Consumer behaviour of environmentally sustainable agricultural practices:

Consumer acceptance of and willingness to pay for gene editing and reduced methane beef

A thesis submitted to McGill University in partial fulfillment of the requirements of the degree of

Master of Science

Name: Yury Simons

Supervisor: Prof. Mary Kathryn Doidge

Department of Agricultural Economics

McGill University, Montreal

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Abstract

The agricultural sector is under increasing pressure to mitigate its environmental impact, with livestock production being a significant contributor to greenhouse gas emissions. This study explores consumer willingness to pay (WTP) for beef cattle engineered with lower methane emissions through the genetic editing of the rumen microbiome. Using a choice experiment approach, we conducted surveys of Canadian consumers to estimate their preferences and WTP for ground beef produced from genetically edited cattle, as well as those fed feed additives to reduce methane emissions. Our findings reveal a positive WTP for beef produced with lower methane emissions but a negative WTP for gene-edited ground beef. We also find that consumers' preferences are influenced by factors such as their food technology neophobia, their perception of naturalness, and information presentation. There was no statistically significant difference in participants' WTP for conventional beef and that produced with methane-reducing feed additives, suggesting that feed additives may be a more viable strategy to reduce greenhouse gas emissions from beef production in the near term. The study shows the potential market acceptance of gene-edited livestock and feed additives as a viable strategy for sustainable agricultural practices if they are cheaper than conventional production methods, providing valuable insights for differing beef production methods aiming to balance environmental sustainability with economic viability.

Résumé

Le secteur agricole est de plus en plus contraint d'atténuer son impact sur l'environnement, la production animale contribuant de manière significative aux émissions de gaz à effet de serre. Cette étude explore la volonté des willingness to pay (WTP) pour des bovins de boucherie conçus pour produire moins d'émissions de méthane grâce à l'édition génétique du microbiome du rumen. À l'aide d'une expérience de choix, nous avons mené des enquêtes auprès de consommateurs canadiens afin d'estimer leurs préférences et leur consentement à payer pour du bœuf haché produit à partir de bovins génétiquement modifiés, ainsi que pour des bovins nourris avec des additifs alimentaires destinés à réduire les émissions de méthane. Nos résultats révèlent un WTP positif pour le bœuf produit avec des émissions de méthane plus faibles, mais un WTP négatif pour le bœuf haché génétiquement modifié. Nous constatons également que les préférences des consommateurs sont influencées par des facteurs tels que la néophobie des participants à l'égard des technologies alimentaires, leur perception du naturel et la présentation de l'information. Il n'y a pas de différence statistiquement significative entre la volonté des participants d'acheter du bœuf conventionnel et du bœuf produit avec des additifs alimentaires réduisant le méthane, ce qui suggère que les additifs alimentaires peuvent être une stratégie plus viable pour réduire les émissions de gaz à effet de serre de la production de bœuf à court terme. L'étude montre que le bétail génétiquement modifié et les additifs alimentaires peuvent être acceptés par le marché comme une stratégie viable pour des pratiques agricoles durables s'ils sont moins chers que les méthodes de production conventionnelles, ce qui donne des indications précieuses sur les différentes méthodes de production de viande bovine visant à équilibrer la durabilité environnementale.

Acknowledgements

I would like to take this opportunity to thank my parents for their constant support of me through my master's journey. Their help and guidance were the reason I could push through hard times.

My siblings Ada and Peter were always there for me and were always there to fallback on. You guys have a great future ahead of you.

I couldn't have done it without my friends Kuzey, Colton, Tom, and Ben. They provided me with constant support and helped me during both easy and hard times. Thanks guys.

My best friend, colleague, and my motivation 听听. Thank you for the revisions, writing tips, emotional support, and always being there for me throughout this trip.

My colleagues were the best to communicate about the entire process, constantly discussing and questioning things only we could relate with. A huge shoutout to Wendy for being someone I can constantly talk to.

Finally, the best supervisor I could have asked for, Mary was always pushing me past my limits and putting me in the right direction. Without her, I would be nowhere in this project and a huge thanks for putting up with my writing difficulties.

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Introduction

A growing global population and the increased demand for beef products have led to a significant increase in methane emissions from livestock production in recent years (FAO, 2023). As such, strategies to reduce greenhouse gas emissions that focus on livestock may be an avenue to lower methane emissions from the agricultural sector. For context, agriculture constitutes approximately one fifth of anthropogenic greenhouse gas emissions worldwide and 30% of worldwide anthropogenic methane emissions (Beauchemin et al., 2022). Livestock production specifically accounts for approximately 80% of global agricultural methane emissions (Reisinger et al., 2021).

The primary source of livestock emissions is the process of enteric fermentation, the digestive process that occurs within the stomachs and intestines of ruminant animals such as cattle, sheep, and goats (Smith et al., 2022). These animals have specialized stomach compartments, including the rumen, where microbial fermentation of ingested feed takes place. This microbial fermentation produces methane, which is 28 times more potent than carbon dioxide at containing heat in the atmosphere (Thompson and Rowntree, 2020) and is one of the three main targets for emission reduction in the agricultural sector, alongside carbon dioxide and nitrous oxide (Government of Canada, 2023). With the goal of reducing greenhouse gas emissions by 40% by 2030 and net zero by 2050 (Government of Canada, 2023), livestock production needs both the application of current greenhouse gas mitigation strategies (Alemu et al., 2017; Beauchemin et al., 2022), along with the introduction of new strategies that target emission reduction.

Current livestock mitigation strategies include methane-reducing feed additives such as seaweed (Kinley et al., 2020) and manure management strategies such as solid covers over manure storage (Ambrose et al., 2023). Feed additives have been shown to reduce methane by as much as 98% (Kinley et al., 2020), but have low adoption rates among Canadian farmers (Davidson et al., 2019). Feed additives cost money to implement throughout an animal's lifespan, and constant exposure to feed additives could lead to unprecedented effects on the cattle due to trace elements and minerals found in additives (Kinley et al., 2020). As such, new strategies that could decrease methane emissions along with lifelong application to cattle may be promising. A novel strategy that fits these conditions is gene editing, which has emerged as an avenue to mitigate methane emissions from cows by altering the bacteria present in the rumen microbiome, consequently lowering methane output (Subedi et al., 2023).

Gene editing may be a solution in greenhouse gas-reducing practices due to its potential to reduce methane emissions and long-term applicability to livestock, compared to strategies such as feed additives. However, because gene editing is a new technology in the field of agriculture, there are questions about its consumer acceptance. Canadian consumers are reluctant to purchase gene-edited foods, perhaps due to a lack of information about this technology (Vasquez et al., 2022; Shigi and Seo, 2023). Although consumers have been shown to have a lower willingness to pay for gene-edited products compared to conventional products (Marette et al., 2021), they may be willing to purchase gene-edited foods with environmental benefits (Muringai et al., 2020; Martín-Collado et al., 2022; Shigi and Seo, 2023). A product that brings environmental benefits through gene editing thus holds promise for consumers by providing an option for consumers who value climate change mitigation.

As consumers may be willing to purchase such a product, the way the information is presented through labelling is also important to consider, as differing labelling procedures may have different effects on consumer acceptance (Rondoni and Grasso, 2021). Some examples include carbon footprint labelling, sustainability labels such as organic and fair-trade labels, and product origin and production method labelling, all leading to differing willingness to pay (Rondoni and Grasso, 2021). Although there is some implementation of greenhouse gas mitigation labelling around the world, there is a lack of it in the Canadian food system (Dobson et al., 2023). There has been research about differing labelling procedures for both gene editing (Hu et al., 2022), and methane mitigation for beef (Tan et al., 2014), but none in the context of consumer acceptance of beef from cattle with gene-edited rumen bacteria (henceforth referred to as gene-edited beef) for lower methane emissions. Such research could provide insight into the real-market feasibility of such a product.

This thesis uses a discrete choice experiment to examine consumer acceptance of and willingness to pay (WTP) for ground beef produced with practices to lower methane emissions, including beef from cattle that are fed seaweed additives and cattle produced with gene editing of the rumen bacteria responsible for methane emissions. We will also investigate how food technology neophobia and consumers' perception of food naturalness influence acceptance of novel technologies. This thesis attempts to address the gap of economic research surrounding gene editing's application to beef production to lower methane emissions. We use a survey to acquire data from Canadians about their beef consumption and beef purchasing habits. We use mixed logit models to determine the factors that affect consumers demand for beef in contrast to beef fed feed additives and gene-edited beef for lower methane emissions. The results of this study provide valuable insight into whether gene editing of beef cattle is a viable option for reducing the carbon footprint of individuals meat consumption.

1. Literature Review

To understand the current economic landscape for gene editing and greenhouse gas mitigation for beef, recent studies are an important tool for assessing present-day market acceptability. This section will review the existing literature on agriculture's contribution to greenhouse gas emissions and climate change, along with literature on consumer behaviour regarding environmentally friendly and gene-edited agricultural products. The effect of information and labelling on consumers' decisions will also be reviewed. There is no research regarding consumer willingness to pay (WTP) for beef products from gene-edited cattle with lower methane emissions, but there are parallel studies for other livestock and plant breeds that are of note and can be applied to this context.

1.1. Greenhouse Gas Mitigation in Livestock Production

Several strategies have been applied to target the rumen and the process of enteric fermentation to reduce methane emissions from livestock. A common technique is adjusting animal feed composition, which can improve digestion efficiency and reduce the process of enteric fermentation and methane production (Kinley et al., 2020; Honan et al., 2021). One such way is through lipid supplementation as dietary lipids mitigate methane production (Beauchemin et al., 2022; Eugène et al., 2008; Honan et al., 2021). One of the cheapest additive options is an oilseed additive, which has been shown to reduce methane emissions by 36% (Bayat et al., 2018). Oilseed additives are seen as safe for both animals and humans (Beauchemin et al., 2022), and hold potential for farmers who can afford them and want to reduce methane emissions. Although they are effective at reducing methane emissions, the financial costs of the constant lipid feed additives into cattle diets pose the largest problem for the wide-scale implementation of additives (Beauchemin et al., 2022). An alternative to lipid supplementation is chemical supplementation to feed. For example, 3-nitrooxypropanol is a molecule that inhibits methane production in the rumen (Beauchemin et al., 2022; Pitta et al., 2022). The addition of 3-nitrooxypropanol to cattle feed has been shown to reduce methane emissions by as much as 82% (Yu et al., 2021). Another feed additive is seaweed, with certain seaweed additives reaching up to 98% reduction in methane production (Kinley et al., 2020). Finally, feed supplemented with forages has been shown to reduce methane emissions in ruminant animals by up to 34.4% (Bayat et al., 2017).

Genetic modification of feed crops has also been implemented to lower methane emissions in the rumen in laboratory settings. Genetic modification is the process of manipulating an organism's genome through engineering where parts of an organism's genome are replaced with another part of a different organism's genome. This is also commonly referred to as transgenic modification. Winichayakul et al. (2020) genetically modified ryegrass to have a higher lipid content and applied it to rumen fluid in vitro for 24 hours, finding 10-15% lower methane production. This finding leads to possible application in animal feeding trials but has the same economic implementation problem as other feed additives (Winichayakul et al., 2020).

Experimental attempts to combine multiple methane reduction strategies have shown mixed results. An experiment by Van Zijderveld et al. (2011) attempted to combine lipid and chemical feed additives in lactating dairy cows and found that the combination of feed additives did not yield lower methane emissions than conventional dairy. Contrasting that result, Beauchemin et al. (2011) estimated a combined reduction of 17% being achieved from a combination of feeding oilseeds, improved forage quality, and an increasing number of calves weaned. This reduction in greenhouse gas was more than the 8% reduction from a singular mitigation strategy of feeding canola seed. These results indicate the lack of consistent conclusions for the use of multiple methane reduction strategies.

Early-life intervention is another attractive avenue for methane mitigation. Permanent methane reduction has been achieved when livestock are fed methane-reducing additives such as 3-nitrooxypropanol for 14 weeks when young (Meale et al., 2021). Compared to the post-weaning use of feed additives, the pre-weaning application has shown lower methane emissions continuing through the cattle's lifespan even post-treatment (Meale et al., 2021). Although an attractive avenue, little research has been done on the long-term effects of early-life intervention.

Selective breeding of livestock has also been used to attain desired effects. Selective breeding is the process of selecting plants or animals with desired traits and including them in a breeding program to achieve the desired traits in the offspring (Løvendahl et al., 2018; De Haas et al., 2021). Breeding programs aimed at selecting animals with both lower methane emissions per unit of productivity and higher feed efficiency are potential strategies to reduce the greenhouse gas emissions of ruminant livestock (Beauchemin et al., 2022; Løvendahl et al., 2018). There have been genetic traits identified in cattle that tie directly to both feed efficiency and methane emissions of the rumen microbiome (Løvendahl et al., 2018). Despite its potential for reductions in methane emissions, selective breeding usually takes multiple generations to achieve desired results in offspring due to the possibility of unforeseen and unwanted correlated effects through the breeding process, such as reduction of the gene pool (Mrutu et al., 2023; De Haas et al., 2021). With a lack of a diverse gene pool, it becomes harder to be selective about desired traits as they are less frequent in less diverse pools, along with a possibility of a negative genetic effect being more common throughout the population. Along with taking time for noticeable effects, selecting specific traits such as lower methane emissions could lead to suboptimal results for the cattle's health and other non-selected traits (Løvendahl et al., 2018).

1.1.1. Current Use of Mitigation Strategies

Some strategies discussed in the previous section have had some real-world applications. A study by Glenk et al. (2014) focused on dairy farmers' greenhouse gas emission reduction and their adoption of mitigation practices. The data were collected from 235 Scottish farmers, who were surveyed about their use of 20 practices. The results indicate that feed and ration management was one of the most adopted practices for greenhouse gas reduction, with an adoption rate of 94.9%; conversely, adding lipid additives to feed was adopted by only 3.8% of farmers (Glenk et al., 2014). The reasons for such a large discrepancy in the implementation of animal nutrition practices may be due to farmers' unfamiliarity of novel practices such as adding lipids to feed, along with a lack of economic incentives to include such practices in their production systems (Glenk et al., 2014).

The use of 3-nitrooxypropanol (3-NOP) was implemented on 56 Holstein cows to measure the reduction in methane emissions by Melgar et al (2020). They found that after administering 60mg of 3-NOP per kilogram of Holstein weight, methane emissions were reduced by 26% compared to cows without the feed additive (Melgar et al., 2020). The treatment had no effect on milk or body composition, indicating its effectiveness in reducing emissions with lack of side-effects. 3-NOP also increased feed efficiency in the cows as dry matter intake decreased yet the cows sustained their weight (Melgar et al., 2020). This finding highlights the efficacy of 3-NOP on Holstien cows in reducing emissions and not tainting the quality of milk or the health of the cow.

In the Canadian context, Davidson et al. (2019) found that 71% of Albertan beef farmers added forage and legume crops to animal feed to lower emissions, but only 39% implemented the more effective lipid and oilseed feed additives. This discrepancy is due to the lack of economic incentives of adoption, as there are no economic benefits for farmers to implement feed additives that lower emissions (Davidson et al., 2019). An interesting finding in the study is that 79% of Albertan farmers have adopted animal breeding decisions to improve feed efficiency, and 15% are willing to adopt the practice (Davidson et al., 2019). This high percentage of animal breeding adoption is due to its lack of economic burden to implement, along with other positives that come with selective animal breeding such as larger size (Davidson et al., 2019).

1.2. The Promise of Gene Editing

Although many strategies target the rumen to reduce methane emissions, the adoption of the strategies is limited and insufficient to reach the goals set by the Government of Canada (Islam and Lee, 2019). Even all current effective rumen mitigation practices were adopted by all livestock producers globally, enteric methane emissions would decrease by only 14%. This is sufficient to reach the 2030 goal of 1.5 °C set by the Paris Agreement, but even 100% adoption is insufficient to reach the 2050 goal of net zero set by the Paris Agreement and the Government of Canada (Arndt et al., 2022). As such, novel mitigation strategies are important to consider. One such strategy is gene editing bacteria in the rumen for lower methane emissions. Compared to the strategies discussed previously, gene editing has the potential to be widespread in agriculture on a large scale with low adoption costs for producers (Eş et al., 2019). It is also a technique that has multiple applications for affecting the enteric fermentation process, both applicable to novel feeds, which can be fed to cattle and altering the genetic makeup of the cattle itself (Subedi et al., 2022).

Gene editing is a form of technology called genetic engineering. Genetic engineering is a set of biotechnological techniques that directly manipulate an organism's genes. Scientists can modify an organism's genetic material, such as DNA or RNA, to achieve specific traits or characteristics. Genetic modification is also a form of genetic engineering, also known as the transgenic process, in which an organism's genome is altered by the introduction of foreign genetic material to create new variations of the organism (Bawa and Anilakumar, 2012). In contrast, gene editing is primarily an intragenic process by which organism's own genetic material is edited by cutting and manipulating to achieve desired effects (Bullock et al., 2021).

Gene editing, particularly Clustered Regularly Interspaced Short Palindromic Repeats (CRISPR), has been proposed as a method to lower methane emissions from cattle by extracting methanogenic archaea, single-celled organisms that produce methane in the rumen, and editing their genes to inhibit methane emissions (Subedi et al., 2022). The proposed method edits the genes of the archaea in vitro to produce less methane, reinserting them into the host after they have been edited (Subedi et al., 2022). Alterations in methane-emitting genes can lead to decreased methane production without compromising the animal's overall health and productivity or impacting the animals' nutritional efficiency (Sicard, 2023). CRISPR can also be used to disrupt the defence system of the organism that defends against methanogen-destroying lytic phages, leaving the organism able to take in more phage DNA that attacks methanogenic genomes, subsequently reducing emissions (McAllister et al., 2015).

There has been a growing prospect of CRISPR and its application to mitigating methane emissions from the rumen microbiome (Subedi et al., 2022; Mrutu et al., 2023). This is in part due to its regulatory contrast to genetic modification, which is regulated more strictly than gene editing by regulatory bodies such as the U.S. and Canada (Subedi et al., 2022; Mrutu et al., 2023). This growing prospect leads to questions about the future applicability of such a mitigation strategy for consumer perception, particularly for cattle and beef.

1.3. Consumer WTP for Genetically Engineered Products and Greenhouse Gas Mitigation

Although novel, the economic effects of gene-edited livestock and its subsequent food products are a fascinating prospect, as consumer attitudes to genetic editing have been negative (Zanoli et al., 2013; Bearth et al., 2024) and positive for environmentally friendly products (Burnier et al., 2021). Consumers may have conflicting motivations when faced with the option of purchasing and consuming gene-edited foods that provide emission reduction. The negative stigma associated with gene editing, especially in food products, could lower WTP for gene-edited beef. However, this could be offset by a higher WTP for greenhouse gas emission reduction provided by the gene-edited beef. The following discussion will explore the WTP associated with gene editing and greenhouse gas mitigation, and the conflicting motivations consumers have regarding gene-edited low-methane beef. As gene editing is a novel technology and has a lack of economic literature regarding food products, genetic modification studies will also be considered due to both being forms of genetic engineering.

Gene-edited food products are almost always less accepted in the hypothetical food market, and that can be reflected in the lower WTP. This lower WTP can be shown in an example by a study by Muringai et al. (2020), who compared consumer willingness to pay for gene-edited potatoes versus genetically modified potatoes (Muringai et al., 2020). The researchers used a stated preference questionnaire to determine WTP for multiple attributes of potatoes (Muringai et al., 2020). They found that gene-edited potatoes are more favoured than genetically modified potatoes, with the WTP for gene-edited potatoes $0.31 higher than that for genetically modified potatoes (Muringai et al., 2020). Genetically modified potatoes were seen as less natural than gene-edited potatoes, even though both products are novel and affect the genome of the potato (Muringai et al., 2020).

This result is consistent with other studies examining consumer willingness to purchase genetically modified ingredients. Colson et al. (2011) used an auction experiment where participants could bid on broccoli, tomatoes, and potatoes in multiple rounds (Colson et al., 2011). Labels to indicate foods produced with intragenic and transgenic techniques presented in other rounds of the auction (Colson et al., 2011). The study found that 48% of participants preferred intragenic food labelling and 20% preferred the plain label alternative, suggesting that intragenic foods were better received than transgenic foods (Colson et al., 2011).

A study by Ding et al. (2023) found similar results for gene-edited versus genetically modified foods using a multiple price list contingent valuation method to elicit consumer WTP (Ding et al., 2023). The authors asked participants to choose their preferred choice among conventional, genetically modified rice, and gene-edited rice, finding a WTP of 3.64 Chinese Yuan more for gene-edited versus genetically modified rice compared to conventional rice (Ding et al., 2023). This means that gene-edited rice was seen as a more favourable alternative to conventional rice than genetically modified rice (Ding et al., 2023). The reason for this difference in WTP is differences in consumer perception of the impact on health, the environment, and ethical concerns surrounding genetic modification compared to the more positive view of gene editing (Ding et al., 2023). This study also states that gene-edited foods have more market potential than genetically modified foods (Ding et al., 2023), consistent with the previously mentioned studies.

Zanoli et al. (2013) used choice modelling to estimate Italian consumers' WTP for multiple beef products, including hypothetical cattle fed genetically modified feed. The researchers wanted to measure consumer perception of genetically modified cattle with the newly introduced regulation regarding mandatory labelling for genetically modified foods (Zanoli et al., 2013). This was contrasted with organic production methods, conventional production methods, and production methods highlighting animal welfare (Zanoli et al., 2013). Organic beef was favoured most, with a WTP of approximately 14 €/kg more than conventional beef (Zanoli et al., 2013). Consumers were also willing to pay 24.69 €/kg more for beef produced within their own country's borders and 6.4 € more for high biodiversity preservation, compared to conventional beef (Zanoli et al., 2013). However, consumers were willing to pay 0.76 € less, on average, for beef fed genetically modified feed than for conventional beef (Zanoli et al., 2013).

This trade-off faced by consumers who value one attribute higher than another is presented in a paper by Burnier et al. (2021), in which the researchers focused on the socio-environmental concerns that consumers may face when purchasing beef. To do this, a qualitative study was first conducted to determine which attributes mattered most to consumers when purchasing beef. The attributes include traceability, brand, greenhouse gas (CO_2) emission reduction, and animal welfare certifications, along with price. For the quantitative step, they used a discrete choice experiment to determine WTP (Burnier et al., 2021). Participants were asked to choose among two choices that varied in price, traceability, brand, greenhouse gas emissions reduction, and animal welfare certification. The WTP for lower greenhouse gas emissions was not significantly different from conventional beef, while WTP for sustainable brands with positive socioenvironmental attributes was $2.89 more than conventional (Burnier et al., 2021).

Britton et al. (2019) estimated consumer WTP for a type of gene editing technology called RNA interference. RNA interference introduces new RNA into the organisms' cells that can affect the animal's muscle growth, sex ratio, and physiological changes. The researchers used an online survey to collect data from 3,000 U.S. consumers. Participants were given a choice experiment to determine their WTP for beef products with antibiotic use, RNA interference use, and USDA grade (e.g., standard, commercial, utility, cutter, and canner) (Britton et al., 2019). Participants were presented with base information about RNA interference technology, and three different labelling regimes, including a sentence which has no mention of labelling, a sentence which approves labelling, and a sentence with mandatory approval for labelling. A multinomial logit was used to estimate WTP (Britton et al., 2019). The researchers found that participants had the lowest WTP for meat produced with RNA interference, with a WTP of around $3 less than USDA-approved meat (Britton et al., 2019). It was also found that mention of the negative attribute of biotechnology application leads to lower WTP, indicating that not mentioning the attribute could increase WTP for the beef (Britton et al., 2019).

Yang et al. (2019) examined consumer preferences for genetically edited apples, particularly those produced with CRISPR. They used a survey to determine cultural cognition scales, along with a discrete choice experiment. Attributes presented in the choice experiment were the price, appearance of the apples, health benefits, and production methods which included gene editing and genetic modification, along with conventional and edible coating. The choice experiment was administered to a sample of 697 Canadian adults. A random parameters logit model was applied to the data which considered the cultural scores of each respondent. Those who held hierarchical worldviews (i.e., those who value individual characteristics in determining the distribution of social resources and opportunities), were found to be willing to pay less for genetically modified foods than those with egalitarian worldviews (Yang et al., 2019). Those with communitarian worldviews and those who value solidarity amongst society, were more accepting of gene editing.

Ortega et al. (2022) focused on consumer preferences for gene-edited pork and rice in China. Using a stated preference method, they found that consumers had a lower willingness to pay for food products altered with biotechnology (i.e., genetic modification and gene editing) compared to food produced without the use of biotechnology, but they were more willing to purchase gene-edited products than genetically modified products (Ortega et al., 2022). The study notes varying consumer responses between rice and pork products regarding biotechnology information and product traceability, suggesting perceptions of food safety threats influence consumer choices negatively (Ortega et al., 2022). Biotechnology solutions were perceived as a signal of susceptibility to food safety threats as only where the food was cultivated in a non-safe area would need that kind of biotechnology to be applied (Ortega et al., 2022). It also highlights that reducing skepticism toward food biotechnologies could increase consumer acceptance, particularly among younger, educated, and higher-income individuals (Ortega et al., 2022).

Lombardi et al. (2017) examined Tuscan consumers' behaviour towards milk produced without negative climate effects of milk production on greenhouse gas emissions using a choice experiment and presenting participants with information about climate change. The sample size was relatively small, only 39 respondents, but the results were of note regardless. The results showed the importance of information presentation in climate-conscious products (Lombardi et al., 2017). More information about climate change was presented with each step, which led to the significance of the price decreasing more with each step. Participants were more willing to purchase climate-neutral milk, compared to the beginning of the experiment. The role of information is useful to take away from this study as the pre-information treatment populations' knowledge of climate change was low.

A study by Vasquez et al. (2022) examining Canadian consumers' preferences for genetically edited foods found that the largest difference in willingness to consume is the environmental impact of the food product (Vasquez et al., 2022). They state that environmental impact is the only food value that strongly affects willingness to consume, with consumers less likely to select gene-edited apples if they value the environment highly (Vasquez et al., 2022). This is due to the fear by consumers that gene editing is environmentally harmful and risks lowering biodiversity and original plant varieties. They also found that consumers who were averse to new food technologies were also less likely to consume all novel food products (Vasquez et al., 2022). Participants knew little about the science of food production, as deducted from 62% of respondents thought that corn is virtually unchanged from those of several thousand years ago, but were confident in Canada's food safety systems (Vasquez et al., 2022).

Hu et al. (2005) used a choice experiment to examine how consumers behave under mandatory and voluntary labelling procedures for genetically modified bread. Four hundred and twenty-seven participants were presented with bread choices that varied in their brand name, flour type, price, and presence of genetically modified ingredients (Hu et al., 2005). The presence of genetically modified ingredients led to lower utility for the consumer, such that they were willing to pay between $1.50 to $2.50 for more genetic modification information about the ingredients, and thus can be interpreted as the presence of genetically modified ingredients in bread being a negative attribute for bread and thus less likely to be purchased (Hu et al., 2005).

The final research of note is the one by Kilders and Caputo (2021) in which they used a hypothetical discrete choice experiment to elicit consumer WTP for milk from gene-edited cows. Dehorning dairy cows was a development of gene editing at the time to enhance animal welfare of horned dairy cows, and thus Kilders and Caputo wanted to find the consumer response to such a novel technology in terms of WTP for the milk from those gene-edited cows (Kilders and Caputo, 2021). From a survey of 1043 U.S. consumers, they determined that although the WTP for the milk was always negative, the more information that was delivered to the participant, the more willing they were to consume the milk leading to a higher WTP (Kilders and Caputo, 2021). The control group with no information had a WTP of -$2.67 for the milk from gene-edited cows but went up to -$2.16 when provided with a video explaining gene-editing prior to the choice experiment (Kilders and Caputo, 2021). This research indicates the role that information has on a hypothetical food product like milk from gene-edited cows.

1.4. Naturalness and Food Technology Neophobia

The debate surrounding gene editing often centres on the idea of naturalness, with discussions ranging from the ethics of manipulating an organisms' genetic material to the potential consequences on ecosystems and human health (Beghin and Gustagon, 2021). The complexities of the naturalness argument in the context of gene editing include both the perceptions and realities surrounding the use of biotechnology in altering the genetic makeup of organisms (Van Haperen et al., 2011; Beghin and Gustagon, 2021). While traditional breeding is often perceived as more natural, both breeding and gene editing introduce genetic changes, raising questions about the inherent naturalness of each method (Van Haperen et al., 2011; Vasquez et al., 2022). Products of selective breeding techniques are common in consumers’ consumption patterns, even though genetically it rearranges more of the organism's genome as opposed to editing its genes. Despite the controlled and specific nature of the edits done by gene editing, primarily due to their intragenic methods, concerns about naturalness persist prompting discussions about the boundaries between natural and engineered organisms (Van Haperen et al., 2011; Vasquez et al., 2022).

Public perception plays a crucial role in shaping the discourse on naturalness in genetic engineering (Van Haperen et al., 2011). Some consumers associate traditional breeding with naturalness, viewing it as a continuation of age-old agricultural practices. Gene editing, however, is often perceived as a radical departure from nature, raising questions about the safety and authenticity of genetically engineered organisms (Vasquez et al., 2022; Beghin and Gustagon, 2021). Different cultures and ethical frameworks contribute to diverse perspectives on what is deemed natural (Van Haperen et al., 2011). Some argue that the ability to enhance crops for improved nutrition or develop disease-resistant animals aligns with humanity's historical role in shaping its environment (Van Haperen et al., 2011). Others express concerns about the unintended consequences of manipulating genetic material and the potential disruption of natural ecosystems (Van Haperen et al., 2011). There is an argument that gene editing is responsible for maintaining naturalness and that ethical genetic engineering is a natural extension of humanity's ongoing efforts to improve agricultural practices and enhance the well-being of living organisms (Van Haperen et al., 2011). There can also be a difference in the valuation of naturalness between consumers who think a product is not natural yet still consume the product (Beghin and Gustagon, 2021). One such example is sugar-free sodas, which are not natural or perceived as natural, yet are still purchased by consumers. This disconnect between consumer demand and their perception of a product's naturalness is interesting to consider in the framework of gene-edited beef.

As it is not yet available to purchase, there is no concrete evidence of consumer demand for gene-edited beef with lower methane emissions. This can lead to skepticism of new technologies entering the market. The skepticism towards food biotechnologies is called food technology neophobia, or aversion to foods produced with novel technologies (Verneau et al., 2014; Vasquez et al., 2022; Cox and Evans, 2008). Food technology neophobia indicates the reluctance consumers have about consuming foods produced with novel technologies (Cox and Evans, 2008). This means that the more food technology neophobic someone is, the less likely will be willing to consume foods from novel technologies. The technology of gene editing is relatively new, especially when applied to food products; thus consumers may be much more reluctant to consume foods that have undergone gene editing (Vasquez et al., 2022). Consumer knowledge of gene editing and genetic mutation is lacking, leading to confusion and mistrust in gene-edited products (Cummings and Peters, 2022). This lack of knowledge leads to decisions being made through spontaneous associations, otherwise known as the affect heuristic, skewing negatively for acceptance of gene editing (Bearth et al., 2024). The affect heuristic encompasses the idea that people rely on emotions to make decisions; in the case of gene-edited food products, people's emotions would likely affect their purchasing decisions. If people viewed gene editing negatively, they might place immediate skepticism and likewise negative feelings on any food product that mentions gene editing. Although genetic mutation is a natural part of any organism, mentioning gene mutation leads to lower trust in the product stating that it is less natural (Cummings and Peters, 2022). There are undesired effects of gene editing, such as selecting undesired DNA sequences that could bring harm to the host and long-term genetic consequences such as permanent negative changes in genomic makeup which could reverberate through multiple generations (Camargo et al., 2023). These undesired effects are all a part of the hesitancy to allow gene-edited food products into the market (Cummings and Peters, 2022).

1.5. Is there a Market for Gene-Edited Beef?

All the issues highlighted bring up the question of whether there is market potential for such a food product. Kilders and Caputo (2024) found that there is a market for environmentally friendly beef. Using a discrete choice experiment and a reference price-informed design to determine consumer preference for low-carbon beef compared to conventional, USDA-approved, and animal welfare-focused beef, they found that the share of the market that environmentally friendly low-carbon beef can be as high as 5% (Kilders and Caputo, 2024). This percentage is close to the market share of organic of 7% and animal welfare-certified beef of 6% found in the study (Kilders and Caputo, 2024). The 5% was found using the base model in only one of the treatments, and it was much lower in the other treatments and models (Kilders and Caputo, 2024). Although the lowest percentage of all options, there is some interest in low-carbon beef. The demand curve elicited from the experiment found that an average price of $18 per pound of beef ribeye would lead to a 15% market share for low-carbon beef, and a price of $24.99 per pound would lead to an 11% share (Kilders and Caputo, 2024). This means that even with price variation, there is still demand for low-carbon beef from consumers (Kilders and Caputo, 2024).

Although the acceptance of environmentally friendly beef by consumers is a sign of the possibility for gene-edited beef to enter the market, the presence of gene-edited beef in consumer decision-making has complications regarding consumer acceptance and its consequent willingness to pay. Societal shifts may be necessary for gene-edited foods be more present in consumers' purchasing decisions. For example, other countries have very different perspectives on gene editing and genetic modification technology, primarily those in Asia. China is currently leading the technological push in gene-edited agriculture, with multiple research avenues on their agricultural systems (Zhao et al., 2019). Such avenues include gene editing animals for milk modification, meat production, meat composition, meat quality, and disease resistance (Zhao et al., 2019).

A more applicative societal shift to the Canadian context is that of cell-cultured beef and its growth as a potential food option. Consumer studies of consumer WTP for cell-cultured beef may reflect consumers' attitudes about gene-edited beef. One such study by Kantor and Kantor (2021) found that consumers were willing to pay $1.11 more for cell-cultured beef burgers than conventional burgers, and when framed as a better-tasting alternative than conventional burgers found an increase in willingness to pay $1.66 more than conventional. These results did not account for the positive environmental effect of cell-cultured beef as opposed to conventional beef, bringing more potential for novel beef products to environmentally conscious consumers.

Gene-edited cattle with lower methane emissions are driven by a dual commitment to sustainable agriculture and matching beef demand. Gene editing offers a promising solution to lowering agricultural greenhouse gas emissions by targeting specific genes involved in methane production, thereby reducing the environmental impact of beef production. Consequently, as illustrated by the literature, there is a growing field of research for genetically edited beef that aligns with these values, providing an opportunity for the livestock industry to meet consumer expectations for environmentally friendly meat while addressing concerns about the environmental impact of traditional beef production methods. This emerging market not only responds to the urgent need for sustainable agriculture practices but also reflects a broader societal shift towards more environmentally conscious and responsible consumption. As such, research finding consumers' willingness to pay for genetically edited cattle with lower methane emissions is warranted.

1.6. Research Question

There is a lack of literature that examines consumer willingness to pay for gene-edited food products, particularly the use of gene editing to lower to greenhouse gas emissions from cattle. The research question of this thesis is what the willingness is to pay for ground beef from gene-edited beef cattle designed for lower methane emissions. We will explore the factors that influence these attitudes, such as awareness, perceived benefits, perceived naturalness, and willingness to pay for sustainably produced beef products.

This research contributes to the literature in several ways. First, there is little research on consumer attitudes toward gene-edited beef cattle and less about the trade-off faced by consumers between gene editing and lower greenhouse gas emissions. The trade-off that will be evaluated is between the commonly negative public-perceived gene editing and the positively perceived environmental sustainability. And second, this research will show how participants' food technology neophobia and their perceptions of naturalness affect their WTP for gene-edited beef products.

2. Conceptual Framework

Understanding consumer willingness to pay for gene-edited, low methane-emitting beef requires a robust understanding of the economic theory that integrates various factors influencing consumer preferences and behaviour. The foundation for determining consumer behaviour is the theory of utility maximization under a budget constraint proposed by Lancaster in 1966 (Lancaster, 1966). This theory states that the utility derived from a good comes from the attributes of the good rather than just the good itself (Lancaster, 1966). This can be thought of as a consumer choosing good A over good B due to the perceived utility of the attributes of good A being higher than that of good B.

Random utility theory stems from the Lancastrian approach and is used to perform quantifiable analysis of consumer preferences. Random utility theory was developed by McFadden in 1974 to link the deterministic model with the statistical model of human behaviour (McFadden, 1974). A consumer's utility for a good is both deterministic, meaning that the outcome of any consumer's choice can be predicted given a product with identical attributes and levels of the attributes, and random, which is the individual tastes and perceptions of the good.

Random utility theory states that the utility of each choice presented to the consumer can be represented as a function of the attributes of the good along with an error term. This is shown in Equation (1), such that

$$U_{nj} = \beta X_{nj} + \varepsilon_{nj} \tag{1}$$

where U_{nj} represents the utility of individual *n* from alternative *j*, X_{nj} represents the attribute *X* for individual *n* based on the alternative options *j*, β is the vector of coefficients for the observed variables for individual n, and ε_{nj} is the error term. The βX_{nj} is the deterministic part of the equation which can be estimated through the choice experiment.

The likelihood of a consumer selecting a specific good over another is determined by the probability that the utility derived from the chosen option surpasses the utility derived from all other options. Buyers opt for the product option that yields the greatest utility. In the scenario where there are two options for a product, j and k, buyer n will select option j if its utility exceeds that of the option k. To express this formally:

$$U_{nj} = V_{nj} + \varepsilon_{nj} \quad (2)$$

where U_{nj} represents the utility from the combination of V_{nj} and ε_{nj}, which are both the deterministic part and stochastic part of a consumer n's choice for good j. V_{nj} is equal to βX_{nj} from Equation 1. Subsequently, the utility for consumer k can be represented as such:

$$U_{nk} = V_{nk} + \varepsilon_{nk} \quad (3)$$

Utility for good j is greater than utility for good k is written as such:

$$V_{nj} + \varepsilon_{nj} > V_{nk} + \varepsilon_{nk} \quad \text{for all } j \neq k \quad (4)$$

The probability that a consumer chooses one good over the other is described through the good that is not chosen, meaning:

$$\begin{aligned} Pr\,(y_n = j) &= Pr\,\left(U_{nj} \geq U_{nk}\right) \forall\, j \quad (5) \\ &= Pr\left(U_{nk} - U_{nj} \leq 0\right) \forall\, j \\ &= Pr\,(\varepsilon_{nj} - \varepsilon_{nk} < V_{nj} - V_{nk}) \forall j \end{aligned}$$

Where $Pr\ (y_n = j)$ is the probability that consumer n chooses alternative j and $Pr\ \left(U_{nj}\ \geq\ U_{nk}\right)$ is the probability that the utility of consumer *n* for alternative *j* is higher than or equal to the utility of consumer *n* for alternative *k*.

Parameters from the random utility model can be estimated using logit models in econometric analysis. With the logit model, WTP and consumer preferences for goods can be estimated empirically. Due to this research having more than two options in the choice set, a mixed logit model will be used to determine WTP.

3. Choice Experiment and Survey Design

3.1. Choice Experiment Design

When employing a stated preference method, researchers have the option to use both direct and indirect approaches (Adamowicz et al., 1994; Breidert et al., 2006). Direct methods, such as consumer surveys commonly known as contingent valuation, directly inquire about individuals' willingness to pay (Portney, 1994). Indirect methods, on the other hand, aim to infer willingness to pay through techniques like choice experiments (Morey et al., 2002), contingent rating (Álvarez-Farizo, 2001), contingent ranking (Merino-Castello, 2003), and pair-wise testing (Cameron et al., 2002).

Choice experiments, as used in this study, present hypothetical scenarios with alternative bundles of attributes, each accompanied by a price. Respondents are then asked to choose between options 'A,' 'B,' or neither. Contingent ranking involves presenting various scenarios and requesting respondents to rank each option on a given scale, while pair-wise comparisons require respondents to indicate their preference between options and demonstrate the strength of their preference (Alpizar et al., 2003).

In choice experiments, hypothetical profiles featuring different attribute levels are created, each assigned a monetary value. Respondents choose between two scenarios, enabling the derivation of their utility for attribute levels relative to a baseline. Unlike contingent valuation, choice experiments derive willingness-to-pay from rankings of presented options, sparing respondents from assigning direct monetary values (Pearce et al., 2002).

Stated preference methods, particularly choice experiments using product attributes, offer desired willingness-to-pay values with several advantages over other approaches. They are less costly to implement than revealed preferences, as one survey response can yield multiple data points. Additionally, these methods afford researchers greater control over the parameters presented to respondents. However, they may diverge from real-life scenarios, potentially becoming overly simplistic, and are susceptible to hypothetical bias, as respondents' decisions in hypothetical situations may not align with actual preferences (Bridges, 2002).

The choice experiment methodology provides a versatile approach by offering participants a range of attribute combinations and the opportunity to evaluate more than two alternatives. This research provides a subset of parameters that are most relevant and meaningful for the research question at hand, price, and greenhouse gas reduction. The main parameter we will focus on is the level of greenhouse gas reduction, such as presenting mitigation through percentage reduction in methane, quantities of methane, differing label designs, and in equivalency terms of cars off the road for a day. The attribute and attribute levels used in this research can be seen below in Table 1.

Table 1. Choice experiments attributes and levels

Attribute	**Levels**
Production method	Conventional
	Feed additives
	Gene-edited bacteria
GHG reduction	0
	Taking a car off the road for 1.5 months (25%, 20 lbs methane, red logo)
	Taking a car off the road for 2 months (33%, 30 lbs methane, yellow logo)
	Taking a car off the road for 3 months (50%, 40 lbs methane, green logo)
Price	$6/lb
	$8/lb
	$10/lb
	$12/lb

The three attributes considered for this research are the production method of ground beef, the level of greenhouse gas reduction, and price. It is of note that conventional beef will never have any greenhouse gas reduction due to its standard production procedure. The production methods chosen were conventional, beef produced with feed additives, and gene edited beef. Feed additives are effective in reducing emissions and are less genetically invasive than gene editing. This provides a comparison of the greenhouse gas reduction between a genomic method and a non-genomic method. The greenhouse gas (GHG) reduction levels were chosen by a literature review to quantify the average expected greenhouse gas reduction. Although there are levels of reduction higher in trials, we have taken a conservative estimate with comparable values for our research purposes. The price levels were dictated by a search in grocery store flyers across Canada during late 2023 and early 2024. The flyers are shown in Appendix A.4.

The way in which the GHG emission reduction was presented to the participants varied among four different groups. The four presentations were: a percentage methane reduction (25%, 33%, and 50%), weight of methane reduction (20, 30, and 40 pounds per pound of ground beef), a car-equivalent reduction of methane (¼ cars off the road, 1/3 cars off the road, and ½ cars off the road), and a logo (red signifying a low level of reduction, yellow signifying a medium-level reduction, and green for high-level reduction). The greenhouse gas equivalent for cars was calculated with the Greenhouse Gas Equivalencies Calculator from the US EPA (Greenhouse Gas Equivalencies Calculator).

A D-efficient design was implemented for this choice experiment, as having 4 attributes with varying levels leads to the impracticality of a full factorial design. Certain conditions had to be met in the choice experiment, one of which included no reduction of greenhouse gas emission for the conventional production method, and subsequently the feed-additive and gene-edited both having some level of greenhouse gas reduction. Another restriction was the presence of dominant choices, many of which had to be removed so as not to have options with high pick rates.

A D-efficient design in experimental design and statistical modelling aims to maximize the precision and efficiency of parameter estimation by strategically structuring data collection. This approach prioritizes obtaining the most accurate estimates of model parameters using the fewest possible data points. D-optimality guides the design process to ensure that each observation contributes as much information as possible to the estimation process.

The image that is presented to the participants is shown below in Figure 1 as an example. Participants choose which of the following three options they would pick to purchase, and also had an opportunity to choose none of the meat options. Each participant was shown six choice sets.

Figure 1. Choice set example

Which of the following would you purchase?

	A	B	C
			
Production Method	Conventional	Feed-Modified Beef	Gene-edited beef
Price	$10/lb ($22.04/kg)	$12/lb ($26.46/kg)	$8/lb ($17.637/kg)
GHG Emission Reduction	None	50%	50%

As participants are presented with varying ways of greenhouse gas reduction, the bottom row of the set varies with the associated attribute levels. The one specific case where the greenhouse gas reduction is not presented as text is through the logos, which are shown below in Figure 2.

Figure 2. Choice experiment logo options for participants in the logo information treatment

3.2. Survey Design

A survey was created and conducted to obtain data for the experiment. LimeSurvey, an online surveying platform provided by McGill for use in research, was used to administer the survey. Questions were asked to determine basic demographic data on participants, with questions such as “How old are you?” and “What is your personal basic income?”. The demographic questions were accompanied by questions regarding participants’ frequency of beef consumption, beef purchasing behaviour, their environmental standpoint on different types of beef production and its effect on the environment, how their diet affects climate change, and their views on gene editing and its application in agriculture. These questions were asked to determine the interaction between participants’ view on the environment and their purchasing habits and outlook on beef and beef production. These questions can be used to group individuals based on their viewpoints and compare groups with differing stances on gene editing and environmental perspectives. Being able to compare differing groups based on their viewpoints can provide insight into the reasoning for individuals to purchase gene-edited beef that lowers methane emissions, and whether certain groups are more likely to purchase such a product. Food technology neophobia questions were asked on a 5-point Likert scale, with the whole list of questions in Appendix A.1. These questions were asked to ascertain a food technology neophobia score for each participant based on their responses to multiple statements regarding food technology. Willingness to consume questions and perception of naturalness questions for multiple types of foods were given on a 5-point Likert scale to the participant, with the whole list of food types seen in Appendix A.2. These questions were asked to ascertain a naturalness score based on their answers. The choice sets were asked as questions to participants through six questions with eight differing randomization blocks, totalling 48 choice sets. Each block had different ways of representing methane emission reduction, with four differing types (weight, percent, logo, and car-equivalent). Two blocks were made for each way of representing methane emission reduction.

4. Empirical Framework

An effective approach in consumer choice modelling is the mixed logit model, which offers flexibility in addressing preference variation (Hensher and Greene, 2003). Models are estimated with maximum likelihood estimation techniques, which seek to find the parameter values that maximize the likelihood of observing the actual choices made by consumers in the dataset (Hensher and Greene, 2003). However, it is essential to consider the trade-offs involved in model complexity and interpretability. Including many parameters in the model may lead to increased computational demands and challenges in model estimation (Hensher and Greene, 2003). Moreover, the interpretation of results becomes more complex as the number of parameters increases, making it difficult to discern the underlying drivers of consumer preferences (Hensher and Greene, 2003). To elicit consumer preferences for gene-edited beef, there are many attributes such as production method, environmental sustainability, and price.

4.1. Mixed Logit Model

The mixed logit model specification involves incorporating parameters for each attribute. In this mixed logit framework, parameters can vary across individuals according to a specified distribution.

The base model equation for this research can be expressed as follows:

$$U_j = \beta_0 + \beta_{ASC}ASC_j + \beta_{GE}GE_j + \beta_{FA}FA_j + \beta_{ME}ME_j + \beta_p P_j + \varepsilon_j \quad (7)$$

where U_j represents the utility derived from choosing alternative j. GE_j, FA_j, ME_j, and P_j denote whether the product is from gene-edited cows, whether the product was from cows fed feed additives, its level of methane reduction, and price, respectively, for alternative j. β_k represents the parameter associated with attribute k. Finally, ε_j is the error term capturing unobserved factors affecting utility. In the mixed logit framework, the parameters β_k are assumed to follow a normal distribution across the population.

To discover more about the intricacies of the data, interaction terms were added to the base regression. By incorporating interaction terms of naturalness and food technology neophobia, the model can accurately capture conditional relationships based on participant predispositions for this type of technology. Participants' scores from the Food Technology Neophobia Scale (FTNS) and participants' views on naturalness could affect their choices and thus their WTP for differing beef production methods, giving insight into participant behaviour. Moreover, interaction terms provide insights into the underlying mechanisms driving participants' decisions. The interaction terms used in the regression were ones that pertain to the technophobia and naturalness scales on the differing production methods to see how participants' food technology neophobia and their perception of naturalness would affect their willingness to pay. The food technology neophobia variable is binary, equal to 1 if they are higher than the mean of the sample and 0 otherwise. The naturalness score is also binary but is equal to 1 if the naturalness score is above the mean of the sample, along with if the naturalness score is below 1, which indicates that their valuation of naturalness is high and thus a lower consumption score. This can be interpreted as the binary variable for naturalness score indicating a 1 if they are on the high-end of the valuation of naturalness. The regression that includes interaction terms for food technophobia and naturalness and production technologies are shown in Equation 8.

$$U_j = \beta_0 + \beta_{ASC}ASC_j + \beta_{GE}GE_j + \beta_{FA}FA_j + \beta_{ME}ME_j + \beta_p P_j + \beta_1(GE_j * FTNS) + \beta_2(GE_j * NAT) + \beta_3(FA_j * FTNS) + \beta_4(FA_j * NAT) + \varepsilon_j \quad (8)$$

where the regression variables are the same as the base regression model in Equation 7, but with four interaction terms: $GE_j * FTNS$, which interacts the binary gene-edited variable with the binary variable for individuals whose food technology neophobia score is above the sample average; $GE_j * NAT$, which interacts the binary gene-edited variable with the binary variable indicating the individual's naturalness score is within the high-end valuation of naturalness; $FA_j * FTNS$, which interacts the binary feed additives variable with the binary individuals food technology neophobia score being above average; and $FA_j * NAT$, which interacts the binary feed additives variable with the binary individuals naturalness score is within the high-end valuation of naturalness. These interaction variables will show the effects of an individual's food technology neophobia and their perception of naturalness of food on the different production methods.

The probability that individual n chooses option j, conditional on β_k is defined by Equation 9:

$$P_{nk}(\beta) = \left(\frac{\exp\,(\beta X_{nj})}{\sum_{j=1}^{J}(\beta X_{nj})}\right) \tag{9}$$

X_{nj} is observable and ε_{nj} is non-observable to the researcher. The mixed logit probabilities are thus the integral of the $P_{nk}(\beta)$ function.

4.2. Willingness to Pay

Willingness to pay (WTP) refers to the maximum amount of money an individual is willing to pay in exchange for a good or service. We will derive WTP from the marginal utility gained from each attribute. The function for determining WTP is as such:

$$\text{WTP}_j = -\frac{\beta_j}{\beta_{price}} \tag{6}$$

where the numerator is the coefficient estimated for attribute j, and the denominator β_{price} is the coefficient estimated on the price of the good.

4.3. Adaptation of FTNS and Naturalness Scales

To use the naturalness and technophobia variables we created binary variables to indicate high and low levels of both neophobia and naturalness. The food technology neophobia variable we used in the regressions was set equal to one if the participant's neophobia score was greater than the mean score of all participants. A variation of the Food Technology Neophobia Scale (FTNS) developed by Cox and Evans (2008) was used to capture technophobia. The FTNS is a tool used to measure individuals' reluctance or resistance to trying new food technologies. The scale consists of 13 statements rated on a 7-point Likert scale, for which respondents indicate their level of agreement or disagreement. We chose 8 of the 13 statements that we found most applicable to this experiment and used a 5-point Likert scale (from strongly disagree (1) to strongly agree (5)) instead of 7 for brevity for participants. The statements we used are shown in Appendix A.1. The statements assess attitudes toward new food technologies, perceived risks, and general food-related concerns. High scores on the FTNS indicate greater resistance and skepticism towards new food technologies, while low scores suggest openness and acceptance.

We also measured participants' views of the naturalness of different foods and food technologies. Participants were shown a list of 22 foods and/or agricultural practices and asked (a) how natural they considered them to be (on a 5-point Likert scale from completely unnatural (1) to completely natural (5)), and (b) how willing they were to consume them (on a 5-point Likert scale from Not at all willing to eat (1) to Very willing to eat (5) along with a 6^{th} option of not familiar if they hadn't heard of the food or technology). The foods used for determining naturalness score are shown in the table Appendix A.2.

The naturalness score for each food is determined by multiplying the participant's rankings of naturalness and willingness for each food/food technology and dividing by 5. For example, participants were asked about how natural they considered aspartame to be, as well as how willing they were to consume it. If the participant considered aspartame to be somewhat unnatural and gave it a score of 2 and was somewhat willing to consume it and reported a willingness of 4, the naturalness score for aspartame would be 8 divided by 5, or 1.6. Participants who thought of technology as very natural and were highly willing to consume the technology have a high naturalness score. Conversely, participants who do not rate a technology as natural and do not want to consume the technology have a low naturalness score. The other two options (i.e., thinking the food is natural and not willing to consume it, and thinking the food was unnatural and willing to consume it) would result in similar naturalness scores.

For example, if a participant did not perceive a food to be natural, assigning it a score of 2 out of 4, but was very willing to consume it with a score of 5, their score would be 2. The 2 represents a naturalness score for participants that do not value naturalness in their consumption choices very highly. The technologies we listed in the survey were a mix of current food technologies and novel technologies. This captures participants' valuation of food naturalness as foods perceived to be highly natural with high consumption scores indicate natural foods being consumed based on their naturalness, whilst foods perceived as unnatural with low consumption scores indicate unnatural foods being not consumed based on their perceived naturalness. The foods perceived as unnatural with low consumption scores indicate participants who value naturalness highly in their consumption choices, thus for the binary variable for high naturalness scores, any participants with over the mean average of the sample in terms of naturalness scores and anyone below 1 in their naturalness scores are given a 1 in the binary variable. Every participant who is below the sample mean and above 1 is given a 0 in the binary variable.

4.4. Hypotheses

This study examines how consumers will react to a hypothetical product gene-edited, low methane-emitting beef. Therefore, there are multiple hypotheses as to which attributes will determine consumers' willingness to pay:

1. Consumers will have a positive WTP for higher methane emission reduction. Formally, this can be written as $\beta_{ME} > 0$ (Equation 7).
2. Consumers will have a lower WTP for gene-edited or feed additive beef compared to conventional beef. This can be written as $WTP_{GE} < 0$ and $WTP_{FA} < 0$ (Equation 7).
3. Participants with high food neophobia will have lower WTP for non-conventional production methods than conventional. This can be expressed as $WTP_{GE*FTNS} < 0$ and $WTP_{FA*FTNS} < 0$ (Equation 8).

4. Participants with higher naturalness scores will have lower WTP for non-conventional production methods than for conventional ground beef. This can be expressed as $WTP_{GE*NAT} < 0$ and $WTP_{FA*NAT} < 0$ (Equation 8).
5. Participants will have differing levels of WTP for greenhouse gas reduction depending on the way the information on methane reduction is presented. For the differing information treatments, the hypothesis is that $WTP_{logo} > WTP_{percent} > WTP_{weight} > WTP_{cars}$

4.5. Survey Distribution

Participants were recruited through Prolific Academic. The potential sample was restricted to Canadians registered with Prolific Academic who did not identify as vegan, vegetarian, or pescatarian. The participants answered 27 questions in the survey. Participants were compensated approximately $5 for completing the survey[1]. The survey was released on April 11th, 2024, and data collection was completed at the end of that day. Five hundred and two surveys were completed, with five hundred fully completed surveys used in this research. The survey completion time was an average of 12 minutes.

[1] Participants were compensated £3, which is approximately equal to 5 CAD.

5. Results

5.1. Summary Statistics

Sample summary statistics are presented in Table 2. Overall, our sample consisted of 47% female participants and 51% male, with an average age of 35.63 years (see Table A.3 in the Appendix). Over 36% of participants were in the age bracket of 18 to 29, with the largest being the 30 to 49 age bracket. Only 16% of participants were in aged 50 and over. Over three quarters (77.8%) of our sample had a household income of more than $50,000, with 22.2% having an income under $50,000 and 39.8% having an income between $50,000 and $99,999. Almost one third (32.8%) of participants had an income between $100,000 and $249,999 and the remaining 5.2% had an income of greater than $250,000.

Table 2. Sample gender, age, and income

Variable	Frequency	Percent
Gender		
Male	255	51.00
Female	235	47.00
Other	8	1.60
Not Specified	2	0.40
Age		
18 to 29	183	36.60
30-49	237	47.40
50 and over	80	16.00
Income		
Under $50,000	111	22.20
$50,000-$99,999	199	39.80
$100,000-$249,999	164	32.80
$250,000+	26	5.20
Total	500	

Summary statistics for province of residence, education, and political alignment are presented in Table 3. The geographic distribution of our sample was broad, with 48.5% of respondents residing in Ontario, the most participants in our sample from a single province. The second largest is British Columbia, with 18.8% of participants, and the third largest from Alberta with 11% of participants. A majority, 63.4%, had received a bachelor's degree or higher; 18.6%, received a college-equivalent diploma. Fifteen percent had received a master's degree and 2.6% received a doctorate-equivalent degree. For political alignment, 50.8% considered themselves liberal (40% liberal and 10.8% strongly liberal). Just over 16% considered themselves conservative (15.2% conservative and 1% strongly conservative). Thirty three percent considered themselves neither liberal nor conservative.

Table 3. Sample province, education, and political alignment

Variable	**Frequency**	**Percent**
Province		
Alberta	55	11.00
British Columbia	94	18.80
Ontario	242	48.50
Québec	34	6.80
Education		
High school diploma	86	17.20
College, CEGEP, or trades certificate/diploma	93	18.60
Bachelor's degree	229	45.80
Master's degree	75	15.00
Doctoral or professional degree	13	2.60
Political Alignment		
Conservative	76	15.20
Neither conservative nor liberal	165	33.00
Liberal	200	40.00
Strongly liberal	54	10.80
Total	500	

We also asked participants about their purchasing habits, frequency of beef consumption, and whether they had heard of gene editing to reduce GHG emissions. Summary statistics for these responses are shown in Table 4. In terms of beef consumption, 75.4% of respondents reported consuming beef at least weekly, with 1.4% never eating beef. A large portion of respondents ate beef once or twice a week, equating to 41.6% of the sample. Only 14.8% of respondents have heard of gene-edited beef with lower methane emissions. Price was the most important factor for participants when determining beef purchases, with 55.8% of participants considering it the most important factor. The second-most was the taste of the beef, with 14.4% of participants selecting taste.

Table 4. Participant beef consumption frequency, knowledge of gene editing, purchasing considerations

Variable	Frequency	Percent
How often do you consume beef (e.g., steaks, burgers, ground beef)		
Occasionally, but not every week	116	23.20
Once or twice a week	208	41.60
3 or 4 times a week	132	26.40
5 or more times a week	37	7.40
Never	7	1.40
Have you heard of gene editing bacteria in cow's guts to reduce methane emissions?		
Yes	74	14.80
No	426	85.20
What is the most important thing you consider when purchasing beef?		
Price	279	55.80
Convenience	6	1.20
How it was produced	71	14.20
Nutritional Value	37	7.40
Taste	72	14.40
Where it was produced	27	5.40
Total	500	

Participants were asked about their concern about climate change and how concerned they were about their diet contributing to climate change. As shown in Table 5, participants' views on climate change indicate that most participants are at least somewhat concerned about climate change. Over three quarters (80.2%) of participants indicated they were concerned about climate change, while 4.4% said they were not concerned at all. There were fewer participants concerned about their diet affecting climate change, with 42.6% of the participants being at least somewhat concerned about their diet affecting climate change.

Table 5. Additional participant behaviour questions about climate change perception

Variable	**Frequency**	**Percent**
In general, how concerned are you about climate change?		
Not concerned at all	22	4.40
Not very concerned	35	7.00
Neither concerned nor unconcerned	42	8.40
Somewhat concerned	274	54.80
Extremely concerned	127	25.40
How concerned are you about your diet contributing to climate change?		
Not concerned at all	69	13.80
Not very concerned	130	26.00
Neither concerned nor unconcerned	88	17.60
Somewhat concerned	183	36.60
Extremely concerned	30	6.00
Total	500	

The scores for both food technology neophobia and naturalness are presented in Table 6. As explained earlier, binary variables were created to represent high and low levels of food technology neophobia and naturalness. Participants with a neophobia score higher than the average were assigned a value of one. A modified version of the Food Technology Neophobia

Scale (FTNS), originally developed by Cox and Evans (2008), was used to measure technophobia. Eight of the original thirteen statements were selected for this experiment, rated on a 5-point Likert scale to assess attitudes towards new food technologies, perceived risks, and food-related concerns. High FTNS scores indicate greater resistance to new food technologies, while low scores indicate lower resistance.

Participants also rated the naturalness of twenty-two foods and food technologies on a 5-point Likert scale and their willingness to consume them. A naturalness score was calculated by multiplying a participant's naturalness and willingness ratings and dividing by five. This score ranged from high (natural and willing to consume) to low (unnatural and unwilling to consume). A binary variable for high naturalness was assigned if a participant's score was above the sample mean or below one. Those below the sample mean but above one were assigned a zero. The two components of the naturalness score, the naturalness perception and willingness to consume the food types, are also shown.

The mean score for food technology neophobia is 3.16, indicating a neutrality towards new food technology, but slightly leaning towards nonacceptance of new food technology. For the naturalness score, the average score was 2.29 for all 22 foods. The naturalness score is made up of the naturalness perception of the food technology and the willingness to consume the food technology, both of which are shown in the table. The mean for the naturalness perception of the food technologies is 2.81, indicating a relatively even perception of naturalness for the food technologies listed. The mean for the willingness to consume the food technologies is 3.72, indicating participants were open to consuming the food technologies. This difference in mean indicates that participants do not value the naturalness highly when consuming the food technologies, as the means would be more similar to one another.

Table 6. Mean food technophobia and naturalness scores

Variable	Obs.	Mean	Std. Dev.	Min	Max
FTNS score	500	3.16	0.56	1.71	5
Naturalness score	500	2.29	0.62	0.28	4.47
Natural perception	500	2.81	0.49	1.27	4.77
Willingness to consume	500	3.72	0.62	1	5

5.2. Regression Results

A mixed logit regression model was used to analyze the factors influencing WTP for gene-edited low-methane beef using Equation 7. The dependent variable is the variable choice, also known as the binary outcome variable for the log odds of the outcome, and the independent variables included were if the beef was gene-edited as a binary variable, a feed additive variable as a binary variable, a greenhouse gas reduction, and a variable indicating price. The interaction terms are between the production methods and the binary high food technology neophobia score variable and the binary high naturalness score variable. The "asc" variable is the alternative-specific constant, which captures the aggregate average effect on utility that is not captured by the model. This can be interpreted as the "none of the above" option. The results are presented in Table 7, below, while estimates of WTP are presented in Table 8.

Table 7. Base mixed logit regression results alongside the interaction regression results

	Base Regression	Interaction Regression
Feed	0.206	0.201
	(0.155)	(0.173)
Gene	-1.065***	-1.099***
	(0.160)	(0.187)
GHG	0.706*	0.696*
	(0.403)	(0.412)
Price	-0.375***	-0.388***
	(0.013)	(0.014)
asc	-6.607***	-6.746***
	(0.207)	(0.210)
High Neophobia * Gene		-0.950***
		(0.125)
High Neophobia * Feed		-0.515***
		(0.096)
High Naturalness * Gene		0.960***
		(0.124)
High Naturalness * Feed		0.619***
		(0.097)
Number of observations	11,968	11,968
Number of Participants	500	500
BIC	5,378.479	5,238.584

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 8. Marginal willingness to pay, per pound of ground beef

Attribute	**Base Regression**	**Interaction Regression**
Feed	Not significant	Not significant
Gene	-$2.82	-$2.83
GHG	$1.88	$1.79
High Neophobia * Gene		-$2.45
High Neophobia * Feed		-$1.33
High Naturalness * Gene		$2.47
High Naturalness * Feed		$1.60

Starting with the base regression, the coefficient for the feed variable was not statistically significant, indicating no significant difference in the likelihood of choosing feed-additive beef over conventional. The coefficient on greenhouse gas emission reduction indicates the estimated effect of a 100% reduction in greenhouse gas emission on the outcome variable. This is due to the coding of the greenhouse gas variable being on a scale from 0 to 1, with the percent reductions being 0.25, 0.33, and 0.50. As the greenhouse gas coefficient was positive and statistically significant, participants were more likely to choose beef with greenhouse gas emission reduction. The variable itself was statistically significant at the 10% level. The WTP for greenhouse gas reduction is $1.88/lb more than conventional beef for a 100% reduction. This can likewise be interpreted as approximately $0.02/lb per 1% reduction in methane. This means that participants would be willing to pay $1.88/lb more for 100% greenhouse gas emission reduction as opposed to conventional beef with no emission reduction. The negative and statistically significant gene-editing coefficient indicates that beef with gene editing was less likely to be picked by participants. The willingness to pay for gene-edited beef was -$2.82/lb compared to conventional beef. This shows that gene-editing acts as a deterrent, rather than an incentive, for consumers when making choices regarding low-methane beef.

When we include interaction terms in the regression, the feed-additive coefficient was not statistically significant, indicating no difference in the likelihood of choosing feed-additive and conventional beef among participants with low food technophobia and low naturalness valuation. The greenhouse gas coefficient was positive and statistically significant, indicating participants were more likely to choose beef with greenhouse gas emission reduction even with additional regression terms. The WTP for greenhouse gas reduction is $1.79/lb for a 100% reduction, which can be interpreted as participants willing to pay approximately $0.02/lb for a 1% reduction in methane. This WTP in the interaction regression is lower than the base regression by $0.09/lb, not significant enough of a difference to note.

The gene-edited coefficient was once again negative and statistically significant, indicating that consumers are less likely to choose beef if it has been gene-edited. This is reflected in the willingness to pay for gene-edited beef of -$2.83/lb. The regression includes the food technophobia and naturalness scores of participants and separating participants with high and low scores. Those with low scores are represented by base gene editing variable, while the high scores are represented in the interaction terms. The interaction between high food technophobia and gene editing is negative and statistically significant, suggesting that those with higher food technology neophobia are less likely to pick gene-edited beef. This is reflected in the willingness to pay, as participants with high food technophobia scores are willing to pay $2.45/lb less for gene-edited beef than those with low food technophobia.

Similarly, the coefficient on the interaction term between high food technophobia and feed additives was negative and statistically significant, suggesting that those with high food technophobia are less likely to select feed additive beef than conventional. The negative WTP value associated with this interaction term indicates that consumers are willing to pay $1.33/lb less for beef products containing feed additives compared to conventional beef when they are highly neophobic. The feed variable is statistically significant in this interaction, indicating that participants with high neophobia scores are more concerned about the feed additives production method as opposed to those with low neophobia scores, indicating more sensitivity towards this production method in their WTP.

The interaction term between naturalness and gene editing yielded a positive coefficient, indicating that participants with high naturalness scores are more likely to choose the gene-edited beef product. The WTP value for the interaction term is $2.47/lb more than conventional beef, indicating that participants with high naturalness scores would pay $2.47/lb more for beef produced from gene-edited livestock. This can be thought of as participants who think of the food as being very natural and are willing to consume the food are willing to pay $2.47/lb more for gene-edited ground beef than those who think of food naturalness being low and who do not want to consume such foods. The associated WTP is $0.36/lb less than conventional beef, showing a large gap in WTP compared to the base gene-editing WTP of $2.83/lb less than conventional. Consumers with high naturalness scores are much more willing to purchase gene-edited beef than those with low naturalness scores.

The interaction term between naturalness and feed additives revealed a statistically significant positive coefficient, meaning that participants with high naturalness scores are more likely to choose beef from livestock fed feed additives. The WTP value associated with this interaction term suggests that participants with high naturalness scores are willing to pay a premium of $1.60/lb for feed additive ground beef. Participants with high naturalness scores show that they are more willing to purchase differing production methods than their low-score counterparts.

Given the significant influence of naturalness and food technophobia on consumer preferences for beef products, incorporating interaction terms with greenhouse gas emissions could provide additional insights into consumer behaviour. This regression will be separate from the model equations listed earlier. Understanding how consumers' perceptions of naturalness and technophobia interact with greenhouse gas reduction efforts in beef production can elucidate the relative importance of environmental sustainability alongside other attributes.

Table 9. Mixed logit model with GHG interaction terms

Feed	0.106
	(0.181)
Gene	-0.812***
	(0.240)
GHG	0.958**
	(0.434)
Price	-0.390***
	(0.014)
asc	-6.762***
	(0.210)
Gene * GHG	-1.037*
	(0.555)
High Neophobia * Gene	-0.951***
	(0.125)
High Neophobia * Feed	-0.514***
	(0.096)
High Naturalness * Gene	0.962***
	(0.124)
High Naturalness * Feed	0.620***
	(0.097)
Number of observations	11,968
Number of Participants	500
BIC	5,243.081

Standard errors in parentheses
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 10. Willingness to pay for GHG interactions per pound of ground beef

Attribute	**WTP**
Feed	Not significant
Gene	-\$2.08
GHG	\$2.46
Gene * GHG	-\$2.65
High Neophobia * Gene	-\$2.44
High Neophobia * Feed	-\$1.32
High Naturalness * Gene	\$2.47
High Naturalness * Feed	\$1.59

The interaction terms included in this regression were the greenhouse gas reduction and the production methods. The greenhouse gas interaction with the production method led to the feed and greenhouse gas interaction variable being collinear with the gene and greenhouse gas interaction variable, thus not showing up in the results. As shown in Table 9, the interaction term for greenhouse gases and gene editing is negative. The interaction term is significant, along with the greenhouse gas reduction variable being more statistically significant than in previous regressions, giving the willingness to pay for greenhouse gases of $2.46/lb more weight compared to the regressions in Table 7. The negative interaction term is statistically significant, like the greenhouse gas variables in previous regressions. The WTP for the interaction term is -$2.65/lb, indicating that participants were willing to pay $2.65/lb less for GHG emission reduction when the ground beef was produced with gene editing. This means that participants with low food technophobia scores and low naturalness scores would only choose gene-edited beef with low methane emissions if it was cheaper than conventional beef.

The WTP for gene-edited beef is now $2.08/lb less than conventional, a higher amount than previous regressions, and higher by $0.75/lb more than in the Table 8 base regression. All the other terms in the regression are similar to those in Table 7.

To investigate how the different GHG emission information presentation in influenced participants' choices, the regression with interaction terms was run separately for the four random groups. The regression results were estimated for each group separately based on how the methane reduction was presented. Results are presented in Table 11, and WTP estimates are presented in Table 12.

Table 11. Mixed logit model results estimated separately for each information treatment

	Percent	Weight	Logo	Car
Feed	0.058	0.707*	-0.106	-0.028
	(0.377)	(0.371)	(0.371)	(0.325)
Gene	-0.993**	-0.938**	-1.642***	-1.015***
	(0.400)	(0.430)	(0.419)	(0.333)
GHG	0.654	0.611	0.882	0.991
	(0.913)	(0.927)	(0.821)	(0.812)
Price	-0.417***	-0.380***	-0.418***	-0.323***
	(0.028)	(0.027)	(0.035)	(0.023)
asc	-8.682***	-6.401***	-7.624***	-5.586***
	(0.756)	(0.399)	(0.649)	(0.315)
High Neophobia * Gene	-0.876***	-1.500***	-0.904***	-0.690***
	(0.232)	(0.281)	(0.303)	(0.221)
High Neophobia * Feed	-0.603***	-0.798***	-0.173	-0.628***
	(0.195)	(0.214)	(0.194)	(0.183)
High Naturalness * Gene	0.764***	1.443***	1.382***	0.565***
	(0.231)	(0.283)	(0.293)	(0.220)
High Naturalness * Feed	0.492**	0.573***	1.018***	0.481***
	(0.195)	(0.209)	(0.205)	(0.183)
Number of observations	2,944	2,664	3,224	3,136
Number of Participants	123	111	135	131
BIC	1,274.703	1,181.756	1,282.617	1,585.809

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 12. Willingness to pay for information treatment per pound of ground beef

Attribute	**Percent**	**Weight**	**Logo**	**Car**
Feed	Not significant	$1.86	Not significant	Not significant
Gene	-$2.38	-$2.47	-$3.93	-$3.14
GHG	Not significant	Not significant	Not significant	Not significant
High Neophobia * Gene	-$2.10	-$3.95	-$2.16	-$2.13
High Neophobia * Feed	-$1.45	-$2.10	-$0.41	-$1.94
High Naturalness * Gene	$1.83	$3.80	$3.31	$1.75
High Naturalness * Feed	$1.18	$1.51	$2.44	$1.49

The presentation of greenhouse gas emission reduction in our choice experiment influenced consumer preferences for gene-edited low-methane beef. The coefficients for the gene-edited variable were consistently negative and statistically significant, along with nearly all the interaction terms. The only interaction terms not significant are the high food technology neophobia and feed additives for the logo presentation.

Surprisingly, the feed variable has for the first time become statistically significant when GHG emission reduction was presented as pounds of kilograms. This means that the WTP for beef produced with feed additives was $1.86/lb more than conventional ground beef. The largest effect on gene editing was the logo presentation, with the lowest WTP of -$3.93 for the gene-edited coefficient. Compared to the other presentations of -$2.38 WTP for “Percent”, -$2.47 WTP for “Weight”, and -$3.14 WTP for “Car” presentations, the logo conveyed the message of gene editing effectively. All the greenhouse gas coefficients were not statistically significant.

Due to the gene editing technology being novel, participants were asked if they had heard of gene-edited low methane beef possibilities in a survey question. This question was used to determine whether participants who have heard about such a technology would be more likely to consume the product, or if because they have heard about the technology, they would be more skeptical about consuming it by determining the WTP for both sets of participants. Results are presented in Table 13.

Table 13. Knowledge of gene editing technology regression

	Yes	No
Feed	-0.514	0.322*
	(0.480)	(0.187)
Gene	-1.844***	-0.962***
	(0.525)	(0.202)
GHG	1.149	0.601
	(1.158)	(0.446)
Price	-0.411***	-0.388***
	(0.038)	(0.015)
asc	-8.908***	-6.574***
	(1.068)	(0.217)
High Neophobia * Gene	-1.284***	-0.915***
	(0.327)	(0.137)
High Neophobia * Feed	-1.307***	-0.420***
	(0.270)	(0.103)
High Naturalness * Gene	2.232***	0.744***
	(0.338)	(0.135)
High Naturalness * Feed	1.770***	0.456***
	(0.275)	(0.104)
Number of observations	1,772	10,196
Number of Participants	74	426
BIC	732.822	4,500.242

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 14. Willingness to pay for knowledge of gene editing technology regression

Attribute	**Yes**	**No**
Feed	Not significant	$0.83
Gene	-$4.49	-$2.47
GHG	Not significant	Not significant
High Neophobia * Gene	-$3.12	-$2.36
High Neophobia * Feed	-$3.18	-$1.08
High Naturalness * Gene	$5.43	$1.92
High Naturalness * Feed	$4.31	$1.18

The regression analysis revealed noteworthy differences in WTP between participants who had prior knowledge of gene-edited low-methane beef and those who did not. Of particular interest was the unexpected finding that the WTP for gene editing was lower for participants who had heard of gene-edited low-methane beef. Participants who were familiar with gene-edited low methane beef exhibited a WTP of -$4.49 for gene editing, whereas participants who had no prior knowledge of this product displayed a WTP of -$2.47/lb. Feed additives are not statistically significant in the "have heard" group but in the "have not heard" group. The WTP for feed additives is $0.83/lb more than conventional. Greenhouse gas emission reduction was not statistically significant for either group.

The interaction terms provide some insight into participant behaviour. The WTP for the interaction between high neophobia and both gene editing and feed additive production methods was negative, indicating participants with high food technology neophobia were less willing to consume gene-edited and feed additive beef than conventional beef. Of note was the high naturalness score interaction for gene editing in the participants who had heard of gene editing. The WTP was $5.43/lb more than conventional, indicating participants with high naturalness scores were willing to pay a premium for gene-edited beef if they had heard of the technology.

Following the knowledge of technology regression, we considered the most important factor when purchasing beef for consumers, which can give us insight into what participants value and how those values are reflected in their WTP. This was done to determine the way consumers react to specific production methods and greenhouse gas reduction based on what they think is the most important factor when they are purchasing beef. We ran the regression separately, based on the top three most important factors in beef selection: price, taste, and production method. The options chosen by very few participants (convenience, nutritional value, where it was produced, and other factors) were omitted. Results are presented in Table 15, and WTP estimates in Table 16.

Table 15. The most important factor for participants when purchasing beef

	Price	Taste	Prod. Method
Feed	0.576**	-0.035	0.017
	(0.239)	(0.388)	(0.351)
Gene	-0.646***	-1.296***	-1.876***
	(0.243)	(0.403)	(0.390)
GHG	0.408	1.012	0.467
	(0.611)	(1.026)	(0.943)
Price	-0.572***	-0.271***	-0.095***
	(0.023)	(0.031)	(0.030)
asc	-8.387***	-21.556	-3.932***
	(0.327)	(1149.148)	(0.449)
Number of observations	6,688	1,720	1,696
Number of Participants	279	72	71
BIC	2,549.119	808.814	853.284

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 16. Willingness to pay for beef purchasing factors per pound of ground beef

Attribute	**Price**	**Taste**	**Production Method**
Feed	$1.01	Not significant	Not significant
Gene	-$1.13	-$4.78	-$19.75
GHG	Not significant	Not significant	Not significant

Of note for this regression is the WTP for people who value the production method of beef the most have a very low WTP for gene-edited beef of -$19.75/lb, the lowest WTP of all regressions. This result does lack confidence due to the small sample size and the lack of interpretation of the WTP value. Paying almost $20 less per pound of ground beef does not hold any valuable interpretation, especially due to the highest price for ground beef in our experiment being $12/lb. For participants who value price the most, gene-edited beef has a WTP of -$1.13/lb, the highest seen so far in these regressions. Feed additives once again become statistically significant when the most important factor for participants is price. The WTP for feed additives is $1.01/lb more than conventional, indicating that the production method is regarded when considering the price of ground beef the most.

The final regression ran was that of the interactions with demographic data such as age, income, and education. This regression was run to investigate patterns among the sample based on their demographic data. This could help determine what kind of participants are more likely to accept gene editing or value greenhouse gas reduction in their beef.

Table 17. Mixed logit regression results accounting for demographic variables

Feed	0.193
	(0.155)
Gene	-0.649**
	(0.310)
GHG	0.865
	(0.695)
Price	-0.378***
	(0.013)
asc	-6.637***
	(0.207)
Gene * Age	-0.014***
	(0.005)
GHG * Age	-0.012
	(0.010)
Gene * Income	-0.116*
	(0.069)
GHG * Income	0.593***
	(0.147)
Gene * Education	0.088
	(0.056)
GHG * Education	-0.267**
	(0.118)
Number of observations	11,968
Number of Participants	500
BIC	5,392.069

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 18. Willingness to pay with demographic data per pound of ground beef

Attribute	WTP
Feed	Not significant
GHG	Not significant
Gene-Edited	-$1.72
Gene * Age	-$0.04
GHG * Age	-$0.03
Gene * Income	-$0.30
GHG * Income	$1.57
Gene * Education	$0.23
GHG * Education	-$0.71

This regression sheds insight into how certain demographics may or may not favour gene editing and greenhouse gas reduction. Feed additive interactions were not considered due to collinearity. The WTP for gene editing has increased significantly in this regression to -$1.72/lb compared to the base regression in Table 7. Of note for the interaction terms, the interaction terms for gene editing and age, gene editing and income, greenhouse gas reduction and income, and greenhouse gas reduction and education are all statistically significant. The interaction term between gene editing and age has a negative coefficient, indicating the older the participant is, the less likely they are to select gene-edited beef. The WTP for the interaction term is -$0.04/lb compared to conventional.

The following significant terms are gene editing and the income level. The coefficient is negative, showing that the higher the income of the participant, the less likely they are to select gene-edited ground beef. The WTP for this interaction term is -$0.30/lb compared to conventional, showcasing that even though if participants had more income, they are less inclined to spend on gene-edited beef as opposed to conventional beef.

The next interaction term of note is the greenhouse gas reduction and income level of the participant. The coefficient for the interaction term is positive, indicating that the higher the income of the participant, the more greenhouse gas reduction they would want to have in their beef purchases. The WTP for the term is $1.57/lb more than conventional ground beef, meaning that the higher the income of the individual, the more they would want to spend on greenhouse gas-reduced beef.

The final interaction term is the greenhouse gas reduction and education level of the participant, which has a negative coefficient. This shows that the higher the education level of the participant, the less likely they are to select greenhouse gas-reducing beef, although slightly. The associated WTP for this interaction term is -$0.71/lb than conational beef, indicating that the higher the education level, the lower the WTP for greenhouse gas reduction.

6. Discussion

6.1. Hypotheses

6.1.1. Hypothesis 1

The first hypothesis is that consumers will have a positive WTP for methane emission reduction. From the regression results, participants consistently exhibited positive WTP for greenhouse gas emission reduction. Consumers value greenhouse gas emission reduction positively throughout all our regression tests. In the base regression, the WTP for greenhouse gas reduction was \$1.88/lb more than non-reduced beef, as shown in Table 8. Converting this to incremental greenhouse gas reduction, for a 1% increase in greenhouse gas reduction, participants' WTP was approximately \$0.02/lb. This result means that varying levels of greenhouse gas reduction can be achieved for a set price above conventional beef. If a consumer wants to have a 50% emission reduction in their gene-edited beef product, they would be willing to pay roughly \$1.00/lb more than conventional beef. This is in line with other research surrounding greenhouse gas reduction through agricultural products, such as a recent paper by Chen et al. (2024) who found a positive WTP of \$2.46/lb more for beef with carbon-neutral labelling, like reducing 100% emissions from the beef production. This can prove to be useful in determining prices for ground beef with emission reduction based on our results. It is also encouraging to see that Canadian consumers are willing to spend more for greenhouse gas mitigation, implying that they care about how agriculture, specifically beef production, affects the environment and how their food choices affect methane emissions.

6.1.2. Hypothesis 2

The second hypothesis is that consumers will have a lower WTP for feed additive or gene-edited beef compared to conventional beef. The results from most of the mixed logit regressions indicate that the feed additive coefficients lack statistical significance, unlike the gene editing coefficients. This is interpreted as there being a lack of differentiation between conventional beef and feed additive beef, as statistically there was no difference in most of the regressions ran. Two occasions where that was not the case were when the greenhouse gas reduction was presented in the form of the weight of methane reduced and when price was the most important factor in participants' beef purchasing choices. The only other time the feed additive was statistically significant was when it was interacted with high naturalness scores and high technophobia scores. When food technology neophobia was interacted with feed additives, the coefficients were always negative thus being unlikely to be accepted by neophobic consumers. For naturalness scores, the coefficients were always positive indicating that high naturalness scoring participants are accepting of feed additives. From this information, we can conclude that feed additives might be an option for participants who want greenhouse gas reduction from their beef and are already willing to purchase conventional beef.

On the other hand, participants consistently exhibited negative WTP for gene edited beef. In contrast to feed additives, the gene editing coefficient is always statistically significant in the regression run and is always negative. The negative WTP for gene-edited ground beef indicates that participants are deterred by gene editing, and that gene-edited ground beef must be cheaper than conventional beef for consumer acceptance. Another result of note is that those who have heard of gene-edited cattle with low methane emissions have lower WTP of -\$4.49/lb compared to -\$2.47/lb for those who have not heard of the novel technology (Table 14). This means that participants who are more informed about the production method are willing to pay less than people who have not.

Participants who value price the most when making food purchasing decisions do not care as much about the production method of the beef if it is cheap. All of the results point to the conclusion that, for gene-edited beef to be viable in the market, it must consistently be of lower price than conventional ground beef. This may be possible with gene editing holding promise in other beef production factors like size and health benefits, but as of now has low promise. This leads to the second hypothesis holding with gene editing, as consumers have consistently lower WTP than conventional ground beef. Overall, we fail to reject the null hypothesis due to the production method of feed additives not having consistently lower WTP than conventional. Although we fail to reject the hypothesis, there is some promise for the feed additive production method being used to lower methane emissions as it is not statistically different than the conventional production method, thus giving an avenue for consumers who want greenhouse gas emissions reduction through their beef purchases.

6.1.3. Hypothesis 3

The third hypothesis states that participants with high food technology neophobia have lower WTP for gene-edited beef than those with low food technology neophobia. Our results suggest that participants with high food technology neophobia had lower WTP for beef produced with gene-editing and feed additives than those with low food technology neophobia. This makes intuitive sense as those who are wary of novel food technologies in general are willing to pay less for beef produced with unfamiliar practices. The novelty of gene editing, and feed additive production methods will dissuade consumers from selecting those options if they value conventional methods. As those with high food technophobia were found to consistently have negative WTP for gene edited beef, we reject the null hypothesis.

6.1.4. Hypothesis 4

The fourth hypothesis states that participants with higher naturalness scores will be willing to pay less for non-conventional production methods, especially towards gene editing reflecting in a negative WTP. Based on other research regarding consumer WTP for genetically modified foods, naturalness plays a significant role in consumer purchasing decisions, with participants who value naturalness highly in their food purchases being less likely to purchase foods they deem as unnatural (Delmond et al., 2018; Beghin and Gustafson, 2021). Our results suggest that participants with high food naturalness scores have consistently higher WTP for both gene-edited and feed additive beef compared to those with low food naturalness scores. This suggests that consumers' perceptions of naturalness may not be strongly linked to their attitudes towards gene editing in beef production, in contrast to what is mentioned in previous literature (Delmond et al., 2018; Beghin and Gustafson, 2021).

A reason for this differing result may be because participants' views on the naturalness of gene editing does not translate to their dietary choices. Products like aspartame are not seen as natural but are still consumed by some people despite this. Research by Delmond et al. (2018) found that naturalness was a factor in influencing consumer choices for genetically modified bread, while research by Beghin and Gustafson (2021) found that participants considered gene editing to be more natural than genetic modification. This could mean that gene editing is not viewed the same as genetic modification in the eyes of the consumer, such that gene editing may be seen as a positive for participants with high naturalness scores translating to a higher WTP.

This is the opposite of gene editing literature like that by Bearth et al. (2024), who found that participants were more skeptical of gene editing based on their perception of gene editing as unnatural .

Another way of interpreting this result is that consumers who are more willing to consume foods perceived as somewhat unnatural are more willing to purchase non-conventional beef production methods. As the naturalness score included participants' willingness to consume food technologies, the novel production methods presented in this research may be more willing to be consumed by participants who are more willing to consume novel food technologies like gene-edited beef. Whatever the case may be for the differing result compared to previous literature, we reject the fourth null hypothesis. The results we attained contribute to the gap in the literature for how naturalness plays a role for consumer perceptions of gene edited beef, as this result is opposite of the results found in the genetic modification literature.

6.1.5. Hypothesis 5

The final hypothesis states that the way greenhouse gas reduction is presented to the participants will affect their WTP, with the logo presentation having the largest effect on WTP followed by percent presentation, then weight presentation, and finally cars presentation. Our results show that, regardless of the information presentation, no greenhouse gas emission reduction coefficients were statistically significant. We conclude that information presentation does not affect WTP for methane emission reduction, and we therefore fail to reject the null hypothesis. This means that having differing presentations for greenhouse gas reduction for ground beef on the packaging will not affect consumer WTP for the beef.

The information presentation treatments did however affect WTP for gene-edited beef, with the logo representation resulting in the lowest WTP for gene-edited beef compared to conventional. This was followed by the percent methane emission reduction, weight of methane, and car-equivalent of methane presentation. While the logo used to convey GHG emission reduction was the most effective in terms of consumers' WTP for gene-edited beef, it had no significant impact on WTP for GHG reduction itself. This means that the best method to convey gene editing in beef may be to not show that the beef was gene-edited in the first place, as notifying consumers that their product is gene-edited has negative effects on WTP. This contrasts other literature surrounding gene-edited food products as in the study by Hu et al. where they found that labelling does play a role in affecting WTP positively (Hu et al., 2022). They also found that consumer preference for CRISPR orange juice with infographic treatment had positive WTP as opposed to word or video treatment having negative WTP, indicating that infographic labelling is the most effective in affecting WTP positively (Hu et al., 2022). This result is opposite to ours as the logo treatment was the most effective in conveying gene-editing negatively, with the logo having the lowest WTP.

6.2. Other Notable Results and Interpretations

Participants who had heard of gene-editing cattle rumen microbiomes to reduce methane emissions were less willing to purchase gene-edited ground beef with lower methane emissions. The willingness to pay difference was not substantial, with those who have heard of gene-edited beef having a WTP of -$4.49/lb compared to conventional, as opposed to those who haven't heard of gene-edited beef having a WTP of only -$2.47/lb compared to conventional (Table 9). This suggests that those who have heard of gene editing cattle rumen microbiome may be slightly more skeptical of the technology, perhaps due to not being confident in the ability of the technology to reliably lower methane emissions.

When we investigated participants' most important factor when purchasing beef, the majority were primarily concerned with the price. Participants who listed price as their primary concern were willing to pay more for beef produced with feed additives (Table 16). This makes intuitive sense as consumers who are more price-sensitive care less about the production method used for manufacturing beef. This indicates that feed additives are a viable choice if it is cheaper than the other options.

When demographic variables were accounted for in the base regression, we found that older participants were less likely to select gene-edited beef. The WTP for this interaction term was \$0.04/lb per year older than 18 compared to conventional (Table 18). With the highest age participant of our sample of 77, extrapolating the WTP for the oldest individual would be \$3.08/lb less than conventional. This can be thought of as older participants being less open about certain novel food production methods and preferring conventional methods of beef production.

The interaction term between gene editing and income is of note as well. The coefficient for this interaction term is negative, indicating that the higher the participant's income is, the more they prefer conventional beef over gene editing. This can be brought back to the figures in Table 16, where the WTP for price-wary consumers for gene-edited beef was the highest WTP for any other of the calculated gene-edited WTP at -\$1.13/lb compared to conventional. More price-wary participants did not care as much about the production method of the ground beef but rather the price, thus those who have higher income would not care as much about the price of gene-edited beef or feed additive beef. They would care more about other factors of their beef purchases, such as production methods and taste.

Participants' income levels produced surprising results. The WTP for the interaction term is $1.57/lb more than conventional, indicating that participants who have higher incomes value greenhouse gas emission reduction higher than those do have lower incomes (Table 18). This makes sense following the previous income interaction term as the richer a participant is, the less they care about the price of beef and more about the other attributes associated with ground beef. In this case, greenhouse gas emission reduction is seen as a positive attribute for beef, thus those who can afford to not care as much about the price of beef are inclined to alter their diet choices to help the environment.

The WTP associated with greenhouse gas reduction and education level indicates that the higher the education level of the participant, the lower the WTP for greenhouse gas emission reduction in their beef purchases. This indicates that those who are more educated value greenhouse gas emission reduction through ground beef less, whether that is due to the lack of incentive for reducing greenhouse gas emissions from beef production or a general lack of trust in greenhouse gas emission reduction through beef production. In any case, this highlights that those of higher education are willing to pay less for greenhouse gas reduction through ground beef production.

6.3. Limitations

As we use a survey in this research, there may be limitations in the sample population gathered here compared to the general Canadian population. Biases are always present in surveys, and all attempts to limit them were considered, yet there is still a chance for certain biases to be at the forefront of our results. Hypothetical bias is the main bias for consumer research that involves hypothetical products. As gene-edited beef with low methane emissions is not currently a real product that consumers can purchase on store shelves, the reality of consumer choice for such a product may be different than that presented from the results of this research.

6.4. Future Research

Expanding upon this research offers numerous avenues for future investigation to delve deeper into the complexities of consumer preferences in the beef market. The results surrounding greenhouse gas reduction presentation leave questions unanswered in this research, as finding the best way of presenting such a technology to the consumer could lead to promising results in the future of the technology (Hu et al., 2022). The information presentation done in this research indicates that greenhouse gas reduction does not need to be conveyed on ground beef as it does not affect WTP, or that the information presentation does not lead to any significant change in WTP. Finding a way to convey greenhouse gas emission reduction effectively would be useful to find in future research as it could help researchers determine the best way to convey greenhouse gas reduction and in turn convey to the consumer effectively.

Other production methods are also avenues for further research, as the need for greenhouse gas emissions reduction from agriculture is ever-growing to meet the goals set by the Paris Agreement. Feed additives are a promising avenue from this research that should be explored, as feed additives were not the primary focus of this research. However, feed additives hold widespread promise of mitigating greenhouse gas emissions from livestock and have market feasibility compared to gene editing cattle microbiomes for lower methane emissions. Other ways of implementing consumer perceptions of naturalness could lead to insight into how consumers value naturalness in their purchasing decisions. From this research, there are many avenues to be explored further.

A question raised from our results is what kind of level of greenhouse gas mitigation is needed to offset the negative WTP from gene editing entirely. We had limited the mitigation presented to participants to 50% GHG emission reduction, trying to maintain a realistic goal from such a technology as the science of CRISPR for ruminant methane reduction has not been implemented on any level. Continuous values of greenhouse gas emission reduction, not limited to the 4 levels of greenhouse gas reduction as was done in this research, could help find the intersection between environmental sustainability and novel gene editing technology. This could help researchers aim for a specific goal when targeting the rumen with CRISPR, and see what consumers are wanting from novel technologies.

Another question for this research is whether there is a different way to implement consumer perception of food naturalness that can capture participants view of a food technologies naturalness. Due to the number of questions asked to determine consumer naturalness perception and willingness to consume, multiplication of the results from the 5-point Likert scale was appropriate for the naturalness score to be derived. The use of the high naturalness score binary variable made it so that we had to consider the low-end of the scores, the scores below zero, and the higher end of scores, above the sample mean, in our regressions calculations. This method also provided important distinctions such as having a minimum of a participant's choice being three (indifference) for either their willingness to consume or their perception of the naturalness of the food technology. There are possibly better ways on implementing naturalness in discrete choice experiments, and thus could be saved for future research. Multiplying participants willingness to eat score and their naturalness perception score with each other for each specific technology may not be the best method of implementing participants views of naturalness in their beef. Naturalness is only a portion of the consumer mindset when purchasing beef products, and thus does not reflect in the coefficients ran in this research. However, further research may be warranted to explore this relationship in greater depth.

7. Conclusion

The livestock industry is a major emitter of methane, a potent greenhouse gas. Novel technologies, such as feed additives and gene editing, offer effective methods of greenhouse gas emissions reduction for livestock. With Canada's goal of achieving net-zero greenhouse gas emissions by 2050, gene editing offers a direct method to mitigate the environmental impact of livestock by modifying the gut microbiome of cattle to reduce methane production. This research contributes to the literature by giving insight into how Canadian consumers would react to the novel beef production method of gene-edited ground beef that provides greenhouse gas reduction. Feed additives for cattle feed were also considered as a production method due to its efficiency for reducing emissions and contrast to gene editing. This research also considers how participants' food technology neophobia and their perception of naturalness affect their WTP for the novel beef production methods. Differing presentations of greenhouse gas reduction were implemented to determine the differences in WTP.

We designed a choice experiment and survey to estimate consumer acceptance of ground beef from cattle with gene-edited rumen microbiomes for lower methane emissions. The survey and choice experiment were distributed online to a sample of 500 Canadian consumers. The WTP for the attributes of the ground beef such as production methods, price, greenhouse gas emissions reduction and its presentation were estimated with a mixed logit model.

Our results suggest that beef produced with gene editing need to be cheaper than conventional beef to be accepted by consumers. Consumers' likelihood of choosing beef produced with feed additives is not statistically different from conventional beef, indicating that beef from feed additives is a possible avenue for consumer acceptance. Food technology neophobia, characterized by a fear and/or mistrust of food produced using novel technologies, remains a significant barrier to consumer acceptance. Those with higher food technology neophobia scores are less willing to purchase any form of beef production method that is not conventional than their low score counterparts. Participants with high naturalness scores, meaning participants who are think of foods more naturally and are willing to consume those foods, are more willing to consume gene-edited beef than their low score counterparts. These results of the high food technology neophobia scores and the high naturalness scores indicate that participants who are more open to trying novel food technologies are willing to consume gene-edited beef, meaning that gene-edited beef may have potential in the beef market.

We also find that the way in which greenhouse gas reduction was presented to participants did not significantly affect participant behaviour and WTP for GHG emission reduction in ground beef. However, we did find that the way that information was presented to participants affected their WTP for gene-edited beef. There is much more hope for future market trends to sway public perception of gene editing, like those of cell-cultured meat and other novel food technologies. Due to the presence of neophobia amongst consumers for novel food technologies, it may take time for these technologies to be accepted in the market. Positive effects of novel food technologies could help in acceptance. Greenhouse gas mitigation should be at the forefront of issues in the coming years to meet the goals set by the Government of Canada for mitigating the effects of climate change, thus finding any feasible consumer food product that effectively reduces greenhouse gas emissions is vital for the future.

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Appendix A

A.1. Food Technology Neophobia Scale Statements

Statements
New food technologies may have long term negative environmental effects
The benefits of new food technologies are often grossly overstated
It may be risky to shift too hastily towards new food technology
New products produced using new food technologies can help people have a balanced diet
Society should not depend so greatly on new technologies to solve food issues
There are plenty of tasty foods around so we don't need to use new food technologies to produce more
New food technologies decrease the natural quality of food
The media usually provides a balanced and unbiased view of new food technologies

A.2. Naturalness Score Statements

Both the perception and willingness statements are the same for the naturalness score determination. The statements were asked twice but with differing headings for the question, with one question asking how natural they think the technology is, and the second question asking if they were willing to consume it. The answers were given on a 5-point Likert scale.

Statements
Foods with additives that enhance their nutritional quality (e.g., vitamins, omega-3 fatty acids)
Organic food
Livestock whose feed was formulated to reduce greenhouse gas emissions
Foods with additives that extend their shelf life
Cell cultured (labgrown) meat
Foods with artificial sweeteners (e.g., aspartame, sucralose)
Pasteurised food
Livestock genetically engineered for specific traits (e.g. higher milk production, shorter time to maturity)
Food or drinks sweetened with plant extracts like stevia
Freeze-dried food
Crops genetically engineered for specific traits (e.g., higher yield, disease resistance)
Livestock raised with genetically engineered gut bacteria
Hunted meat/game
Plant-based meat alternatives, like Impossible Burgers or Beyond Meat
Foods made with

synthetic fertilizers and pesticides
Livestock bred for specific traits (e.g., higher milk production, shorter time to maturity)
Crops bred for specific traits (e.g., higher yield, disease resistance)
Irradiated food
Crops grown with synthetic fertilizers and pesticides
Upcycled foods (i.e., foods made with ingredients that otherwise would have been discarded)
Prepared meals (e.g., frozen meals, canned soup)
Food from hydroponic production

A.3. Extra Regression Variable Information

Variable	Obs	Mean	Std. Dev.	Min	Max
age	500	35.63	12.29	18	77
gender	500	1.514	.554	1	4
income	500	2.21	.846	1	4
education	500	3.648	1.038	1	6
politics	500	3.444	.91	1	5
concern climate	500	3.898	1.003	1	5
concern diet	500	2.95	1.191	1	5
beefFreq	500	2.152	.909	0	4
heardGene	500	.148	.355	0	1
mostImportant	500	2.614	1.999	1	7

A.4. Beef Flyers

Metro Flyer (ON):

Loblaws Flyer (ON):


air chilled
8.49 lb
extra lean ground beef
family size
18.72/kg
8.99 lb
FREE FROM
PC® Free From® chicken breasts
air chilled, boneless skinless, Club Pack®
19.82/kg
15.99
PC® Easy-Carve™ turkey breast roast
1.17 kg
7.99 lb
PC® Free From® pork loin centre-cut chops or roast
boneless
family size
3.99 lb
pork side ribs
whole
8.80/kg
ONTARIO
7.99 lb
eye of round oven roast
17.62/kg
2/$12
less than 2 $8 ea.
PC® Blue Menu® ground chicken or turkey
7.49 lb
PREPARED in-store
marinated pork back ribs

Provigo Flyer (QC):

Superstore Flyer (BC):

A.5. Survey PDF

A study on consumer meat and food purchasing habits

Please read this document before continuing to the survey. Submitting your survey responses indicates that you consent to participate in this study.

This survey asks questions about your food and meat consumption habits. The results will help us understand people's food and meat purchasing behaviour and general knowledge of food production. You must consume beef at least once in a while to be eligible for this survey.

We anticipate this survey will take between 15 and 25 minutes to complete.

Your participation is completely voluntary, and you may skip any questions you do not wish to answer. Your choice to participate or not will not result in any loss of benefit to which you are otherwise entitled. If at any time you do not wish to continue, you may leave the survey at no penalty to yourself. However, if you do not reach the end of the survey you will not be eligible for compensation.

Your responses will be completely confidential. The information you provide here will only be connected to your Prolific Academic ID; we will not collect any other identifying information. If you wish to withdraw your data, you may contact the research team and provide them with your Prolific Academic ID. When data collection is complete, we will delete identifying information and all data will be anonymous. It will therefore not be possible to remove your data after data collection is completed (we anticipate completing data collection in April 2024).

There are no anticipated risks to you by participating in this research. Participating in the study will have no direct benefit for you; however, we hope to learn more about consumer attitudes towards meat products. De-identified data from this survey may be shared on a public database for research purposes. Any data uploaded to a public research database will not contain personal information that could identify you. If you do not consent to having your de-identified data uploaded to a public research database, please check the box at the bottom of this page.

You will be compensated the equivalent of approximately $5 (£3) for your participation. Upon competing the survey, you will be redirected back to the Prolific website to register your completion. The survey may only be completed once; duplicate submissions from the same Prolific Academic ID will not receive compensation.

Please save or print a copy of this page to keep for your own reference. If you have any questions about the survey, please do not hesitate to contact Prof. Mary Doidge (mary.doidge@mcgill.ca (mailto:mary.doidge@mcgill.ca)) or Yury Simons, M.Sc. student (yury.simons@mail.mcgill.ca (mailto:yury.simons@mail.mcgill.ca)).

If you have any ethical concerns or complaints about your participation in this study, and want to speak with someone not on the research team, please contact the Associate Director, Research Ethics at 514-398-6831 or lynda.mcneil@mcgill.ca (mailto:lynda.mcneil@mcgill.ca) citing REB file number 23-12-053.

Thank you for your participation!

There are 75 questions in this survey.

Prolific ID

Please enter your Prolific ID *

Please write your answer here:

Precursor

Do you consent to have your de-identified data uploaded to a public research database?

Please choose **only one** of the following:

- ◯ Yes
- ◯ No

How often do you consume beef (e.g., steaks, burgers, ground beef) in a typical week?

❗ Choose one of the following answers

Please choose **only one** of the following:

- ◯ Never
- ◯ Occasionally, but not every week
- ◯ Once or twice a week
- ◯ 3 or 4 times a week
- ◯ 5 or more times a week

Demographics - age/gender

{rand(1,8)}

How old are you?

Only numbers may be entered in this field.
Please write your answer here:

What is your gender?

Choose one of the following answers
Please choose **only one** of the following:

- Male
- Female
- Non-Binary
- Prefer not to say
- Other (Please Specify)

Demographics - race/ethnicity

Which best describes you? Please select all that apply.

Check all that apply

Please choose **all** that apply:

- [ ] Black
- [ ] East Asian
- [ ] Indigenous (First Nations, Inuk/Inuit, Métis)
- [ ] Latin American
- [ ] Middle Eastern
- [ ] South Asian
- [ ] Southeast Asian
- [ ] White
- [ ] Other (Please Specify):

Demographics - income, province

What is your approximate household income, before tax?

Choose one of the following answers

Please choose **only one** of the following:

- ( ) Under $50,000
- ( ) $50,000 - $99,999
- ( ) $100,000 - $249,999
- ( ) $250,000+

In what province or territory do you live?

❗ Choose one of the following answers
Please choose **only one** of the following:

- ◯ Alberta
- ◯ British Columbia
- ◯ Manitoba
- ◯ New Brunswick
- ◯ Newfoundland and Labrador
- ◯ Nova Scotia
- ◯ Ontario
- ◯ Prince Edward Island
- ◯ Québec
- ◯ Saskatchewan
- ◯ Northwest Territories
- ◯ Nunavut
- ◯ Yukon

Demographics - education, politics

What is the highest level of education you have completed?

❗ Choose one of the following answers
Please choose **only one** of the following:

- Less than high school
- High school diploma
- College, CEGEP, or trades certificate/diploma
- Bachelor's degree
- Master's degree
- Doctoral or professional degree

Which of the following best describes you, politically?

❗ Choose one of the following answers
Please choose **only one** of the following:

- Strongly conservative
- Conservative
- Neither conservative nor liberal
- Liberal
- Strongly liberal

Technophobia

Please indicate how strongly you agree with each of the statements below:

Please choose the appropriate response for each item:

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
New food technologies may have long term negative environmental effects	○	○	○	○	○
The benefits of new food technologies are often grossly overstated	○	○	○	○	○
It may be risky to shift too hastily towards new food technology	○	○	○	○	○
New products produced using new food technologies can help people have a balanced diet	○	○	○	○	○
Society should not depend so greatly on new technologies to solve food issues	○	○	○	○	○
There are plenty of tasty foods around so we don't need to use new food technologies to produce more	○	○	○	○	○

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
New food technologies decrease the natural quality of food	◯	◯	◯	◯	◯
The media usually provides a balanced and unbiased view of new food technologies	◯	◯	◯	◯	◯

Naturalness - perception

People have different opinions about whether foods and agricultural practices can be considered natural. For each of the items below, please rate the naturalness on a scale of 1 (very unnatural) to 5 (completely natural).

Please choose the appropriate response for each item:

	1 (very unnatural)	2	3	4	5 (completely natural)
Foods with additives that enhance their nutritional quality (e.g., vitamins, omega-3 fatty acids)	○	○	○	○	○
Organic food	○	○	○	○	○
Livestock whose feed was formulated to reduce greenhouse gas emissions	○	○	○	○	○
Foods with additives that extend their shelf life	○	○	○	○	○
Cell cultured (lab-grown) meat	○	○	○	○	○
Foods with artificial sweeteners (e.g., aspartame, sucralose)	○	○	○	○	○
Pasteurised food	○	○	○	○	○
Livestock genetically engineered for specific traits (e.g. higher milk production, shorter time to maturity)	○	○	○	○	○

	1 (very unnatural)	2	3	4	5 (completely natural)
Food or drinks sweetened with plant extracts like stevia	○	○	○	○	○
Freeze-dried food	○	○	○	○	○
Crops genetically engineered for specific traits (e.g., higher yield, disease resistance)	○	○	○	○	○

People have different opinions about whether foods and agricultural practices can be considered natural. For each of the items below, please rate the naturalness on a scale of 1 (very unnatural) to 5 (completely natural).

Please choose the appropriate response for each item:

	1 (very unnatural)	2	3	4	5 (completely natural)
Livestock with genetically engineered gut bacteria	○	○	○	○	○
Hunted meat/game	○	○	○	○	○
Plant-based meat alternatives, like Impossible Burgers or Beyond Meat	○	○	○	○	○
Foods with artificial flavours	○	○	○	○	○
Livestock bred for specific traits (e.g., higher milk production, shorter time to maturity)	○	○	○	○	○
Crops bred for specific traits (e.g., higher yield, disease resistance)	○	○	○	○	○
Irradiated food	○	○	○	○	○
Crops grown with synthetic fertilizers and pesticides	○	○	○	○	○

	1 (very unnatural)	2	3	4	5 (completely natural)
Upcycled foods (i.e., foods made with ingredients that otherwise would have been discarded)	◯	◯	◯	◯	◯
Prepared meals (e.g., frozen meals, canned soup)	◯	◯	◯	◯	◯
Food produced with hydroponics	◯	◯	◯	◯	◯

Naturalness - willingness

How willing are you to eat each of the foods from the previous question? For each item, please say how willing you are to eat the food or product made with the practice from "Not at all" to "Very". You can also check “Not familiar with this” if you haven’t heard of the product or practice.

Please choose the appropriate response for each item:

	Not at all willing to eat	Unwilling	Neutral	Willing	Very willing to eat	I'm not familiar with this
Foods with additives that enhance their nutritional quality (e.g., vitamins, omega-3 fatty acids)	○	○	○	○	○	○
Organic food	○	○	○	○	○	○
Livestock whose feed was formulated to reduce greenhouse gas emissions	○	○	○	○	○	○
Foods with additives that extend their shelf life	○	○	○	○	○	○
Cell cultured (lab-grown) meat	○	○	○	○	○	○
Foods with artificial sweeteners (e.g., aspartame, sucralose)	○	○	○	○	○	○
Pasteurised food	○	○	○	○	○	○

	Not at all willing to eat	Unwilling	Neutral	Willing	Very willing to eat	I'm not familiar with this
Livestock genetically engineered for specific traits (e.g. higher milk production, shorter time to maturity)	◯	◯	◯	◯	◯	◯
Food or drinks sweetened with plant extracts like stevia	◯	◯	◯	◯	◯	◯
Freeze-dried food	◯	◯	◯	◯	◯	◯
Crops genetically engineered for specific traits (e.g., higher yield, disease resistance)	◯	◯	◯	◯	◯	◯

How willing are you to eat each of the foods from the previous question? For each item, please say how willing you are to eat the food or product made with the practice on a scale of 1 (not at all willing) to 5 (very willing). You can also check "Not familiar with this" if you haven't heard of the product or practice.

Please choose the appropriate response for each item:

	Not at all willing to eat	Unwilling	Neutral	Willing	Very willing to eat	Not Familiar With This
Livestock raised with genetically engineered gut bacteria	◯	◯	◯	◯	◯	◯
Hunted meat/game	◯	◯	◯	◯	◯	◯
Plant-based meat alternatives, like Impossible Burgers or Beyond Meat	◯	◯	◯	◯	◯	◯
Foods made with synthetic fertilizers and pesticides	◯	◯	◯	◯	◯	◯
Livestock bred for specific traits (e.g., higher milk production, shorter time to maturity)	◯	◯	◯	◯	◯	◯
Crops bred for specific traits (e.g., higher yield, disease resistance)	◯	◯	◯	◯	◯	◯
Irradiated food	◯	◯	◯	◯	◯	◯

	Not at all willing to eat	Unwilling	Neutral	Willing	Very willing to eat	Not Familiar With This
Crops grown with synthetic fertilizers and pesticides	◯	◯	◯	◯	◯	◯
Upcycled foods (i.e., foods made with ingredients that otherwise would have been discarded)	◯	◯	◯	◯	◯	◯
Prepared meals (e.g., frozen meals, canned soup)	◯	◯	◯	◯	◯	◯
Food from hydroponic production	◯	◯	◯	◯	◯	◯

Trust in Canadian food system

The following statements deal with food labelling and the safety of the Canadian food system. Please say how strongly you agree with each of the statements below on a scale of 1 (strongly disagree) to 5 (strongly agree).

Please choose the appropriate response for each item:

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Genetically modified ingredients and foods are safe to eat	○	○	○	○	○
Currently, enough testing is done on genetically modified foods to ensure their safety before they reach consumers	○	○	○	○	○
Genetically modified or engineered crops and livestock will be important in reducing GHG from agriculture	○	○	○	○	○
When the Canadian Food Inspection Agency (CFIA) approves a new food product for consumption, it is safe to eat	○	○	○	○	○
I am concerned about the health effects of genetically modified or engineered foods	○	○	○	○	○

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
All genetically modified foods/ingredients should be clearly labelled as such on food packages	○	○	○	○	○
Gene edited ingredients and foods are safe to eat	○	○	○	○	○

Food labels - importance

What do you pay attention to when reading food labels? Check all that apply.

❗ Check all that apply

Please choose **all** that apply:

- ☐ Nutritional information
- ☐ Environmental attributes (e.g., lower GHG emissions, made with solar energy)
- ☐ Where it was produced
- ☐ Whether it contains GMOs
- ☐ Whether it adheres to my religious dietary requirements (e.g., Kosher or Halal)
- ☐ Product weight/size
- ☐ Whether it contains certain ingredients
- ☐ I don’t pay attention to food labels

Labelling and knowledge of gene editing

How important is clear labelling and information about the production method of beef products when making your purchasing decisions?

❗ Choose one of the following answers
Please choose **only one** of the following:

- Very important
- Somewhat important
- Not very important
- Not important at all

Have you heard of gene-editing bacteria in cow's guts to reduce methane emissions?

❗ Choose one of the following answers
Please choose **only one** of the following:

- Yes
- No

Choice Experiment (%)

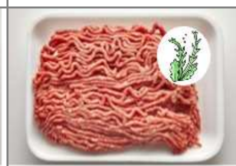
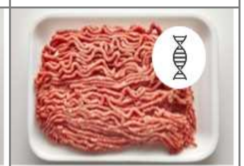
Before answering the next six questions, please take a moment to read the information below

Livestock production accounts for up to 15% of global greenhouse gas emissions and 40% of total methane emissions, which is produced by bacteria in the stomachs of animals like cows and sheep. The yearly methane from a typical cow is equivalent to half of the emissions of a gas-powered car. Producing a pound of regular ground beef produces an amount of methane that is equivalent to roughly 80lbs of CO_2 per pound of beef (or 80 kg of CO_2 per kg of beef).

Feed additives have been developed to lower methane emissions from cows. One of the most promising additives is derived from seaweed. In scientific trials, red seaweed added to a cow's regular feed has been shown to reduce methane emissions by more than 50%. There is no difference between the taste of beef from cattle fed with seaweed and cattle fed a seaweed-free diet.

Scientists are also exploring **gene editing** as a way to reduce methane emissions from cows. Unlike genetic modification, which adds genes from different organisms, gene editing uses the organism's own genetic material. The most widely used gene editing tool is CRISPR, which works like molecular "scissors" to edit specific genes. With CRISPR, the DNA of bacteria can be edited and fed to cows, significantly lowering the amount of methane they emit.

Which of the following would you purchase?

	A	B	C
			
Production Method	Conventional	Feed-Modified Beef	Gene-edited beef
Price	$10/lb ($22.04/kg)	$12/lb ($26.46/kg)	$8/lb ($17.637/kg)
GHG Emission Reduction	None	50%	50%

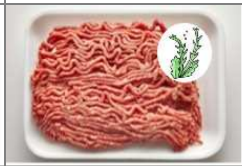
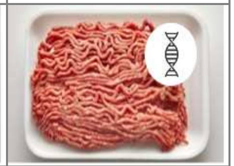
I would choose:

❗ Choose one of the following answers

Please choose **only one** of the following:

- ◯ A
- ◯ B
- ◯ C
- ◯ None of the above

Which of the following would you purchase?

	A	B	C
			
Production Method	Conventional	Feed-Modified Beef	Gene-edited beef
Price	$6/lb ($13.23/kg)	$6/lb ($13.23/kg)	$10/lb ($22.04/kg)
GHG Emission Reduction	0	33%	25%

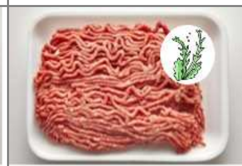
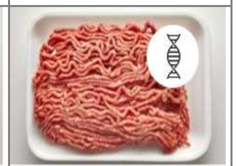
I would choose:

❗ Choose one of the following answers

Please choose **only one** of the following:

- ◯ A
- ◯ B
- ◯ C
- ◯ None of the above

Which of the following would you purchase?

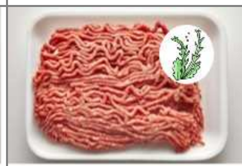
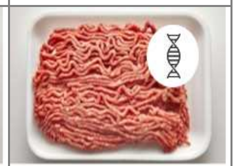
	A	B	C
			
Production Method	Conventional	Feed-Modified Beef	Gene-edited beef
Price	$10/lb ($22.04/kg)	$12/lb ($26.46/kg)	$6/lb ($13.23/kg)
GHG Emission Reduction	0	50%	50%

I would choose:

❗ Choose one of the following answers
Please choose **only one** of the following:

- ◯ A
- ◯ B
- ◯ C
- ◯ None of the above

Which of the following would you purchase?

	A	B	C
			
Production Method	Conventional	Feed-Modified Beef	Gene-edited beef
Price	$6/lb ($13.23/kg)	$10/lb ($22.04/kg)	$6/lb ($13.23/kg)
GHG Emission Reduction	0	25%	33%

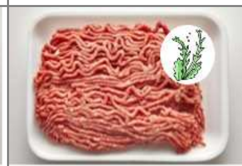
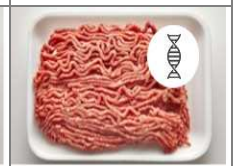
I would choose:

❗ Choose one of the following answers

Please choose **only one** of the following:

- ◯ A
- ◯ B
- ◯ C
- ◯ None of the above

Which of the following would you purchase?

	A	B	C
			
Production Method	Conventional	Feed-Modified Beef	Gene-edited beef
Price	$12/lb ($26.46/kg)	$6/lb ($13.23/kg)	$10/lb ($22.04/kg)
GHG Emission Reduction	0	33%	25%

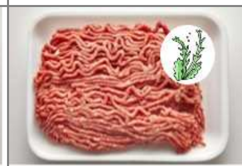
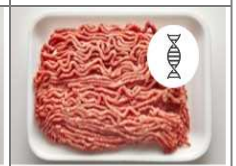
I would choose:

❗ Choose one of the following answers

Please choose **only one** of the following:

- ◯ A
- ◯ B
- ◯ C
- ◯ None of the above

Which of the following would you purchase?

	A	B	C
			
Production Method	Conventional	Feed-Modified Beef	Gene-edited beef
Price	$12/lb ($26.46/kg)	$12/lb ($26.46/kg)	$12/lb ($26.46/kg)
GHG Emission Reduction	0	33%	33%

I would choose:

❗ Choose one of the following answers
Please choose **only one** of the following:

◯ A
◯ B
◯ C
◯ None of the above

Choice Experiment (%)

Before answering the next six questions, please take a moment to read the information below

Livestock production accounts for up to 15% of global greenhouse gas emissions and 40% of total methane emissions, which is produced by bacteria in the stomachs of animals like cows and sheep. The yearly methane

from a typical cow is equivalent to half of the emissions of a gas-powered car. Producing a pound of regular ground beef produces an amount of methane that is equivalent to roughly 80lbs of CO_2 per pound of beef (or 80 kg of CO_2 per kg of beef).

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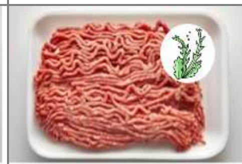
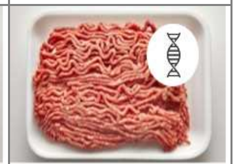
Which of the following would you purchase?

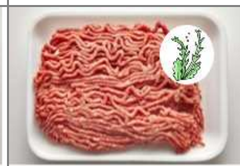
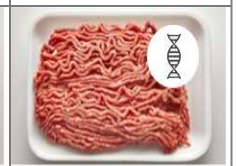
	A	B	C
			
Production Method	Conventional	Feed-Modified Beef	Gene-edited beef
Price	$8/lb ($17.63/kg)	$12/lb ($26.46/kg)	$8/lb ($17.63/kg)
GHG Emission Reduction	None	50%	50%

I would choose:

❗ Choose one of the following answers
Please choose **only one** of the following:

- ◯ A
- ◯ B
- ◯ C
- ◯ None of the above

Which of the following would you purchase?

	A	B	C
			
Production Method	Conventional	Feed-Modified Beef	Gene-edited beef
Price	$10/lb ($22.04/kg)	$6/lb ($13.23/kg)	$12/lb ($26.46/kg)
GHG Emission Reduction	0	50%	50%

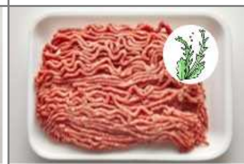
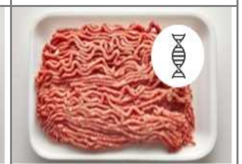
I would choose:

❶ Choose one of the following answers

Please choose **only one** of the following:

- ◯ A
- ◯ B
- ◯ C
- ◯ None of the above

Which of the following would you purchase?

	A	B	C
			
Production Method	Conventional	Feed-Modified Beef	Gene-edited beef
Price	\$8/lb (\$17.63/kg)	\$10/lb (\$22.04/kg)	\$12/lb (\$26.46/kg)
GHG Emission Reduction	0	25%	33%

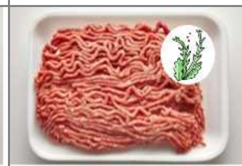
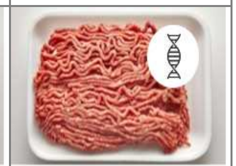
I would choose:

❗ Choose one of the following answers

Please choose **only one** of the following:

- ◯ A
- ◯ B
- ◯ C
- ◯ None of the above

Which of the following would you purchase?

	A	B	C
			
Production Method	Conventional	Feed-Modified Beef	Gene-edited beef
Price	$12/lb ($26.46/kg)	$8/lb ($17.63/kg)	$6/lb ($13.23/kg)
GHG Emission Reduction	0	25%	25%

I would choose:

❗ Choose one of the following answers
Please choose **only one** of the following:

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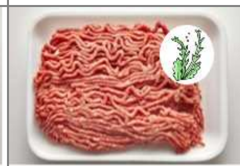
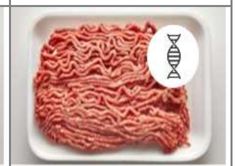
- ◯ B
- ◯ C
- ◯ None of the above

Which of the following would you purchase?

	A	B	C
			
Production Method	Conventional	Feed-Modified Beef	Gene-edited beef
Price	$8/lb ($17.63/kg)	$8/lb ($17.63/kg)	$10/lb ($22.04/kg)
GHG Emission Reduction	0	33%	25%

I would choose:

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- ◯ C
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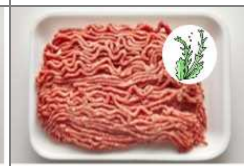
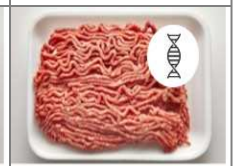
Which of the following would you purchase?

	A	B	C
			
Production Method	Conventional	Feed-Modified Beef	Gene-edited beef
Price	$6/lb ($13.23/kg)	$10/lb ($22.04/kg)	$10/lb ($22.04/kg)
GHG Emission Reduction	0	33%	25%

I would choose:

❗ Choose one of the following answers
Please choose **only one** of the following:

- ◯ A
- ◯ B
- ◯ C
- ◯ None of the above

Choice Experiment (Weight)

Before answering the next six questions, please take a moment to read the information below

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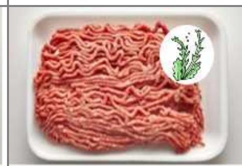
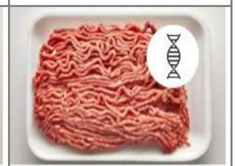
Which of the following would you purchase?

	A	B	C
			
Production Method	Conventional	Feed-Modified Beef	Gene-edited beef
Price	$12/lb ($26.46/kg)	$10/lb ($22.04/kg)	$8/lb ($17.63/kg)
GHG Emission Reduction	0	20lbs of Methane	30lbs of Methane

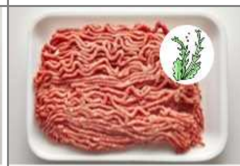
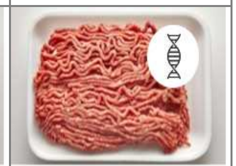
I would choose:

❗ Choose one of the following answers

Please choose **only one** of the following:

- ◯ A
- ◯ B
- ◯ C
- ◯ None of the above

Which of the following would you purchase?

	A	B	C
			
Production Method	Conventional	Feed-Modified Beef	Gene-edited beef
Price	\$8/lb (\$17.63/kg)	\$10/lb (\$22.04/kg)	\$6/lb (\$13.23/kg)
GHG Emission Reduction	0	20lbs of Methane	30lbs of Methane

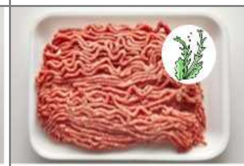
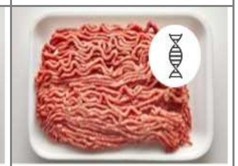
I would choose:

❗ Choose one of the following answers

Please choose **only one** of the following:

- ◯ A
- ◯ B
- ◯ C
- ◯ None of the above

Which of the following would you purchase?

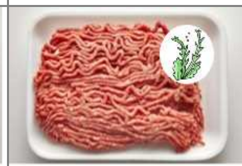
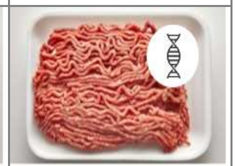
	A	B	C
			
Production Method	Conventional	Feed-Modified Beef	Gene-edited beef
Price	$6/lb ($13.23/kg)	$10/lb ($22.04/kg)	$12/lb ($26.46/kg)
GHG Emission Reduction	0	20lbs of Methane	30lbs of Methane

I would choose:

❗ Choose one of the following answers
Please choose **only one** of the following:

- ◯ A
- ◯ B
- ◯ C
- ◯ None of the above

Which of the following would you purchase?

	A	B	C
			
Production Method	Conventional	Feed-Modified Beef	Gene-edited beef
Price	$10/lb ($22.04/kg)	$8/lb ($17.63/kg)	$10/lb ($22.04/kg)
GHG Emission Reduction	0	40lbs of Methane	40lbs of Methane

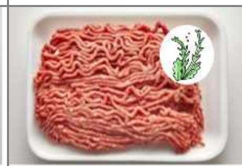
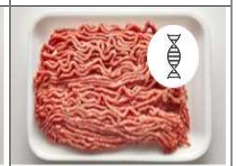
I would choose:

❗ Choose one of the following answers

Please choose **only one** of the following:

- ◯ A
- ◯ B
- ◯ C
- ◯ None of the above

Which of the following would you purchase?

	A	B	C
			
Production Method	Conventional	Feed-Modified Beef	Gene-edited beef
Price	$8/lb ($17.63/kg)	$12/lb ($26.46/kg)	$6/lb ($13.23/kg)
GHG Emission Reduction	0	40lbs of Methane	40lbs of Methane

I would choose:

❶ Choose one of the following answers

Please choose **only one** of the following:

- ◯ A
- ◯ B
- ◯ C
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Which of the following would you purchase?

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		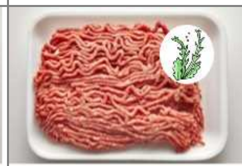	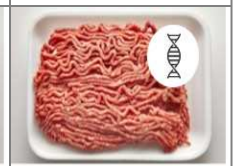
Production Method	Conventional	Feed-Modified Beef	Gene-edited beef
Price	$10/lb ($22.04/kg)	$6/lb ($13.23/kg)	$12/lb ($26.46/kg)
GHG Emission Reduction	0	20lbs of Methane	20lbs of Methane

I would choose:

❗ Choose one of the following answers
Please choose **only one** of the following:

- ◯ A
- ◯ B
- ◯ C
- ◯ None of the above

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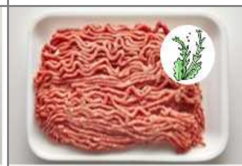
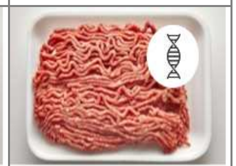
Which of the following would you purchase?

	A	B	C
			
Production Method	Conventional	Feed-Modified Beef	Gene-edited beef
Price	$6/lb ($13.23/kg)	$8/lb ($17.63/kg)	$10/lb ($22.04/kg)
GHG Emission Reduction	0	30lbs of Methane	20lbs of Methane

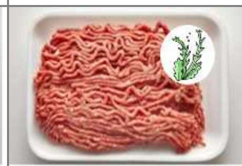
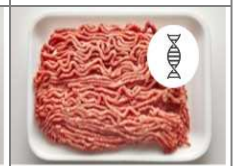
I would choose:

Choose one of the following answers

Please choose **only one** of the following:

- ◯ A
- ◯ B
- ◯ C
- ◯ None of the above

Which of the following would you purchase?

	A	B	C
			
Production Method	Conventional	Feed-Modified Beef	Gene-edited beef
Price	$12/lb ($26.46/kg)	$10/lb ($22.04/kg)	$6/lb ($13.23/kg)
GHG Emission Reduction	0	20lbs of Methane	30lbs of Methane

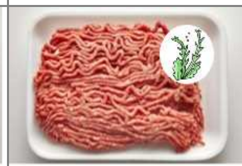
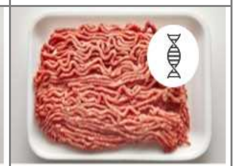
I would choose:

❗ Choose one of the following answers

Please choose **only one** of the following:

- ◯ A
- ◯ B
- ◯ C
- ◯ None of the above

Which of the following would you purchase?

	A	B	C
			
Production Method	Conventional	Feed-Modified Beef	Gene-edited beef
Price	$6/lb ($13.23/kg)	$12/lb ($26.46/kg)	$12/lb ($26.46/kg)
GHG Emission Reduction	0	30lbs of Methane	30lbs of Methane

I would choose:

❗ Choose one of the following answers

Please choose **only one** of the following:

- ◯ A
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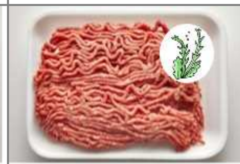
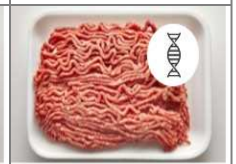
Which of the following would you purchase?

	A	B	C
			
Production Method	Conventional	Feed-Modified Beef	Gene-edited beef
Price	$10/lb ($22.04/kg)	$8/lb ($17.63/kg)	$12/lb ($26.46/kg)
GHG Emission Reduction	0	40lbs of Methane	40lbs of Methane

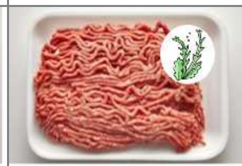
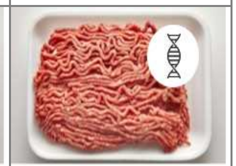
I would choose:

❶ Choose one of the following answers

Please choose **only one** of the following:

- ◯ A
- ◯ B
- ◯ C
- ◯ None of the above

Which of the following would you purchase?

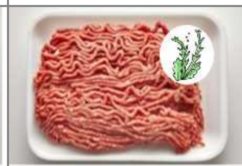
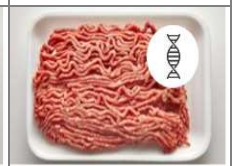
	A	B	C
			
Production Method	Conventional	Feed-Modified Beef	Gene-edited beef
Price	$12/lb ($26.46/kg)	$12/lb ($26.46/kg)	$10/lb ($22.04/kg)
GHG Emission Reduction	0	30lbs of Methane	20lbs of Methane

I would choose:

❗ Choose one of the following answers
Please choose **only one** of the following:

- ◯ A
- ◯ B
- ◯ C
- ◯ None of the above

Which of the following would you purchase?

	A	B	C
			
Production Method	Conventional	Feed-Modified Beef	Gene-edited beef
Price	$12/lb ($26.46/kg)	$10/lb ($22.04/kg)	$12/lb ($26.46/kg)
GHG Emission Reduction	0	20lbs of Methane	30lbs of Methane

I would choose:

❗ Choose one of the following answers

Please choose **only one** of the following:

- ◯ A
- ◯ B
- ◯ C
- ◯ None of the above

Choice Experiment (Logo)

Before answering the next six questions, please take a moment to read the information below

Livestock production accounts for up to 15% of global greenhouse gas emissions and 40% of total methane emissions, which is produced by bacteria in the stomachs of animals like cows and sheep. The yearly methane

from a typical cow is equivalent to half of the emissions of a gas-powered car. Producing a pound of regular ground beef produces an amount of methane that is equivalent to roughly 80lbs of CO_2 per pound of beef (or 80 kg of CO_2 per kg of beef).

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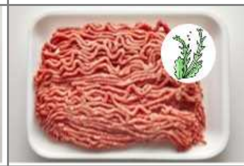
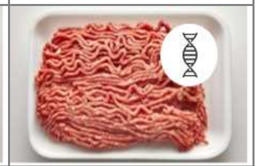
Which of the following would you purchase?

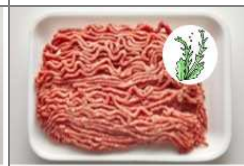
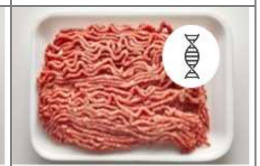
	A	B	C
			
Production Method	Conventional	Feed-Modified Beef	Gene-edited beef
Price	$8/lb ($17.63/kg)	$6/lb ($13.23/kg)	$6/lb ($13.23/kg)
GHG Emission Reduction	None		

I would choose:

❗ Choose one of the following answers
Please choose **only one** of the following:

- ◯ A
- ◯ B
- ◯ C
- ◯ None of the above

Which of the following would you purchase?

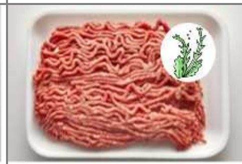
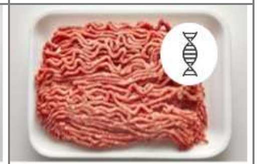
	A	B	C
			
Production Method	Conventional	Feed-Modified Beef	Gene-edited beef
Price	$6/lb ($13.23/kg)	$6/lb ($13.23/kg)	$8/lb ($17.63/kg)
GHG Emission Reduction	None		

I would choose:

❗ Choose one of the following answers
Please choose **only one** of the following:

- ◯ A
- ◯ B
- ◯ C
- ◯ None of the above

Which of the following would you purchase?

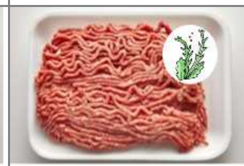
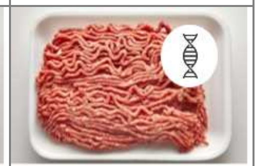
	A	B	C
			
Production Method	Conventional	Feed-Modified Beef	Gene-edited beef
Price	$8/lb ($17.63/kg)	$6/lb ($13.23/kg)	$8/lb ($17.63/kg)
GHG Emission Reduction	None		

I would choose:

❶ Choose one of the following answers
Please choose **only one** of the following:

- ◯ A
- ◯ B
- ◯ C
- ◯ None of the above

Which of the following would you purchase?

	A	B	C
			
Production Method	Conventional	Feed-Modified Beef	Gene-edited beef
Price	$8/lb ($17.63/kg)	$8/lb ($17.63/kg)	$8/lb ($17.63/kg)
GHG Emission Reduction	None		

I would choose:

❶ Choose one of the following answers
Please choose **only one** of the following:

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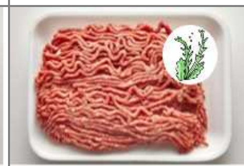
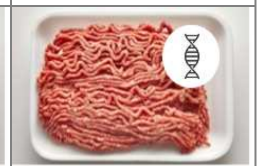
- ◯ B
- ◯ C
- ◯ None of the above

Which of the following would you purchase?

	A	B	C
			
Production Method	Conventional	Feed-Modified Beef	Gene-edited beef
Price	$12/lb ($26.46/kg)	$8/lb ($17.63/kg)	$10/lb ($22.04/kg)
GHG Emission Reduction	None		

I would choose:

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Please choose **only one** of the following:

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- ◯ C
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		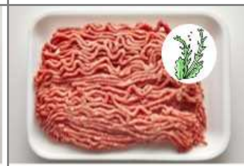	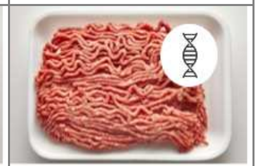
Production Method	Conventional	Feed-Modified Beef	Gene-edited beef
Price	\$10/lb (\$22.04/kg)	\$8/lb (\$17.63/kg)	\$6/lb (\$13.23/kg)
GHG Emission Reduction	None	High GHG reduction	High GHG reduction

I would choose:

❶ Choose one of the following answers

Please choose **only one** of the following:

- ◯ A
- ◯ B
- ◯ C
- ◯ None of the above

Choice Experiment (Logo)

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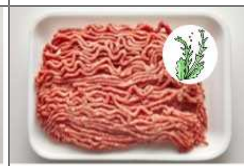
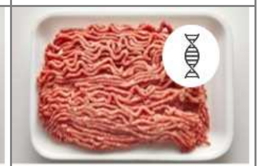
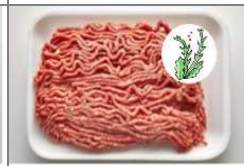
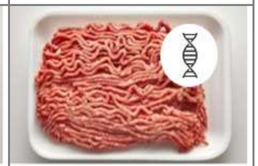
	A	B	C
			
Production Method	Conventional	Feed-Modified Beef	Gene-edited beef
Price	$10/lb ($22.04/kg)	$6/lb ($13.23/kg)	$8/lb ($17.63/kg)
GHG Emission Reduction	None		

I would choose:

❗ Choose one of the following answers
Please choose **only one** of the following:

- ◯ A
- ◯ B
- ◯ C
- ◯ None of the above

Which of the following would you purchase?

	A	B	C
			
Production Method	Conventional	Feed-Modified Beef	Gene-edited beef
Price	$8/lb ($17.63/kg)	$6/lb ($13.23/kg)	$10/lb ($22.04/kg)
GHG Emission Reduction	None		

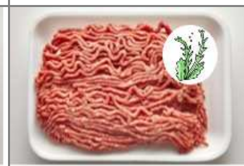
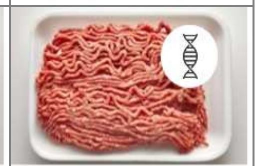
I would choose:

❗ Choose one of the following answers

Please choose **only one** of the following:

- ◯ A
- ◯ B
- ◯ C
- ◯ None of the above

Which of the following would you purchase?

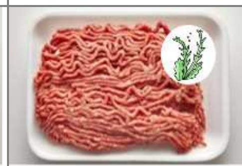
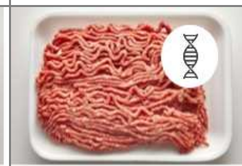
	A	B	C
			
Production Method	Conventional	Feed-Modified Beef	Gene-edited beef
Price	$8/lb ($17.63/kg)	$8/lb ($17.63/kg)	$6/lb ($13.23/kg)
GHG Emission Reduction	None		

I would choose:

❶ Choose one of the following answers
Please choose **only one** of the following:

- ◯ A
- ◯ B
- ◯ C
- ◯ None of the above

Which of the following would you purchase?

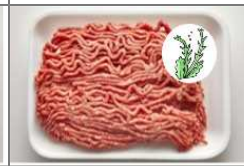
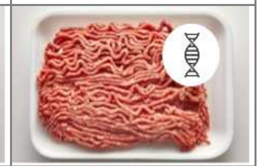
	A	B	C
			
Production Method	Conventional	Feed-Modified Beef	Gene-edited beef
Price	\$6/lb (\$13.23/kg)	\$12/lb (\$26.46/kg)	\$10/lb (\$22.04/kg)
GHG Emission Reduction	None		

I would choose:

❗ Choose one of the following answers
Please choose **only one** of the following:

- ◯ A
- ◯ B
- ◯ C
- ◯ None of the above

Which of the following would you purchase?

	A	B	C
			
Production Method	Conventional	Feed-Modified Beef	Gene-edited beef
Price	$8/lb ($17.63/kg)	$6/lb ($13.23/kg)	$8/lb ($17.63/kg)
GHG Emission Reduction	None		

I would choose:

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Please choose **only one** of the following:

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Which of the following would you purchase?

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		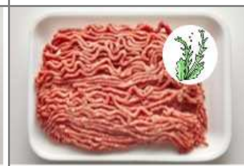	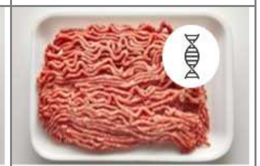
Production Method	Conventional	Feed-Modified Beef	Gene-edited beef
Price	$10/lb ($22.04/kg)	$8/lb ($17.63/kg)	$8/lb ($17.63/kg)
GHG Emission Reduction	None		

I would choose:

❗ Choose one of the following answers
Please choose **only one** of the following:

- ◯ A
- ◯ B
- ◯ C
- ◯ None of the above

Choice Experiment (Car)

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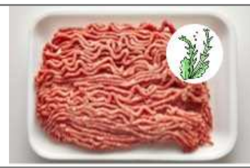
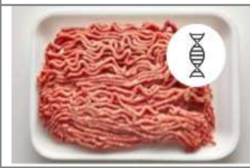
Which of the following would you purchase?

	A	B	C
			
Production Method	Conventional	Feed-Modified Beef	Gene-edited beef
Price	$12/lb ($26.46/kg)	$12/lb ($26.46/kg)	$6/lb ($13.23/kg)
GHG Emission Reduction	None	Taking a car off the road for 2 months	Taking a car off the road for 2 months

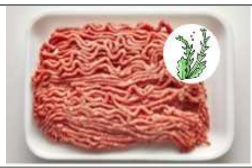
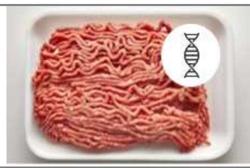
I would choose:

❗ Choose one of the following answers

Please choose **only one** of the following:

- ◯ A
- ◯ B
- ◯ C
- ◯ None of the above

Which of the following would you purchase?

	A	B	C
			
Production Method	Conventional	Feed-Modified Beef	Gene-edited beef
Price	$12/lb ($26.46/kg)	$12/lb ($26.46/kg)	$8/lb ($17.63/kg)
GHG Emission Reduction	None	Taking a car off the road for 2 months	Taking a car off the road for 2 months

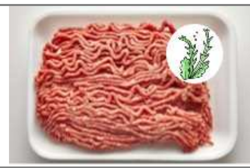
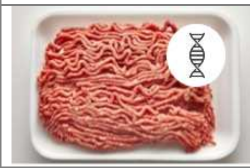
I would choose:

❗ Choose one of the following answers

Please choose **only one** of the following:

- ◯ A
- ◯ B
- ◯ C
- ◯ None of the above

Which of the following would you purchase?

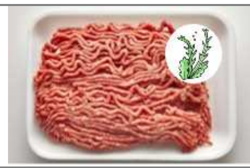
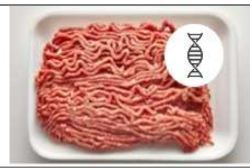
	A	B	C
			
Production Method	Conventional	Feed-Modified Beef	Gene-edited beef
Price	\$6/lb (\$13.23/kg)	\$10/lb (\$22.04/kg)	\$8/lb (\$17.63/kg)
GHG Emission Reduction	None	Taking a car off the road for 1.5 months	Taking a car off the road for 2 months

I would choose:

❶ Choose one of the following answers
Please choose **only one** of the following:

- ◯ A
- ◯ B
- ◯ C
- ◯ None of the above

Which of the following would you purchase?

	A	B	C
			
Production Method	Conventional	Feed-Modified Beef	Gene-edited beef
Price	$6/lb ($13.23/kg)	$10/lb ($22.04/kg)	$10/lb ($22.04/kg)
GHG Emission Reduction	None	Taking a car off the road for 1.5 months	Taking a car off the road for 1.5 months

I would choose:

❶ Choose one of the following answers
Please choose **only one** of the following:

- ◯ A
- ◯ B
- ◯ C
- ◯ None of the above

Which of the following would you purchase?

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		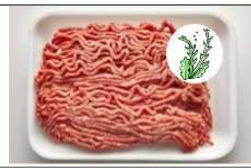	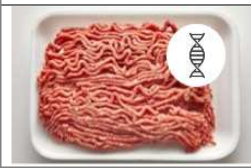
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Price	$10/lb ($22.04/kg)	$10/lb ($22.04/kg)	$12/lb ($26.46/kg)
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		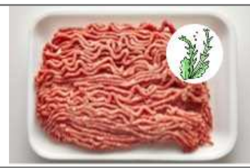	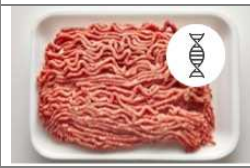
Production Method	Conventional	Feed-Modified Beef	Gene-edited beef
Price	$12/lb ($26.46/kg)	$6/lb ($13.23/kg)	$12/lb ($26.46/kg)
GHG Emission Reduction	None	Taking a car off the road for 2 months	Taking a car off the road for 2 months

I would choose:

❗ Choose one of the following answers
Please choose **only one** of the following:

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	A	B	C
			
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Price	$6/lb ($13.23/kg)	$12/lb ($26.46/kg)	$6/lb ($13.23/kg)
GHG Emission Reduction	None	Taking a car off the road for 2 months	Taking a car off the road for 2 months

I would choose:

❗ Choose one of the following answers

Please choose **only one** of the following:

- ◯ A
- ◯ B
- ◯ C
- ◯ None of the above

Which of the following would you purchase?

	A	B	C
			
Production Method	Conventional	Feed-Modified Beef	Gene-edited beef
Price	$8/lb ($17.63/kg)	$8/lb ($17.63/kg)	$12/lb ($26.46/kg)
GHG Emission Reduction	None	Taking a car off the road for 3 months	Taking a car off the road for 3 months

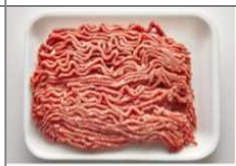
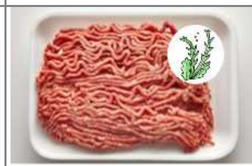
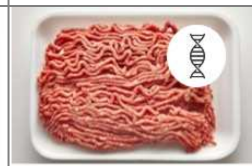
I would choose:

❗ Choose one of the following answers

Please choose **only one** of the following:

- ◯ A
- ◯ B
- ◯ C
- ◯ None of the above

Which of the following would you purchase?

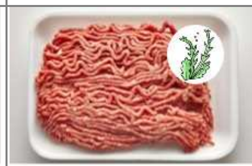
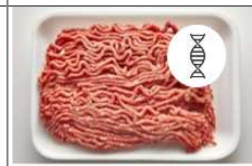
	A	B	C
			
Production Method	Conventional	Feed-Modified Beef	Gene-edited beef
Price	$6/lb ($13.23/kg)	$8/lb ($17.63/kg)	$6/lb ($13.23/kg)
GHG Emission Reduction	None	Taking a car off the road for 1.5 months	Taking a car off the road for 1.5 months

I would choose:

❗ Choose one of the following answers
Please choose **only one** of the following:

- ◯ A
- ◯ B
- ◯ C
- ◯ None of the above

Which of the following would you purchase?

	A	B	C
			
Production Method	Conventional	Feed-Modified Beef	Gene-edited beef
Price	$12/lb ($26.46/kg)	$10/lb ($22.04/kg)	$10/lb ($22.04/kg)
GHG Emission Reduction	None	Taking a car off the road for 2 months	Taking a car off the road for 1.5 months

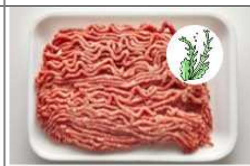
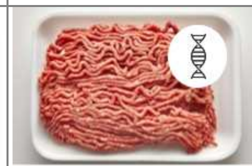
I would choose:

❗ Choose one of the following answers

Please choose **only one** of the following:

- ◯ A
- ◯ B
- ◯ C
- ◯ None of the above

Which of the following would you purchase?

	A	B	C
			
Production Method	Conventional	Feed-Modified Beef	Gene-edited beef
Price	\$10/lb (\$22.04/kg)	\$12/lb (\$26.46/kg)	\$12/lb (\$26.46/kg)
GHG Emission Reduction	None	Taking a car off the road for 3 months	Taking a car off the road for 3 months

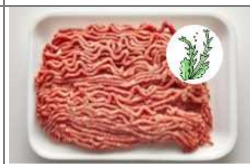
I would choose:

❗ Choose one of the following answers

Please choose **only one** of the following:

- ◯ A
- ◯ B
- ◯ C
- ◯ None of the above

Which of the following would you purchase?

	A	B	C
			
Production Method	Conventional	Feed-Modified Beef	Gene-edited beef
Price	$10/lb ($22.04/kg)	$6/lb ($13.23/kg)	$8/lb ($17.63/kg)
GHG Emission Reduction	None	Taking a car off the road for 3 months	Taking a car off the road for 3 months

I would choose:

❗ Choose one of the following answers

Please choose **only one** of the following:

- ◯ A
- ◯ B
- ◯ C
- ◯ None of the above

Debrief

What is the most important thing you consider when purchasing beef?

❗ Choose one of the following answers
Please choose **only one** of the following:

- Taste
- Price
- Nutritional value
- Where it was produced
- Convenience
- How it was produced (e.g., grass fed, pasture raised)
- Other [ ]

After price, what is the most important thing you consider when purchasing beef?

Only answer this question if the following conditions are met:
Answer was 'Price ' at question '69 [Q21]' (What is the most important thing you consider when purchasing beef?)

❗ Choose one of the following answers
Please choose **only one** of the following:

- Taste
- Nutritional value
- Where it was produced
- Convenience
- How it was produced (e.g., grass fed, pasture raised)
- Other [ ]

In general, how concerned are you about climate change?

❗ Choose one of the following answers
Please choose **only one** of the following:

- ◯ Extremely concerned
- ◯ Somewhat concerned
- ◯ Neither concerned nor unconcerned
- ◯ Not very concerned
- ◯ Not concerned at all

Debrief

How concerned are you about your diet contributing to climate change?

❗ Choose one of the following answers
Please choose **only one** of the following:

- ◯ Extremely concerned
- ◯ Somewhat concerned
- ◯ Neither concerned nor unconcerned
- ◯ Not very concerned
- ◯ Not concerned at all

Suppose beef from cattle with genetically engineered bacteria, with lower methane emissions than traditional beef, was available in the grocery store. How likely would you be to choose it over conventionally produced beef if they were the same price?

❗ Choose one of the following answers
Please choose **only one** of the following:

- ◯ Very likely
- ◯ Somewhat likely
- ◯ Not sure
- ◯ Somewhat unlikely
- ◯ Very unlikely

Suppose beef from cattle with genetically engineered bacteria, with lower methane emissions than traditional beef, was available in the grocery store. How much more than conventionally produced beef would you pay for it?

Only answer this question if the following conditions are met:
Answer was 'Very unlikely' at question '73 [Q25]' (Suppose beef from cattle with genetically engineered bacteria, with lower methane emissions than traditional beef, was available in the grocery store. How likely would you be to choose it over conventionally produced beef if they were the same price?)

❗ Choose one of the following answers
Please choose **only one** of the following:

- ◯ Less than $1/lb ($2.20/kg) more than conventional beef
- ◯ $1/lb to $2/lb ($2.20 to $4.40/kg) more than conventional beef
- ◯ $2/lb to $3/lb ($4.40 to $6.60/kg) more than conventional beef
- ◯ More than $3/lb ($6.60/kg) more than conventional beef

Debrief

Please share any additional comments or thoughts you have about meat production in Canada:

Please write your answer here:

Thank you for completing the survey! Your feedback is greatly appreciated and will help us better understand consumer preferences and beef choices.

Please click on this link to register your response with Prolific: https://app.prolific.com/submissions/complete?cc=C1NRJW9X (https://app.prolific.com/submissions/complete?cc=C1NRJW9X)

If you have any questions or concerns about the survey, please contact Yury Simons (yury.simons@mail.mcgill.ca (mailto:yury.simons@mail.mcgill.ca)) or Prof. Mary Doidge (mary.doidge@mcgill.ca (mailto:mary.doidge@mcgill.ca)). If you have any ethical concerns or complaints about your participation in ths study and want to speak with someone not on the research team,please contact the Associate Director, Research Ethics at 514-398-6831 or lynda.mcneil@mcgill.ca citing REB file number 23-12-053.

Submit your survey.
Thank you for completing this survey.