# The Public's Perceptions of Genome Editing in Agriculture: A Review

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**Abstract:** Genome editing has been debated by scientists, consumers, and the general public since its conception. It is important to understand these debates and every side's views in order to move forward with the technology. The members of the public are involved in the laws and legislations that govern the use of technologies like gene editing. Scientists can use the public's opinions to determine how to move forward with gene editing. Genome editing consists of using sequence specific nucleases (SSNs) to edit a genome for a desired effect. There are various uses of genome editing which have varying levels of acceptance by the public. Studies have found more acceptance towards gene editing use in agriculture when compared to use in humans. There is a lack of research in the area of the public's perception of genome editing in agricultural and animal agriculture applications. Many consumers would agree to consume genetically edited food products in certain situations, but not in all. There are specific instances, such as gluten intolerance, that drive the public's acceptance of gene editing technologies in food production. There are also varying levels of acceptance of genome editing in animal agriculture, with more acceptance of genetic editing use in animal agriculture when it impacts animal welfare positively. Applications such as using this technology to create polled cattle through genome editing are more accepted because of its impact on animal welfare. A large portion of the literature on this topic looks into the public's perception of genome editing in humans, which can be used to make valuable inferences about what the public might think about the same technology used in agriculture or animals. There is also a lack of education on these topics which may influence the public's opinions. Without full education on the topic people may argue against genome editing simply because they do not understand it. Understanding the public's perceptions of gene editing and why they have those perceptions is important to the future of the technology and any laws or regulations that may be created around it.

## Introduction

Genome editing has been a hot topic in public debate for some time. As a developing biotechnology, it is often compared to GMOs and has received some backlash for that. The purpose of this literature review is to compare studies that have been completed reviewing the public's perceptions of genome editing in agriculture. It also looks at the perceptions of genome editing in other fields, to see how those fields influence the opinion of gene editing in agriculture. There is a much larger sample of studies done on the public's perception of genome editing and other biotechnologies' use in human applications, particularly in human medicine. There is an understanding that education of the general public on the process of genome editing could be very beneficial to the future of the technology. Public engagement has been shown to be very effective in helping biotechnologies like gene editing move forward.

This review will look into how this recent biotechnology can improve both animal health and livestock production if accepted by the public. With a focus on the public's perception of genome editing, and the concerns raised by consumers. It will also look into the misinformation that affects consumer perception of genome editing. This will also require looking into potential ways to increase acceptance of this technology through education, as there is a major lack of understanding in the public.

## Genome Editing Technologies

It is important to understand the mechanisms and applications of genome editing before looking into the public's opinions and perceptions of these technologies. Sequence-specific nucleases, called SSNs, are an important component of gene editing technology (Plaza Reyes et al., 2017). These SSNs include meganucleases, zinc-finger nucleases (ZFNs), transcription activator-like nucleases (TALENs) and CRISPR-associated nucleases (Cas, CRISPR-Cas9)

(Plaza Reyes et al., 2017). These SSNs are used to create a double stranded break in DNA at a specific site (Li et al., 2020). These sites are then repaired using non homologous end joining or homology directed repair (Li et al., 2020). Figure 1 demonstrates these double stranded breaks and repairs. According to Plaza Reyes et al. Cas nucleases like CRISPR-Cas9 are the most ideal for most genome editing projects (2017). Cas nucleases use an RNA molecule where many other SSNs use a protein which is not as easily programmed for gene editing (Plaza Reyes et al., 2017). This makes CRISPR-Cas9 a DNA targeting mechanism that is guided by RNA which can be used for many applications including gene editing (Jiang et al., 2017). The clustered regularly interspaced short palindromic repeats that are the namesake of CRISPR are part of an adaptive immune system found in microbes (Plaza Reyes et al., 2017). This immune system functions by cleaving a nucleic acid sequence of a virus and holding on to a piece of that sequence to protect against later infections (Plaza Reyes et al., 2017). CRISPR-Cas9 genome editing is accomplished by combining parts of the CRISPR immune system to a more simplified molecule (Plaza Reyes et al., 2017). One unique feature of CRISPR is that is gives the ability to target multiple parts of a genome at once, allowing the study of more than one gene at a time (Jiang et al., 2017).

ZFNs are an earlier gene editing technology that uses zinc-finger nucleases to mutate genes (Joung et al., 2013). These mutations can be used to introduce changes to the genome (Joung et al., 2013). TALENS are another gene editing technology which uses transcription activator-like effectors to alter gene transcription and effectively edit genes (Joung et al., 2013). These can be created quickly and are therefore considered a better application than ZFNs (Joung et al., 2013). Both of these gene editing technologies show similar efficiency, but Joung et al. explains that TALENS have a greater speed of design, higher rates of cleavage activity, and a more broad range of applications (2013). Many of the studies discussed in this literature review

use these and other genome editing technologies. The majority of the studies in this literature review use CRISPR-Cas9 as the major source of genome editing.

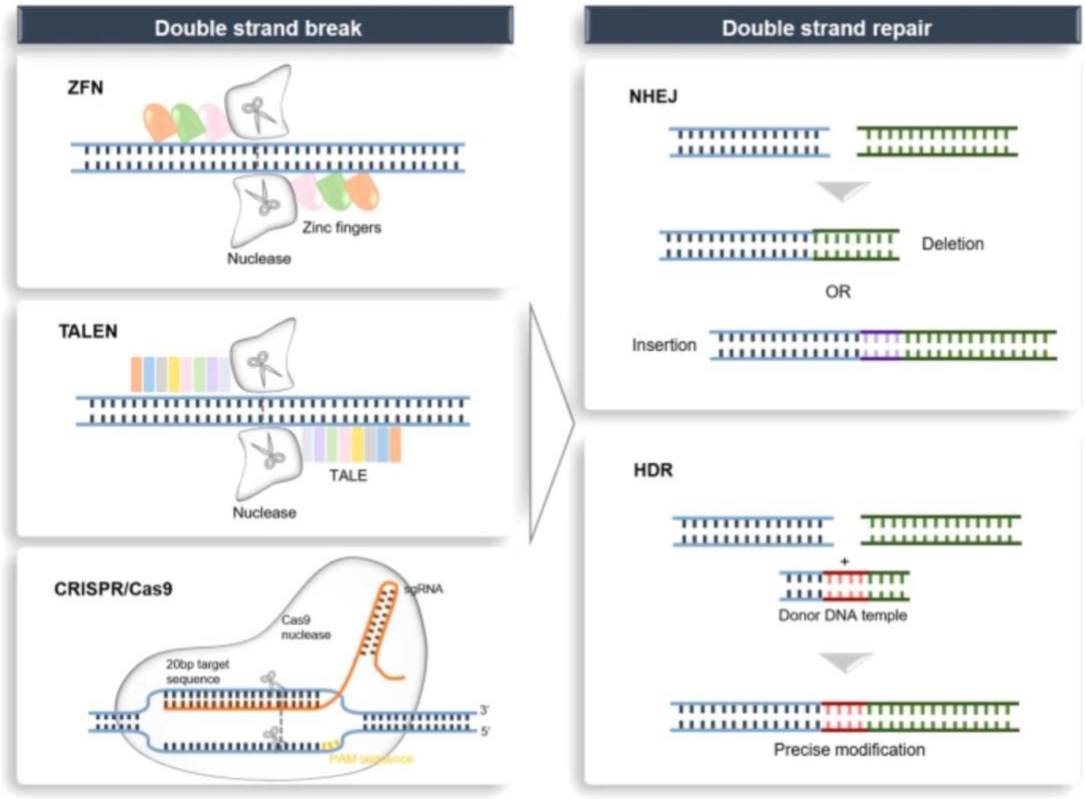


*Figure 1: A diagram showing how genome editing works. On the left three SSN variations are shown creating a double stranded break in DNA. These three SSNs are: ZFN, TALEN, and CRISPR/Cas9. The right of the diagram shows the repair of these double stranded breaks through non-homologous end joining (NHEJ) and homology directed repair (HDR) (Li et al., 2020).*

## Public's opinion on agricultural applications

The studies have shown that the general population is divided on their opinions of genome editing. Some find it too risky and believe it should not be acceptable for use, some believe it is very beneficial to society, and many lie in between these two extremes. Gatica-Arias found that half of their respondents saw low to no risk to quality of life, health, and environment

from the use of CRISPR-Cas9 gene editing (2019). This study also looked into what would motivate consumers to purchase products created with CRISPR-Cas9 and found that 70.8% of respondents would purchase CRISPR products if they were more nutritious, 60% if they were cheaper than comparable products, and 59.4% if they were available for purchase (Gatica-Arias, 2019). They also found that respondents typically agreed that gene edited foods would increase crop production in their country, improve their economy, and be overall beneficial to the people as well as the environment (Gatica-Arias, 2019). Hendriks et al. found that respondents would be willing to accept gene editing more in certain situations, such as 73.5% accepting the use to modify wheat for consumers with gluten intolerance (2018). Shew et al. found that around half of their respondents were willing to consume products created using genome editing, finding that 56% of respondents from the USA, 47% from Canada, 46% from Belgium, 30% from France, and 51% from Australia would consume GM and CRISPR foods (2018). In this study consumers that were only willing to consume products made from either GM or CRISPR were found to be more likely to consume foods created with CRISPR (Shew, 2018). The only country that Shew found to have similar willingness to consumer CRISPR and GM was Australia, all other countries we're more willing to consume either GM or CRISPR foods but not both (Shew, 2018). This shows that consumers lean towards accepting foods created with CRISPR, but some still have reservations. Many can see the benefits of gene edited foods but want to see additional benefits like added nutrition or cheaper prices. These can be important things to note when creating genome edited products.

### Public's opinion on animal agriculture applications

Other publications have looked at the opinions of the public on the use of genome editing as an animal agriculture tool, such as creating polled cattle where 66% of interviewees indicated

that this was a good use of the biotechnology (McConnachie, 2019.) In that same study 66% of respondents said they would consume products made from cattle that were polled through genetic editing (McConnachie, 2019). On the other hand, McConnachie et al. also found that 23% of their respondents thought that using gene editing to create polled cattle was a bad idea and that they would be unwilling to consume products from these cattle (2019). Responses in McConnachie's survey had themes of pain, quality of life, humane treatment, health, and affect when asked about how genome editing relates to animal welfare (2019). Overall though, they believed that their findings contrasted previous findings that found mostly negative associations with genetic modification of animals through genome editing (2019). This shows that the public's opinion of the use of gene editing is not a simple thing and can vary greatly depending on the use of the biotechnology. In the same vein of animal welfare, McConnachie et al. found that their respondents thought farmers had a responsibility to reduce animal pain and suffering and agreed that using genome editing to create polled cattle was one way to do that (2019). It was also found that these respondents wanted to see more testing on cattle polled through genome editing and to have more data on any effects that this biotechnology could have on the cattle (McConnachie et al., 2019). Many of the studies found that respondents need a clearer education on CRISPR-Cas9, gene editing, and biotechnologies in order to give informed opinions and understand what their opinions mean.

Schultz-Bergin et al. discussed the arguments that respondents tended to have against the use of genome editing in animals and animal agriculture and how scientists and farmers tend to combat those arguments (2018). They pointed out that many respondents claim that genetic engineering is unnatural, and the scientists tend to argue that genetically edited animals are no different than selectively bred animals (Schults-Bergin et al., 2018). Many of these scientists

argue that genetic engineering has been happening for thousands of years, just through selective breeding (Schultz-Bergin, 2018). Schultz-Bergin et al. argued that creating polled cattle through selective breeding, while possible, would take much more time than using gene editing to induce this natural occurrence (2019). It is important to understand why consumers disagree with using genome editing in animals or animal agriculture to enhance future studies. It is also important to know what arguments scientists are using to combat the opposition to aid in education efforts.

While a major concern of the public towards the use of genome editing and other biotechnologies in animals is that it would negatively impact animal welfare, Schultz-Bergin et al. argued that CRISPR can positively impact animal welfare (2019). They argue that through better precision than other gene-editing technologies CRISPR can reduce the negative effects of gene-editing on the animals in question (2019). They also argue that many CRISPR projects can improve animal welfare, as projects such as created polled cattle have been deemed too expensive to take on with other technologies (Shultz-Bergin et al., 2019). Another project that demonstrates this is using gene editing to create beef cattle that are only male or are females with a Y-chromosome, to prevent females from being slaughtered early due to their lack of meat production (Schultz-Bergin et al., 2018). This also creates a more sustainable practice, where farmers are able to get the most product out of their livestock, and effectively not wasting food.

## Public's Opinion on Human Applications

It is also important to note that the large majority of studies on this topic relate to the public's perception of genome editing used in human applications. These results can be used to make inferences about the public's possible attitudes toward genome editing use in animals but is not a replacement for studies that specifically ask about the use in animals or animal agriculture.

More research is needed in the area of the public's perception and opinions on genome editing use in animals and animal agriculture.

McCaughey et al. found that there was more support for genome editing when used to improve the health of humans, but much less for applications of eugenic changes (2019). However, they found that their respondents did not differ in their agreement based on whether the editing was somatic or embryonic, suggesting that their respondents did not care about the details of the use of genome editing (McCaughey et al., 2019). Other studies found that respondents support genome editing when it is used for human health reasons, but do not support it when its desired use it to change the way someone looks (Critchley et al., 2019).

Calabrese et al. looked into the semantics of the public's perception of CRISPR on the popular social media website Twitter (2020). They found that most of the words associated with tweets regarding CRISPR had to do with human applications. Things like human medicine, cancer, and cures popped up with regards to humans and CRISPR use (Calabrese, 2020). They found that the term "CRISPR babies" had a large part of the tweets regarding CRISPR, following a major news event of the scientist He Jiankui's scandal in editing a human embryo genome (Calabrese et al., 2020). This made the researchers conclude that certain events that gain popularity in the press could influence the public's perception of new technologies such as CRISPR (Calabrese et al., 2020). Calabrese et al. also found that things other than human-related topics were mentioned alongside CRISPR on Twitter, highlighting things such as agriculture in the terms "food" and "plant" (2020).

Marcon et al. looked at the instances of CRISPR-Cas9 mentions in the North American popular press (2019). They found that 96.1% of the articles discussed the benefits of CRISPR. 46.9% of these articles mentioned treatments for genetic disorders as a benefit from the use of

CRISPR in human medicine (Marcon et al., 2019). 34.2% mentioned improving scientific research as benefit of CRISPR-Cas9 (Marcon et al., 2019). Finally, 26.3% mentioned eliminating disease as a potential benefit of the biotechnology (Marcon et al., 2019). This indicates a largely positive outlook on CRISPR-Cas9 in the North American popular press. Three topics in these articles painted CRISPR-Cas9 in a negative light: with mentions of human embryos, physical baby traits, and baby personality traits as concerns of the use of CRISPR-Cas9 use (Marcon et al., 2019). These highlight important topics to address when discussing the use of CRISPR and possible laws or bans of the use of the CRISPR.

Marcon et al. also pointed out the discrepancies in the contexts of CRISPR in the North American popular press (2019). They found that 83.8% of articles discuss CRISPR with regards to human health, 26.3% discuss it in regard to animals, and 20.6% discuss CRISPR with regards to plants (Marcon et al., 2019). They also found that increased food quality came up in 2.6% of articles and the creation of virus-resistant animals came up in 2.2% of the articles (Marcon et al., 2019).

## Education

Some studies have looked into the education levels of their respondents in comparison to their opinions of the use of genome editing. It is important to look at how well respondents understand gene editing technology in order to understand why they might hold certain views. It is important to know if respondents are making an informed decision on their opinion of the biotechnology or disagreeing with it because they do not understand the science behind it. Gatica-Arias et al. found that their respondents, consisting of adults in Costa Rica, did not understand the use of CRISPR-Cas9 but did accept various uses of the technology, they also agreed that CRISPR could have benefits to their society through better crop production,

economic growth, and a better environment (2019). The same study found that as education and income levels increased, so did the number of respondents that had prior knowledge of CRISPR-Cas9 (2019). Kessler et al. found that of their respondents, up to 1/3 of German adults had knowledge of the terms CRISPR-Cas9 or genome editing, but only 7% of the 1/3 knew what those terms meant (2020). This suggests that though people may respond that they know what CRISPR-Cas9 or genome editing are, they may not understand what the terms mean.

Some of the studies suggested that respondents are likely to disagree because of a lack of understanding of the technology and the risks associated with it, such as the study done by Gatica-Arias (2019). This can be dangerous because people are disagreeing because of a lack of knowledge, not because they think the technology should not be used. The consumers should be given a better understanding of the technology so that they can make informed opinions about it, rather than disapproving of it due to lack of knowledge. Shew et al. found that respondents that had knowledge of genetic modification had more positive levels of willingness to consume both CRISPR and GM agricultural products (2018).

Calabrese et al. found that consumers that disapprove of genome editing may be because they develop their opinions of the technology through social media, rather than through traditional media (2020). This could mean that the scientific community needs to have a greater presence on social media in order to educate these consumers. Scientists need to add to these discussions on social media and provide valuable conversations to help aid in understanding. Kessler et al. found that the internet was a primary source for consumers to find information about scientific technologies, such as gene editing and other biotechnologies (2020). The same study suggested the importance of understanding how consumers use the internet to gain an understanding of scientific technologies is fundamental for helping them understand the

technologies (Kessler, 2020). Gatica-Arias et al. believe that scientists communicating their knowledge from scientific research to consumers could determine the success or lack thereof of genetically edited products (2019). They also suggested that creating educational programs at schools about biotechnologies such as CRISPR could help aid in the acceptance of gene edited products in the agricultural industry (Gatica-Arias, 2019).

These studies also found that there is a lack of understanding of the difference in CRISPR-Cas9 and GM technologies, meaning that consumers often confuse them. Consumers can sometimes react negatively to CRISPR-Cas9 products because they associate them with genetically modified products (Gatica-Arias, 2019). This further compounds the notion that more education is needed in order to give consumers and respondents the information to make decisions about these technologies.

There is also a lack of data on the actual education level of respondents in many studies regarding the public's opinion of genome editing compared to education levels. Many of these studies ask the respondents to assess their own understanding of the biotechnologies, while Scheufele et al. decided to take that a step further and measure the education levels through questions about the technologies in question (2017). This study found that when respondents could answer more questions about the technology correctly, there was a correlation of greater support for the use of these technologies (2017). Respondents that were able to answer at least two-thirds of their questions correctly were more likely to support the use of genome editing, at levels of 76% somewhat supporting its use for treatment and 41% supporting its use for enhancement (Sheufele, 2017). Respondents that did not answer any of the nine questions posed by the researchers showed less indication for the use of genome editing for both treatment and enhancement (Sheufele, 2017). 32% of those respondents who could not answer any of the

questions correctly supported the use for treatment and 19% supported the use for enhancement (Sheufele, 2017). Sheufele et al. concluded that the knowledge level of respondents regarding these technologies did not directly correlate to more support, but instead that both sides of the spectrum related to stronger views on enhancement, whether the knowledge level was very low or very high (2017). This suggests that more understanding on the topic relates to stronger opinions toward either acceptance or disapproval. This may relate to other studies that found respondents disapproved due to a desire to understand the technology before accepting it. It was also found that religiousness played a part in the respondent's views on gene editing. It was discovered that highly religious respondents that had less understanding of the biotechnologies were less likely to trust scientists to give all of the information about these technologies (Sheufele, 2017). On the other hand, they found that respondents with less religious affiliation and more understanding of the subject were more likely to trust the scientists to provide accurate information about these technologies (2017). The knowledge level of consumers, then, plays a pivotal role in the chances of the general public accepting the use of these technologies in any field. This further supports the idea that education of consumers on these topics must come before asking opinions to make decisions regarding the use of genome editing or other biotechnologies.

McConnachie et al. also assessed their respondents' knowledge level through a series of questions relating to the topic (2019). They found that their respondents on average were able to answer 4/5 of the genetics-based questions correctly. This study concluded that a better ability to answer questions related to the topic correlated to more positive associations with genetic modification as well as greater willingness to consume products created by these biotechnologies (McConnachie, 2019). This contradicts Sheufele et al's findings that greater knowledge of the

topic does not correlate with more support (2017). This shows that more research is needed in this topic to understand how exactly knowledge level correlates with support of these biotechnologies.

McConnachie et al. also concluded that using specific examples instead of asking about genetic modification in general provides better and more accurate results (2019). They found that many studies ask about GM animals in general rather than specific applications of genetic modification in animals (2019). They concluded that using specific examples, such as using CRISPR-Cas9 to create polled cattle, would provide more accurate results (2019). Often, consumers have varied opinions depending on the use of these biotechnologies such as CRISPR, so getting opinions on each as their own subject is ideal.

## Conclusion

In conclusion, the public's perception of genome editing is varied. It is important to poll the public on their attitudes toward biotechnologies like CRISPR, in order to make decisions that will impact their lives. Therefore, it is important to survey the public's attitudes not just on gene editing in general, but on uses in different applications. It is also important to implement educational programs in order to inform the public about biotechnologies like gene editing so that they can make informed decisions. It is also important to understand why the public may be for or against certain applications of genomic editing, to understand what will work going forward. Finally, it is important to conduct more studies on the public's perception of genomic editing in animals and animal agriculture, as the vast majority of studies look at the opinion of the public on genomic editing applications in humans. These studies need to quantify the knowledge of the respondents, rather than going off a self-assessment tool. This provides more data for researchers to understand how the level of education of genetics topics can influence the

opinion of a respondent. It can also highlight demographics where educational programs need to be implemented. The use of genome editing has been a hot topic in the media for a while now and understanding the public's perceptions of the biotechnology can be a valuable tool to researchers and lawmakers.

References

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. 14:954–970. doi:10.1080/17524032.2019.1699135.

Critchley, C., D. Nicol, G. Bruce, J. Walshe, T. Treleaven, and B. Tuch. 2019. Predicting Public Attitudes Toward Gene Editing of Germlines: The Impact of Moral and Hereditary Concern in Human and Animal Applications. Front. Genet. 9:704. doi:10.3389/fgene.2018.00704.

Hendriks, S., N. A. A. Giesbertz, A. L. Bredenoord, and S. Repping. 2018. Reasons for being in favour of or against genome modification: a survey of the Dutch general public. Human Reproduction Open. 2018. doi:10.1093/hropen/hoy008. Available from: https://academic.oup.com/hropen/article/doi/10.1093/hropen/hoy008/4996571

Jiang, F., and J. A. Doudna. 2017. CRISPR–Cas9 Structures and Mechanisms. Annu. Rev. Biophys. 46:505–529. doi:10.1146/annurev-biophys-062215-010822.

Joung, J. K., and J. D. Sander. 2013. TALENs: a widely applicable technology for targeted genome editing. Nature Reviews Molecular Cell Biology. 14:49–55. doi:10.1038/nrm3486.

Gatica-Arias, A., M. Valdez-Melara, G. Arrieta-Espinoza, F. J. Albertazzi-Castro, and J. Madrigal-Pana. 2019. Consumer attitudes toward food crops developed by CRISPR/Cas9 in Costa Rica. Plant Cell Tiss Organ Cult. 139:417–427. doi:10.1007/s11240-019-01647-x.

Kessler, S. H., N. G. Mede, and M. S. Schäfer. 2020. Eyeing CRISPR on Wikipedia: Using Eye Tracking to Assess What Lay Audiences Look for to Learn about CRISPR and Genetic

Engineering. Environmental Communication. 14:886–903. doi:10.1080/17524032.2020.1723668.

Li, H., Y. Yang, W. Hong, M. Huang, M. Wu, and X. Zhao. 2020. Applications of genome editing technology in the targeted therapy of human diseases: mechanisms, advances and prospects. Sig Transduct Target Ther. 5:1. doi:10.1038/s41392-019-0089-y.

Marcon, A., Z. Master, V. Ravitsky, and T. Caulfield. 2019. CRISPR in the North American popular press. Genet Med. 21:2184–2189. doi:10.1038/s41436-019-0482-5.

McCaughey, T., D. M. Budden, P. G. Sanfilippo, G. E. C. Gooden, L. Fan, E. Fenwick, G. Rees, C. MacGregor, L. Si, C. Chen, H. H. Liang, A. Pébay, T. Baldwin, and A. W. Hewitt. 2019. A need for better understanding is the major determinant for public perceptions of human gene editing. Human Gene Therapy. 30:36–43. doi:10.1089/hum.2018.033.

McConnachie, E., M. J. Hötzel, J. A. Robbins, A. Shriver, D. M. Weary, and M. A. G. von Keyserlingk. 2019. Public attitudes towards genetically modified polled cattle. I. A. S. Olsson, editor. PLoS ONE. 14:e0216542. doi:10.1371/journal.pone.0216542.

Plaza Reyes, A., and F. Lanner. 2017. Towards a CRISPR view of early human development: applications, limitations and ethical concerns of genome editing in human embryos. Development. 144:3–7. doi:10.1242/dev.139683.

Scheufele, D. A., M. A. Xenos, E. L. Howell, K. M. Rose, D. Brossard, and B. W. Hardy. 2017. U.S. attitudes on human genome editing. Science. 357:553–554. doi:10.1126/science.aan3708.

Schultz-Bergin, M. 2018. Is CRISPR an Ethical Game Changer? J Agric Environ Ethics. 31:219–238. doi:10.1007/s10806-018-9721-z.

Shew, A. M., L. L. Nalley, H. A. Snell, R. M. Nayga, and B. L. Dixon. 2018. CRISPR versus GMOs: Public acceptance and valuation. Global Food Security. 19:71–80. doi:10.1016/j.gfs.2018.10.005.