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Expert and public perceptions of gene-edited crops: attitude changes in relation to scientific knowledge

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ABSTRACT This study empirically examined expert and public attitudes toward applying gene editing to agricultural crops compared with attitudes toward other genetic modification and conventional breeding technologies. Regulations regarding the application of gene editing on food are being debated around the world. New policy measures often face issues of public acceptance and consensus formation; however, reliable quantitative evidence of public perception toward such emerging breeding technologies is scarce. To fill this gap, two web-based surveys were conducted in Japan from December 2016 to February 2017. Participants ($N = 3197$) were categorised into three groups based on the domain-specific scientific knowledge levels (molecular biology experts, experts in other fields, and lay public). Statistical analysis revealed group differences in risk, benefit, and value perceptions of different technologies. Molecular biology experts had higher benefit and value perceptions, as well as lower risk perceptions regarding new technologies (gene editing and genetic modification). Although the lay public tended to have more favourable attitudes toward gene editing than toward genetic modification, such differences were much smaller than the differences between conventional breeding and genetic modification. The experts in other fields showed some characteristics that are similar to the experts in molecular biology in value perceptions, while showing some characteristics that are similar to the lay public in risk perceptions. The further statistical analyses of lay attitudes revealed the influence of science literacy on attitudinal change toward crops grown with new breeding technologies in benefit perceptions but not in risk or value perceptions. Such results promoted understanding on distinguishing conditions where deficit model explanation types are valid and conditions where they are not.

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Introduction

Gene editing as a new breeding technology. Interest in gene editing in agricultural crops has increased remarkably. Countries such as the United States have taken a proactive stance on utilising this technique; however, the products and even the technology itself still need time in many countries for clear positioning beyond technical, normative, ethical, and political concerns Schultz-Bergin, 2018; Sprink et al., 2016a; Tachikawa, 2017). Japan, which has relatively strict regulations on genetically modified (GM) crops, also is at the final stage of decision-making process (Japan 224th Food Safety Group, 2019). Genetic modification and gene editing are indeed different technologies, and if there are differences in public perceptions between those two, empirically investigating such differences in a country with a lower acceptance of GM food, Japan in the case of the present study, should promote clearer understandings of determinants for perceptions of gene edited crops.

There are two different political standpoints related to gene editing (Sprink et al., 2016b). First, *product-based policy* regards gene editing as a technology that is closer to conventional breeding than to genetic modification. This view is seen in the case when no exogenous gene is introduced in gene editing; conventional breeding can also bring the same desired results after a much longer time. Thus, the safety of these two should be considered to be similar. The second idea, *process-based policy*, situates gene editing closer to genetic modification: as long as DNA manipulation exists, the outcome brings higher risks and uncertainties; therefore, the method should be considered unconventional.

In previous research investigating both expert and public perceptions of risk of biotechnology application on food, experts significantly perceived less risk compared with the lay public (Savadori et al., 2004). This result leads to the prediction that with great expectations about emerging technology, researchers who have domain-specific scientific knowledge in biotechnology would tend to adopt product-based policy. Meanwhile, according to a recent interview report by Hopp et al. (2017), the public tends to take the process-based policy. However, a salient shortage exists in quantitative evidence on people's risk perceptions toward application of gene editing in agricultural crops in relation to different levels of scientific knowledge. Thus, we statistically examined this topic in contrast with other existing technologies in genetic modification and conventional breeding using samples categorised into three groups by level of domain-specific scientific knowledge (experts in molecular biology, experts in other fields, and the lay public). Observing how different levels of domain-specific knowledge affect the response to each technology, including the latest, would deepen the understanding of public perceptions toward new science and technology (S&T), advancing related research.

Scientific knowledge, provided information, and attitude change. Psychological literature offers comprehensive evidence of the relationship between provided information and attitudinal change. People use available information when they make judgements (Finucane et al., 2002; Slovic et al., 1981). Thus, information should play an important role also in public risk, benefit, and value perceptions concerning food. The literature also suggests that outcomes are complex (Forgas, Cooper and Crano, 2011; Hyland and Birrell, 1979). A vast body of literature has discussed this topic in relation to scientific knowledge. For example, Zhu and Xie (2015) investigated the role of scientific knowledge in the above relationship and showed the effects of knowledge of both benefit and risk on attitudinal change related to GM foods, attributed to information provided. However, Frewer et al. (1998) claimed that the most important determinant of attitude changes toward genetic engineering after information provision was prior attitude. These findings suggest that an analysis capable of verifying changes within subjects would be necessary by taking differences in scientific knowledge into consideration.

Therefore, we focus first on the role of domain-specific scientific knowledge in the relationship between provided information and attitudinal change concerning the application to food of three technologies. As researchers in public communication of science stress the need of promoting reflections on scientific communities and stimulating dialogue between experts and the lay public (Kato-Nitta et al., 2017), answering this question should provide better mutual understanding. For this purpose, single-factor within-subject design of experimental survey was employed. By testing differences in responses to identical items by the same respondent for four conditions (before the information is provided and after information on three respective technologies is provided), other conditions, including the individual factors of respondents, are assumed to be controlled. Thus, this method matches our research goal.

Our first research question is as follows. RQ 1: How do attitudinal changes on different breeding technologies differ in three groups stratified by domain-specific knowledge? Our empirical study of statistically observing this issue would yield essential information on public perceptions of gene editing as new S&T.

Boundary conditions of deficit model framework. Our second research question aims to shed light on how the general scientific knowledge or science literacy of the lay public influences attitudinal change concerning acceptance of science owning to the information provided. The relationship between science literacy and people's acceptance toward emerging S&T such as GM crops has been studied extensively in connection with the deficit model framework—in other words, an increase in 'proper' scientific knowledge among the public linearly improves their acceptance of new S&T. These studies were mainly associated with criticism for its oversimplified assumption, and there is also empirical evidence rejecting this. For instance, Bucchi and Neresini (2002) proved that better-informed people do not always show more positive attitudes toward GM food. Midden et al. (2002) reported that scientific knowledge or information may promote negative perceptions of the lay public.

Some researchers explain that scientists' preconception of the public and its affinity with easily implemented policy may explain why the deficit model's assumption continues to occupy a prominent position in science communication (Simis et al., 2016; Suldovsky, 2016). Nonetheless, as Slovic (1999) claimed, even if it is not the most dominant variable, scientific knowledge remains closely and importantly linked with public attitudes toward S&T. Ahteensuu (2012) attends to relevance by stating that scientific knowledge does explain, at least partially, public negative attitudes of new S&T. He further stressed the need of distinguishing between cases in which deficit-model explanations are warranted and cases in which they are not.

This discussion demonstrates that further studies must be conducted on the relationship between public science literacy and acceptance of food-related applications of new S&T. To explore this issue, the current study examines attitudinal changes in various facets of people's perceptions, particularly of changes in risk, benefit, and value perceptions. It can be considered that people's acceptance is promoted if decreases in risk perception and increases in benefit perceptions or value perceptions were observed. By investigating those three aspects of people's perceptions, we multidimensionally provide insight into people's acceptance of emerging S&T. Furthermore, this study introduces to the above discussion the elaboration likelihood model (Petty and Cacioppo, 1986) to explore the relationship among science literacy, provided information, and attitude change. The model's foundational assumption is that attitude change is achieved with not only individual knowledge but also individual relevance to the information.

Therefore, we address RQ 2: Does science literacy influence the attitudinal changes that result from information provision about the differences in applied breeding technologies on agricultural crops? A confirmation of the empirical results for this question by taking into account individual relevance and different cases of applied technologies should contribute to the discussion on the relationship between scientific knowledge and the lay public's acceptance toward emerging S&T.

Methods

Data. Two web-based surveys were conducted from December 2016 to February 2017. The surveys were entrusted with a survey company, Nippon Information Incorporated. Survey 1 used a quasi-representative sample from the company's large opt-in panel of approximately 1,100,000 volunteers from the online population in Japan. An initial screening was made to mitigate the potential bias in demographic distributions, and allocation was made in proportion to the size according to region, gender, and age based on the 2015 Japan national population census, and drew 3350 respondents aged between 20 and 69 years on a first-come, first-serve-basis. Then, the final participants of 3000 were selected by excluding respondents with extreme-shorter response time (from the shorter side of time to be about less than 1/10 of median total response time). This treatment was made to enhance reliability of the data based on the idea of 'satisficing' in quantitative survey methodology (Krosnick, 1991; Maniaci and Rogge, 2014; Tourangeau et al., 2013). This idea is based on behaviour which respondents do not pay enough amount of cognitive effort to provide the suitable answers in a survey.

The participants for Survey 2 were scientists with and without expertise in molecular biology. We adopted an opportunistic sampling method in addition to recruiting volunteers using academic societies' websites, such as the Molecular Biology Society of Japan and the Physical Society of Japan. We also utilised electronic mailing lists for recruiting participants, including TENNET (operated by the Japan Astronomical Society) and Jeconet (a Japanese academic mailing list related to ecology). Survey 2 participants' fields of specialty were distributed as follows: Micro-biology, such as molecular biology, 56.3%; macro-biology, such as ecology, 13.7%; physical sciences, informatics, chemistry, or geology, 11.6%; social sciences and humanities, 6.1%; medicine, nursing, or health, 4.6%; other disciplines, 7.6%. The final sample size for the second survey was 197. Table 1 shows the survey demographics.

The data in this study were used in previous studies (Kato-Nitta et al., 2017; Tachikawa et al., 2017), and the surveys utilised were conducted under Japanese Privacy Information Protection Law. Participation was completely voluntary, and participants could withdraw at any time. Informed consent of all participants was obtained by Nippon Information Incorporated.

The surveys provided fundamental information, starting with the definition of *genome* and to textual explanation of the basic genome research, as well as health and agricultural applications of genome research. At this point, the initial attitudes, as a baseline of within-subject experimental design, were measured with 11 items on benefit, risk, and value perceptions toward genome research applied to agricultural crops. Details of the fundamental information provided are shown in Fig. 1.

Table 1 Demographic distributions of survey 1 and survey 2

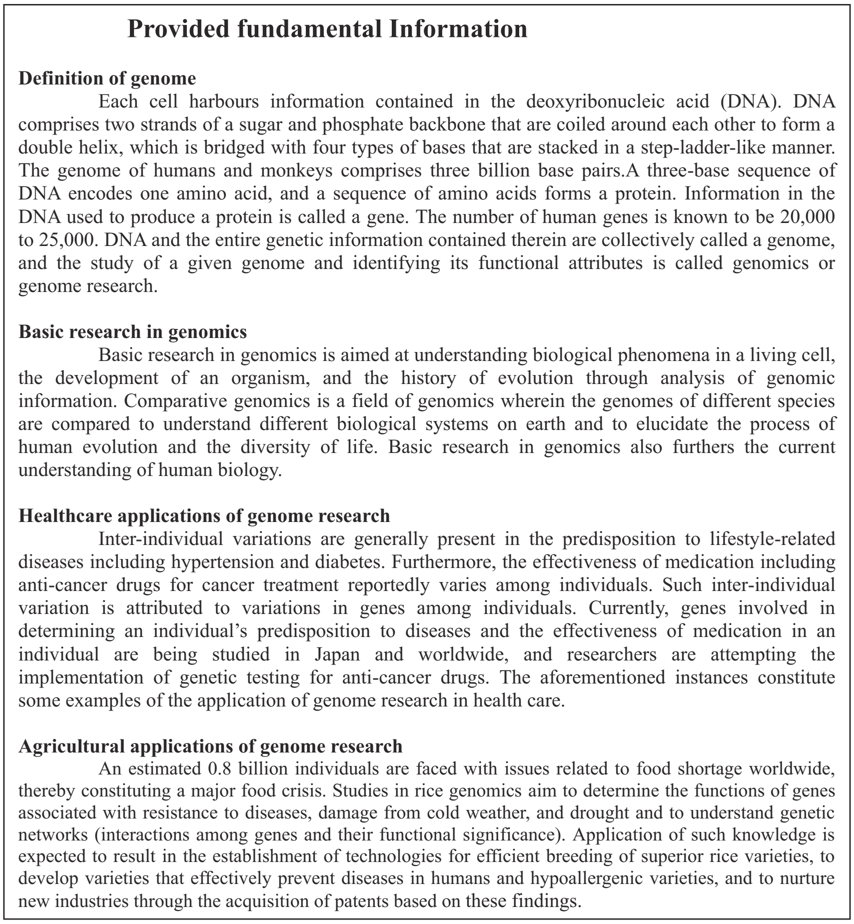
	Survey 1	**Survey 2**	
	Lay public	**Experts in other fields**	**Experts in molecular biology**
Gender			
Male	50.0%	70.9%	82.0%
Female	50.0%	29.1%	18.0%
Age			
20–29 years	15.5%	12.8%	11.7%
30–39 years	19.6%	33.7%	22.5%
40–49 years	23.0%	23.3%	27.0%
50–59 years	19.3%	20.9%	30.6%
60–69 years	22.6%	9.3%	8.1%
Education			
High school or less	29.0%	0.0%	0.0%
Vocational college	11.8%	0.0%	0.0%
Junior college	11.2%	0.0%	0.0%
College	42.9%	18.6%	10.8%
Graduate	5.0%	81.4%	89.2%
Annual income			
Under 3,000,000 JPY	60.3%	10.8%	12.0%
3,000,000 JPY or over	39.7%	89.2%	88.0%
n	3000	86	111

Then, figures with texts (Figs. 2 and 3) were used when explaining the differences among the three existing breeding technologies of conventional breeding, genetic modification, and gene editing. The tomato is considered as a fine model plant by biologists (Busch et al., 1991), so we used figures depicting tomatoes to explain the technological differences. Next, three measurements—one of perceptions of applying conventional breeding, one of perceptions of applying genetic modification, and one of perceptions of applying gene editing—were made, each using 11 items (33 total items) spanning the oldest to the newest technologies. In order to answer these items, participants were allowed to refer to the figures (Fig. 2) and access the provided URL links to the website of the Ministry of Agriculture, Forestry, and Fisheries during the survey.

Measures and analyses

Relationship between domain-specific knowledge and attitudinal change. To answer the first research question, we assessed various facets of perceptions on applying genome research to agricultural crops with the 11-item scale. Nine of the eleven items were adopted from the JSPS KAKENHI (17019024) research project 'Public attitudes toward genomic researches in Japan (g-elsi)', and two extra items were added for the current study. Four measurements were made using this scale: before the explanation of technical differences (1st, baseline) and after presentation of technical differences among the three breeding technologies (2nd, 3rd, and 4th). The details of the 11 items are provided below, as well as in Fig. 4 and Table 4. The participants were asked to answer using a five-point scale (1 = disagree to 5 = agree).

What do you think of a genome research application for breeding agricultural crops using the technology of (conventional breeding/genetic modification/gene editing)?



Provided fundamental Information

Definition of genome

Each cell harbours information contained in the deoxyribonucleic acid (DNA). DNA comprises two strands of a sugar and phosphate backbone that are coiled around each other to form a double helix, which is bridged with four types of bases that are stacked in a step-ladder-like manner. The genome of humans and monkeys comprises three billion base pairs.A three-base sequence of DNA encodes one amino acid, and a sequence of amino acids forms a protein. Information in the DNA used to produce a protein is called a gene. The number of human genes is known to be 20,000 to 25,000. DNA and the entire genetic information contained therein are collectively called a genome, and the study of a given genome and identifying its functional attributes is called genomics or genome research.

Basic research in genomics

Basic research in genomics is aimed at understanding biological phenomena in a living cell, the development of an organism, and the history of evolution through analysis of genomic information. Comparative genomics is a field of genomics wherein the genomes of different species are compared to understand different biological systems on earth and to elucidate the process of human evolution and the diversity of life. Basic research in genomics also furthers the current understanding of human biology.

Healthcare applications of genome research

Inter-individual variations are generally present in the predisposition to lifestyle-related diseases including hypertension and diabetes. Furthermore, the effectiveness of medication including anti-cancer drugs for cancer treatment reportedly varies among individuals. Such inter-individual variation is attributed to variations in genes among individuals. Currently, genes involved in determining an individual's predisposition to diseases and the effectiveness of medication in an individual are being studied in Japan and worldwide, and researchers are attempting the implementation of genetic testing for anti-cancer drugs. The aforementioned instances constitute some examples of the application of genome research in health care.

Agricultural applications of genome research

An estimated 0.8 billion individuals are faced with issues related to food shortage worldwide, thereby constituting a major food crisis. Studies in rice genomics aim to determine the functions of genes associated with resistance to diseases, damage from cold weather, and drought and to understand genetic networks (interactions among genes and their functional significance). Application of such knowledge is expected to result in the establishment of technologies for efficient breeding of superior rice varieties, to develop varieties that effectively prevent diseases in humans and hypoallergenic varieties, and to nurture new industries through the acquisition of patents based on these findings.

Fig. 1 Provided fundamental Information on genome research. Fundamental textual information provision about definition of genome, basic genome research, and health and agricultural applications of genome research

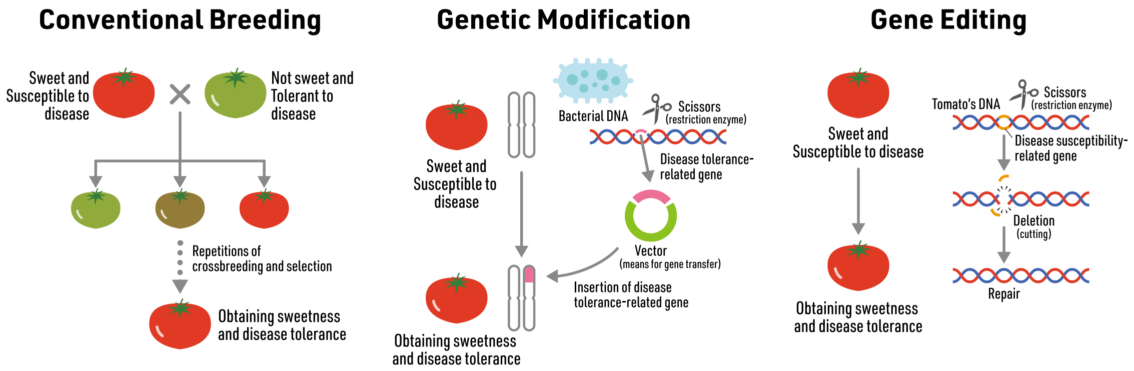
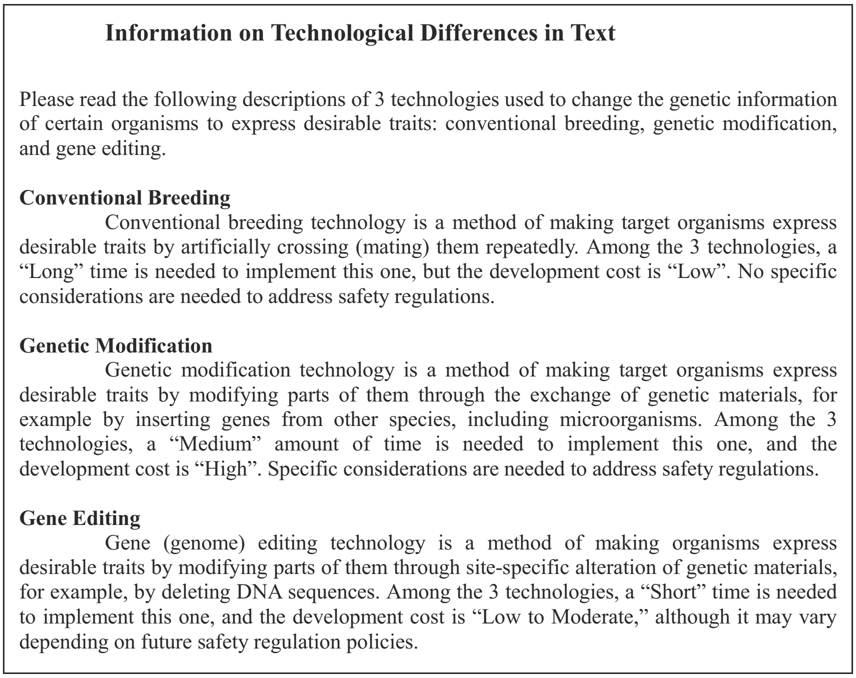


Fig. 2 Information on technological differences. Information provision by illustrations with text to explain the differences among the three existing breeding technologies of conventional breeding, genetic modification, and gene editing

1. Beneficial to stable food supply
2. Beneficial to human health care
3. Beneficial to economic development
4. Impacts plant and insect ecology
5. Insufficient safety confirmation
6. Fear of unexpected adverse effects
7. Possibility of misusing this technology
8. Bioethically questionable
9. Cannot understand well and feel somewhat fearful
10. Universally favoured to be promoted
11. Research considered insignificant

On the above 11 items, we statistically explored the differences in mean values of the four conditions of (1) before information on technologies, (2) conventional breeding, (3) genetic modification, and finally, (4) gene editing, using a single-factor repeated measures ANOVA. As the result of the statistical test depends on the sample size, we further calculated effect sizes to determine the extent of attitudinal changes and also conducted power analyses.



Information on Technological Differences in Text

Please read the following descriptions of 3 technologies used to change the genetic information of certain organisms to express desirable traits: conventional breeding, genetic modification, and gene editing.

Conventional Breeding

Conventional breeding technology is a method of making target organisms express desirable traits by artificially crossing (mating) them repeatedly. Among the 3 technologies, a "Long" time is needed to implement this one, but the development cost is "Low". No specific considerations are needed to address safety regulations.

Genetic Modification

Genetic modification technology is a method of making target organisms express desirable traits by modifying parts of them through the exchange of genetic materials, for example by inserting genes from other species, including microorganisms. Among the 3 technologies, a "Medium" amount of time is needed to implement this one, and the development cost is "High". Specific considerations are needed to address safety regulations.

Gene Editing

Gene (genome) editing technology is a method of making organisms express desirable traits by modifying parts of them through site-specific alteration of genetic materials, for example, by deleting DNA sequences. Among the 3 technologies, a "Short" time is needed to implement this one, and the development cost is "Low to Moderate," although it may vary depending on future safety regulation policies.

Fig. 3 Information on technological differences in text. Information provision in text to explain the differences among the three existing breeding technologies of conventional breeding, genetic modification, and gene editing. This information is provided with the information described in Fig. 2

Table 2 Cronbach's alpha for aggregated variables for calculation on dependent variables

	Genome research application for agricultural crops		Cronbach's α			
Variables	**Number of Items**	**Items**	**Baseline**	**Conventional breeding**	**Genetic modification**	**Gene editing**
Benefit	3	Beneficial to stable food supply Benefical to human health care Beneficial to economic development	0.705	0.728	0.726	0.750
Risk	6	Impacts plant and insect ecology Insufficient safety confirmation Fear of unexpected adverse effects Possibility of misusing this technology Bioethically questionable Cannot understand well and feel somewhat fearful	0.816	0.903	0.869	0.871

We categorised participants into three groups by level of domain-specific knowledge of molecular biology: (A) lay public ($n = 3000$), (B) experts in the other fields ($n = 86$), (C) experts in molecular biology ($n = 111$). We also observed differences in attitudinal changes of the three groups from the data including the above three groups.

Influence of science literacy on attitudinal change. To answer the second research question, we tested the following hypothesis with regression analyses: people's scientific knowledge influences their attitudinal change on agricultural crops owing to information provided that explains the differences among applied technologies. For these analyses, we exclusively used the data from Survey 1 (the lay public).

Dependent variables. We constructed two composite variables using nine items out of the above 11 items: benefit perception comprised three items and risk perception comprised six items. A Cronbach's alpha coefficient for each of these constructs was calculated to confirm the internal consistency and reliability for each item. These values are shown in Table 2.

There were two items related to value perception: 'Universally favoured to be promoted' and 'Research considered insignificant'. Since the former is assessing individual perception of other individuals' value perception and the latter is assessing individual perception per se, the two items were considered to be unsuitable for aggregation; therefore, we used only the latter item to be included in regression models for the purpose of analysis in assessing individual attitude change on value perceptions.

After the above operationalisation, we calculated the sizes of the respective changes (difference scores) described as follows (Y1 to Y9) and then used them as dependent variable in regression analysis.

[Benefit perceptions]
Y1 = Gene editing minus before information

Y2 = Genetic modification minus before information
Y3 = Conventional breeding minus before information
[Risk perceptions]
Y4 = Gene editing minus before information
Y5 = Genetic modification minus before information
Y6 = Conventional breeding minus before information
[Value perceptions]
Y7 = Gene editing minus before information
Y8 = Genetic modification minus before information
Y9 = Conventional breeding minus before information

We decided to use the difference score (gain score) after weighing both its pros (Cronbach and Furby, 1970) and cons (Edwards, 1970) and its intuitive appeal on interpretability of results. Our dependent variables represented the perceived superiority or inferiority of each technology to the baseline of 'before the information on technological differences'. R-squares of regression equations are generally lower compared with the analysis not using such operation, as is characteristic when the major source of variations (baseline) is subtracted from the dependent variable. When the size of Y1 to Y3 and Y7 to Y9 are positive, the change can be interpreted as positive, and the benefit or value perception is higher compared with the perception before information provision. When the size of Y4 to Y6 is positive, the change can be interpreted as positive, and the risk perception is higher compared with the perception before information provision.

Independent variables. Science literacy: We measured participants' general scientific knowledge with 11 items that have been repeatedly used in international comparative studies (European Union, 2001; National Science Board, 2016), as well as by the Japanese government (Ministry of Education, Culture, Sports, Science and Technology, 2004). The scale consists of items such as 'Antibiotics kill viruses, as well as bacteria: True or false'. We calculated the total sum of the correct answers to the 11 questions. The current study's participants (the lay public) in Survey 1 recorded a correct answer rate of 53.6%, which was about a same correct answer rate of 54% reported in the previous survey conducted by the Japanese government (Ministry of Education, Culture, Sports, Science and Technology, 2004).

Individual relevance to the information (benefit of general genome research, risk of general genome research, and value of general genome research): We measured participants' individual relevance to the information by measuring participants' benefit, risk, and value perceptions on general genome research. As this research focuses on people's perceptions of genome research application on agricultural crops, we defined perceptions on general genome research as 'perceptions on basic genome science and genome research as applied to medicine'. We adopted *benefit of general genome research* as control variables for models Y1 to Y3, *risk of general genome research* for Y4 to Y6, and *value of general genome research* for Y7 to Y9. Items for construct variables of individual relevance were measured before provision of information on technological differences (Figs. 2, 3) and the respective Cronbach's alpha values for each of the aggregated independent variables are provided in Table 3. As is shown in Table 3, Cronbach's alphas for the aggregated independent variables yielded adequate internal consistency and reliability.

Trust in food governance: Previous studies noted that trust has been considered the essential variable to understanding people's risk perceptions (Lobb, 2005; Slovic, 1999; Slovic et al., 1981). Recent empirical studies have also shown that trust was an important factor for both risk and benefit perceptions on the application of biotechnology to agricultural crops (Rodríguez-Entrena, M. and Salazar-Ordóñez, 2013; Slovic, 1999). We introduced this concept as controls to test the hypothesis associated with the second research question. Trust in Japanese food governance was assessed with items used in previous Japanese studies (Kato-Nitta et al., 2017). This scale consists of four items evaluating participants' trust in governmental food safety policy, as well as safety measures of food business companies. The participants were asked to answer using a seven-point scale (1 = completely disagree to 7 = completely agree). The Cronbach's alpha value for this scale is shown in Table 3.

Risk-avoidance orientation: We utilised this concept for controlling the level of original disposition of the participants with respect to risk. The part of this scale was used in the previous studies (and two extra items were added for the purpose of the current study (Kato-Nitta et al., 2017). The scale consists of six items and was developed to assess if the participants have a 'zero-risk' orientation or whether they favourably evaluate products described as 'additive-free' or 'pesticide-free'. The answers to this scale was made with a five-point scale (1 = Do not praise at all to 5 = Praise highly). The Cronbach's alpha value for this scale is shown in Table 3.

Results

Evaluation of mean differences of four conditions. Figure 4 shows the mean values of the four measurements from left to right (1 = before the information on technological differences is provided; after the information on technological differences is provided: 2 = conventional breeding, 3 = genetic modification, and 4 = gene editing) of the three groups, categorised with domain-specific knowledge of molecular biology. Table 4 shows the result of single-factor repeated measures ANOVA in the mean value of the responses in each group.

Considering the overall positions of the three curves shown in Fig. 4, the following trends were observed. Experts in molecular biology showed the highest benefit perceptions, the lay public showed the lowest, and experts in other fields were in the middle. For risk perceptions, experts in molecular biology were the lowest, the lay public was the highest, and experts in other fields were in the middle. By reading the comprehensive shapes of the three curves, it can be observed that for both benefit and risk perceptions, there is a similarity among the lay public and experts in other fields. In contrast, for the two items of value perceptions, experts in other fields showed a similar trend with that of experts in molecular biology. Thus, the domain-specific knowledge of genome literacy affects the relationship between the provision of information and attitudinal change concerning food application of three technologies.

Group A (the lay public). The red curve in Fig. 4 and statistical tests in Table 4 revealed that the lay public's perception of food-related application changed after the information was provided. As for benefit perceptions, all statistical tests were significant. The results of multiple comparisons with Bonferroni correction shown in Table 4 also suggest that people consider benefit aspects of gene editing higher than those of genetic modification out of all three items assessing benefit perceptions. As for the two items of 'beneficial to stable food supply' and 'beneficial to economy', the values of effect size f were smaller than 0.10, as shown in Table 4. According to the criteria proposed by Cohen (1988), the interpretations for effect size f include the following: $f \geq 0.10$ as "small", $f \geq 0.25$ as "medium", and $f \geq 0.40$ as "large". Therefore,

Table 3 Cronbach's alpha for aggregated independent variables

Variables	Number of items	Usage	Items	Cronbach's α
Benefit of general genome research	6	Basic genome research	Promising future applications New findings are valuable in themselves It is essential that research in Japan is leading worldwide	0.860
		Genome research application in medicine	Beneficial for the treatment I receive Development of novel therapies Allowing for a definitive diagnosis	
Risk of general genome research	12	Basic genome research	Research is costly Does not yield immediate benefits Fear of occurrence of unexpected adverse effect Possibility of misusing this technology Bioethically questionable Cannot understand well and feel somewhat fearful	0.874
		Genome research application in medicine	Research is costly Allowing for discrimination based on illness and disability Fear of occurrence of unexpected adverse effects Possibility of misusing this technology Bioethically questionable Cannot understand well and feel somewhat fearful	
Value of general genome research	2	Basic genome research	Research considered insignificant (Used in inverted values)	0.733
		Genome research application in medicine	Research considered insignificant (Used in inverted values)	
Trust in food governance	4	What do you think about the following opinions? Please select the answer that most closely matches your own feelings	Food safety inspections conducted by the government are sufficiently reliable The government is making efforts to ensure food safety and security Food safety standards set in Japan are strict, even compared with international standards Overall, food business operators in Japan are making efforts to ensure food safety and security	0.890
Risk-avoidance orientation	6	How highly do you value the following foods, products, or services?	Foods labeled as "Additive free" Foods labeled as "No artificial coloring" Foods labeled as "No genetically modified soybean used" Foods labeled as "No agricultural chemicals" or "Zero residual agricultural chemicals" Water filters labeled as "Complete removal of radioactivity" Grocery supermarkets declaring "Aiming for zero radioactivity"	0.920

although the results of statistical tests were significant for those two items, the degree of changes was small.

All statistical tests were significant for risk and value items, and the values of effect size f were larger than 0.10. The overall tendency of the red curves indicates that the lay public considers the risks of conventional breeding as the lowest and those of genetic modification as the highest. The results of multiple comparisons with Bonferroni correction, suggest that the risk perception for gene editing was lower than that for genetic modification; however, such difference was relatively small compared with the difference between conventional breeding and genetic modification.

Group B (experts in other fields). The green coloured curve in Fig. 4 and statistical tests in Table 4 revealed that Group B's attitudes changed after the information was provided, except for one item of 'beneficial to food supply'. The results suggest that this group consider the benefit aspects of gene editing as similar to those of genetic modification out of all three items assessing benefit perceptions. This finding is based on the lack of statistical difference found between the two technologies. Because the mean of 4 (gene editing) is higher than that of 3 (genetic modification), and there is a statistical difference between 3 and 4 in Group B for the item 'possibility of misusing this technology', risk perception of gene editing was marked higher than that of genetic modification. The value of effect size f for this item was 0.823, which was much larger than Cohen's criterion: $f \geq 0.40$ as "large".

Group C (experts in molecular biology). The blue coloured curve in Fig. 4 and statistical tests in Table 4 revealed that Group C's perceived benefits did not change after the provision of information. The results of statistical tests in Table 4 suggest that risk perceptions of the experts in molecular biology changed before and after the information technological differences was provided, except for one item, 'cannot understand well and feel somewhat fearful'.

In this group, there were no statistically significant differences among the three technologies for the risk perception items,

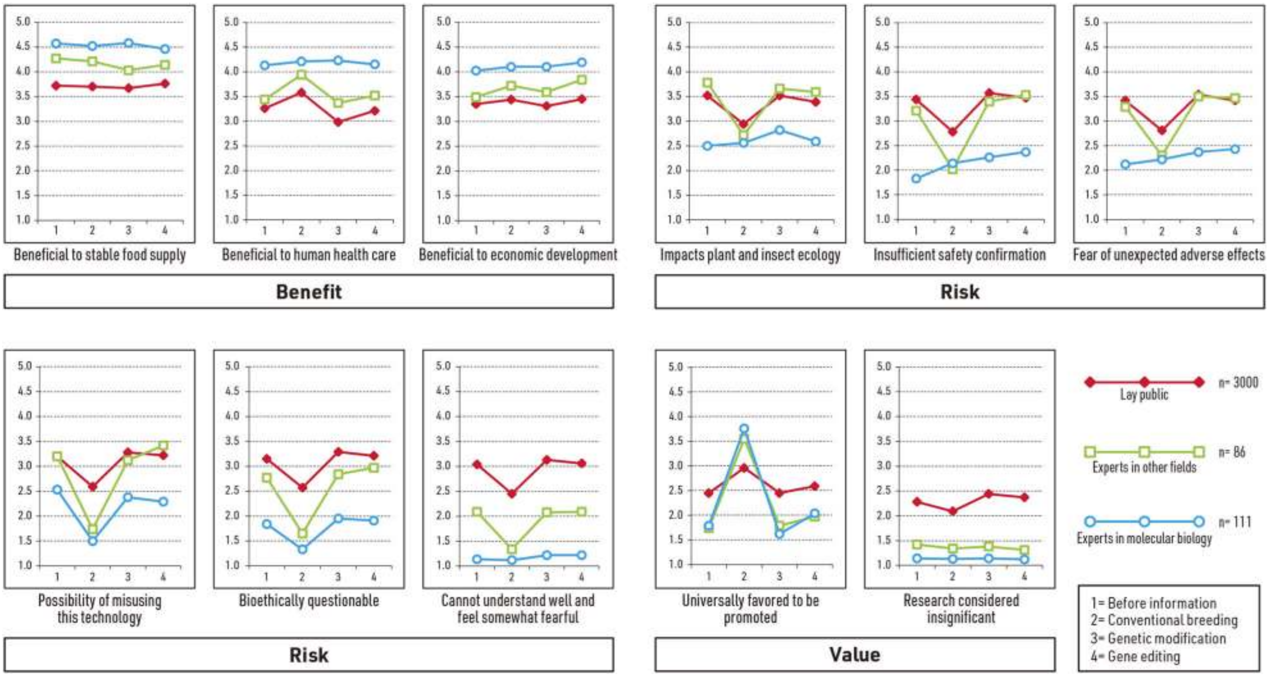


Fig. 4 Group mean differences of four conditions. Line charts of each item represent the mean values of the four measurements assessing benefit, risk, and value perceptions (1 = before the information on technological differences is provided; after the information on technological differences is provided: 2 = conventional breeding, 3 = genetic modification, and 4 = gene editing) of the three groups, categorised with domain-specific knowledge of molecular biology. Red coloured lines = Lay public, Green coloured lines = Experts in other fields, Blue coloured lines = Experts in molecular biology. Note: Given that the variable on the *x* axis is not strictly continuous, bar charts are more appropriate. However, we used the line charts for readability

including 'impacts plant and insect ecology', 'insufficient safety confirmation', and 'fear of unexpected adverse effects'. The shapes of the curves of these items are distinct from those of the other two groups. Given the statistical differences between 2 (conventional breeding) and 3 (genetic modification) and between 2 and 4 (gene editing) for the items of 'possibility of misusing this technology', and 'bio-ethically questionable', the risk aspects of those items were considered as being 'differently natured' in this group from those of 'insufficient safety confirmation' or 'fear of unexpected adverse effects'. The values of effect size f for those items were 0.551 and 0.398, which were higher than the Cohen's criteria: $f \geq 0.40$ as "large"; $f \geq 0.25$ as "medium", respectively.

As the large sample size of lay public participants might have influenced the result, we further conducted power analyses. For example, concerning the item with the smallest effect size f of 0.045 in Table 4 (beneficial to stable food supply), a sample size capable of obtaining the Cohen's proposed convention of power value of 0.8 ($\alpha = 0.05$) was 271. Therefore, we would have obtained the same results even if the sample size of the lay public had been less than 1/10 of the current study. This result enabled us to conclude that the results of the statistical tests were not dependent on the sample size.

Evaluation of effects of science literacy on attitudinal change. To test the hypothesis based on RQ 2 that science literacy influences attitudinal change on agricultural crops caused by the provision of information, regression analyses were used. Table 5 shows the results of benefit perceptions, Table 6 shows those of risk perceptions, and Table 7 shows those of value perceptions.

The results showed that the hypothesis above was confirmed for benefit perceptions of all three breeding technologies. It was also confirmed for risk perceptions and value perceptions of conventional breeding. However, it was not confirmed for risk perceptions and value perceptions of the two new technologies of genetic modification and gene editing. The details of regression analyses are as follows.

Benefit perceptions. All three models (Table 5) were statistically significant. Looking at the effects of science literacy, this variable has a positive coefficient and is statistically significant for all the three models of benefit perceptions. Thus, the results for the benefit perceptions supported the hypothesis by showing the positive effects of scientific knowledge in increasing benefit perceptions after the information was provided as for all three breeding technologies.

Risk perceptions. All three models (Table 6), were statistically significant. As to the effects of science literacy, this variable has a negative coefficient and is statistically significant for Model Y6. In contrast, this variable is not statistically significant for the models of new S&T (Models Y4 and Y5). Thus, the result for Model Y6 supported the hypothesis, but those for Models Y4 and Y5 did not. Therefore, the positive effects of scientific knowledge to reduce risk perceptions, after the information is provided, was observed only for the conventional breeding technique. There were no effects of scientific knowledge to reduce risk perceptions of the two new S&T of gene editing and genetic modification.

Value perceptions. Model Y9 was statistically significant whereas Models Y7 and Y8 were not statistically significant. As to the effects of science literacy, this variable has a positive coefficient and is statistically significant for Model Y9. Thus, the result for Model Y9 supported the hypothesis, but those for Models Y7 and Y8 did not. Therefore, the positive effects of scientific knowledge to increase value perceptions, after the information is provided,

Table 4 Attitudinal change caused by information on differences among three breeding technologies

	Item	Groups	Average (SE)					ANOVA	Effect size f	Multiple comparison (Bonferroni method)
			Information	Before		After				
			Conditions	1	2 Conventional breeding	3 Genetic modification	4 Gene editing	F (p value)		
Benefit	Beneficial to stable food supply	A		3.724 (0.019)	3.704 (0.020)	3.666 (0.020)	3.756 (0.019)	7.509 ($p < 0.001$)	0.045	4 > 3 ($p < 0.001$), 1 > 3 ($p < 0.05$)
		B		4.267 (0.093)	4.209 (0.105)	4.035 (0.109)	4.140 (0.104)	1.764	0.143	
		C		4.568 (0.075)	4.523 (0.086)	4.577 (0.072)	4.459 (0.085)	0.750	0.084	
	Beneficial to human health care	A		3.262 (0.022)	3.580 (0.021)	2.978 (0.022)	3.206 (0.021)	223.012 ($p < 0.001$)	0.272	4 > 3, 2 > 4, 2 > 3, 2 > 1, 1 > 3 ($p < 0.001$)
		B		3.442 (0.127)	3.942 (0.116)	3.372 (0.141)	3.523 (0.131)	7.107 ($p < 0.001$)	0.289	2 > 3 ($p < 0.001$), 2 > 1 ($p < 0.01$) 2 > 4 ($p < 0.05$)
		C		4.126 (0.116)	4.207 (0.108)	4.225 (0.105)	4.153 (0.109)	0.352	0.055	
	Beneficial to economic development	A		3.347 (0.020)	3.438 (0.021)	3.309 (0.020)	3.446 (0.020)	19.653 ($p < 0.001$)	0.084	4 > 3, 4 > 1, 2 > 3 ($p < 0.001$) 2 > 1 ($p < 0.01$)
		B		3.488 (0.125)	3.721 (0.132)	3.593 (0.129)	3.837 (0.110)	2.731 ($p < 0.05$)	0.179	4 > 1 ($p < 0.05$)
		C		4.018 (0.114)	4.099 (0.106)	4.099 (0.106)	4.189 (0.104)	0.833	0.090	
Risk	Impacts plant and insect ecology	A		3.520 (0.021)	2.942 (0.023)	3.521 (0.021)	3.388 (0.021)	245.404 ($p < 0.001$)	0.287	4 > 2, 3 > 4, 1 > 4, 3 > 2, 1 > 2 ($p < 0.001$)
		B		3.779 (0.130)	2.721 (0.152)	3.663 (0.128)	3.593 (0.136)	31.310 ($p < 0.001$)	0.607	1 > 2, 3 > 2, 4 > 2 ($p < 0.001$)
		C		2.495 (0.132)	2.559 (0.132)	2.820 (0.139)	2.586 (0.134)	3.179 ($p < 0.05$)	0.170	3 > 1 ($p < 0.05$)
	Insufficient safety confirmation	A		3.445 (0.021)	2.782 (0.024)	3.567 (0.021)	3.471 (0.022)	378.247 ($p < 0.001$)	0.355	4 > 2, 3 > 4, 3 > 2, 3 > 1, 1 > 2 ($p < 0.001$)
		B		3.209 (0.145)	2.023 (0.120)	3.395 (0.140)	3.535 (0.138)	49.268 ($p < 0.001$)	0.761	1 > 2, 3 > 2, 4 > 2 ($p < 0.001$), 4 > 1 ($p < 0.05$)
		C		1.829 (0.115)	2.144 (0.124)	2.261 (0.136)	2.369 (0.134)	6.186 ($p < 0.001$)	0.237	4 > 1 ($p < 0.001$), 3 > 1 ($p < 0.01$)
	Fear of unexpected adverse effects	A		3.419 (0.021)	2.805 (0.024)	3.543 (0.021)	3.419 (0.021)	372.119 ($p < 0.001$)	0.352	4 > 2, 3 > 4, 3 > 2, 3 > 1, 1 > 2 ($p < 0.001$)
		B		3.291 (0.146)	2.302 (0.132)	3.500 (0.140)	3.465 (0.149)	34.480 ($p < 0.001$)	0.638	1 > 2, 3 > 2, 4 > 2 ($p < 0.001$)
		C		2.117 (0.119)	2.216 (0.115)	2.369 (0.132)	2.432 (0.133)	2.944 ($p < 0.05$)	0.163	4 > 1 ($p < 0.05$)
	Possibility of misusing this technology	A		3.200 (0.021)	2.595 (0.023)	3.277 (0.022)	3.216 (0.022)	346.192 ($p < 0.001$)	0.339	4 > 2, 3 > 2, 1 > 2 ($p < 0.001$), 3 > 4, 3 > 1 ($p < 0.01$)
		B		3.198 (0.149)	1.744 (0.119)	3.116 (0.156)	3.419 (0.152)	57.719 ($p < 0.001$)	0.823	1 > 2, 3 > 2, 4 > 2 ($p < 0.001$), 4 > 3 ($p < 0.01$)
		C		2.532 (0.130)	1.495 (0.092)	2.378 (0.131)	2.288 (0.138)	33.428 ($p < 0.001$)	0.551	1 > 2, 3 > 2, 4 > 2 ($p < 0.001$)
	Bioethically questionnable	A		3.145 (0.021)	2.570 (0.024)	3.292 (0.022)	3.212 (0.022)	379.413 ($p < 0.001$)	0.355	4 > 2, 3 > 4, 3 > 2, 3 > 1, 1 > 2 ($p < 0.001$), 4 > 1 ($p < 0.05$)
		B		2.767 (0.148)	1.651 (0.104)	2.837 (0.159)	2.965 (0.162)	41.543 ($p < 0.001$)	0.699	1 > 2, 3 > 2, 4 > 2 ($p < 0.001$)
		C		1.838 (0.116)	1.333 (0.074)	1.955 (0.124)	1.910 (0.124)	17.428 ($p < 0.001$)	0.398	1 > 2, 3 > 2, 4 > 2 ($p < 0.001$)
	Cannot understand well and feel somewhat fearful	A		3.038 (0.022)	2.448 (0.023)	3.129 (0.023)	3.063 (0.023)	385.051 ($p < 0.001$)	0.359	4 > 2, 3 > 2, 3 > 1, 1 > 2 ($p < 0.001$), 3 > 4 ($p < 0.01$)
		B		2.093 (0.139)	1.337 (0.094)	2.081 (0.142)	2.093 (0.144)	22.383 ($p < 0.001$)	0.512	1 > 2, 3 > 2, 4 > 2 ($p < 0.001$)
		C		1.135 (0.043)	1.117 (0.047)	1.216 (0.062)	1.216 (0.062)	2.620	0.153	
Value	Universally favored to be promoted	A		2.455 (0.020)	2.956 (0.021)	2.450 (0.020)	2.588 (0.020)	210.792 ($p < 0.001$)	0.266	4 > 3, 2 > 4, 4 > 1, 2 > 3, 2 > 1 ($p < 0.001$)
		B		1.744 (0.109)	3.547 (0.137)	1.791 (0.099)	1.965 (0.116)	89.571 ($p < 0.001$)	1.026	2 > 1, 2 > 3, 2 > 4 ($p < 0.001$)
		C		1.793 (0.102)	3.757 (0.127)	1.622 (0.082)	2.036 (0.112)	118.378 ($p < 0.001$)	1.037	2 > 1, 2 > 3, 2 > 4, 4 > 3 ($p < 0.001$)
	Research considered insignificant	A		2.275 (0.020)	2.088 (0.020)	2.445 (0.021)	2.368 (0.021)	110.928 ($p < 0.001$)	0.193	4 > 2, 4 > 1, 3 > 4, 3 > 2, 3 > 1, 1 > 2 ($p < 0.001$)
		B		1.419 (0.087)	1.337 (0.087)	1.384 (0.081)	1.314 (0.073)	0.807	0.095	
		C		1.135 (0.049)	1.126 (0.054)	1.144 (0.056)	1.117 (0.054)	0.081	0.032	

Groups: A = Lay public ($n = 3000$), B = Experts in other fields ($n = 86$), C = Experts in molecular biology ($n = 111$)

P-values for F tests for ANOVA are adjusted with Geisser-Greenhouse corrections

P-values for F tests for ANOVA larger than 0.05 are not shown

Table 5 Influence of science literacy on attitudinal changes of benefit perceptions

Variables	Benefit perception					
	Model Y1 (gene editing)		Model Y2 (genetic modification)		Model Y3 (conventional breeding)	
	B	95%CI	B	95%CI	B	95%CI
Constant	0.320	[−0.307, 0.947]	0.723*	[0.063, 1.383]	0.273	[−0.414, 0.961]
Gender						
Male	0		0		0	
Female	−0.268*	[−0.488, −0.048]	−0.482***	[−0.714, −0.251]	−0.148	[−0.389, 0.093]
Age						
20–29 years	0		0		0	
30–39 years	0.390*	[0.076, 0.704]	0.299	[−0.031, 0.630]	0.467**	[0.123, 0.811]
40–49 years	0.268	[−0.039, 0.574]	0.086	[−0.237, 0.408]	0.413*	[0.077, 0.749]
50–59 years	0.057	[−0.262, 0.375]	0.010	[−0.325, 0.346]	0.325	[−0.024, 0.675]
60–69 years	0.032	[−0.276, 0.340]	−0.087	[−0.412, 0.237]	0.402*	[0.064, 0.740]
Education						
High school and lower	0		0		0	
Higher than high school	−0.190	[−0.384, 0.005]	−0.111	[−0.316, 0.094]	−0.215*	[−0.428, −0.002]
Family income						
Less than JPY 5,000,000	0		0		0	
JPY 5,000,000 and above	0.097	[−0.095, 0.289]	0.189	[−0.013, 0.391]	0.080	[−0.131, 0.290]
Occupation						
White collar	0		0		0	
Blue collar	0.039	[−0.216, 0.295]	−0.152	[−0.421, 0.117]	0.109	[−0.171, 0.390]
Unemployed	0.031	[−0.241, 0.303]	−0.113	[−0.400, 0.173]	0.062	[−0.236, 0.360]
Housewife	−0.055	[−0.337, 0.228]	−0.272	[−0.569, 0.026]	−0.030	[−0.340, 0.279]
Benefit of general genome research	0.034**	[0.013, 0.056]	−0.003	[−0.026, 0.020]	0.002	[−0.022, 0.026]
Trust in food governance	−0.043***	[−0.064, −0.021]	−0.037**	[−0.059, −0.014]	−0.073***	[−0.097, −0.049]
Risk-avoidance orientation	−0.029**	[−0.049, −0.009]	−0.024*	[−0.045, −0.002]	0.027*	[0.005, 0.050]
Science literacy	0.064**	[0.026, 0.101]	0.061**	[0.021, 0.100]	0.106***	[0.065, 0.147]
F (df1, df2)	5.436 *** (14,2893)		6.416*** (14, 2893)		6.253*** (14,2893)	
R^2	0.026		0.030		0.029	
Adjusted R^2	0.021		0.025		0.025	
n	2908					

Reference group: gender = male; Age = 20–29 years; Education = Lower than high school; Family Income = Less than JPY 5,000,000; Occupation = White-collar worker
Due to the use of the difference scores for dependent variables, R-squares of the models are generally low (Cohen, 1988)
***$p < 0.001$, **$p < 0.01$, *$p < 0.05$

was observed only for the conventional breeding technique. There were no effects of scientific knowledge to increase value perceptions of the two new S&T of gene editing and genetic modification. Overall trends of the models of value perceptions were similar to those of risk perceptions.

Discussion

We investigated both expert and lay perceptions on food application of new S&T by statistically examining whether attitude changes toward applied technologies were observed in relation to people's scientific knowledge. The approach of the current study, which empirically elucidated the perceptions of three groups (experts in molecular biology, experts in other fields, and the lay public) on gene editing compared with genetic modification and conventional breeding techniques, provides essential evidence for stakeholders concerning new breeding technologies.

Results of the current study demonstrated that domain-specific scientific knowledge affects people's risk, benefit, or value perceptions, according to the stratification of participants into three groups of experts in molecular biology, experts in other fields, and the lay public. The experts in molecular biology showed the highest benefit and lowest risk perceptions compared to the other two groups. As stated by Sandin and Moula (2015), those who believe in the potential of new agricultural technologies tend to refer to benefit aspects, while those who criticise tend to raise concerns of risk aspects.

The lay public tended to consider gene editing as closer to genetic modification by clearly differentiating the conventional breeding technique from the two newer techniques. They showed a dramatic increase in benefit perceptions and a significant reduction in risk perceptions after being provided information of conventional breeding (Fig. 4 and Table 4). Thus, the lay public appraised this technique with respect to outcomes as the one with the lowest risk and the highest benefit. However, the results of the single-factor within-subject ANOVA among the lay public also suggested that their perceptions of gene editing slightly improved compared with genetic modification. As such, the lay public somewhat identified the technical differences between gene editing and genetic modification, perhaps through process-based thinking.

The current study's approach of differentiating experts into two groups according to domain-specific scientific knowledge

Table 6 Influence of science literacy on attitudinal changes of risk perceptions

Variables	Risk perception					
	Model Y4 (gene editing)		Model Y5 (genetic modification)		Model Y6 (conventional breeding)	
	B	95%CI	B	95%CI	B	95%CI
Constant	0.685	[−0.558, 1.928]	0.743	[−0.455, 1.941]	3.614***	[1.796, 5.433]
Gender						
Male	0	0		0		
Female	0.124	[−0.280, 0.529]	0.341	[−0.049, 0.731]	−0.787**	[−1.379, −0.194]
Age						
20–29 years	0	0		0		
30–39 years	0.530	[−0.048, 1.107]	0.434	[−0.123, 0.990]	0.559	[−0.285, 1.404]
40–49 years	0.272	[−0.292, 0.836]	0.447	[−0.096, 0.991]	0.582	[−0.243, 1.407]
50–59 years	0.232	[−0.355, 0.819]	0.361	[−0.204, 0.927]	0.175	[−0.684, 1.033]
60–69 years	−0.127	[−0.695, 0.441]	0.624*	[0.077, 1.171]	−0.734	[−1.564, 0.097]
Education						
High school and lower	0	0		0		
Higher than high school	0.063	[−0.296, 0.421]	−0.007	[−0.353, 0.338]	−0.127	[−0.652, 0.397]
Family income						
Less than JPY 5,000,000	0	0		0		
JPY 5,000,000 and above	0.176	[−0.177, 0.529]	0.240	[−0.100, 0.581]	0.153	[−0.363, 0.670]
Occupation						
White collar	0	0		0		
Blue collar	−0.060	[−0.531, 0.410]	0.085	[−0.368, 0.539]	−0.942**	[−1.631, −0.254]
Unemployed	0.287	[−0.214, 0.788]	0.140	[−0.343, 0.622]	−1.390***	[−2.123, −0.658]
Housewife	−0.199	[−0.718, 0.320]	−0.270	[−0.770, 0.230]	−1.824***	[−2.583, −1.065]
Risk of general genome research	0.038***	[0.020, 0.057]	0.017	[−0.001, 0.035]	−0.059***	[−0.087, −0.031]
Trust in food governance	−0.056**	[−0.094, −0.018]	−0.059**	[−0.096, −0.022]	0.048	[−0.008, 0.104]
Risk-avoidance orientation	−0.066***	[−0.103, −0.029]	−0.028	[−0.064, 0.007]	−0.046	[−0.100, 0.008]
Science literacy	−0.038	[−0.103, 0.027]	0.018	[−0.045, 0.080]	−0.629***	[−0.724, −0.533]
F (df1, df2)	3.620*** (14, 2893)		2.075* (14, 2893)		22.592*** (14, 2893)	
R^2	0.017		0.010		0.099	
Adjusted R^2	0.012		0.005		0.094	
n	2908					

Reference group: gender = male; Age = 20–29 years; Education = Lower than high school; Family Income = Less than JPY 5,000,000; Occupation = White-collar worker
Due to the use of the difference scores for dependent variables, R-squares of the models are generally low (Cohen, 1988)
***$p < 0.001$, **$p < 0.01$, *$p < 0.05$

empirically showed that the perceptions of a specific science or technology will be different if scientists' expertise is different. Similar to those of the lay public, experts in other fields differentiated the benefit outcomes of the three technologies, probably based on process-based thinking. Contrary to the other two groups, experts in molecular biology did not differentiate the benefit outcomes of the three technologies. This finding is noteworthy because it empirically supported our hypothesis, suggesting that experts in molecular biology assessed the benefit aspects of gene editing through product-based thinking, not through process-based thinking.

Our further investigation revealed that the levels of perceptions of experts in other fields fall between those of experts in molecular biology and of the lay public in many items. That said, it is important to note that there were some characteristics that the two groups of experts generally shared and some aspects they did not share. As to the value perception concerning the application and promotion of scientific research to food, experts in other fields showed similar responses to experts in molecular biology to all three breeding technologies. Nevertheless, they responded similarly to the lay public concerning most of the items assessing risk perceptions. In fact, they displayed higher risk perception toward gene editing than toward genetic modification for the item ‘possibility of misusing this technology’, while the lay public showed higher risk perception toward genetic modification than toward gene editing for this item. As there was no statistical

Table 7 Influence of science literacy on attitudinal changes of value perceptions

Value perception

	Model Y7 (gene editing)		Model Y8 (genetic modification)		Model Y9 (conventional breeding)	
Variables	**B**	**95%CI**	**B**	**95%CI**	**B**	**95%CI**
Constant	−0.252	[−0.571, 0.068]	−0.014	[−0.338, 0.310]	−0.105	[−1.392, −0.256]
Gender						
Male	0		0		0	
Female	0.056	[−0.046, 0.158]	0.032	[−0.071, 0.136]	0.185**	[0.131, 0.460]
Age						
20–29 years	0		0		0	
30–39 years	−0.078	[−0.223, 0.068]	−0.117	[−0.264, 0.030]	−0.041	[−0.179, 0.290]
40–49 years	−0.032	[−0.174, 0.110]	−0.046	[−0.190, 0.098]	0.024	[−0.196, 0.262]
50–59 years	0.024	[−0.123, 0.172]	−0.001	[−0.150, 0.149]	0.139	[−0.023, 0.453]
60–69 years	0.038	[−0.105, 0.181]	−0.013	[−0.158, 0.132]	0.232**	[0.152, 0.612]
Education						
High school and lower	0		0		0	
Higher than high school	−0.003	[−0.093, 0.088]	0.100*	[0.008, 0.191]	−0.010	[−0.128, 0.163]
Family income						
Less than JPY 5,000,000	0		0		0	
JPY 5,000,000 and above	−0.008	[−0.097, 0.081]	−0.010	[−0.100, 0.080]	0.045	[−0.076, 0.211]
Occupation						
White collar	0		0		0	
Blue collar	−0.036	[−0.154, 0.083]	−0.062	[−0.182, 0.058]	0.022	[−0.181, 0.201]
Unemployed	0.019	[−0.107, 0.146]	−0.051	[−0.179, 0.077]	0.146	[0.049, 0.456]
Housewife	−0.034	[−0.165, 0.097]	−0.089	[−0.222, −0.044]	0.005	[−0.120, 0.302]
Value of general genome research	−0.003	[−0.025, 0.019]	−0.011	[−0.033, 0.012]	−0.014	[−0.016, 0.040]
Trust in food governance	0.014**	[0.004, 0.023]	0.011*	[0.001, 0.020]	−0.008	[0.006, 0.037]
Risk-avoidance orientation	−0.003	[−0.012, 0.007]	−0.006	[−0.016, 0.003]	0.008	[−0.023, 0.006]
Science literacy	−0.003	[−0.020, 0.014]	−0.021*	[−0.039, −0.004]	0.027**	[0.105, 0.158]
F (df1, df2)	1.019 (14, 2893)		1.657 (14,2893)		4.348*** (14, 2893)	
R^2	0.005		0.008		0.021	
Adjusted R^2	0.000		0.003		0.016	
n	2908					

Reference group: gender = male; Age = 20–29 years; Education = Lower than high school; Family Income = Less than JPY 5,000,000; Occupation = White-collar worker
Due to the use of the difference scores for dependent variables, R-squares of the models are generally low (Cohen, 1988)
***$p < 0.001$, **$p < 0.01$, *$p < 0.05$

difference between the two technologies in the group of experts in molecular biology for this item, the relationship between domain-specific scientific knowledge and risk perceptions on new S&T remains complex; perhaps there is no linear situation in their association.

The regression analyses of Tables 5–7 revealed that the influence of science literacy on the lay public's attitudinal change toward agricultural crops is confirmed all in benefit, value, and risk perceptions for the conventional breeding technique. For this technique, the effects after information provision were inverse: science literacy increased the benefit and value perceptions and reduced the risk perception. This hypothesis based on RQ2 was also confirmed in the benefit perceptions for the two new S&T of gene editing and genetic modification. Notably, however, such assumption was rejected by the analyses of risk perceptions and value perceptions for the two new S&T.

In interpreting the contradictory results presented above, one possible interpretation is that the assumption of the deficit model was valid only for conventional S&T, knowledge on which can be acquired through classroom education, but not valid for emerging S&T, knowledge on which may be acquired mainly through informal learning. An alternative interpretation is that the model's assumption on new S&T is valid only for increasing benefit perceptions but not for reducing risk perceptions or increasing value perceptions. We propose that the two interpretations above together constitute a new hypothesis about the relationship between scientific knowledge and public perceptions toward emerging S&T. In proposing the above hypotheses, we empirically demonstrated the deficit model's boundary conditions, and offered logic to explain previous empirical studies' inconsistency on deficit model type of explanations.

Limitations and future suggestions. Further empirical investigation should be conducted to confirm our new hypotheses about the deficit model. The assumption of the model was valid only for conventional S&T but not for emerging S&T; moreover, the model's assumption on new S&T is valid only for increasing benefit perceptions but not for reducing risk perceptions or increasing value perceptions, including all the possible other interpretations.

Because it was almost impossible for the current study to exclusively extract experts in molecular biology without a conflict of interest in this field, our participants who were experts in molecular biology may face this conflict, as their major earnings might be from gene editing or genetic modification. As a previous study investigating people's attitudes toward climate change risks (Kahan et al., 2012) proposed that attitude stemmed more from conflict of interest than from scientific knowledge, future studies may be needed methodologically to exclude experts in molecular biology with conflicts of interest in this field.

The statistical analyses were focused on attitudinal changes before and after the provision of information on the technological differences among gene editing, genetic modification, and conventional breeding. Our interest was in the factors of technological differences among the three technologies; therefore, we could not cover the contextual-specific factors related to gene editing. This point was raised by Bauer, Heinz (2002): context-specific factors, such as knowledge gaps and information gaps related to specific S&T in different countries or in different cultures, would affect study results. Further examinations should be conducted in different national and cultural contexts by methodologically separating these two factors.

The analyses were conducted using datasets obtained through online surveys. This method was suitable for the current study's approach of within-subject experimental design, but further studies should be conducted including utilising different modes of measurement. Replications should also be made with different items to assess people's benefit, risk, and value perceptions because number format and framing conditions of items may influence the obtained results (Peters et al., 2011). In addition, as we did not have a control group, we could not completely control the order effect or the effect from information provision. This is a limitation of the current study, and the accumulation of data for reproducibility shall ensure that the results can stand as foundation for future related work.

Conclusion

In this study, the lay public attitudes toward gene edited crops tended to be higher both in benefit and value perceptions and lower in risk perceptions than attitudes toward GM crops. Obtaining such results even in Japan, with its relatively lower acceptance and strict regulations on GM food, may further boost the potential of this emerging technology. We must note, however, the differences between gene editing and genetic modification were exceedingly small, compared to the differences between conventional breeding and genetic modification. Further, the effect of the lay public's science literacy on perceptions toward new S&T of gene editing or genetic modification after the information provision on applied technological differences was observed only for increased benefit perceptions and not for increased value perceptions or decreased risk perceptions.

We empirically demonstrated the deficit model's boundary conditions and offered logic to explain previous empirical studies' inconsistency in deficit model-type explanations. We demonstrated that (1) the model's assumption is valid for conventional science and technology (S&T) but not for emerging S&T, and (2) the model's assumption regarding emerging S&T was valid for increasing benefit perceptions but not for increasing value perceptions or reducing risk perceptions. These empirical results emphasise the uncertainty of people's attitude toward emerging breeding technologies. The ability of scientists, as well as policy makers to face such a complex situation is put to the test.

Data availability

The datasets generated and/or analysed during the current study are not publicly available due to the regulation from Japanese privacy protection law, but are available from the corresponding author on reasonable request.

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Author contributions

N.K.N. designed the current research, designed and organised the experimental questionnaire surveys, conducted the statistical analyses, and wrote the paper; T.M. designed the experimental questionnaire surveys; Y.I. conducted the statistical analyses; M.T. designed and organised the research project. All authors reviewed the paper.

Competing interests

The authors declare no competing interests.

Additional information

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