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Cultures in the laboratory: mapping similarities and differences between Māori and non-Māori in engaging with gene-editing technologies in Aotearoa, New Zealand

Lyn Kathlene [1], Debashish Munshi [1✉], Priya Kurian [1] & Sandra L. Morrison[1]

Public engagement on rapidly advancing gene-editing technologies requires attention not merely to science and economics, but also to culture. In focusing on the similarities and differences between Indigenous and non-Indigenous perspectives on new and emerging genetic technologies, this article reports on a national survey in Aotearoa New Zealand among a stratified random sample of an equal number of Māori and non-Māori participants. Identifying approaches to the experimentation, use, and potential commercialization of genetic technologies, the article moves along the continuum of nuanced cultural insights into gene editing for purposes ranging from human medical treatments and food production to conservation of native species of plants and animals and pest eradication. The development of typologies using K-means cluster analysis reveals the public's complex responses to genetic modification as well as gene editing. The article signals how recognizing a diversity of values on gene-editing technologies can help shape a robust policy design on the use and regulation of gene technologies in a variety of sectors and contexts.

[1] University of Waikato, Hamilton, New Zealand. ✉email: munshi@waikato.ac.nz

Introduction

New gene-editing technologies with an ability to splice DNA sequences seamlessly in vivo are at the cutting edge of biomedical, agricultural, and human disease-treatment research (e.g., Bortesi and Fischer, 2015; Khalil, 2020; Li et al., 2020; Osakabe et al., 2020; Oura et al., 2021). Pioneered in the laboratories of Jennifer Doudna and Emanuelle Charpentier, winners of the Nobel Prize for Chemistry in 2020, the CRISPr-Cas9 technology to edit genomes (see e.g., Jinek et al., 2012) has revolutionized applications of genetic research, leading to the development of gene-edited crops and insects and clinical trials on treating human conditions such as anemia, blindness, and even cancer (Ledford and Callaway, 2020). As with most new and emerging technologies, gene-editing technologies have sparked both exhilaration about their potential to improve the quality of human life and food and concern about the ethical consequences of altering living systems. Typically, those who have faith in such new technologies ramp up their benefits and those who are critical of these technologies emphasize the risks they pose (Kato-Nitta et al., 2019; see also Sandin and Moula, 2015).

As recent research has shown, public engagement is not merely about expanding science literacy. An exhaustive study by Kato-Nitta et al. (2019), for example, shows that assumptions about the deficit model are not necessarily as relevant for new genetic technologies as they were for older technologies and while increased scientific knowledge could increase the lay public's perceptions about the benefits of newer technologies, they did not make much difference to their risk perceptions.

We argue that communication on new technologies requires attention not merely to science and economics, but also to culture, especially when public opinion on the use of such technologies is polarized. Public engagement frameworks on gene technologies have not kept pace with the rapid pace of developments both inside and outside laboratories. More importantly, they have not adequately engaged with the wide diversity of cultural aspects of gene-editing applications. Emphasizing a scholarly "obligation to consider the place of culture seriously," Epstein (2008) points out that it is only a focus on culture that allows for "understanding matters like the downstream consumption and everyday grappling with science and technology; the engineering of communication across epistemic gulfs within 'knowledge societies'; and the fundamental intertwining of science, the state, and the market" (p. 166).

An extensive scholarship on science and technology studies (STS) (e.g., Felt et al., 2017; Jasanoff et al., 1995) and feminist science studies (Mayberry et al., 2001; Cipolla et al., 2017) has demonstrated how modern science and technology is suffused with Eurocentrism, colonialism, racism and sexism, among other isms—reflective of the social and political contexts in which they are grounded. As Harding (2001) has pointed out, science has always been a part of the culture of its time; and there is perhaps much greater acknowledgement today that all knowledge claims are imbued with cultural values. It is unsurprising then that scientific and technological developments are often marked by controversies, representing as they do "struggles over meaning and morality, over the distribution of resources, and over the locus of power and control" (Nelkin, 1995, p. 445). Some of the common disputes identified by Nelkin (1995) include those triggered by social, moral or religious perspectives on science, and ones arising from conflicts between environmental commitments and political or economic agendas or between individual priorities and community objectives.

Biotechnology and the creation of transgenic organisms, in particular, has long been a source of moral, political and social tensions (Krimsky, 1991; Haraway, 1997; Jasanoff and Hurlbut, 2018), invoking questions around commercial interests versus public good, whether and in what ways it may constitute "tampering with nature", and concerns around purity and a transgression of boundaries (Kurian and Munshi, 2006). In such fraught contexts, science policy can only hope to foster public trust by engaging with the cultural and moral imperatives that shape the issue at hand.

In the space of climate science communication, for example, scientists have done significant work on generating and disseminating climate modeling data to help plan adaptation processes in climate-vulnerable locations. Yet, to get local communities to adapt needs "a culture-centered engagement process" that can "deliver on the diverse demands and requirements of locally specific climate change adaptation" (Munshi et al., 2020, p. 574). In their research on climate change adaptation, Munshi et al. (2020) identified "values, place, power, and narrative" as four domains of a culture-centered framework (p. 574) to support any science-based communication with at-risk communities. Such a framework rests on a definition of culture as the lived experiences of people in a variety of contexts. An acknowledgement of culture as an important part of communicating science in general, and communicating biology in particular, guides our study on public understandings and attitudes towards genetic technologies, especially among the Indigenous Māori communities of Aotearoa New Zealand.

Genetic technologies in Aotearoa New Zealand

In Aotearoa New Zealand, genetic research has historically been as much a science and technology issue as a cultural issue with cutting-edge laboratory work in the area juxtaposed against strong public opinion opposing the research moving out of the laboratory into public spaces. Indeed, a Royal Commission on Genetic Modification (RCGM), set up to look into the issue two decades ago, noted the "uniqueness of our cultural heritage" as one of the core values for "a framework for reaching conclusions about genetic modification" in the country (RCGM, 2001). Among the recommendations of the commission were to establish Toi te Taiao: The Bioethics Council to "act as an advisory body on ethical, social and cultural matters in the use of biotechnology in New Zealand" (RCGM, 2001), and to strengthen a section of the Hazardous Substances and New Organisms (HSNO) Act on the Treaty of Waitangi, the country's founding document signed by the British Crown and Māori chiefs in 1840. Since then, Māori, the first peoples of Aotearoa New Zealand, have made significant contributions to regulatory processes that "provide specific recognition of Māori values within decision-making processes for new organisms including GMOs" (Hudson et al., 2019; see also Cram et al., 2000).

Current legislation in the country regulates genetic modification (e.g., genetically modified crops cannot be grown outside laboratories in the country), with gene editing subsumed within it. The advent of new editing tools is a greater challenge for policy makers and the public, because the boundaries around what constitutes genetic modification have become blurred. While some officials in the US and Europe now claim that gene editing does not constitute genetic modification (Nature Plants Editorial, 2018), others argue that gene editing is a form of modification and therefore carries risks to people and the environment (Environmental Protection Authority, 2013; Food Standards Australia New Zealand, 2019; Sustainability Council, 2018). It is in this context that an expert panel on gene editing set up by the Royal Society of New Zealand Te Apārangi (2019) concluded that "it's time for an overhaul of the regulations and that there's an urgent need for wide discussion and debate about gene editing within and across all New Zealand communities." The panel's co-chair David Penman said "that there is a need to move on from a black and white view of 'GM or not GM'—to a much more nuanced view that recognizes a wide range of applications of the technology, some of which may be more acceptable to New Zealand communities than others" (Royal Society of New Zealand Te Apārangi, 2019).

The panel presented a set of scenarios to evaluate the pros and cons of the use of gene-editing technologies across healthcare, pest control, and primary industries with the aim of informing regulatory change that was "more future-focused and fit for purpose" and "assessing the risks and opportunities of particular applications of gene editing rather than focusing on the gene-editing process itself" (Scott and Penman, 2019, p. 11). The panel's exercise was supported by a Māori reference group, which provided expert advice on the importance of Māori values in decision-making on gene-editing technologies.

In a foundational study on incorporating Māori cultural values in assessing and analyzing the risks and benefits of gene editing, Hudson et al. (2019) outline the importance of concepts of whakapapa (genealogy), mauri (life essence), mana (power/authority), kaitiakitanga (guardianship), mātauranga (Indigenous knowledge), tikanga (protocols), Papatuānuku (earth mother), and tangata whenua (Indigenous people, literally people of the land). This study showed that there were a range of views within Māori communities and that "participants are prepared to consider the use of gene editing on a case dependent basis, especially where it aligns with Māori worldviews" (Hudson et al., 2019, p. 7).

Building on Hudson et al.'s (2019) work on Indigenous perspectives and gene editing in Aotearoa New Zealand, this article looks at the similarities, differences, and complex interfaces between Māori and non-Māori on specific applications of gene editing. In doing so, it moves along the continuum of nuanced cultural insights into gene editing for purposes ranging from human medical treatments and food production to conservation of native species of plants and animals and pest eradication.

The article is based on an analysis of a national survey of a stratified random sample of an equal number of Māori and non-Māori participants. Although Māori comprise 16.7 percent of Aotearoa New Zealand's overall population (Stats, 2020), the survey used an oversampling of the Māori population to directly compare and contrast Indigenous and non-Indigenous perspectives on gene editing. Of the 830 respondents who completed the survey, 50 percent were Māori. The survey covered people's awareness of specific gene-editing technologies, especially in relation to broader genetic modification, attitudes to different applications of such technologies, level of support for current legal frameworks on genetic work, and approaches to Māori values on providing guidance on the use, control, regulation, and commercialization of gene editing.

Research design and methods

The online survey, conducted in July 2019, covered six major topics: (1) Familiarity with genetic modification and the level of support or opposition for such technologies generally and in specific applications (e.g., human medical treatments, extending human life, use in the food system to enhance productivity/reduce pests/etc., restore extinct native species, improve resilience of native species, and so on); (2) familiarity with gene editing and the level of support or opposition to gene editing generally and in specific applications mentioned above; (3) views on current NZ legal framework governing genetic modification and gene editing; (4) importance of Māori values such as kaitiakitanga, whakapapa, mana, and mauri, with respect to providing guidance and consideration in the use of gene editing; (5) level of support for using gene-editing technology to alter taonga (native species); and (6) conditions under which commercialization of products using gene editing were considered appropriate. The survey began by gathering perspectives on genetic modification. After asking respondents if they were aware of genetic modification, we queried where they heard the term and what they thought it meant. Then we provided a short description of genetic modification followed by a series of questions on respondents' level of support (or opposition) to its use in specific applications. After completing questions on genetic modification, we repeated the same format for a set of questions on gene editing.

The survey consisted of 21 Likert scale questions, 12 open-ended questions, nine multiple choice questions, four thermometer questions, and eight demographic questions. We also collected open-ended responses to better understand key ratings about genetic modification and gene editing. All questions were required to be answered, with options such as "don't know" available for scale questions. While we designed the survey instrument, the random sample data collection was conducted by an independent third party (Qualtrics) via an online survey software. New Zealand citizenship or permanent residency was a required criterion for selecting respondents. The survey data was cleaned and analyzed by us in IBM SPSS Statistics version 25 software. Descriptive statistics and bi-variate analyses were run prior to conducting a multivariate analysis. Cluster analysis (MacQueen, 1967) was chosen to find homogenous groups of cases, specifically to explore potential attitudinal differences toward genetic technologies within Māori and non-Māori populations as well as compare attitudinal differences between Māori and non-Māori populations. As Maurice Lorr points out "construction of a taxonomy simplifies the observations with a minimal loss of information" and contributes "significantly to an understanding of the problem studied" (Lorr, 1983: p. 4). Importantly, natural groupings (i.e., cluster types) resonate with non-scientists, such as policy makers, and turn large social survey data sets into actionable information. The latter was the main reason for undertaking this research.

Cluster analysis identifies subgroups in the data such that data points in the same subgroup (cluster) are very similar while data points in different clusters are very different. Because of the large number of cases ($n = 830$), we chose K-means algorithm to classify cases. K-means is an iterative algorithm that partitions a data set into pre-defined distinct non-overlapping subgroups (clusters) where each case belongs to only one group. Initial cluster centers are chosen using a Euclidean distance measure (a straight-line distance between two axiomatic points) with subsequent iterations based upon the nearest Euclidean distance to the mean of the cluster. Multiple iterations are conducted until the cluster means no longer shifted. Such iterations have the advantage of producing discrete groups that are usually easy to interpret (Lorr, 1983; Romesburg, 1984; Kaufman and Rousseeuw, 2005; Everitt et al., 2011).

Cluster analysis, also known as segmentation analysis or taxonomy analysis, is an exploratory data mining method that does not distinguish between dependent and independent variables (Bijnen and Stouthard, 1973; Kaufman and Rousseeuw, 2005). Hence, inferential statistics to discuss the results are neither used nor appropriate for assessing differences between clusters. However, there are several ways in which to assess the goodness of fit of the clusters. One is to look at the iteration history output table. Clusters are stabilized once convergence is achieved. In this analysis, convergence was achieved in 18 iterations with the coordinate change for each cluster center set to 0.000 (the most stringent criteria to converge). To assess the usefulness of the variables used to classify the cases, an ANOVA test was conducted for each variable by cluster. In our data, the F-test for each

Table 1 Variables used in the cluster analysis and ANOVA tests.

Question	ANOVA		
	Cluster mean sq.	Error mean Sq.	*F*
Have you heard/read of the term genetic modification (GM)?	3.02	0.42	7.18**
Based on your knowledge and/or the description above, what is your general reaction to GM technologies?	116.77	1.11	105.19**
Please rate your general level of support for the use of GM in humans, animals, and plants:			
• Human medical treatments (e.g., cancer)	172.00	1.01	171.15**
• Overcoming human reproductive barriers	148.91	0.90	165.90**
• Human longevity or extending life	150.70	0.99	157.65**
• Human cosmetic enhancements	126.86	1.01	125.74**
• Modification of animal livestock (e.g., sheep, cattle, deer) for improved farm profitability, sustainability, resilience	207.22	0.86	242.40**
• Modification of animal livestock for resistance to recently introduced pest or pathogen	231.81	0.81	285.67**
• Control of unwanted pests (e.g., possums, stoats, weasels, wasps)	172.91	0.78	165.93**
• Modification of plants, crops, fruit, timber species to improve profitability, sustainability, and resilience	241.46	0.78	309.63**
• Modification of plants, crops, fruit, timber species for resistance to recently introduced pest or pathogen	222.70	0.82	272.82**
• Restoration of extinct native species of animals or plants	218.20	0.97	226.14**
• Restoration of extinct non-native species of animals or plants	191.65	0.95	201.02**
• Improving resilience of native species (flora and fauna) to unwanted pests and pathogens	219.23	0.79	278.09**
Have you heard of gene editing?	2.68	0.46	5.89**
Based on your knowledge and/or the definitions provided, what is your general reaction to GENE EDITING technologies?	144.89	1.06	136.60**
Please rate your general level of support for the use of GENE EDITING in humans, animals, and plants:			
• Human medical treatments (e.g., cancer)	243.93	0.89	274.78**
• Overcoming human reproductive barriers	210.50	0.852	247.01**
• Human longevity or extending life	201.46	0.84	240.76**
• Human cosmetic enhancements	139.50	0.96	145.41**
• Modification of animal livestock (e.g., sheep, cattle, deer) for improved farm profitability, sustainability, resilience	252.80	0.63	403.25**
• Modification of animal livestock for resistance to recently introduced pest or pathogen	270.65	0.63	428.20**
• Control of unwanted pests (e.g., possums, stoats, weasels, wasps)	256.90	0.74	347.07**
• Modification of plants, crops, fruit, timber species to improve profitability, sustainability, and resilience	283.83	0.50	567.22**
• Modification of plants, crops, fruit, timber species for resistance to recently introduced pest or pathogen	278.64	0.53	528.73**
• Restoration of extinct native species of animals or plants	230.87	0.83	277.19**
• Restoration of extinct non-native species of animals or plants	213.10	0.85	250.85**
• Improving resilience of native species (flora and fauna) to unwanted pests and pathogens	261.20	0.65	402.42**

**$p < 0.001$.

variable was statistically significant. One important caveat: statistical tests can be used for descriptive purposes only because the clusters were formed to maximize the differences among cases. However, as a descriptive, we know that all the variables used in the cluster analysis contributed to the formation of unique clusters (each variable was significant at $p < 0.001$). See Table 1 below.

In the convention of cluster analysis within the social sciences, we gave each cluster a memorable and meaningful name to explore the issues of interest in the study. In this case, the clusters were named to represent the (1) majority demographic (Māori or non-Māori) and (2) perspective on GM/GEd (opposed to supportive) of each cluster. Five clusters initially emerged, of which four clusters had a majority demographic (either Māori or non-Māori, see Table 2 below) along with a distinct perspective about genetic technologies (either opposed or leaning supportive). One cluster, which strongly supported GM/GEd, was composed of nearly equal numbers of Māori and non-Māori. To facilitate the project's policy-focused substantive analysis (i.e., to examine whether there were differences in support for GM/GEd between Māori and non-Māori populations) and to create parallel analysis with the other four clusters that had emerged as predominantly Māori or non-Māori, we divided the strongly supportive cluster by ethnicity thereby creating Māori and non-Māori strongly supportive clusters. The analysis and discussion is, therefore, based on six clusters, three of which are predominantly Māori and three of which are predominantly non-Māori. Table 2 provides key demographics by cluster types.

The open-ended questions were extracted for each cluster and analysed in Dedoose, an online qualitative software analysis platform (https://www.dedoose.com/). Descriptors were added to the data files to allow for a mixed methods quantitative and qualitative analysis of the text.

Cultural similarities and differences

The survey results found both similarities and differences between Māori and non-Māori on certain gene technology applications but the development of typologies using K-Means cluster analysis revealed the public's more complex response to genetic modification and gene editing. Six clusters are explored, of which there were three Māori clusters (*Strongly Supportive*, *Leaning Supportive*, and *Strongly Opposed*) and three non-Māori clusters (*Strongly Supportive*, *Leaning Supportive*, and *Opposed*). As Fig. 1 below shows, 11% of the respondents were in the Māori

Table 2 Key demographics by cluster types.

Demographics	Cluster types					
	Strongly opposed	Opposed	Leaning supportive		Strongly supportive	
	Māori	Non- Māori	Māori	Non- Māori	Māori	Non- Māori
N (total = 824)	107	70	272	187	90	98
Age (mean)	44.3	43.1	38.7	43.5	37.3	44.0
Ethnicity (% Māori)	63%	33%	68%	27%	100%	0%
Gender (% Female)	61%	54%	74%	52%	50%	49%
Education level (%)						
Up to 5th/6th form/NCEA Level 3	34%	41%	40%	35%	38%	26%
Completed 7th form/ NCEA Level 3	21%	14%	20%	23%	28%	19%
Bachelor's degree or equivalent	35%	34%	26%	32%	24%	28%
Professional degree	5%	6%	7%	4%	3%	10%
Post-graduate degree (Masters/Ph.D.)	7%	4%	7%	7%	8%	17%
Years in NZ (%)						
Born in NZ	69%	67%	72%	65%	83%	52%
Less than 5 years	3%	1%	3%	3%	1%	9%
5–10 years	3%	4%	4%	5%	2%	10%
11–20 years	5%	4%	7%	9%	3%	12%
Over 20 years	21%	23%	14%	18%	10%	16%

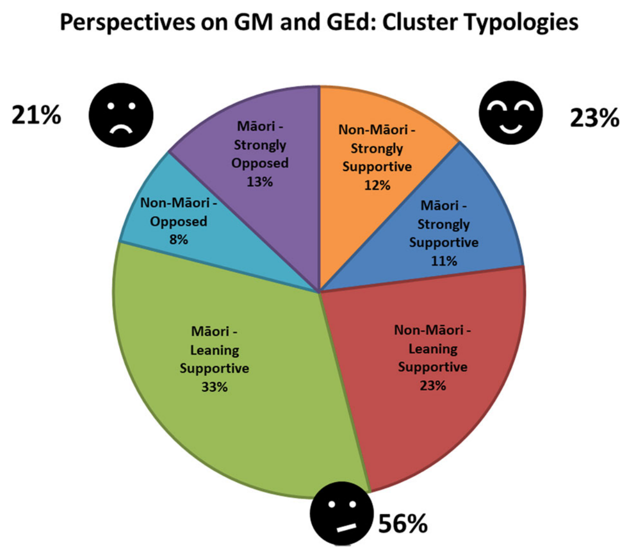

Fig. 1 Typologies of survey participants' perspectives on GM and GEd. Six typologies emerged through K-Means cluster analysis that reveal that both Māori and non-Māori have multiple perspectives about GM and GEd, ranging from strongly supportive to Leaning Supportive to Opposed. Non-Māori Strongly Supportive areshown in orange, Māori Strongly Supportive dark blue, non-Māori Leaning Supportive red, Māori Leaning Supportive green, non-Māori Opposed light blue, and Māori Strongly Opposed purple.

Table 3 Percent of respondents citing familiarity of GM/GEd by cluster types.

Question	Cluster types					
	Strongly opposed	Opposed	Leaning supportive		Strongly supportive	
	Maori	Non-Maori	Maori	Non-Maori	Maori	Non-Maori
Have you heard/read of the term genetic modification (GM)?						
Yes	83%	83%	73%	82%	78%	82%
No	12%	6%	14%	8%	12%	7%
Unsure	5%	11%	13%	10%	10%	11%
Have you heard/read of gene editing (GEd)?						
Yes	30%	27%	21%	34%	37%	45%
No	55%	51%	61%	48%	52%	31%
Unsure	15%	21%	18%	18%	11%	24%

Strongly Supportive cluster, 33% in the Māori *Leaning Supportive* cluster, and 13% in the Māori *Strongly Opposed* cluster. The remaining respondents were in three non-Māori clusters, 12% non-Māori *Strongly Supportive*, 23% non-Māori *Leaning Supportive*, and 8% non-Māori *Opposed*. See Table S1, Supplementary information, for descriptive statistics of each clustering variable by cluster type.

The percentage of respondents in support of gene technologies is similar in both Māori and non-Māori groups. However, more Māori are opposed to such technologies than non-Māori; indeed, those Māori who are opposed are not just opposed but are "strongly" opposed. Interestingly, well over half of all the respondents (56%) were in the middle clusters labeled *Leaning Supportive*. Although the leaning supportive clusters (both Māori and non-Māori) had a quantitative score that leaned closer toward support for the technologies, the open-ended responses found strong ambivalence, especially among Māori, due to the uncertainty respondents felt about benefits and risks. For example, the qualitative responses of those in the Māori leaning supportive cluster listed significantly more concerns than opportunities with several apprehensions about unintended consequences, ethical breaches, and lack of adequate information to make considered opinions. The following quotes on gene editing provide a representative sample of the ambivalence of many of those leaning supportive.

> Sounds great when you (talk of) positive impact but for every action there is an equal and opposite reaction, so I am unsure.

> My major concern is that when you alter a small thing, sometimes it stops other aspects you are not expecting to from working.

Genetic modification was a term a vast majority of the respondents across the groups had heard of but gene editing was not (see Table 3 below).

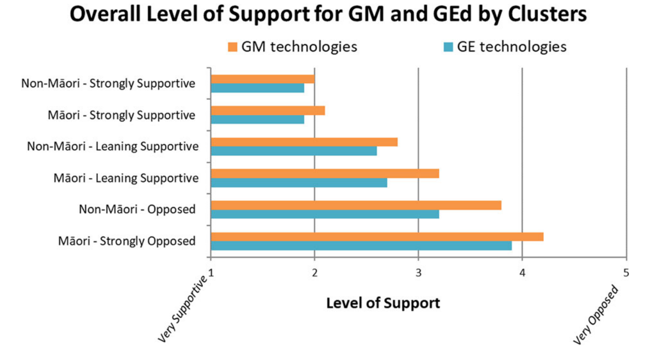

Fig. 2 Overall level of support for GM and GEd by cluster types. Each of the six cluster typologies, regardless of overall perspective on gene technologies, was more supportive of GEd technologies than GM technologies.

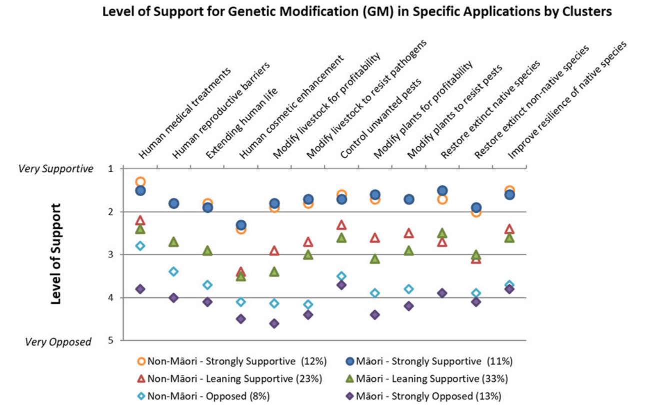

Fig. 3 Level of support for genetic modification (GM) in specific applications by cluster types. Circles represent Strongly Supportive clusters; triangles represent Leaning Supportive clusters; and diamonds represent Opposed clusters. In each of the three perspectives, the opaque points are Māori clusters and the outlined points are non-Māori clusters. In the Strongly Supportive clusters, both Māori and non-Māori have similar supportive stances to the use of GM in each of the applications. However, in the other four clusters, Māori are generally less supportive (Leaning Supportive cluster) or more opposed (Opposed cluster) than their non-Māori counterparts.

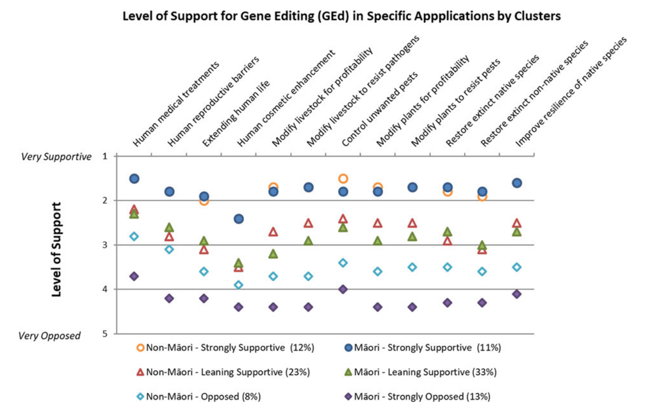

Fig. 4 Level of support for gene editing (GEd) in specific applications by cluster types. Circles represent Strongly Supportive clusters; triangles represent Leaning Supportive clusters; and diamonds represent Opposed clusters. In each of the three perspectives, the opaque points are Māori clusters and the outlined points are non-Māori clusters. In the Strongly Supportive clusters, both Māori and non-Māori have similar supportive stances to the use of GEd in each of the applications. In the Leaning Supportive clusters, Māori and non-Māori have generally similar stances, although Māori are less supportive of several applications. In the Opposed clusters, Māori are much more opposed to all the GEd applications than non-Māori.

Yet, respondents in every cluster were more favorably disposed towards gene editing than towards genetic modification (see Fig. 2 below). Given that only about one-third of the respondents had heard of gene editing, fewer would have set opinions and most would be making judgements based on information learnt in the survey and connecting it to their prior views of genetic modification. We know that people who were supportive of GM were also supportive of GEd; those who were leaning supportive of GM also leaned supportive of GEd; and finally, those opposed to GM were opposed to GEd. In other words, there were no clusters of mixed support on the technologies (e.g., supportive of GM but opposed to GEd, etc.). At a minimum, this tells us that people's views of genetic modification very likely serve as the basis for their views of gene editing, at least until they have a clearer understanding and interest in knowing the differences.

Nevertheless, a deeper analysis shows that people care more about the specific focus of genetic technology applications (for example, for human health or control of pests or for cosmetic changes) rather than which genetic technique (i.e., genetic modification or gene editing) is more desirable. The figures below show the level of support people have for various applications of genetic modification (Fig. 3) or gene editing (Fig. 4) by cluster type.

It is easy to see the grouping of the highest, middle, and lowest supportive types and the patterns that emerge. For the middle and lowest groups, Māori tend to be less supportive than their non-Māori cluster counterparts. That is, Māori among the *Strongly Opposed* are more opposed than non-Māori. Māori among the *Leaning Supportive* are less supportive of most genetic applications than non-Māori. Among the *Strongly Supportive* clusters, however, there is no meaningful difference in enthusiasm levels between Māori and non-Māori as can be seen in their nearly same ratings across different uses of genetic technologies. The lack of differences among the *Strongly Supportive* is to be expected as originally this was one cluster. While there are no meaningful differences in support across GM/GEd applications in the *Strongly Supportive* clusters, we will see important differences emerge between these two clusters regarding the role of Māori values and genetic manipulation of native species (see analysis and discussion in the following sections).

Among all clusters, "human medical treatments" is given a more supportive value than any other application. In fact, five of the six groups rate this above the neutral value of "3". Only Māori who are strongly opposed also oppose this application. On the other hand, "human cosmetic enhancement" receives the least support. Four of the six clusters are opposed to it. Only the two clusters that are strongly supportive of genetic technologies rate it favorably (though it is the lowest favorable rating they give). "Control unwanted pests" is an application where there is somewhat higher support compared to other applications among both the *Leaning Supportive* and *Opposed* clusters, indicating that some uses of GM and GEd are more palatable even among those who are less enthused and even opposed to the technologies. Notably, the two *Leaning Supportive* clusters do not support all applications of genetic technologies, vacillating between being slightly supportive to slightly opposed.

Looking closely at how the support or opposition to gene editing pans out on a range of applications other than ones mentioned above, most Māori are more opposed to the modification of livestock for profitability than non-Māori. Those in

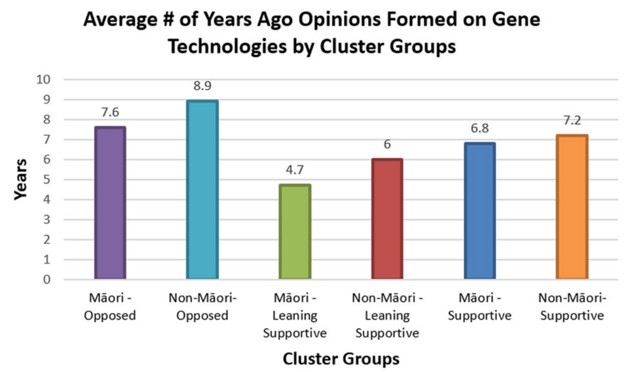

Fig. 5 Average no. of years since opinions on genetic technologies had been formed. The figure shows how long ago opinions about genetic technologies were formed. This varied by cluster types. Non-Māori Strongly Supportive are shown in orange, Māori Strongly Supportive dark blue, non-Māori Leaning Supportive red, Māori Leaning Supportive green, non-Māori Opposed light blue, and Māori Strongly Opposed purple.

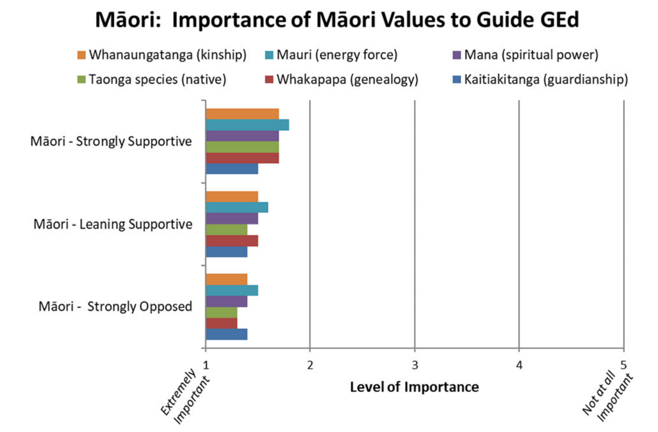

Fig. 6 Support for Māori values in guiding decisions about GEd among Māori respondents byclusters. Māori respondents in all cluster perspectives – Strongly Supportive, Leaning Supportive, and Opposed – believe that Māori values are important in guiding decisions about the use of GEd. The Māori value of Whanaungatanga (kinship) is shown in orange, Mauri (life force) light blue, Mana (spiritual power) purple; Taonga species (native species) green, Whakapapa (genealogy) red, and Kaitiakitanga (guardianship) dark blue.

the Māori *Strongly Opposed* cluster are very opposed to human cosmetic enhancement. Notably, even those in the Māori *Leaning Supportive* cluster are opposed to this application, as indicated by their rating of well under the neutral value of 3. Non-Māori, on the other hand, have very different ratings. Those in the non-Māori *Opposed* cluster are less opposed to this application than Māori who are opposed, and those in the non-Māori *Leaning Supportive* cluster show higher levels of support for this application with a rating that is higher than the neutral value.

A comparison of the ratings of applications by those in the Māori and non-Māori *Leaning Supportive* clusters shows that Māori are relatively less supportive of GEd than their non-Māori counterparts when it comes to controlling unwanted pests, modifying plants for profitability, and modifying plants to resist pests. However, although *Leaning Supportive* Māori are marginally more supportive of addressing human reproductive barriers and restoring both native and non-native species than *Leaning Supportive* non-Māori, they are less supportive than non-Māori on improving the resilience of non-native species.

Respondents were asked how long ago they had formed their opinion on genetic technologies. Those *Opposed* had, on average, determined their stance 8.3 years ago, while those *Leaning Supportive* came to their middling position most recently, an average of 5.4 years ago. The *Supportive* clusters fell between the two other groups, with an average of 7.0 years (see Fig. 5 below). Notably, those who are opposed to genetic technologies formed their opinion at a time when controversies around genetic modification were most prominent in Aotearoa New Zealand, including, for example, the approval of a proposal to insert human genes into cattle in 2010 that led to vocal public opposition (Kurian and Wright, 2012). To the extent that opposition to GM/GEd is grounded in the 2010 contentious public discourse, it is unlikely that the cluster types identified in this research will be amenable to reconsidering their stance. In a separate analysis that examines the qualitative data reporting on concerns about GM/GEd, people in the two groups opposed to genetic technologies express strong and unwavering opposition similar to the vocal outcry in 2010. Unlike the more malleable perspectives of the *Leaning Supportive* cluster types, who are willing to consider new information and weigh the pros and cons of the technologies, the *Opposed* cluster types are staunchly against GM and GEd. However, the strict regulatory control of genetic modification has seen the issue fall out of the public domain in more recent times, and this may be reflected in the more recently formed opinions of the moderate and supportive stances of the *Leaning Supportive and Strongly Supportive* clusters.

Importance of Māori values

The divergence among Māori and non-Māori respondents' views on various applications of genetic technologies can be attributed to a significant extent to the importance respondents place on intrinsic values to guide their thinking on gene editing. The section of the survey that specifically discussed six Māori values offers some insights into the prioritization of values by respondents across the cultural groupings. The Māori values covered in the survey were: whakapapa (genealogy), mauri (life essence or force), mana (power), kaitiakitanga (guardianship), whanaungatanga (kinship), and taonga species (native species). Māori across all cluster types—regardless of their level of support for or against genetic technologies—see all these values as extremely important, although the degree of importance for Māori values among Māori clusters increases with opposition to gene technologies (see Fig. 6 below). In contrast, non-Māori show much more limited support of these Māori cultural values in decision-making on gene editing. Non-Māori who are most supportive of Māori values are those who are most supportive of gene technologies, and those that rate Māori values the lowest are also the most opposed to both genetic modification and gene editing (see Fig. 7 below). These inverse relationships of Māori values and support/opposition to gene technologies reveal, perhaps unsurprisingly, that all Māori clusters are more supportive of the role for Māori values to guide gene editing than are any of the non-Māori clusters. We speculate that the support of non-Māori for both gene technologies and Māori values may be explained by two reasons. One, those most supportive of gene editing tend to be more highly educated, with 27 percent holding professional or post-graduate degrees (in comparison to only 10 percent of those opposed to gene editing) (see Table 2). They are, therefore, more likely to have been exposed to understandings of Māori values through the educational system. Two, included among non-Māori most supportive of gene editing would be scientists who recognize that any regulatory change on gene editing in New Zealand can only happen with the support of Māori and mediated through the prism of Māori values.

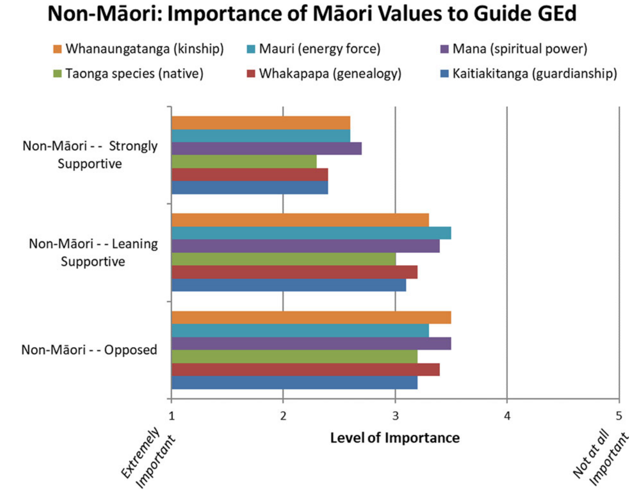

Fig. 7 Support for Māori values in guiding decisions about GEd among non-Māori respondents byclusters. Non-Māori respondents in two of the three cluster perspectives – Leaning Supportive and Opposed – believe that Māori values are not important in guiding decisions about the use of GEd. However, Non-Māori who are Strongly Supportive of genetic technologies believe Māori values are important in guiding decisions about the use of GEd. The Māori value of Whanaungatanga (kinship) is shown in orange,Mauri (life force) light blue, Mana (spiritual power) purple; Taonga species(native species) green, Whakapapa (genealogy) red, and Kaitiakitanga (guardianship) dark blue.

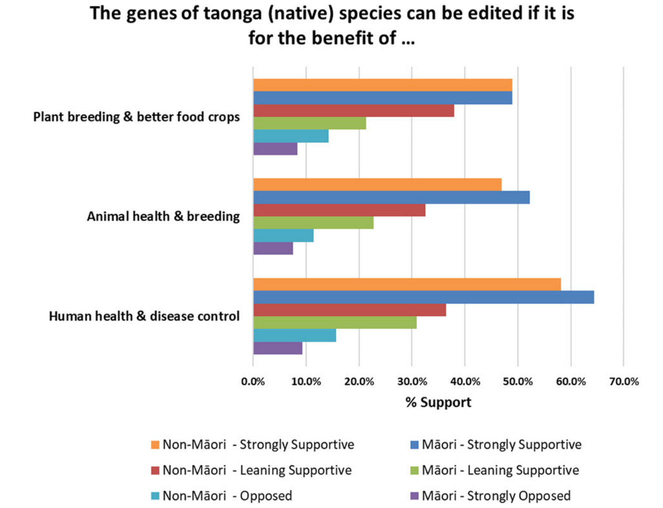

Fig. 8 Level of support by clusters for the conditions under which taonga species can be edited. The Strongly Supportive clusters (both Māori and non-Māori) have the highest percentage across the clusters that support gene editing of taonga (native)species, although the support differs based on its application. The Opposed clusters have the lowest percentage who support editing taonga species, with the Leaning Supportive falling between the other two clusters in their support. Importantly, except for gene editing of "human health & disease control" the level of support for editing native species in other applications is below 50% in all six of the clusters. Non-Māori Strongly Supportive are shown in orange, Māori Strongly Supportive dark blue, non-Māori Leaning Supportive red,Māori Leaning Supportive green, non-Māori Opposed light blue, and Māori Strongly Opposed purple.

Views on taonga (native) species

Respondents were queried further about the use of gene editing on New Zealand's taonga (native) species. Specifically, people were asked about their support for gene editing under three conditions: (1) Human health and disease control; (2) Animal health and breeding; and (3) Plant breeding and better food crops.

Regardless of their overall position on gene editing, all but one of the clusters' respondents were more supportive of editing native species to address human health issues and diseases (the exception was the Non-Māori *Leaning Supportive* cluster) compared to other purposes. Unsurprisingly, the respondents in the *Strongly Supportive* clusters were more likely to support editing genes across all three purposes than were the respondents in the *Leaning Supportive* or *Opposed* clusters. Among the *Supportive* clusters (Māori and non-Māori), 60% supported editing taonga for the benefit of human health or to control human diseases. About half as many respondents in the *Leaning Supportive* clusters compared to the *Strongly Supportive* clusters felt the same way (average of 34%). Less than 16% of respondents in each of the two *Opposed* clusters supported editing native species for human health. As far as animal health and breeding, and plant breeding are concerned, respondents in the Māori *Strongly Supportive* cluster are more supportive than non-Māori *Strongly Supportive* cluster. However, the ethnic comparison flips among respondents in the *Leaning Supportive* and *Opposed* clusters, where it is the non-Māori who are more likely to support editing taonga for animal health or plant breeding compared to the Māori cluster counterparts. Figure 8 below provides the percentage of support for the three applications across all six clusters.

When respondents were asked whether taonga species should NEVER be subjected to gene editing, two-thirds of the Māori in the *Opposed* cluster agreed that native species should never be subjected to gene editing compared to one-third of the non-Māori in the *Opposed* cluster. A similar pattern is found across the other four clusters, with 20% Māori compared to 11% non-Māori in *Leaning Supportive clusters* agreeing the taonga species should never be edited; and 18% Māori compared to 7% non-Māori in the *Strongly Supportive* clusters wanting New Zealand's native species' genes left in its natural state (see Fig. 9 below).

At the heart of using genetic technologies on taonga species is ownership of the genetic material. Māori, as the Indigenous population of New Zealand, have an historically aligned interest in protecting the Indigenous plant and animal species and, perhaps, a moral claim to being the guardians of preserving taonga species. Two to three times as many Māori than non-Māori see the genetic material of Indigenous species as belonging to Māori. However, most Māori (ranging between 63–71% among the Māori clusters) did not agree that Māori should hold the rights to such material, though this is a lower percent than non-Māori where nearly all disagree that Māori should have the rights. Fig. 10 below shows how this perspective is distributed across the clusters.

Centering culture in communicating genetic technologies

The survey found that Māori are no more of one mind about genetic technologies than are non-Māori. There are similar percentages of Māori and non-Māori who are supportive of genetic modification and gene editing as there are of Māori and non-Māori who are opposed to the technologies. Importantly, the largest percentage of both Māori and non-Māori are found in the middle category— *Leaning Supportive*—suggesting that meaningful efforts in designing and enacting public engagement, based on deliberative processes, could help foster deeper and diverse understandings of gene-editing technologies among over half the population. However, generating such understandings among the middle clusters will need to be message-specific to Māori and non-Māori populations. The open-ended comments of respondents in the *Leaning Supportive* Māori cluster revealed far more skepticism about gene editing than their non-Māori counterparts.

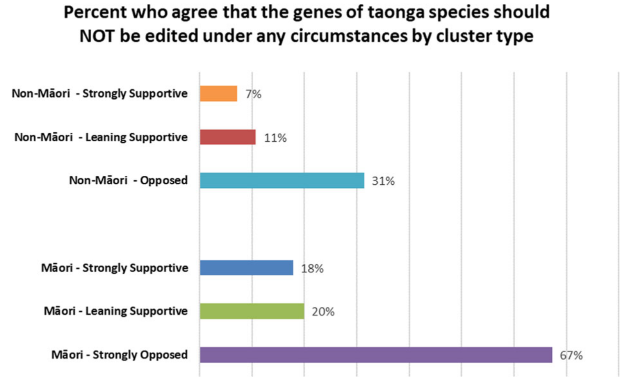

Fig. 9 Percent who are opposed to editing taonga species under any circumstances by clusters. Only one cluster, Māori Strongly Opposed, have a large percentage (67%) of cluster members who agree that the taonga species should never be edited. The other five cluster types have a minority of members who support the stance of never allowing GEd to be used on native species. Non-Māori Strongly Supportive are shown in orange, non-Māori Leaning Supportive red, non-Māori Opposed light blue,Māori Strongly Supportive dark blue, Māori Leaning Supportive green, and Māori Strongly Opposed purple.

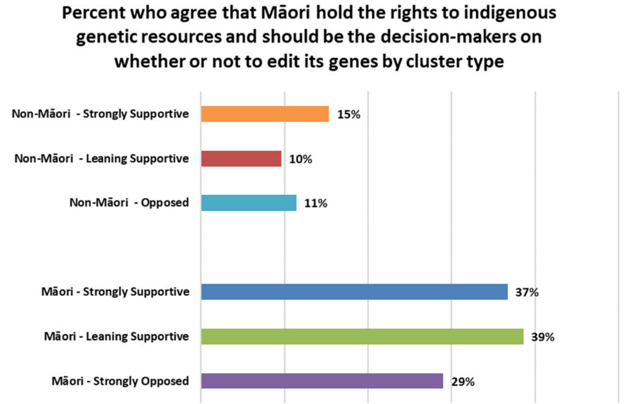

Fig. 10 Support for Māori to have the rights to and final determination of editing taonga species, by clusters. All Māori clusters are more supportive of Māori holding the rights to taonga species than the non-Māori clusters. However, across all six clusters, it is only a minority of members who support the stance (ranging from 10% to 39%). Non-Māori Strongly Supportive are shown in orange, non-Māori Leaning Supportive red, non-Māori Opposed light blue, Māori Strongly Supportive dark blue, Māori Leaning Supportive green, and Māori Strongly Opposed purple.

There are important lessons from the survey for public communication on complex biological concepts such as gene editing of DNA sequences of plants, animals, and humans. As Larson (2011) says, "facts alone do not communicate;" indeed, "people are not passive receptacles for facts … but instead bring their own perspective to bear on information presented to them" (p. 16). So rather than assuming 'facts' to be neutral packages of information, it is crucial to acknowledge the cultural aspects of diverse forms of knowledges that are aligned with the values and contexts of different groups of people, especially Indigenous communities who have a rich repository of knowledge about nature that predates Western science. Culturally, for example, there is a wide chasm between Māori and non-Māori when it comes to the importance of Māori values and the editing of taonga (native) species. Māori across the clusters are strongly in favor of Māori values guiding policy- and decision-making around gene editing. This is in stark contrast to non-Māori, who do not see the importance or maybe relevance of using Māori cultural values in considerations of policy making on gene editing. The exception here are the respondents of the non-Māori cluster who are supportive of both genetic technologies and Māori values. Understanding this at a deeper level would require a separate study, but it is possible that higher levels of education among the respondents in this cluster may result in greater exposure to and understanding of Māori values and their centrality to any kind of legislative change, which may account for this relationship between non-Māori support of gene technologies and that group's support of Māori values. Notably, Māori are *twice as likely*, on average, than non-Māori to be against *any* gene editing of taonga species, no matter the proposed benefits. And Māori are, on average, *three times more likely* than non-Māori to agree that "Māori should hold the rights to Indigenous genetic resources and any decisions about editing its genes". Yet, at the same time, a majority of Māori reject the idea of seeking ownership of rights to Indigenous genetic resources. One explanation for this lies in the centrality of the Māori value of whakapapa (genealogy), which "provides the foundation for how Māori construct their identities and their relationships with other species" (Hudson et al., 2019, p. 6). The genealogical ties between humans and non-humans in te ao Māori (the Māori worldview) perhaps preclude the acceptance of Western notions of ownership and property rights over other species.

Given the divergence in views on genetic technologies, and the acknowledged need to revise current legislation on genetic modification (e.g., Royal Society of New Zealand Te Apārangi, 2019), it is critical to ensure that the range of Māori perspectives inform these discussions. Such representation of Māori perspectives could be possible if the public engagement on new genetic technologies centers culture and responds to the values of the tangata whenua (Indigenous peoples) of Aotearoa New Zealand. The challenge for a culture-centered engagement and communication is to "be true to the science but to appeal simultaneously to people's values" (Larson, 2011, p. 16). Bringing Māori values and their understanding of native species to the center of communicating about genetic technologies is clearly the essential next step in policy making on gene-editing technologies, including changes to the outdated regulatory framework currently in place. Equally important in this process is to recognize that communication and engagement is not a one-way process. Rather, it is critical to acknowledge and address current power imbalances that influence whose voices and perspectives dominate, and create new institutional arrangements that can ensure that diverse cultural and ethical perspectives can collectively help shape the role of genetic technologies in our imagined futures.

Data availability

The data sets are available with the researchers. Aggregated data can be made available to bona fide researchers on request, subject to a non-disclosure agreement.

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References

Bijnen EJ, Stouthard PC (1973) Cluster analysis: survey and evaluation of techniques. Tilburg University Press, Groningen, The Netherlands

Bortesi L, Fischer R (2015) The CRISPR/Cas9 system for plant genome editing and beyond. Biotechnol Adv 33(1):41–52

Cipolla C, Gupta K, Rubin D, Willey A (eds) (2017) Queer feminist science studies: a reader. University of Washington Press, Seattle, WA

Cram F, Pihama L, Barbara GP (2000) Māori and genetic engineering. International Research Institute for Māori and Indigenous Education, Tamaki Makaurau
Environmental Protection Authority (2013) Decision. 19 April https://www.epa.govt.nz/assets/FileAPI/hsno-ar/APP201381/03e845f138/APP201381-APP201381-Decision.pdf
Epstein S (2008) Culture and science/technology: rethinking knowledge, power, materiality, and nature. The annals of the American academy of political and social science, 619 (September)
Everitt BS, Landau S, Leese M, Stahl D (2011) Cluster analysis, 5th edition. John Wiley & Sons, West Sussex, UK
Felt U, Fouche R, Miller C, Smith-Doerr L (eds) (2017) The handbook of science and technology studies. MIT Press, Cambridge MA
Food Standards Australia New Zealand (2019) Final report: review of food derived using new breeding techniques. https://www.foodstandards.gov.au/consumer/gmfood/Documents/NBT%20Final%20report.pdf
Haraway D (1997) Modest_witness@second_millennium.femaleman_meets_oncomouse: feminism and technoscience. Routledge, New York, NY
Harding S (2001) After absolute neutrality: expanding 'science'. In: Mayberry M, Subramaniam B, Weasel L (eds) Feminist science studies: a new generation. Routledge, New York, NY, p 291–304
Hudson M, Mead A, Chagne D, Roskruge N, Morrison S, Wilcox P, Allan A (2019) Indigenous perspectives and gene editing in Aotearoa New Zealand. Frontiers in bioengineering and biotechnology 7(70). https://doi.org/10.3389/fbioe.2019.00070
Jasanoff S, Hurlbut JB (2018) A global observatory for gene editing. Nature. (21 March). https://www.nature.com/articles/d41586-018-03270-w
Jasanoff S, Markle G, Petersen J, Pinch T (eds) (1995) Handbook of science and technology studies. Sage, Thousand Oaks, CA
Jinek M, Chylinski K, Fonfara I, Hauer M, Doudna J, Charpentier E (2012) A programmable dual-RNA-guided DNA endonuclease in adaptive bacterial immunity. Science 337:816–821. https://science.sciencemag.org/content/337/6096/816.abstract
Kato-Nitta N, Maeda T, Inagaki Y, Tachikawa M (2019) Expert and public perceptions of gene-edited crops: attitude changes in relation to scientific knowledge. Palgrave Commun 5 (137). https://www.nature.com/articles/s41599-019-0328-4
Kaufman L, Rousseeuw PJ (2005) Finding groups in data: an introduction to cluster analysis. John Wiley & Sons, Hoboken, New Jersey
Khalil A (2020) The genome editing revolution: review. Journal of genetic engineering and biotechnology 18(68). https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7596157/
Krimsky S (1991) Biotechnics and society: the rise of industrial genetics. Greenwood Press, Westport, CT
Kurian P, Munshi D (2006) Tense borders: culture, identity, and anxiety in New Zealand's interweaving discourses of immigration and genetic modification. Cult Polit 2(3):359–380
Kurian P, Wright J (2012) Science, governance, and public participation: an analysis of decision-making on genetic modification in New Zealand. Public Underst Sci 21(4):447–464
Larson B (2011) Metaphors for environmental sustainability: redefining our relationship with nature. Yale University Press, New Haven, CT
Ledford H, Callaway E (2020) Pioneers of revolutionary CRISPR gene editing win chemistry Nobel. Nature 586:346–347. https://www.nature.com/articles/d41586-020-02765-9
Li H, Yang Y, Hong W, Huang M, Wu M, Zhao X (2020) Applications of genome editing technology in the targeted therapy of human diseases: mechanisms, advances and prospects. Signal transduction and targeted therapy 5(1). https://www.nature.com/articles/s41392-019-0089-y
Lorr M (1983) Cluster analysis for social scientists. Jossey-Bass, San Francisco, CA
MacQueen JB (1967) Some methods for classification and analysis of multivariate observations. In: Le Cam LM, Neyman J (eds) Proceedings of the fifth Berkeley symposium on mathematical statistics and probability (1). University of California Press, Berkeley CA, pp. 281–297
Mayberry M, Subramaniam B, Weasel L (eds) (2001) Feminist science studies: a new generation. Routledge, New York
Munshi D, Kurian P, Cretney R, Morrison S, Kathlene L (2020) Centering culture in public engagement on climate change. Environ Commun 14(5):573–581
Nature Plants Editorial (2018) A CRISPR definition of genetic modification. Nat Plants 4(May):233, https://www.nature.com/articles/s41477-018-0158-1.pdf
Nelkin D (1995) Science controversies: the dynamics of public disputes in the United States. In: Jasanoff S, Markle G, Petersen J, Pinch T (eds.) Handbook of science and technology studies. Sage, Thousand Oaks, CA, pp. 444–456
Osakabe K, Wada N, Miyaji T, Murakami E, Marui K, Ueta R, Hashimoto R, Abe-Hara C, Kong B, Yano K, Osakabe Y (2020) Genome editing in plants using CRISPR type I-D nuclease, Commun Biol 3 (648). https://www.nature.com/articles/s42003-020-01366-6
Oura S, Noda T, Morimura N, Hitoshi S, Nishimasu H, Nagai Y, Nureki O, Ikawa M (2021) Precise CAG repeat contraction in a Huntington's Disease mouse model is enabled by gene editing with SpCas9-NG. Commun Biol 4 (771). https://www.nature.com/articles/s42003-021-02304-w
RCGM (Royal Commission on Genetic Modification) (2001) Report of the royal commission on genetic modification. Wellington
Romesburg HC (1984) Cluster analysis for researchers. Lifetime Learning Publications, Belmont, CA
Royal Society of New Zealand Te Apārangi (2019) Calls for overhaul of gene-technology regulations and wide public discussion (12 August). https://www.royalsociety.org.nz/news/calls-for-overhaul-of-gene-technology-regulations-and-wide-public-discussion/
Sandin P, Moula P (2015) Modern biotechnology, agriculture, and ethics. Agri Environ Ethics 28(5):803–806
Scott B, Penman D (2019) Gene editing: reflections from the panel co-chairs. Royal Society of New Zealand, Wellington, New Zealand, https://www.royalsociety.org.nz/assets/Uploads/Gene-Editing-FINAL-COMPILATION-compressed.pdf Retrieved from
Stats NZ (2020) Māori population estimates: At 30 June 2020 (17 November). https://www.stats.govt.nz/information-releases/Māori-population-estimates-at-30-june-2020#:~:text=This%20release%20contains%20the%20first,percent%20for%20the%20national%20population
Sustainability Council of New Zealand (2018) A constitutional moment: Gene drive and international governance. http://www.sustainabilitynz.org/wp-content/uploads/2018/10/AConstitutionalMoment_September2018.pdf

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Competing interests
The authors declare no competing interests.

Ethical approval
The study was approved by the Human Research Ethics Committee of the Waikato Management School, University of Waikato, Hamilton, New Zealand (Ethics Application WMS 19/44).

Informed consent
This study involved a national survey in Aotearoa New Zealand among a stratified random sample of an equal number of Māori and non-Māori participants to gauge public perceptions on gene-editing technologies. While the authors designed the survey instrument and analyzed the data, the random sample data collection was conducted by an independent third party (Qualtrics) via an online survey software. Information on the research project was provided to potential respondents on the survey platform and the completion of the survey by respondents was deemed to be consent.

Additional information
Supplementary information The online version contains supplementary material available at https://doi.org/10.1057/s41599-022-01104-9.

Correspondence and requests for materials should be addressed to Debashish Munshi.

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