, and we excluded 5 articles from January 2023, when we collected the data.

Table 1

List of Publications Sampled, Grouped by General Content Type (Crop, Animal, and General Ag)

Group	Publication	Number of Articles
Crop Ag	Seed World	148
	Potato Grower	16
	Good Fruit Grower	7
	Sugar Producer	6
Total Crop		*177*
Animal Ag	Feedstuffs	46
	National Hog Farmer	30
	Hoard's Dairyman	9
	Dairy Business	6
	Egg Industry	2
Total Animal		*93*
General Ag	Ag Update (including 14 regional publications)[a]	85
	Farm Progress (including 21 regional publications)[b]	73
	Successful Farming	26
	High Plains Journal	24

	Farm Journal	18
	Lancaster Farming	16
	Modern Farmer	10
	AgriNews	7
Total General		*259*
Grand Total		*529*

[a]***Farm Progress publications****: American Agriculturalist, Beef Producer, Corn & Soybean Digest, Dakota Farmer, Delta Farm Press, Farm Futures, Farm Industry News, Indiana Prairie Farmer, Kansas Farmer, Michigan Farmer, Missouri Ruralist, Nebraska Farmer, Ohio Farmer, Prairie Farmer, Southeast Farm Press, Southwest Farm Press, The Farmer, Wallaces Farmer, Western Farm Press, Western Farmer-Stockman, and Wisconsin Agriculturalist*
[b]***Ag Update publications:*** *Agri-View of Wisconsin, CropWatch, Daily Headlines, Farm and Ranch Guide, Illinois Farmer Today, Iowa Farmer Today, Livestock Roundup, Market Watch Newsletter, Midwest Messenger, Midwest Messenger KS, Minnesota Farm Guide, Missouri Farmer Today, Tri-State Neighbor, and The Prairie Star*

To ensure a detailed examination, we considered the distinct regulatory approaches applied to CRISPR-edited crops and animals while categorizing the agricultural news publications based on the specific sectors they primarily serve. For instance, publications primarily read by crop growers were classified as "Crop Ag" publications, while those targeting livestock producers and the feed industry were grouped as "Animal Ag" publications. News publications whose main audience span geographic regions without a specific topic, crop, or animal of focus were classified as "General Ag" publications. This includes three (of 35) sites from *Ag Update* and *Farm Progress* (*Corn & Soybean Digest*, *Crop Watch*, and *Livestock Roundup*) that could be categorized as Crop Ag or Animal Ag publications but were counted toward General Ag publications in accordance with the overall publisher's aims.

Coding and Analysis

The thematic content of the articles was coded by three trained coders using a predefined codebook. Early in the coding process, the codebook underwent refinement through collaborative meetings and discussions to accommodate variances in interpretation and expectations. For instance, while initially intending to code for whether CRISPR was depicted as superior or inferior to GM, we encountered nuanced instances where clear-cut categorization proved challenging. Consequently, we simplified the code to capture whether GM was mentioned anywhere in the article, facilitating a more reliable coding process.

A random sample of 55 articles was coded by each coder to establish the intercoder reliability (Krippendorf's alpha = 0.78) (Krippendorff, 2017). Following this step, the remaining articles were evenly distributed among the coders. Categories included (1) risks/benefits, (2) social context, (3) social groups quoted, (4) mentions of GM, and (5) mentions of human applications. Both the full body text and title of each article were coded if the articles were about CRISPR related topics only (e.g., regulation, innovation). If the articles covered other topics in addition to CRISPR, we coded the sections discussing agricultural applications of CRISPR for the first three categories. For the risks/benefits category, articles were coded as follows: a score of "1" was given if the articles only discussed the benefits of CRISPR for agriculture, including new scientific advancements that were becoming available for widespread use; a score of "2" was assigned if the discussion centered solely on the risks associated with the technology; and a score of "3" was applied if the article presented both benefits and risks of CRISPR.

Unlike the risks/benefits category, which focused on the technical descriptions of CRISPR and its research process, the social context category looked at characterizations of debates surrounding CRISPR. For example, articles that mentioned critiques or debates regarding regulations, public acceptance, or any other political and societal debates were coded as "1" in the social context category. Articles that did not describe any societal or regulatory disagreement on these matters were coded as a "0." Again, the goal in coding this category was to consider how agricultural publications might represent the sociopolitical forces that would either enable or raise barriers against CRISPR technology.

To identify the social groups, we coded the affiliations of the first individual quoted regarding agricultural applications of CRISPR. Each affiliation was coded as follows: "1" for academia (university scientists and affiliates), "2" for industry (agricultural industry, seed companies, or industry scientists), "3" for politicians and policymakers (e.g., USDA or federal agency affiliates), "4" for interest groups and non-governmental organizations (e.g., trade associations), and "5" for other. The "other" category included individuals such as journalists, representatives from financial institutions, farmers, or anyone whose affiliation could fall under multiple categories. In cases where no one was quoted or the quoted person's affiliation was not immediately discernible to readers, the social group category was coded as "0."

In addition, any mention of GM or related topics and/or terms, such as transgenesis (the transfer of genetic material from one organism to another), genetically modified organisms, genetic modification, GMOs, and similar variations, led the article to receive a code of "1" for the GM mention category. There were two articles that described CRISPR used for transgenesis, which is a less common but still possible application of CRISPR technology, and these were not included in this category. Articles that did not contain any reference to GM or related terms received a code of "0".

Similarly, articles were coded with a "1" if they included any mention of CRISPR's applications in the human context, such as medical applications, animal models, human disease vectors like mosquitoes, transplants, or other human applications. Conversely, articles that did not mention any human CRISPR applications received a code of "0."

Limitations

First, our data collection was limited to online publications, thus precluding analysis of print editions. Discrepancies in content presentation between online and print formats may exist, notwithstanding instances where publications like *Hoard's Dairyman* offer both. In addition, our findings were limited to English-language publications, excluding those in other languages spoken by U.S. producers. Second, in selecting articles, we prioritized CRISPR over alternative gene editing methods such as TALENs gene editing, which is acknowledged for its greater time and labor demands (Nemudryi et al., 2014). Our rationale for prioritizing CRISPR stemmed from its broader media attention and perceived advantages, such as accelerated development and enhanced accessibility, as emphasized by its founders (Doudna & Charpentier, 2014) and other researchers (e.g., Wang et al., 2019). Therefore, discussions pertaining to other gene editing techniques without explicit CRISPR mention may be underrepresented, aligning with the study's deliberate scope. Third, while we did not find any overt discussion in these articles about other major groups of stakeholders involved, future work with RRI and CRISPR management should also consider boundary agents like Extension, who work with both producers and academia, as well as other relevant stakeholders who take part in agricultural technology innovation.

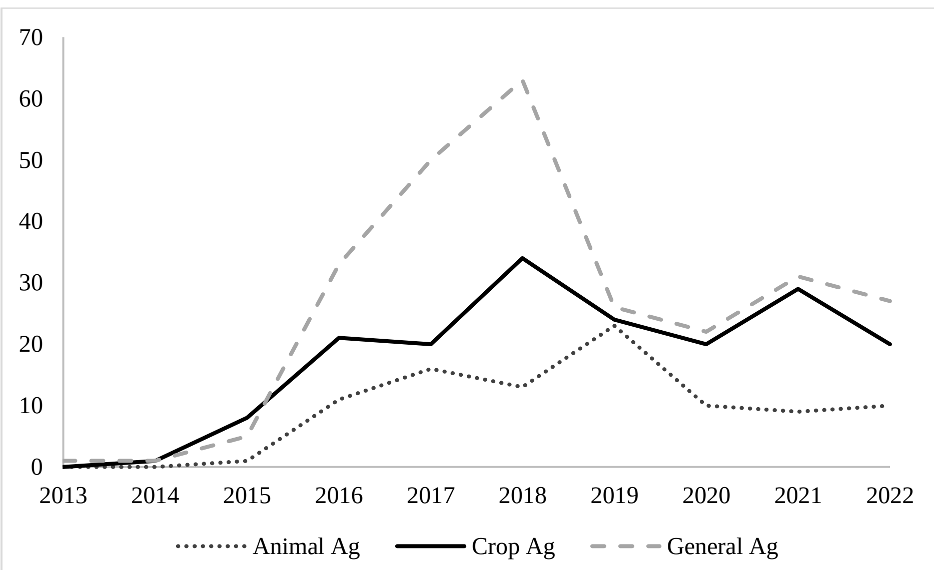
Last, our content analysis intended to explore themes extrapolated from previous research and other news content analyses across various publication types. Given the quantitative nature of the study, qualitative investigations may offer complementary insights into the contextual nuances surrounding this topic. Therefore, the interpretation of our results should be tempered with an understanding of these limitations and the potential need for additional research.

Results

In general, the topic of CRISPR has generated fluctuating interest over the past decade (see Figure 1). While no articles on CRISPR were found in 2012 when the technology was invented, the number of articles in General Ag publications reached its peak in 2018, coinciding with the year when the USDA implemented first CRISPR regulations. In contrast, Crop Ag publications have shown a consistent increase in interest in CRISPR, whereas Animal Ag publications have experienced a slight decline in CRISPR-related content after 2019, perhaps because of changes in priority in the news cycle for these publications.

Figure 1

Total Number of Articles That Mention CRISPR for Agriculture (N = 529) in Each Type of Agricultural News Publication over Time



Coverage on Risks and Benefits

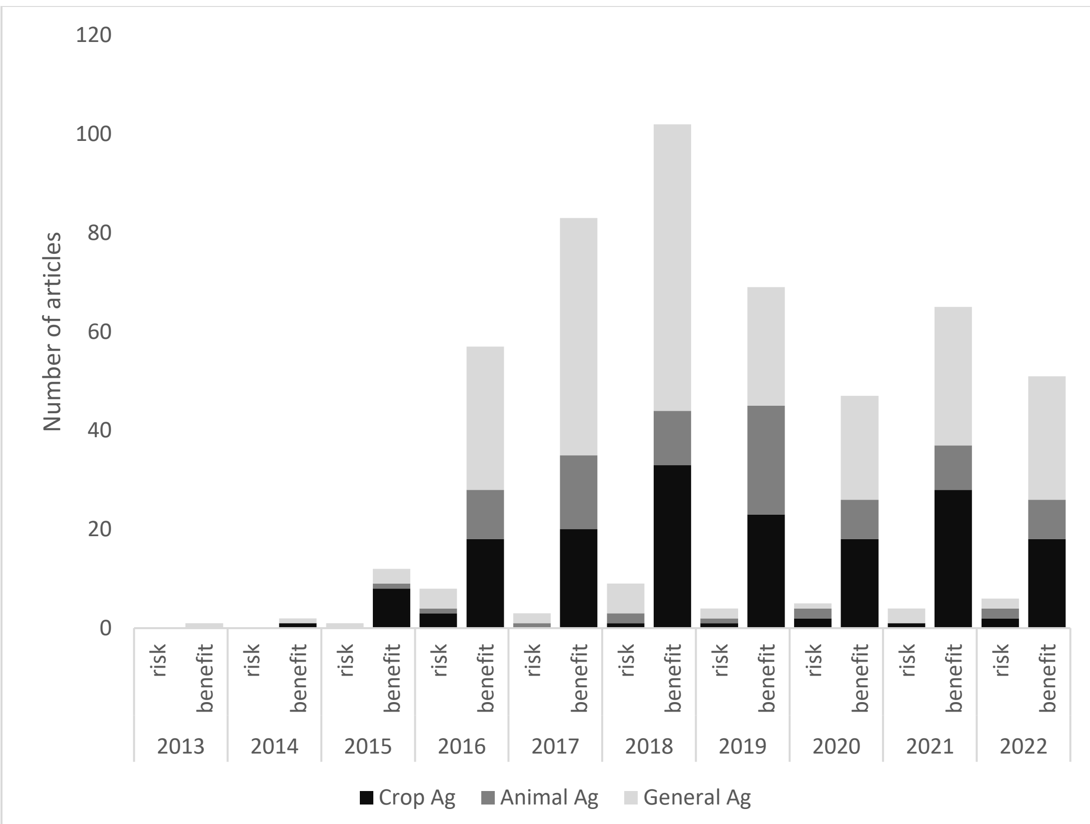
RQ1 asked how agricultural publications depicted the risks and benefits associated with CRISPR technology over time. The results revealed a significant disparity in the mention of benefits compared to risks. Risks were discussed in less than 10% of all articles. Specifically, Animal Ag articles had the highest proportion (9%) of articles mentioning at least one risk of

CRISPR, General Ag had 7% of articles mentioning risks, while Crop Ag had 5% of articles doing so.

Notably, there was an increase in the frequency of risk mentions from 2015 to the implementation of major regulatory decisions in 2016 and 2018, respectively. Otherwise, the coverage of risks remained consistently low between 2015 and 2021 (see Figure 2). It is worth noting that as CRISPR-edited food products have become more prevalent in the market, there could be a potential shift in the news discourse. On the other hand, throughout the years under study, a majority of the articles focused solely on highlighting the benefits of CRISPR technology, accounting for 86% to 97% of total articles in any given year.

Figure 2

Number of Articles Covering Benefits Only Versus at Least One Risk for Each Type of Agricultural News Publications over Time



The benefits mentioned in the articles were diverse, with a strong focus on CRISPR's accuracy compared to previous technologies. Many articles also emphasized the economic impact of CRISPR on farms and agricultural production, citing benefits like increased accessibility and reduced costs, enabling more efficient and cost-effective production processes. Moreover, many articles emphasized broader benefits across various domains, such as the technology's potential to improve environmental resilience, bolster productivity, and promote sustainable agricultural practices.

Articles that addressed both risks and benefits often characterized the risks with either vagueness or uncertainty. Some articles acknowledged the general risks associated with any new technology without specifying them. Potential unintended effects were discussed, but risk was frequently described in terms of unknown consequences, such as the unintentional disruption of non-target species or the establishment of more resilient invasive species. A single article focused exclusively on the risks of CRISPR to the agricultural economy without any mention of benefits (Evanish, 2018).

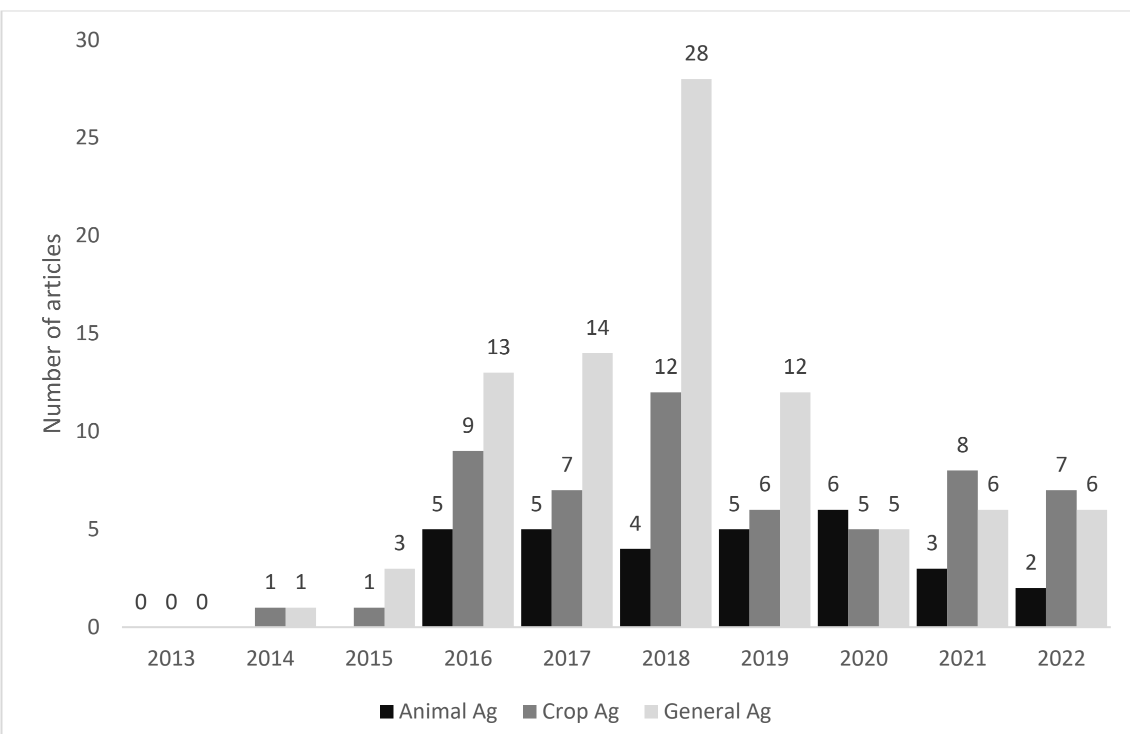
Coverage on Societal and Regulatory Disagreement

RQ2 investigated the coverage of societal and regulatory disagreement in agricultural news publications. Overall, approximately one-third of the articles discussed disagreement, with minimal variation across publication types. Animal Ag, Crop Ag, and General Ag all had a similar proportion of articles (32%, 31%, and 34%, respectively) mentioning societal or regulatory disagreement surrounding CRISPR.

From the invention of the technology in 2012 to 2016, there was an increase in disagreement surrounding CRISPR. This period coincided with the USDA's exemption of the first CRISPR-edited mushroom, which likely fueled intense debate and discussions. Between 2017 and 2018, the mention of disagreement remained consistently high, with over 30% of articles discussing these contentious issues. However, the coverage of disagreement has experienced a decline since 2019 (see Figure 3).

Figure 3

The Number of Articles Mentioning Societal or Regulatory Disagreement in the Social Context Around CRISPR for Each Type of Agricultural News Publications Over Time



https://newprairiepress.org/jac/vol108/iss2/1
DOI: 10.4148/1051-0834.2532

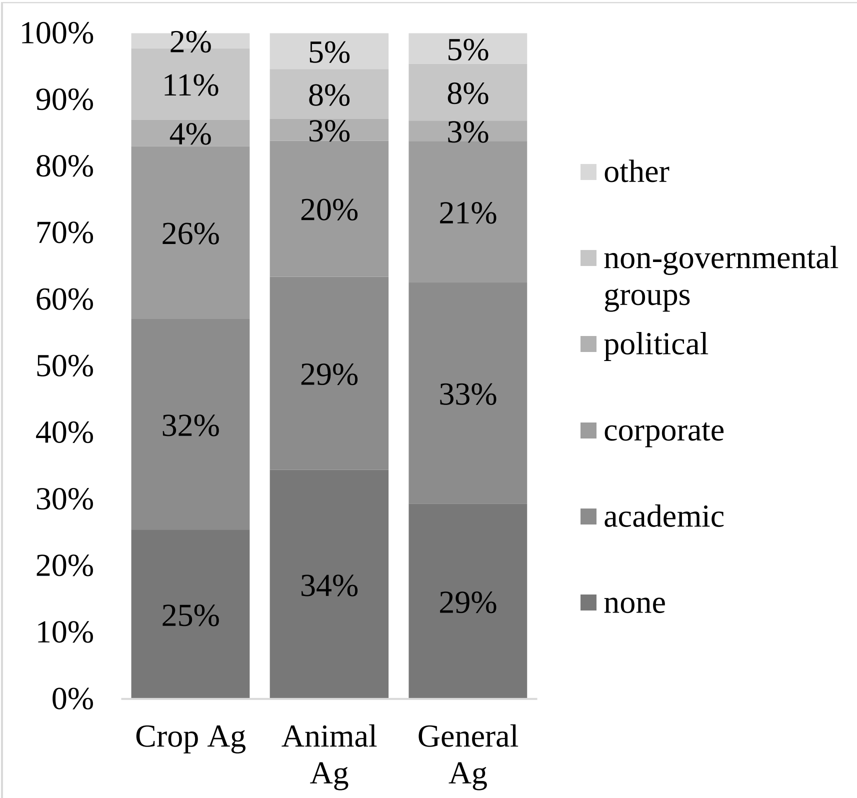
In accordance with the codebook, any article that mentioned societal or regulatory disagreement about CRISPR was coded into this category. Many articles in this category addressed the potential lack of public acceptance of CRISPR technology and the need for improved communication with consumers was emphasized. For example, one article stated, “If we don’t explain science to the public, it could become an insurmountable challenge” (Westerhof, 2022, paragraph 2 under “Next Steps”). Some articles emphasized the need to effectively communicate the benefits of CRISPR-edited food to the public. With regard to regulatory debates, many publications offered contrasting perspectives, sometimes praising and other times condemning more stringent policies in other countries. In addition, regulatory disagreements specific to Animal Ag in the U.S. were mentioned, particularly concerning the costs associated with the FDA regulatory process. Concerns were raised that the high costs would limit access to the regulatory approval process for public institutions and small innovative companies, making this scientific breakthrough available only to larger corporations with industry. In addition, the debates around product-based regulation are particularly pronounced in the context of animal agriculture.

Social Groups

RQ3 aimed to identify the types of organizations and individuals (social groups) cited as expert sources on CRISPR topics in the sample. Notably, approximately one-fourth to one-third of the articles did not quote any social groups (see Figure 4). Among the articles that did, academics were the most frequently quoted, particularly in General Ag publications (33%). Industries were the second most cited, with a higher prevalence in Crop Ag publications (26%). Academics were primarily university researchers, while corporate social groups ranged from well-known, large companies such as Monsanto, to smaller industry corporations, including private research institutions. Politicians and other groups, such as interest groups and non-governmental organizations (e.g., trade associations), were quoted least frequently. We made note of the affiliations of each person quoted when possible, and the “other” category included four farmers, two journalists, and one activist, as well as others that did not fit into the other categories or were unidentifiable.

Figure 4

Sources Quoted in Different Types of Agricultural News Publications



Comparison with GM

RQ4 examined how agricultural publications compared CRISPR-edited foods with GM. Results showed that a significant portion of articles mentioned GM. Specifically, General Ag mentioned GM the most at 43%, followed by Crop Ag at 33%, and Animal Ag publications had only 26% of articles discussing the comparison. Three major topics emerged for the coverage on GM. The first topic focused on technological improvements. For instance, some articles highlighted the distinction between GM and CRISPR-edited food, stating that the former often introduces outside genes to achieve desired outputs, whereas CRISPR technology leverages the natural characteristics available within the crop's genome pool. The second topic revolved around regulatory issues, specifically comparing regulations for CRISPR and GM.

Beyond these, a third topic was public perceptions of CRISPR and GM. It was noted that GM could be widely accepted for medical but not agricultural purposes. Similarly, regarding CRISPR applications in animals, it was observed that CRISPR is generally deemed acceptable for medicinal use but becomes more controversial when it involves food and animals. Other articles expressed concern about the public's confusion between CRISPR-edited foods and GM. They highlighted the importance of avoid repeating the disagreement surrounding GM with CRISPR, urging caution in how CRISPR-edited food is framed for the public. The concern was that if the public conflates CRISPR with GM, public rejection and criticism experienced by GM could extend to CRISPR-edited foods as well. Despite the concerns, some articles expressed optimism that in the long run, CRISPR technology could reshape the public dialogue surrounding GM.

Mentions of Non-Agricultural Applications

Last, to address RQ5, we found that 14% of the articles mentioned non-agricultural, namely human (e.g., medical), applications of CRISPR in the same article as agricultural applications. Most references were brief, addressing potential future applications of CRISPR technology. Noticeably, Animal Ag articles mentioned human applications most frequently, accounting for 19% of the articles. Human applications were mentioned in 9% of Crop Ag articles and 11% of General Ag. While several articles described higher public acceptance of medical applications of gene editing compared to animal applications (e.g., Fatka, 2020), many others simply described CRISPR technology's history and broad applications.

Discussion

This study provides a comprehensive examination of the prevalent discourses regarding CRISPR within the agricultural community since its introduction in 2012. Our sample was extensive, encompassing a diverse array of publications. Existing studies on agricultural news often used small and local samples, limiting the representativeness and generalizability of their findings (e.g., Whitaker & Dyer, 2000). Our study expanded the search to include diverse sectors and regions, providing a more thorough understanding of the discourse surrounding CRISPR in agricultural news. The compiled list of agricultural news publications can be used or further extended by future researchers. Within these publications, we conducted quantitative content analysis on publications from 2012-2022, coding for CRISPR risks and benefits, social and regulatory context of CRISPR, the affiliations of quoted experts, the mention of GM, and the mention of non-agricultural applications such as human gene editing in the same article as agricultural applications.

Many of our research questions asked about change over time from 2012-2022. While CRISPR garnered significant attention during times of uncertainty and regulatory debates, agricultural media's focus on this topic has waned in recent years. There was little to no coverage of CRISPR in agricultural publications between 2012 and 2015, potentially indicating a lack of applications or slower uptake in the technology within the agricultural context during that period. However, there was a steep increase in the number of articles discussing CRISPR between 2016 and 2018. This increase in coverage coincided with a time of uncertainty surrounding how the U.S. would regulate CRISPR technology. In the years following USDA and FDA decisions, article frequency on the topic stabilized and even experienced a decline in 2022, despite the increasing presence of CRISPR-edited products in the market. This trend might stem from reduced regulatory controversy decreased, heightened familiarity with CRISPR among agricultural audiences, or the prioritization of other issues within the agricultural news cycle.

Results also indicate a notable focus on the benefits of CRISPR in comparison to other gene editing technologies, highlighting its speed, accuracy, and cost-efficiency. Many articles exhibited an almost promotional tone when discussing the benefits of CRISPR. Quotes from industry representatives were frequently included, underscoring the economic advantages associated with CRISPR and indicating a pattern of norms across these agricultural publications to highlight industry perspectives. Furthermore, quotes from university and industry scientists describing new research also emphasized a positive outlook surrounding the technology. The prevalent focus on the benefits of CRISPR, especially evident in news publications serving the crop industry, aligns with the overall position held by the USDA. Additionally, this focus correlates with the ongoing discussion about easing strict regulations on gene-edited animal products. These findings suggest a strong endorsement of CRISPR's potential and reflect a promising trajectory for its adoption in the agricultural sector.

In contrast, coverage of risks was very limited in the agricultural news stories. While valid concerns were raised about the economic prospects for small farms adopting CRISPR technology, a broader discussion was largely absent. Relating this to Social Arena theory, this trend suggests that agricultural publications are amplifying messages that promote innovation without consideration of risks or the perspectives of public or producers. Social context was instead discussed largely from the perspective of barriers that might inhibit innovation (e.g., public acceptance, stringent regulations). Moreover, a comparison between agricultural news and mainstream news (e.g., Dahlstrom et al., 2022) unveils a significant discrepancy between the two, with mainstream news placing greater emphasis on risk coverage. This underscores the necessity for a more nuanced and inclusive dialogue within the agricultural community.

In addition to risks and benefits, a large portion of the articles focused on societal or regulatory concerns related to CRISPR. Many articles attributed the potential lack of public acceptance of CRISPR-edited food to consumers' limited awareness of its benefits. This perspective may be somewhat narrow as it assumes that merely informing the public of the benefits will automatically translate into increased acceptance – a notion that has been empirically challenged by many researchers (e.g., as described by Simis et al., 2016).

This viewpoint was notably prevalent in publications focused on animal agriculture, where mentions of human applications were twice as frequent compared to General and Crop Ag publications. Interestingly, our findings suggest that while discussions about human applications may have a stronger influence on CRISPR's acceptance in the livestock industry compared to crop and other sectors, this difference is not primarily driven by ethical concerns over human genome editing. Instead, it appears to reflect a strategic approach to draw parallels between human and animal applications of CRISPR while conveying its benefits to the public.

When covering regulatory disagreement, many articles explored the question of whether it is appropriate to subject animals to the same expensive regulatory process as drugs, prompting debates on the most effective and fair approach. Additionally, debates and disagreement surrounding regulation extended to comparisons with regulatory models in Europe and the UK, with some articles praising and some critiquing these international models. Furthermore, some articles, especially those published before 2018, identified regulation as a significant hurdle or problem within the U.S., claiming that the regulatory landscape remained unpredictable or unsettled.

Furthermore, when General Ag and Crop Ag publications mentioned GM, they did so in two different ways. While some articles simply presented the technical difference between CRISPR and GM, many articles cast a more negative light on the latter, portraying CRISPR as superior in terms of being cheaper, faster, more precise, and more accessible for small farms. These findings raise concerns over the potential negative backlash against GM that such narratives could possibly cause (Doxzen & Henderson, 2020). Many articles intentionally sought to distance CRISPR from GM to make CRISPR more appealing to both producers and consumers. While some articles suggested CRISPR might be more widely accepted and therefore shed positive light on GM discourse, the number of articles portraying GM in a negative light is noteworthy.

DOI: 10.4148/1051-0834.2532

Conclusion and Recommendations

The framework of Responsible Research and Innovation (RRI) emphasizes the importance of aligning various social groups throughout the research and innovation process (Hartley et al., 2016; Foley et al., 2016; Stilgoe et al., 2013). While scientific input is crucial for assessing CRISPR risks, an RRI approach stresses the integration of diverse perspectives, including those of agricultural producers, industry, and policymakers, to ensure responsible governance regarding gene-edited foods (Wickson & Wynne, 2012). Therefore, the results of this study offer valuable insights for policymakers, scientists, and various Social Arena groups for CRISPR agriculture.

Within the Social Arena of risk, where agricultural groups are regarded as trustworthy sources on agricultural biotechnology, they play a pivotal role in adopting CRISPR technology and shaping public opinions. However, our study revealed a concerning trend in the current discourse, where there is a disproportionate focus on securing consumer acceptance of CRISPR without adequately addressing public concerns of risks. This lack of balance might impede meaningful dialogue between producers and consumers (Neuman et al., 2011) or deprive producers of the opportunity to make well-informed decisions about adopting CRISPR. Critical aspects, such as the economic implications for small farms, warrant more extensive coverage.

To promote responsible governance, informed decision-making, and public understanding regarding CRISPR-edited food, we urge agricultural media professionals to improve their coverage of this technology. This includes providing more balanced representation of associated risks and engaging in thoughtful discussions about public perspectives. In addition, expanding the sources of information to include consumer groups and other relevant social groups with valuable knowledge would promote a more well-rounded and collaborative conversation. As concerns over the ethical implications of human involvement in gene editing technologies like CRISPR remain prevalent in the public sphere (e.g., Gatica-Arias et al., 2019), future agricultural media professionals must address ethics within the agricultural context and equip their audiences with knowledge and strategies to respond to these concerns. Embracing a more inclusive and transparent approach to media coverage will facilitate informed public dialogue and pave the way for more responsible development of agricultural biotechnology in accordance to best practices.

Researchers could build on these conceptualizations of RRI and Social Arena in CRISPR and other agricultural technologies. These frameworks could be used as a basis for mapping the involvement, influence, and attitudes of different actors, groups, and issue advocates, as well as identifying social groups excluded within broader discourse. Additional focus is needed to understand the perspectives of producers and the role of Extension and other groups that facilitate agricultural innovation. Communication scholars researching this could also consider additional engagement practices that would help inform stakeholders, such as press releases for agricultural media, interviews, and guest editorials, as well as formal and informal presentations.

In conclusion, both Social Arena theory and RRI offer valuable insights into CRISPR research and management. As CRISPR poses real risks that may have implications for future innovation and development (e.g., Sturme et al., 2022), it is essential to consider a variety of perspectives in its governance and implementation. An analysis of agricultural news discourses allows us to examine a segment of the Social Arena surrounding CRISPR that has been understudied, and certain voices (e.g., industry and university scientists) are elevated in these publications to set the current tone for CRISPR discussion. Incorporating additional perspectives per the RRI framework will be instrumental in shaping CRISPR discourse moving forward.

References

AgEdNet. (2022). *AgEdNet.com—Ag Publications Links*. Ag Links - Ag Publications. https://www.agednet.com/linkpub.shtml

Ahmad, S., Wei, X., Sheng, Z., Hu, P., & Tang, S. (2020). CRISPR/Cas9 for development of disease resistance in plants: Recent progress, limitations and future prospects. *Briefings in Functional Genomics*, *19*(1), Article 1. https://doi.org/10.1093/bfgp/elz041

Akin, H., Yeo, S. K., Wirz, C. D., Scheufele, D. A., Brossard, D., Xenos, M. A., & Corley, E. A. (2019). Are attitudes toward labeling nano products linked to attitudes toward GMO? Exploring a potential 'spillover' effect for attitudes toward controversial technologies. *Journal of Responsible Innovation*, *6*(1), 50–74. https://doi.org/10.1080/23299460.2018.1495026

Alaszewski, A. (2005). Risk communication: Identifying the importance of social context. *Health, Risk & Society*, *7*(2), 101–105. https://doi.org/10.1080/13698570500148905

Arora, L., & Narula, A. (2017). Gene editing and crop improvement using CRISPR-Cas9 system. *Frontiers in Plant Science*, *8*. https://www.frontiersin.org/articles/10.3389/fpls.2017.01932

Baik, E. S., Koshy, A., & Hardy, B. W. (2022). Chapter Eight - Communicating CRISPR: Challenges and opportunities in engaging the public. In T. Bolsen & R. Palm (Eds.), *Progress in Molecular Biology and Translational Science* (Vol. 188, pp. 171–193). Academic Press. https://doi.org/10.1016/bs.pmbts.2021.11.004

Baum, C. M., Kamrath, C., Bröring, S., & De Steur, H. (2023). Show me the benefits! Determinants of behavioral intentions towards CRISPR in the United States. *Food Quality and Preference*, *107*, 104842. https://doi.org/10.1016/j.foodqual.2023.104842

Bickell, E. G. (2023). *USDA's SECURE rule to regulate agricultural biotechnology* (IF11573, Version 4; p. 3). Congressional Research Service. https://crsreports.congress.gov/product/details?prodcode=IF11573

Borrelli, V. M. G., Brambilla, V., Rogowsky, P., Marocco, A., & Lanubile, A. (2018). The enhancement of plant disease resistance using CRISPR/Cas9 technology. *Frontiers in Plant Science*, *9*. https://www.frontiersin.org/articles/10.3389/fpls.2018.01245

Brokowski, C., & Adli, M. (2019). CRISPR ethics: Moral considerations for applications of a powerful tool. *Journal of Molecular Biology*, *431*(1), 88–101. https://doi.org/10.1016/j.jmb.2018.05.044

Brossard, D., Belluck, P., Gould, F., & Wirz, C. D. (2019). Promises and perils of gene drives: Navigating the communication of complex, post-normal science. *Proceedings of the National Academy of Sciences*, *116*(16), 7692–7697. https://doi.org/10.1073/pnas.1805874115

Carlson, D. F., Lancto, C. A., Zang, B., Kim, E.-S., Walton, M., Oldeschulte, D., Seabury, C., Sonstegard, T. S., & Fahrenkrug, S. C. (2016). Production of hornless dairy cattle from genome-edited cell lines. *Nature Biotechnology*, *34*(5), Article 5. https://doi.org/10.1038/nbt.3560

Clarke, L. (1988). Politics and bias in risk assessment. *The Social Science Journal*, *25*(2), 155–165. https://doi.org/10.1016/0362-3319(88)90003-1

Corte, L. E.-D., M. Mahmoud, L., S. Moraes, T., Mou, Z., W. Grosser, J., & Dutt, M. (2019). Development of improved fruit, vegetable, and ornamental crops using the CRISPR/Cas9 genome editing technique. *Plants*, *8*(12), Article 12. https://doi.org/10.3390/plants8120601

Crossland-Marr, L., Giurca, A., Tsingos, M., Schnurr, M. A., Ely, A., Glover, D., Stone, G. D., & Fischer, K. (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. https://doi.org/10.1080/14636778.2023.2248363

Dahlstrom, M. F., Wang, Z., Lindberg, S., Opfer, K., & Cummings, C. L. (2022). The media's taste for gene-edited food: Comparing media portrayals within US and European regulatory environments. *Science, Technology, & Human Values*, 01622439221108537. https://doi.org/10.1177/01622439221108537

Doudna, J. A., & Charpentier, E. (2014). The new frontier of genome engineering with CRISPR-Cas9. *Science*, *346*(6213), 1258096. https://doi.org/10.1126/science.1258096

Doxzen, K., & Henderson, H. (2020). Is this safe? Addressing societal concerns about CRISPR-edited foods without reinforcing GMO framing. *Environmental Communication*, *14*(7), 865–871. https://doi.org/10.1080/17524032.2020.1811451

European Medicines Agency. (2023, December 15). *First gene editing therapy to treat beta thalassemia and severe sickle cell disease*. European Union. https://www.ema.europa.eu/en/news/first-gene-editing-therapy-treat-beta-thalassemia-and-severe-sickle-cell-disease

Evanish, M. (2018, March 19). *Farm innovation: Friend or foe?* Lancaster Farming. https://www.lancasterfarming.com/farming-news/equipment-and-machinery/farm-innovation-friend-or-foe/article_421a76cd-3b57-578c-9709-64798b01453e.html

Fatka, J. (2020, March 10). *Over half of consumers know nothing of gene editing*. Feedstuffs. https://www.feedstuffs.com/news/over-half-consumers-know-nothing-gene-editing

FDA. (2015). Guidance for industry: Regulation of genetically engineered animals containing heritable recombinant DNA constructs. *Biotechnology Law Report #187*, *28*(2), 227–240. https://doi.org/10.1089/blr.2009.9978

FDA. (2017, January 19). *Regulation of intentionally altered genomic DNA in animals; Draft revised guidance for industry*. Federal Register # 187. https://www.federalregister.gov/documents/2017/01/19/2017-00839/regulation-of-intentionally-altered-genomic-dna-in-animals-draft-guidance-for-industry-availability

FDA. (2022, March 7). *FDA makes low-risk determination for marketing of products from genome-edited beef cattle after safety review*. FDA. https://www.fda.gov/news-events/press-announcements/fda-makes-low-risk-determination-marketing-products-genome-edited-beef-cattle-after-safety-review

Feeney, O., Cockbain, J., & Sterckx, S. (2021). Ethics, patents and genome editing: A critical assessment of three options of technology governance. *Frontiers in Political Science*, *3*. https://www.frontiersin.org/articles/10.3389/fpos.2021.731505

Foley, R. W., Bernstein, M. J., & Wiek, A. (2016). Towards an alignment of activities, aspirations and stakeholders for responsible innovation. *Journal of Responsible Innovation*, *3*(3), Article 3. https://doi.org/10.1080/23299460.2016.1257380

Frewer, L. J. (2017). Consumer acceptance and rejection of emerging agrifood technologies and their applications. *European Review of Agricultural Economics*, *44*(4), 683–704. https://doi.org/10.1093/erae/jbx007

Gao, Q., Luo, H., Li, Y., Liu, Z., & Kang, C. (2020). Genetic modulation of RAP alters fruit coloration in both wild and cultivated strawberry. *Plant Biotechnology Journal*, *18*(7), Article 7. https://doi.org/10.1111/pbi.13317

Gasiunas, G., Barrangou, R., Horvath, P., & Siksnys, V. (2012). Cas9–crRNA ribonucleoprotein complex mediates specific DNA cleavage for adaptive immunity in bacteria. *Proceedings of the National Academy of Sciences*, *109*(39), E2579–E2586. https://doi.org/10.1073/pnas.1208507109

Gatica-Arias, A., Valdez-Melara, M., Arrieta-Espinoza, G., Albertazzi-Castro, F. J., & Madrigal-Pana, J. (2019). Consumer attitudes toward food crops developed by CRISPR/Cas9 in Costa Rica. *Plant Cell, Tissue and Organ Culture (PCTOC)*, *139*(2), 417–427. https://doi.org/10.1007/s11240-019-01647-x

Gerbner, G. (1958). On content analysis and critical research in mass communication. *Audiovisual Communication Review*, *6*(3), 85–108. https://doi.org/10.1007/BF02766931

Giau, V. V., Lee, H., Shim, K. H., Bagyinszky, E., & An, S. S. A. (2018). Genome-editing applications of CRISPR Cas9 to promote in vitro studies of Alzheimer's disease. *Clinical Interventions in Aging*, *13*, 221–233. https://doi.org/10.2147/CIA.S155145

Gould, F., Amasino, R. M., Brossard, D., Buell, C. R., Dixon, R. A., Falck-Zepeda, J. B., Gallo, M. A., Giller, K. E., Glenna, L. L., Griffin, T., Magraw, D., Mallory-Smith, C., Pixley, K. V., Ransom, E. P., Stelly, D. M., & Stewart, C. N. (2022). Toward product-based regulation of crops. *Science*, *377*(6610), 1051–1053. https://doi.org/10.1126/science.abo3034

Guo, C., Ma, X., Gao, F., & Guo, Y. (2023). Off-target effects in CRISPR/Cas9 gene editing. *Frontiers in Bioengineering and Biotechnology*, *11*. https://www.frontiersin.org/articles/10.3389/fbioe.2023.1143157

Hartley, S., Gillund, F., Hove, L. van, & Wickson, F. (2016). Essential features of responsible governance of agricultural biotechnology. *PLOS Biology*, *14*(5), Article 5. https://doi.org/10.1371/journal.pbio.1002453

Hemalatha, P., Abda, E. M., Shah, S., Venkatesa Prabhu, S., Jayakumar, M., Karmegam, N., Kim, W., & Govarthanan, M. (2023). Multi-faceted CRISPR-Cas9 strategy to reduce plant based food loss and waste for sustainable bio-economy—A review. *Journal of Environmental Management*, *332*, 117382. https://doi.org/10.1016/j.jenvman.2023.117382

Hoffman, N. E. (2021). Revisions to USDA biotechnology regulations: The SECURE rule. *Proceedings of the National Academy of Sciences*, *118*(22), e2004841118. https://doi.org/10.1073/pnas.2004841118

Huang, Y., Zhang, Y., Wu, M., Porter, A., & Barrangou, R. (2021). Determination of factors driving the genome editing field in the CRISPR era using bibliometrics. *The CRISPR Journal*, *4*(5), 728–738. https://doi.org/10.1089/crispr.2021.0001

Iowa NAMA. (2022, November 3). *Farmers' use of media* [PDF Slides]. https://www.namaiowa.com/events/farmers-use-of-media

Jinek, M., Chylinski, K., Fonfara, I., Hauer, M., Doudna, J. A., & Charpentier, E. (2012). A programmable dual-RNA–guided DNA endonuclease in adaptive bacterial immunity. *Science*, *337*(6096), 816–821. https://doi.org/10.1126/science.1225829

Kawall, K., Cotter, J., & Then, C. (2020). Broadening the GMO risk assessment in the EU for genome editing technologies in agriculture. *Environmental Sciences Europe*, *32*(1), Article 1. https://doi.org/10.1186/s12302-020-00361-2

Krippendorff, K. (2004). Reliability in content analysis. *Human Communication Research*, *30*(3), 411–433. https://doi.org/10.1111/j.1468-2958.2004.tb00738.x
Ku, H.-K., & Ha, S.-H. (2020). Improving nutritional and functional quality by genome editing of crops: Status and perspectives. *Frontiers in Plant Science*, *11*. https://www.frontiersin.org/articles/10.3389/fpls.2020.577313
Kuiken, T., Barrangou, R., & Grieger, K. (2021). (Broken) promises of sustainable food and agriculture through new biotechnologies: The CRISPR case. *The CRISPR Journal*, *4*(1), 25–31. https://doi.org/10.1089/crispr.2020.0098
Kuzma, J., & Grieger, K. (2020). Community-led governance for gene-edited crops. *Science*, *370*(6519), 916–918. https://doi.org/10.1126/science.abd1512
Lee, H., & Kim, J.-S. (2018). Unexpected CRISPR on-target effects. *Nature Biotechnology*, *36*(8), Article 8. https://doi.org/10.1038/nbt.4207
Marcon, A., Master, Z., Ravitsky, V., & Caulfield, T. (2019). CRISPR in the North American popular press. *Genetics in Medicine*, *21*(10), 2184–2189. https://doi.org/10.1038/s41436-019-0482-5
Marette, S., Disdier, A.-C., & Beghin, J. C. (2021). A comparison of EU and US consumers' willingness to pay for gene-edited food: Evidence from apples. *Appetite*, *159*, 105064. https://doi.org/10.1016/j.appet.2020.105064
Marks, L. A., Kalaitzandonakes, N., Wilkins, L., & Zakharova, L. (2007). Mass media framing of biotechnology news. *Public Understanding of Science*, *16*(2), 183–203. https://doi.org/10.1177/0963662506065054
Martin, A. (2018, January 23). *Ethical concerns and CRISPR potential*. Seed World. https://american-seed.com/ethical-concerns-crispr-potential/
Martín-Pizarro, C., & Posé, D. (2018). Genome editing as a tool for fruit ripening manipulation. *Frontiers in Plant Science*, *9*. https://www.frontiersin.org/articles/10.3389/fpls.2018.01415
McCluskey, J. J., Kalaitzandonakes, N., & Swinnen, J. (2016). Media coverage, public perceptions, and consumer behavior: Insights from new food technologies. *Annual Review of Resource Economics*, *8*, 467–486.
McHughen, A. (2016). A critical assessment of regulatory triggers for products of biotechnology: Product vs. process. *GM Crops & Food*, *7*(3–4), 125–158. https://doi.org/10.1080/21645698.2016.1228516
Meer, P. V. D., Angenon, G., Bergmans, H., Buhk, H. J., Callebaut, S., Chamon, M., Eriksson, D., Gheysen, G., Harwood, W., Hundleby, P., Kearns, P., Mcloughlin, T., & Zimny, T. (2023). The status under EU law of organisms developed through novel genomic techniques. *European Journal of Risk Regulation*, *14*(1), 93–112. https://doi.org/10.1017/err.2020.105
Mercier, A. (2018). *The top 10 agricultural publications*. https://muckrack.com/blog/2018/05/31/the-top-10-agricultural-publications
Michno, J.-M., Virdi, K., Stec, A. O., Liu, J., Wang, X., Xiong, Y., & Stupar, R. M. (2020). Integration, abundance, and transmission of mutations and transgenes in a series of CRISPR/Cas9 soybean lines. *BMC Biotechnology*, *20*(1), 10. https://doi.org/10.1186/s12896-020-00604-3
Montenegro de Wit, M. (2020). Democratizing CRISPR? Stories, practices, and politics of science and governance on the agricultural gene editing frontier. *Elementa: Science of the Anthropocene*, *8*, 9. https://doi.org/10.1525/elementa.405

Müller, M., Schneider, M., Salathé, M., & Vayena, E. (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

National Academies of Sciences, E., Studies, D. on E. and L., Technology, B. on C. S. and, Resources, B. on A. and N., Sciences, B. on L., & System, C. on F. B. P. and O. to E. C. of the B. R. (2017). The current biotechnology regulatory system. In *Preparing for Future Products of Biotechnology*. National Academies Press (US). https://www.ncbi.nlm.nih.gov/books/NBK442204/

Naves, E. R., de Ávila Silva, L., Sulpice, R., Araújo, W. L., Nunes-Nesi, A., Peres, L. E. P., & Zsögön, A. (2019). Capsaicinoids: Pungency beyond Capsicum. *Trends in Plant Science*, *24*(2), Article 2. https://doi.org/10.1016/j.tplants.2018.11.001

Nemudryi, A. A., Valetdinova, K. R., Medvedev, S. P., & Zakian, S. M. (2014). TALEN and CRISPR/Cas genome editing systems: Tools of discovery. *Acta Naturae*, *6*(3), 19–40.

Normile, D. (2019). *Chinese scientist who produced genetically altered babies sentenced to 3 years in jail*. https://www.science.org/content/article/chinese-scientist-who-produced-genetically-altered-babies-sentenced-3-years-jail

Owen, R., Macnaghten, P., & Stilgoe, J. (2012). Responsible research and innovation: From science in society to science for society, with society. *Science and Public Policy*, *39*, 751–760. https://doi.org/10.1093/scipol/scs093

Plough, A., & Krimsky, S. (1987). The emergence of risk communication studies: Social and political context. *Science, Technology, & Human Values*, *12*(3/4), 4–10.

Renn, O., Krimsky, S., & Golding, D. (1992). The social arena concept of risk debates. In *Social theories of risk*. Praeger. http://elib.uni-stuttgart.de/handle/11682/7292

Rust, N. A., Stankovics, P., Jarvis, R. M., Morris-Trainor, Z., de Vries, J. R., Ingram, J., Mills, J., Glikman, J. A., Parkinson, J., Toth, Z., Hansda, R., McMorran, R., Glass, J., & Reed, M. S. (2022). Have farmers had enough of experts? *Environmental Management*, *69*(1), 31–44. https://doi.org/10.1007/s00267-021-01546-y

Safari, F., Hatam, G., Behbahani, A. B., Rezaei, V., Barekati-Mowahed, M., Petramfar, P., & Khademi, F. (2020). CRISPR System: A high-throughput toolbox for research and treatment of Parkinson's disease. *Cellular and Molecular Neurobiology*, *40*(4), Article 4. https://doi.org/10.1007/s10571-019-00761-w

Scheufele, D. A., Krause, N. M., Freiling, I., & Brossard, D. (2021). What we know about effective public engagement on CRISPR and beyond. *Proceedings of the National Academy of Sciences*, *118*(22). https://doi.org/10.1073/pnas.2004835117

Shelton, L. (2021, August 20). *These are the 15 best magazines for farmers*. AgronoMag. https://agronomag.com/best-magazines-for-farmers/

Simis, M. J., Madden, H., Cacciatore, M. A., & Yeo, S. K. (2016). The lure of rationality: Why does the deficit model persist in science communication? *Public Understanding of Science*, *25*(4), 400–414. https://doi.org/10.1177/0963662516629749

Stilgoe, J., Owen, R., & Macnaghten, P. (2013). Developing a framework for responsible innovation. *Research Policy*, *42*(9), Article 9. https://doi.org/10.1016/j.respol.2013.05.008

Stokstad, E. (2023, July 7). European Commission proposes loosening rules for gene-edited plants. *Science*, *News*. https://www.science.org/content/article/european-commission-proposes-loosening-rules-gene-edited-plants

Sturme, M. H. J., van der Berg, J. P., Bouwman, L. M. S., De Schrijver, A., de Maagd, R. A., Kleter, G. A., & Battaglia-de Wilde, E. (2022). Occurrence and nature of off-target modifications by CRISPR-Cas genome editing in plants. *ACS Agricultural Science & Technology*, *2*(2), 192–201. https://doi.org/10.1021/acsagscitech.1c00270

Uddin, F., Rudin, C. M., & Sen, T. (2020). CRISPR gene therapy: Applications, limitations, and implications for the future. *Frontiers in Oncology*, *10*. https://www.frontiersin.org/articles/10.3389/fonc.2020.01387

USDA-APHIS. (2020). *Movement of organisms modified or produced through genetic engineering: Vol. 7 CFR Part 340*. https://www.ecfr.gov/current/title-7/part-340

Vilela, A. (2021). An overview of CRISPR-based technologies in wine yeasts to improve wine flavor and safety. *Fermentation*, *7*(1), Article 1. https://doi.org/10.3390/fermentation7010005

Waltz, E. (2016). Gene-edited CRISPR mushroom escapes US regulation. *Nature*, *532*(7599), 293–293. https://doi.org/10.1038/nature.2016.19754

Wang, T., Zhang, H., & Zhu, H. (2019). CRISPR technology is revolutionizing the improvement of tomato and other fruit crops. *Horticulture Research*, *6*, 77. https://doi.org/10.1038/s41438-019-0159-x

Watters, K. E., Kirkpatrick, J., Palmer, M. J., & Koblentz, G. D. (2021). The CRISPR revolution and its potential impact on global health security. *Pathogens and Global Health*, *115*(2), 80–92. https://doi.org/10.1080/20477724.2021.1880202

Westerhof, L. (2022, April 27). *Three reasons CRISPR won't work*. Seed World. https://www.seedworld.com/three-reasons-crispr-wont-work/

Whitaker, B. K., & Dyer, J. E. (2000). Identifying sources of bias in agricultural news reporting. *Journal of Agricultural Education*, *41*(4), 125–133.

Wickson, F., & Wynne, B. (2012). Ethics of science for policy in the environmental governance of biotechnology: MON810 Maize in Europe. *Ethics, Policy & Environment*, *15*(3), Article 3. https://doi.org/10.1080/21550085.2012.730245

Wirz, C. D., Scheufele, D. A., & Brossard, D. (2020). Societal debates about emerging genetic technologies: Toward a science of public engagement. *Environmental Communication*, *14*(7), 859–864. https://doi.org/10.1080/17524032.2020.1811478

Zafar, S. A., Zaidi, S. S.-A., Gaba, Y., Singla-Pareek, S. L., Dhankher, O. P., Li, X., Mansoor, S., & Pareek, A. (2020). Engineering abiotic stress tolerance via CRISPR/ Cas-mediated genome editing. *Journal of Experimental Botany*, *71*(2), Article 2. https://doi.org/10.1093/jxb/erz476

Zhang, D., Zhang, Z., Unver, T., & Zhang, B. (2021). CRISPR/Cas: A powerful tool for gene function study and crop improvement. *Journal of Advanced Research*, *29*, 207–221. https://doi.org/10.1016/j.jare.2020.10.003

Zinn, J. O. (2005). The biographical approach: A better way to understand behaviour in health and illness. *Health, Risk & Society*, *7*(1), 1–9. https://doi.org/10.1080/13698570500042348