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Ethical Eggs: Can Synthetic Biology Disrupt the Global Egg Production Industry?

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Commercial egg production relies on the industry-accepted practice of culling day-old male chicks, which are a live by-product of the egg production industry. Researchers are exploring the use of a transgenic marker gene to allow early identification of male embryos *in ovo* at the point of lay, rather than upon hatching. Here we examine social acceptability of this biotechnology-enabled solution to sex selection, which addresses the key ethical issue of culling and improved sustainability of food systems. A national online survey ($N = 1148$) measured psychological factors influencing public support for the development of the technology and willingness to purchase eggs derived from the novel process. Most participants expressed at least a moderate intention to support the development of gene marking technology, with 1 in 5 people expressing strong support. Participants expressed moderate to high agreement that gene marking of chickens would: (a) help reduce or eliminate the practice of culling male chicks in the egg-laying industry (*response efficacy*), and; (b) that this new synbio approach to sex selection may be better than current methods of identifying and removing male chicks during egg production (*relative advantage*). Of those participants who consumed eggs, almost 60% reported they would be moderately to strongly willing to purchase eggs derived from the gene marking process. A partially-mediated path model comprising both *intention to support* and *willingness to buy eggs* ($R^2 = 0.78$) showed that key factors involved in decision-making, in addition to response efficacy and relative advantage, were evaluative attitudes toward the technology (e.g., was the technology bad/good, risky/safe, unethical/ethical) and emotional reactions. These results suggest that consumers may be primarily basing their decisions and behavioral choices on how valuable they perceive the novel gene marking solution, reflecting on how it compares favorably to current culling practices, yielding a range of benefits such as higher animal welfare, improved sustainability, and reduced waste.

Keywords: social science, genetics, novel food, animal welfare, consumer perception

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INTRODUCTION

The practice of culling male chicks is employed in commercial egg laying enterprises worldwide because male birds are uneconomical for meat production and thus an unwanted by-product of egg production. Until recently, the sex of chicks could only be determined after hatching (Gangnat et al., 2018). Once eggs are laid, they are incubated for ~21 days until hatching;

sex determination takes place when chicks are one-day old. Humane production practices are of paramount importance to the egg production industry. Presently, male chicks are macerated or asphyxiated to maintain relatively high welfare outcomes compared to other methods of culling (Primary Industries Standing Committee, 2002; European Union, 2009). Yet, the process is inefficient given that 14 billion eggs are incubated annually around the world, with 7 billion male chicks emerging only to be disposed of once hatched.

Research shows that while consumers have historically had limited awareness of food provenance, this trend is changing. Consumers are becoming increasingly aware of health and environmental consequences of their food choices, and calling for greater transparency of welfare and quality foods parameters (Gangnat et al., 2018; Zhang et al., 2020). For many consumers, learning that egg production involves culling chicks can evoke strong emotive reactions and elicit concern for animal welfare (e.g., Australian Broadcasting Company, 2016; Danovich, 2021). Further questions remain regarding the ethics of bringing chicks into existence without regard for their purpose or value, and the broader sustainability implications of resource-use inefficiency particularly for supermarket chains aiming for carbon neutrality.

While culling practices employed in the egg production industry are relatively unknown, consumers are more familiar with other welfare issues surrounding egg production, such as commercial housing conditions for chickens (Ochs et al., 2018; Teixeira et al., 2018). As a result, the industry has established various "marketed" tiers of consumer choice—caged, barn laid, free-range eggs and pasture grown—in response to shifting consumer preferences; yet, all of these still require the culling process for large scale production [RSPCA (Australia), 2020; Gautron et al., 2021]. Egg producers globally could soon be forced to abandon their culling practices in response to growing public sentiment around animal welfare, and to facilitate more responsible food sourcing and production outcomes. Evidence suggests consumers are looking to make more environmentally conscious and sustainable food choices (Yang et al., 2018). Public awareness and disapproval of chick culling has increased, particularly in Europe where food provenance transparency is increasing (Gangnat et al., 2018; Reithmayer and Mußhoff, 2019; de Haas et al., 2021). Evidence also suggests the global egg production industry is interested in shifting to more sustainable and humane practices (Australian Eggs, 2021; International Egg Commission, 2022). A key problem remains in finding a novel solution that is not only high welfare but also commercially viable and sustainable (Moens, 2021).

One solution to culling, put forward by various animal rights and interest groups, is to reduce human consumption of egg products. However, this fundamental dietary change may be difficult given that many industrial and developing nations worldwide rely on eggs as an affordable, staple protein source (Godfray et al., 2010; Yang et al., 2018; Shahbandeh, 2021). Accepting the strong market demand for eggs, several countries (e.g., Germany, France, US, Israel) are committed to exploring alternatives to chick maceration. This is recognition, in part, that mass culling of chicks is not likely to appeal to the modern consumer (de Haas et al., 2021). In 2019, the German Federal Ministry of Food and Agriculture (BMEL) announced its aim to end the culling of male chicks, pledging €6.5 million to fund alternative methods for sex determination. Similarly, American-based United Egg Producers announced in 2016 their intention to remove the practice of culling by 2020 or as soon as a viable technology becomes accessible. In addition, the Foundation for Food and Agriculture Research created the Egg-Tech Prize to drive technical developments in this field, estimating that preventing male chick culling could save the egg industry ∼US$500 million in wasted eggs and labor (Foundation for Food Agriculture Research, 2021). However, since these announcements, there has not been a marked shift in culling practices and an updated Statement release by the United Egg Producers (2021) confirms they are yet to find suitable alternatives.

Specialized selective breeding to produce dual purpose poultry (i.e., for eggs and meat); endocrinological and mass spectroscopic analyses; hyperspectral analysis of feather color and; the use of MRI-AI technology provide other examples of novel innovations to culling processes (Weissmann et al., 2014; Göhler et al., 2017; Gangnat et al., 2018; Mueller et al., 2018, 2020; Reithmayer and Mußhoff, 2019; Agri-Advanced Technologies, 2021; IN OVO, 2021; Orbem GmbH, 2022). The literature suggests these alternative approaches and technologies to chick culling have had mixed success and incur significant compromises including reduced efficiency and sustainability. Further, these methods ultimately only shift the ethical dilemma of terminating life to the mid-incubation embryonic stage and still result in low value recovery of carcass material. Thus, a scalable, commercially viable and high welfare alternative to culling is yet to emerge.

Consumer Preferences to Alternatives to Chick Culling

There is limited social research on consumer acceptance of alternatives to chick culling. For example, Gangnat et al. (2018) examined consumer acceptance of dual-purpose poultry and prospective *in ovo* sexing. A survey of supermarket shoppers showed that knowledge of culling practices in general was low, and that respondents had a clear preference for an alternative sexing method over chick culling; however, participants did not show a preference between dual-purpose poultry and *in ovo* sexing. People also strongly stated that they would not be inconvenienced if eggs were smaller due to the dual-purpose method, as long as the eggs were derived from this more ethical sexing method. Reithmayer and Mußhoff (2019) also explored consumer preferences for dual-purpose poultry and *in ovo* sex determination. Data were analyzed using consumer segments on five key characteristics: (1) strong product price sensitivity; (2) strong preference for *in ovo* sex determination; (3) strong price-sensitivity and strong preference for *in ovo* sexing; (4) dual-purpose poultry supports with a strong preference for free-range husbandry; and (5) weak price-sensitivity and strong preference for *in ovo* sexing. Reithmayer et al. (2021a,b) further examined public preferences for *in ovo* sexing by investigating the influence of embryonic developmental stages (using pictures) in determining preferences. Results showed that at all three stages of embryonic development, *in ovo* sexing was preferred over chick culling, with analyses showing a clear preference amongst participants for *in ovo* sexing at earlier stages of embryonic development. Support for *in ovo* testing did slightly decrease, however, if there was perceived to be a higher error rate in gender determination using this method. Interestingly, (Reithmayer et al., 2021a) did also flag that the use of embryonic imagery may cause some association with the broader social discourse on abortion, and further explorations could be done to examine the influence of emotion on preferences for sexing.

Reithmayer and colleagues (Reithmayer and Mußhoff, 2019; Reithmayer et al., 2021b) discuss that preferences for alternatives to chick culling has likely grown due to the increased societal awareness of animal welfare in food production; the authors also cited that there exists wide disapproval of chick culling. Yet, they argue, there is limited research about consumer preferences for alternatives. In addition to animal welfare considerations, the authors state that meaningful usage of by-products and a high rate of sex determination accuracy are crucial factors for acceptance of alternatives to chick culling, such as *in ovo* sex determination.

Gene-Marking Technology

Researchers in Australia are exploring a novel genetic approach whereby a marker gene is placed on the male-determining chromosome that makes a protein visible when illuminated by UV light (Doran et al., 2016, 2017). At the point of lay, the cluster of predominantly undifferentiated cells, the blastoderm, in a male egg will glow at a particular wavelength of light when appropriately illuminated. The male eggs can be identified and removed from the food production system, simultaneously removing the marker gene from the system (Doran et al., 2017). The result is that only half the number of eggs need to be placed in incubators than is currently the case, likely reducing carbon footprint and lowering costs of production. Ultimately, this technology eliminates hatching and subsequent culling of live male chicks. This process is classed as synthetic biology (*synbio* herein) in that it is re-designing an existing gene marker to perform a novel function (i.e., acting as a beacon for filtering out male eggs at the point of lay). However, it should be noted that the marker-assisted sex selection method applied at point of lay results in the genetically modified (GM) material being taken out of the production system in the marked male eggs. The null segregant female eggs (with no marker gene) remain in the system, are incubated, hatched, and will grow into layer hens that are indistinguishable from those in hen houses today. Those hens will also go on to lay eggs identical to those currently in production, it being impossible for the fluorescent genetic marker to appear in the final consumable egg because of its chromosomal placement (Doran et al., 2016).

This genetic approach is considered to be an effective solution to chick sex selection as it not only addresses the ethical issues associated with current methods of commercial egg production, but could be scaled up and would also reduce energy and material inputs—thereby improving industry sustainability (Doran et al., 2016, 2017). Furthermore, there is also an opportunity to create a value-add by-product via the discarded whole eggs, which could be used in vaccine development and other scientific processes that require the use of eggs as incubators (Bruijnis et al., 2015).

Attitudinal Factors

Research in technology acceptance has favored variables linked with an extension of Ajzen and Fishbein (1980) theory of reasoned action (TRA) in understanding user intention to uptake technology (e.g., Davis, 1989; Venkatesh and Davis, 2000). This includes a focus on attitudes and subjective norms as driving technology acceptance. Attitudes comprise a set of emotions, beliefs and behaviors toward a particular object or event; thus, attitudes inherently comprise an affective evaluative component, where they can be either positively- or negatively-valenced (Eagly and Chaiken, 1993). Mankad et al. (2020) argue that, when considering public support for novel synthetic biology technologies, positive emotions can be strong predictors of support—even stronger than negative emotions (e.g., Djamasbi et al., 2010). Mankad and colleagues' research (Mankad et al., 2019, 2020; Zhang et al., 2019; Hobman et al., 2022) also shows that affective judgements (attitudes) toward a synthetic biology technology (e.g., the technology is more safe than risky, more wise than foolish) can further influence support. Further, the literature on perceived threat and negative emotions such as fear and stress (e.g., Rogers, 1975; Rogers and Mewborn, 1976; Floyd et al., 2000; McLeod et al., 2015; Mankad, 2016), shows that people differ in their sensitivity toward particular threats and can use different strategies to evaluate information, particularly related to the threat, recommended responses for alleviating the threat, and perceived risks. For this study, if we consider the threat as "culling male chicks," the recommended response as "gene marking," and perceived risks as those associated with the novel gene marking technology, we can see these as potential drivers of intended support for using gene marking as a means of sex selection, to address the culling of male chicks in the egg production industry.

Social norms has also been linked with technology acceptance, with Ajzen's conceptualization positing that socially normative influences affect attitude formation (Ajzen and Fishbein, 2000; Ajzen, 2001). The technology acceptance model (Davis, 1989; Davis et al., 1989)—an extension of the TRA—would argue that *injunctive social* norms (the belief that important others will approve of people who support the technology) and *descriptive social* norms (the belief that important others would support the technology), significantly influences user acceptance, and this has indeed been supported in the literature (e.g., Venkatesh and Davis, 2000; Venkatesh and Morris, 2000; Ham et al., 2015). It is further argued in this paper that, in addition to these subjective social norms related to approval, *personal* norms (a self-expectation, experienced as feelings of moral obligation) are also likely to influence intention to support this particular technology, given the strong ethical narrative which exists around chick culling. Research examining public attitudes toward, and acceptance of, GM foods has identified a strong influence of value-driven and affect-driven psychological factors (e.g., Mallinson et al., 2018; Shew et al., 2018). These include perceptions of morality and naturalness, emotions, and consumer-oriented behaviors (e.g., purchasing) (Carter et al., 2021). Further, *in situations* of low knowledge, such as with GM foods, research has shown that people tend to rely more on the trusted opinions of others and the prevailing social norms that exist within a family, social group or community (Bandura, 1986). We argue that both social and personal norms will be useful in understanding public attitudes toward a novel food product, such as an egg derived from synbio, to provide additional cognitive information and account for increased uncertainty and lack of information during decision-making.

Finally, in addition to attitudes and social norms explaining acceptance of GM foods, the technology acceptance literature also demonstrates the importance of new technology having a "relative advantage" or comparative benefit over the old approach as described in Rogers' diffusion of innovation approach (Valente and Rogers, 1995; Rogers, 2004). Related research in synthetic biology (e.g., CSIRO Synthetic Biology Future Science Platform, 2021) has found that relative advantage is consistently an important factor when understanding why people intend to support a novel synthetic biology solution in place of traditional alternatives, whether that be in the health, environmental or industrial context. The introduction of gene marking technology in commercial egg production would not only make the process higher welfare, but it would also, arguably, render the existing practice of chick culling as obsolete. Therefore, assessing end-user perceptions of relative advantage of gene marking technology may be an important driver of technology acceptance in the present study. Relatedly, Mankad et al. research highlighted the importance of linking relative advantage and support with perceived response efficacy of novel synthetic biology solutions. Response efficacy refers to one's belief in the effectiveness of a new technology (i.e., gene marking) in addressing the problem (i.e., chick culling). People can be wary of technologies that manipulate DNA and want to know that a new gene technology option will deliver outcomes as intended and not result in unintended consequences (Carter et al., 2021).

Willingness to Purchase Eggs

The primary aim of the present study is to examine contextual and cognitive factors likely to drive support for the development of gene marking chickens for sex selection. However, intention to support the development of gene marking technology does not necessarily mean that people would translate their in-principle support into purchasing behavior. A study by Gangnat et al. (2018) examined Swiss consumers' willingness to pay for dual-purpose poultry products (as an alternative to chick culling). Interestingly, consumers' willingness to pay was positively influenced by knowledge about poultry production (which was shown to be low), pre-existing habits tied to purchasing organic or free-range poultry products, and familiarity with dual-poultry products (which was also limited). Therefore, in the present study, it is desirable to understand the influence of psychological factors on willingness to purchase eggs derived from a GM process, as well as the direct influence that technology support may have on willingness to purchase. This measure of willingness is, in effect, a proxy for intention to engage with the technology as a consumer and give the technology implicit support. This indirect measure of support is valuable to understand as it can highlight other factors influencing support that may not be apparent when only examining direct support for the technology (e.g., Mankad et al., 2021).

Present Study

Consumer values related to gene marking technology are of paramount interest and importance for science and industry stakeholders, given the changing standards of the modern consumer. Past research has shown that public acceptance of GM in food production is relatively low overall (Frewer et al., 2004; Jansma et al., 2019). However, it is not known how the public would perceive the use of GM in a food production process that results in a non-GM food product. In the present study, we explore public *support* for the development of the technology and measure *willingness to purchase* eggs derived from the novel process. Several psychosocial and decision-making factors were also proposed as correlates of support and willingness to buy. Past psychological science literature examining public acceptance of novel solutions suggests that several key factors will likely play a role in public support for gene marking technology, as well key drivers of decision-making. Based on the literature cited, we would hypothesize that attitudes, positive emotions, norms, response efficacy and relative advantage would have a direct positive relationship with intention to support; negative emotions and perceived risks would have a negative direct relationship with support. We further hypothesize that support would have a strong direct relationship with willingness to purchase eggs, however due to the partly exploratory nature of the study, we did not hypothesize any other direct drivers of willingness to purchase.

METHODS

Participants

A demographically (age, gender, and geographical location) representative sample ($N = 1,148$) of the Australian population participated in this study (ABS ref). Approximately 3% of the sample identified as of Aboriginal and/or Torres Strait Islander origin. Participants were recruited from NSW (30%), Victoria (25%), Queensland (21%), Western Australia (10%), South Australia (7%), and Australian Capital Territory (4%); participants from Tasmania and the Northern Territory made up the remaining 3%. Most participants (∼40%) reported having a Bachelor or Postgraduate Degree and a further 35% reporting having completed a Certificate, Advanced Diploma/Diploma, or Graduate Diploma/Graduate Certificate. Regarding employment status of participants, 46% reported being employed full-time, 19% were employed working part-time and 24% were not currently in the labor force. Reporting of annual household income (before tax) showed that 21% of participants had a household income of less than AUD$50,000 per year, 27% had a total household income of between AUD$50,000-$99,999, and 18% earned between AUD$100,000–149,999; ∼19% reported a total household income of AUD$150,000 or over per year.

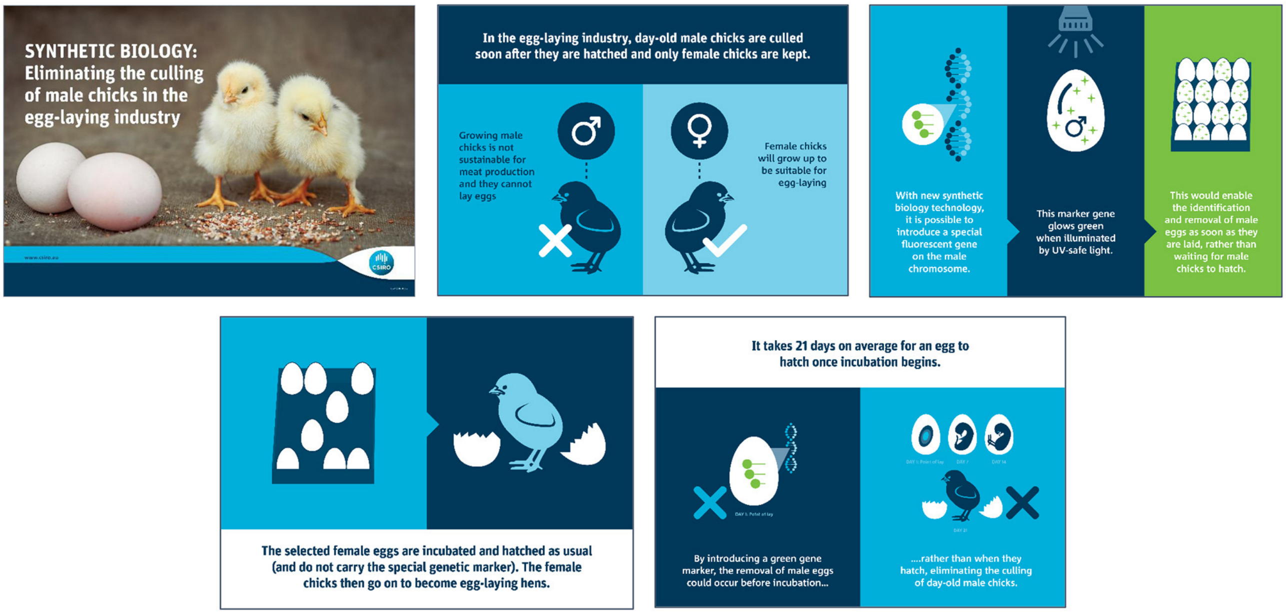

FIGURE 1 | Technology storyboard: eliminating the culling of male chicks in the egg-laying industry using synthetic biology.

Materials

Technology Storyboard

To address the limited awareness of chick culling amongst consumers, described earlier, a bespoke science communication tool called a *Technology Storyboard* (**Figure 1**) was co-developed between the social and biotechnical authors. It was designed to convey the complex gene marking technology simply yet informatively. The Storyboard was framed as a *problem* (chick culling)/*solution* (gene marking) narrative, to provide contextual meaning of the science to an unfamiliar audience (Kallergi et al., 2021; Reithmayer et al., 2021a). The Technology Storyboard added a novel science communication aspect to this study, ensuring all participants had the same baseline understanding of the technology prior to sharing their views. It also enabled an examination of whether basic science comprehension of the technology influenced support for the gene marking technology.

The storyboard was presented in the format of a PowerPoint slideshow with participants moving through several slides at their own pace; both pictures and supporting text were used. The development of the Technology Storyboard was an iterative process, involving the authors first developing a draft narrative and example image sets about the technology, and then seeking guidance from the specific technology experts to refine the technical content. Though simplified, it was important that the fundamental information being conveyed in the storyboards about the technology was accurate.

The team opted not to include mention of explicit risks in its design due to the ongoing nature of the technology development. At the time of publishing, the technology was only at proof-of-concept stage, and it was believed a presentation of possible risks might cognitively bias respondents more than if risks were excluded. As Kahneman and Tversky (1984) have demonstrated, cognitive bias can lead to systematic but potentially flawed patterns of judgement and decision-making. In particular, people tend to weigh the negative aspects of a stimulus more heavily than the positive aspects (Kahneman and Tversky, 1984; Baumeister et al., 2001; Vaish et al., 2008). Therefore, in the present study, although the problem/solution framing may have carried a potential positivity bias, we determined it was less problematic than a negativity bias, which may have "closed off" participants from evaluating the technology from a more balanced position.

An experiment was also embedded within the technology storyboard, with participants receiving additional information (on a final PowerPoint slide) on technology 'regulation,' or public 'engagement' opportunities, or a combination of both 'regulation' and 'engagement' information. A control condition was also included, which did not include the additional information. There were no significant differences in either support[1] ($R^2 = 0.002$, $F(3,1133) = 0.69$, $p = 0.56$) or willingness to purchase eggs[2] ($R^2 = 0.003$, $F_{(3,1114)} = 0.92$, $p = 0.43$) across the four experimental conditions, therefore a decision was made to combine the data into a single dataset for analysis.

Online Survey

The Technology Storyboard was embedded within an online survey (**Table 1**); the survey included several questions measuring a range of demographic and psychological constructs. A small number of demographic questions (age, gender, postcode, and state of residence) were asked at

[1]The mean for support across the 4 experimental conditions was: 3.38 (Control), 3.26 (Regulation), 3.38 (Engagement) and 3.38 (both Regulation and Engagement).
[2]The mean for willingness to buy (minus 30 people who did not eat eggs) was: 3.67 (Control), 3.71 (Regulation), 3.55 (Engagement) and 3.60 (both Regulation and Engagement).

TABLE 1 | Constructs and example items measured in the survey.

Category	Label	Description	*Items*
Psychosocial variables Informed by Fishbein and Ajzen (1975), and Bandura (1986), Ajzen (2011)	Attitudes α = 0.94	Randomized list of seven attitudes, presented on a semantic differential scale where lower scores indicate more negative attitudes, and higher scores indicate more positive attitudes	*I feel this technology would be… harmful………beneficial bad………good foolish………wise unnatural………natural unethical………ethical immoral………moral risky………safe*
	Positive emotion α = 0.82	Three items, measuring positive feeling associated with reading about the technology. Presentation of positive emotions was randomized	*When you read through the information about this technology, to what extent did it make you feel… …hopeful? … excited? … curious?*
	Negative emotion α = 0.84	Three items, measuring negative feeling associated with reading about the technology. Presentation of emotions was randomized.	*When you read through the information about this technology, to what extent did it make you feel… …concerned? … afraid? … angry?*
	Personal norms	A single item reflecting what one ought to do; a feeling of moral obligation	*I would feel morally obliged to support the use of this technology*
	Subjective norms $r = 0.91$	Two items that reflect what important others may do	*If my family and friends knew about this technology, I think they would support it I think my family and friends would encourage me to support this technology*
Decision-making variables Informed by Rogers (1975, 2003, 2014), Rippetoe and Rogers (1987), Sherer and Rogers (1984)	Comprehension	Comprehension was assessed using three questions, each with a TRUE, FALSE or "Don't know" response option. Questions were based on the information provided within the Technology Storyboard.	*Currently, male chicks are culled soon after they hatch (TRUE) With genetic marking, the eggs produced by the grown female chicks (hens) would be identical to the eggs already available for consumption (i.e., not genetically marked) (TRUE) Gene marking would affect both male and female eggs (FALSE).*
	Response efficacy	A single item reflecting the extent which one believes the proposed technological solution will be effective in addressing the problem	*To what extent do you believe that this new technology would help reduce or eliminate the practice of culling male chicks in the egg-laying industry?*
	Relative advantage	A single item reflecting a belief that the proposed technological solution is better than current solution	*I think that this new technology would be better than current methods of identifying and removing male chicks*
	Perceived risk α = 0.91	Three items reflecting concerns (perceived risks) about potential consequences of implementing the proposed technology	*To what extent would you be concerned about … the long-term effects of the technology on humans and animals? … the long-term effects of the technology on the natural environment? … whether the consequences of the technology can be effectively controlled or managed?*
Dependent variables	Intention to support *(attitudinal intention)*	A single item measure of intention to support the development of gene marking technology	*Overall, based on the information provided and your own general knowledge, to what extent would you support the development of this technology?*
	Willingness to purchase eggs *(behavioral intention)*	A single item measure of willingness to purchase eggs derived from using gene marking technology in domestic egg production. Note that participants were reminded at this time that eggs would be laid by hens that were not genetically marked.	*To what extent would you be willing to purchase eggs laid by hens involved in this process? (Reminder: these eggs are laid by hens that are not genetically marked)*

the commencement of the survey to monitor and achieve demographic quotas. Toward the start of the survey, participants were provided with a general definition of synthetic biology:

> *Synthetic biology is a new field of research bringing together genetics, chemistry, and engineering. It allows scientists to design and build new biological organisms, so that they may perform new functions. Synthetic biology can use DNA to create new characteristics, or remove certain functions, in plants, animals, and other organisms (e.g., bacteria, fungi, algae).*

Participants then viewed the Technology Storyboard, which was followed by several questions designed to measure variables deemed to be of interest to the study of public perceptions of this novel synthetic biology solution. The variables were measured with items adapted from previous literature (see relevant column in **Table 1**) and piloted with a small participant sample for refinement. As there were no changes to the survey needed after piloting, the pilot sample was included in the final participant pool.

Procedure

A nationally accredited third-party data collection Provider recruited participants from across Australia, meeting age, gender and location quotas to ensure national population representativeness based on Australian Bureau of Statistics demographic statistics (Australian Bureau of Statistics, 2016). The survey was programmed and hosted online by the Provider and invitation emails were sent to potential participants. In

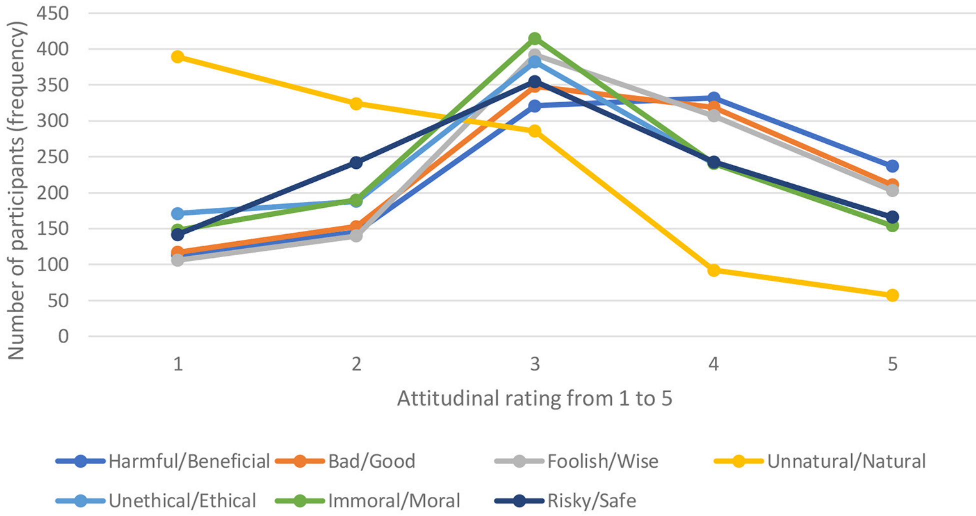

FIGURE 2 | Differential attitudinal rating frequencies for gene marking technology, where lower scores indicate attitudes toward the negative (e.g., harmful, bad, foolish, unnatural, unethical, immoral, risky) and higher scores indicate attitudes toward the positive (e.g., beneficial, good, wise, natural, ethical, moral, safe).

the invitation email, participants were asked to click on the survey link to enter the survey. An information page about the project was presented, followed by an informed consent request to participate. Once informed consent was obtained, participants entered the survey. It took ∼15 mins for participants to complete the survey. Upon completion and submission of the survey, participants received token incentives (in the form of points) for participation from the third-party Provider directly.

Data Analysis

The dataset was imported into the statistical data analysis program, STATA/MP 17.0 (StataCorp, 2021) and all analyses were performed using this program. Prior to the commencement of data analysis, the data were cleaned and screened for missing data, outliers and checked for assumptions. As noted earlier, an experiment was embedded within the survey to examine effects of "regulation" and "engagement" information. However, at the data screening stage, it was determined that no significant differences in support or willingness to purchase existed between participants across the different conditions; therefore, a single dataset was retained.

Descriptive analyses (frequencies, means, correlations), *t*-tests and analysis of variance were carried out on the variables, followed by a path analysis to examine relationships between the variables.

RESULTS

Psychosocial Factors

Overall, participants tended to perceive gene marking technology somewhat positively, with the average score for each attitudinal pair (e.g., harmful/beneficial) hovering slightly above the midpoint of the scale (**Figure 2**). Most people believed the technology to be more unnatural than natural (Mean = 2.22, SD = 1.14). However, participants seemed unsure as to whether the gene marking technology was more ethical than unethical (Mean = 3.03, SD = 1.24), more moral than immoral (Mean = 3.05, SD = 1.19), or more safe than risky (Mean = 3.04, SD= 1.22). Participants held slightly stronger attitudes that the technology was beneficial (Mean = 3.38, SD = 1.22), good (Mean = 3.31, SD = 1.21), and wise (Mean = 3.31, SD = 1.17). In the subsequent path analysis, the individual attitude pairings were combined to form a composite "*attitude*" variable, where higher scores indicated more positive attitude (**Table 2**).

When asked to rate how one felt in response to learning about synbio gene marking technology, the strongest emotion people felt was curiosity, followed by concern and hopefulness (**Figure 3**). The individual emotions listed were later combined by valence, to form two composite variables: "*positive emotion*" and "*negative emotion*" (*see* **Table 1**). A *t*-test comparing positive and negative emotion scores ($t_{(1,147)} = 6.8271, p < 0.001$; Cohen's d^3) showed that people felt significantly more positive than negative about gene marking technology.

Decision-Making Factors

As shown in **Table 2**, participants held moderate to high agreement that gene marking of chickens would help reduce or eliminate the practice of culling male chicks in the egg-laying industry (*response efficacy*). Participants held similarly moderate to strong views that this new synbio approach to sex selection may be better than current methods of identifying and removing male chicks during egg production (*relative advantage*). Overall, comprehension of content within the Technology Storyboard (*see* Methods) was relatively high, with ∼65% of the sample

[3]Cohen's *d* reflects differences between two groups' means, measured by the amount of standard deviation difference (Cohen, 1988); for example a *d* of 0.2 indicates the difference between two groups is 0.2 standard deviations. Interpretation: 0.2 = small effect size, 0.5 = medium effect size, 0.8 = large effect size = 0.20.

correctly answering at least two out of three comprehension test questions correctly.

Perceived risks associated with gene marking technology were measured using three items targeting perceptions of concern about the long-term effects of the technology on humans and animals (Mean = 3.27, SD = 1.18), long-term effects of the technology on the natural environment (Mean = 3.22, SD = 1.18), and whether the consequences of the technology could be effectively controlled or managed (Mean = 3.43, SD = 1.13). A *t*-test showed that the main risk perceived by respondents was related to effective control and management of the technology, which was scored significantly higher than concern for humans and animals ($t_{1147} = -7.12$, $p < 0.001$; Cohen's $d = -0.21$) or concern for the environment ($t_{1147} = -9.00$, $p < 0.001$; Cohen's $d = -0.27$). The individual risk items were later combined to form a composite "*perceived risks*" variable for the path analysis (*see* **Table 1**).

TABLE 2 | Means and standard deviations for the key psychosocial, decision-making and outcome variables.

Category	Variable	Mean (M)	Standard deviation (SD)
Psychosocial factors	Attitudes*	3.05	1.04
	Positive emotion*	2.95[a]	0.99
	Negative emotion*	2.59[b]	1.09
	Personal norm	3.01	1.16
	Subjective norm*	2.97	1.03
Decision-making factors	Comprehension#*	1.82	1.00
	Response efficacy	3.85	1.09
	Relative advantage	3.80	1.06
	Perceived risk*	3.31	1.08
Dependent variables	Intention to support	3.35[a]	1.22
	Willingness to purchase	3.63[b]	1.27

Results are based on the full sample (N = 1,148); scores are based on a 5-point scale (1–5) with higher scores reflecting strength of participant choice.
#Comprehension is based on a 4-point scale (0–3), with higher scores reflecting higher comprehension.
*Variables with a * indicate a composite measure, comprising 2 or more individual items (see **Table 1** for individual items).*
Superscript letters denote statistically different means (p < 0.001) from a simple t-test performed on selected variables within the same construct domain (i.e., emotions, norms, outcome variables).

Dependent Variables: "Intention to Support" and "Willingness to Purchase Eggs"

Almost one in five people stated they would strongly support ($n = 206$, 17.9%) the development of gene marking technology to address culling of male chicks in the egg laying industry (**Figure 4**), with average scores showing moderate support overall (**Table 2**). This level of support differed by gender ($t_{(1,141)} = 4.17$, $p < 0.001$, Cohen's $d = 0.25$), with men (Mean = 3.51, SD = 1.19) reporting slightly higher support for the development of gene marking technology than did women (Mean = 3.21, SD = 1.23). However, this difference was statistically small. Of those participants who ate eggs, most ($n = 658$, 58.8%) reported that they would be moderately to strongly willing to purchase eggs and scored 4 or 5 on the response scale (**Figure 3**). Interestingly, average scores between *intention to support* the gene marking technology and *willingness to purchase* eggs laid by hens involved in the gene marking process were significantly different ($t_{1117} = -8.89$, $p < 0.001$; Cohen's $d = -0.27$). These comparisons suggest that although some people may not be strongly supportive of the development of gene marking

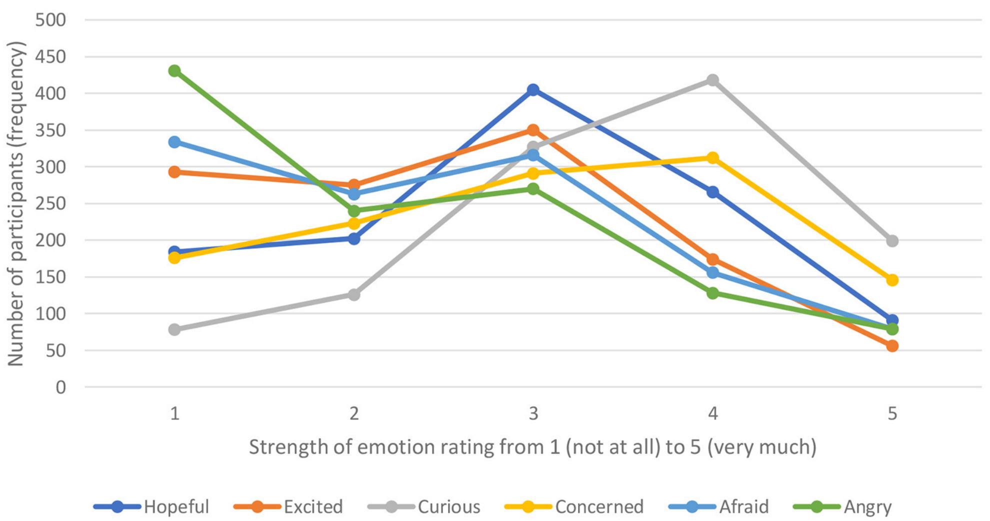

FIGURE 3 | Emotion rating frequencies for feelings toward gene marking technology in chickens, where lower scores indicate a weaker feeling, and higher scores indicate a stronger feeling.

FIGURE 4 | Frequencies for the two dependent variables: support and willingness to purchase eggs ($N = 1,148$).

technology, they may still be willing to buy eggs derived from implementation of the gene marking process.

Path Analyses

Path analyses were performed to examine the relationship between input variables (psychosocial factors, decision-making factors, and personal factors) and the two dependent (outcome) variables: *intention to support* development of gene marking technology, and *willingness to purchase eggs* produced as a result of implementing the gene marking process in egg production.

As shown in **Table 3**, the hypothesized fully-mediated path model did not fit the data well. Modification indices suggested the inclusion of several direct paths between the independent variables and *willingness to buy eggs*. The highest change in modification index (MI) was for relative advantage (MI = 128.79), attitudes (MI = 107.52), response efficacy (MI = 77.97), negative affect (MI = 67.61), perceived risks (MI = 62.70), and social norms (MI = 62.21). Among these, the only theoretically sensible relationships to include were for relative advantage, attitudes, and perceived risks—these are all variables that are evaluative in nature—that is, they reflect an individual's assessment of the technology's benefits and risks.

With these additional paths included, the model fit the data well. The predictor variables accounted for 78.2% of variance in the full model comprising both *intention to support* and *willingness to buy eggs* (**Figure 5**). All associations amongst the variables were in the hypothesized direction and a significant amount of variance was explained in the dependent variable *willingness to buy eggs* (55.4%) and mediator *intention to support* development of the technology (72.6%). These statistics suggest a model with strong explanatory power.

Individually, variables directly predicting *intention to support* gene marking technology accounted for 72.6% of variance in support, with the strongest predictors being attitudes and positive emotion, followed by relative advantage, negative emotion, and social and personal norms. Perceived response efficacy and comprehension were the weakest predictors of intention to support, and perceived risk was not significant. Direct and indirect pathways predicting *willingness to purchase eggs* accounted for 55% of variance in the dependent variables. Interestingly, although intention to support the development of gene marking technology was a strong predictor of willingness to purchase eggs, it was not the strongest. Results showed that other factors, particularly perceived relative advantage of the technology and attitudes toward the technology, exerted slightly more direct influence on willingness to purchase eggs. Perceived risk and age also had small but significant direct relationships with willingness to purchase; the model suggested willingness to purchase eggs tended to decrease as perceived risk increased, and that willingness increased with age. Sex did not have an influence on willingness to purchase. While other predictors, such as positive and negative emotion, and social norms, did not appear to directly influence willingness to purchase eggs, the variables exerted any potential influence via the mediated relationship between willingness to purchase eggs and intention to support.

DISCUSSION

The present study explored public *support* for the development of gene marking technology for sex selection in the egg production industry, and measured *willingness to purchase* eggs derived from the novel process as a further, indirect measure of technology support and engagement. Several psychosocial and decision-making factors were examined, to understand direct and indirect influences of intention. Results revealed that participants showed moderate support for further development

TABLE 3 | Fit statistics for the hypothesized and final path models.

Model	Chi-square (df)	Chi-square/df	CFI	SRMR	RMSEA
Good model fit ranges	ns ($p > 0.05$)	<2.00	>= 0.90	<0.08	<0.08
Hypothesized model (full mediation)	296.45 (11), $p < 0.001$	26.95	0.88	0.05	0.15
Final model (partial mediation)	57.64 (8), $p < 0.001$	7.21	0.98	0.01	0.075

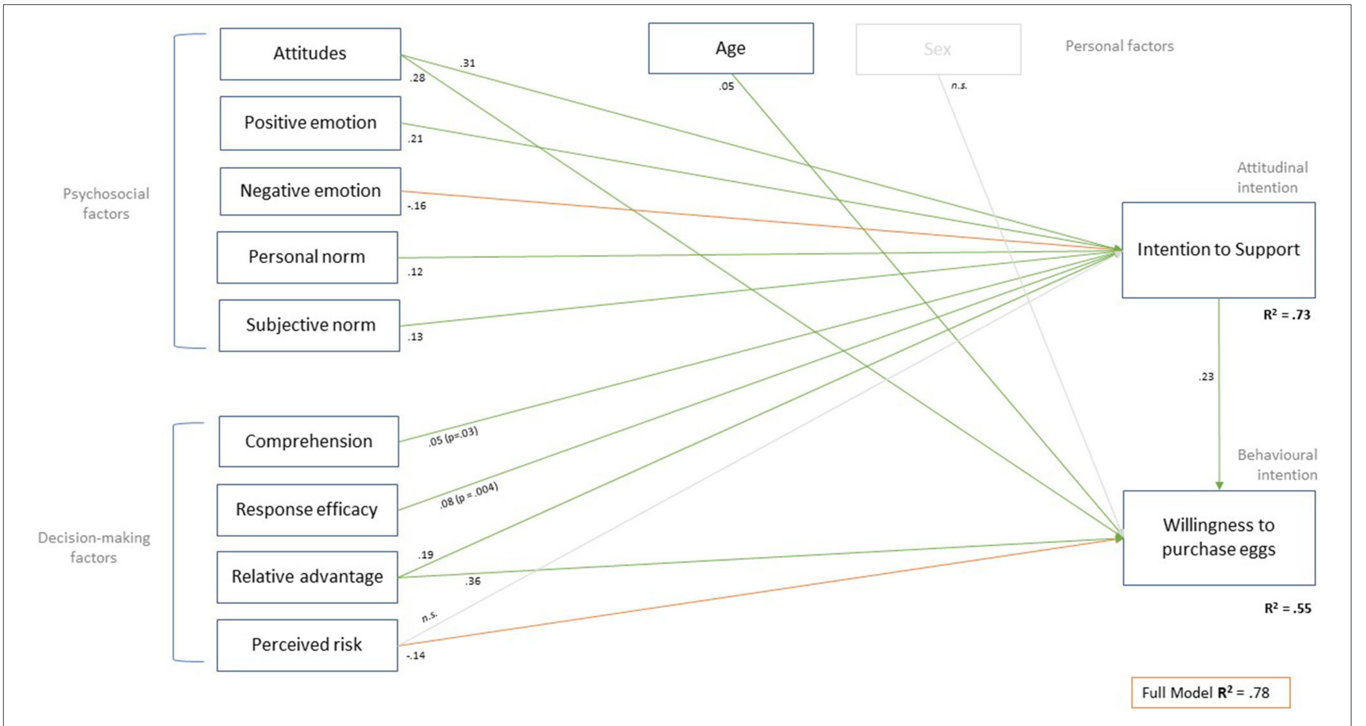

FIGURE 5 | A path model of psychosocial, decision-making, and personal factors predicting public support for development of gene marking technology and willingness to purchase eggs derived from this novel approach. All coefficients listed are significant at $p < 0.001$ unless specified.

of gene marking technology and a willingness to purchase eggs from the novel production process. When deciding whether to support the development of gene marking technology or whether to purchase eggs, people tended to make global evaluations of whether the technology was good or bad, ethical or unethical, wise or foolish. In particular, a belief that gene marking was a better method than chick culling for identifying and removing male chicks from egg production was the dominant influence on intention to purchase eggs derived from the gene marking process. These results lend support for the technology acceptance framings proposed by Davis (1989), Venkatesh and Davis (2000), and Rogers' (2003) diffusion of innovation, where positively-valenced attitudes and a perceived relative advantage of an innovation drive intended support. These results suggest that people are evaluating the value of the novel gene marking solution for sex-selection relative to current culling practices and may be considering the technology's advantages such as higher animal welfare, improved sustainability, and reduced waste.

With respect to individual attitudes toward gene marking as a possible solution to sex selection, it was clear that more people believed the gene marking process to be "unnatural" than "natural." Despite this, support for the technology's development was still reasonably strong. We may have expected a drop in stated support, given that people reported the gene marking process as more unnatural, which would be consistent with the findings from prior research on public attitudes toward GM foods (e.g., Mallinson et al., 2018), but this was not the case. Instead, it may be due to the use of Technology Storyboards, which clearly articulated (according to comprehension scores) the problem context of chick culling in the egg laying industry. The Technology Storyboard also went into some simple detail about the use of a GM-derived technology in providing an alternative to sex selection that would till yield a non-GM food product. Indeed, a review of attitudes indicated that more people viewed the technology in a positive way (i.e., they saw the technology as being more beneficial, good, wise, natural, ethical, moral and safe) rather than holding a more negatively-valenced attitude (i.e., perceiving the technology as harmful, bad, foolish, unnatural, unethical, immoral, and risky). This suggests that perhaps the problem-solution framing was useful in contextualizing the technology and its potential value proposition compared to conventional methods used for sex selection.

Interestingly, the path model showed no direct relationship between perceived risks associated with gene marking and support for the development of the technology. Rather, there was a direct relationship between risks and willingness to purchase, even though the measure of perceived risk used in the study asked participants to rate their concern regarding risks/effects of the technology itself. This suggests a potentially interesting alternative angle, where participants may see the risks associated with this technology lying not with the genetic technology itself, but rather with one or more potential externalities not accounted for by a simple measure of support. Personal factors such as socioeconomics and culture, which were not measured in this study, may also play a role in driving egg purchasing behavior; as might underlying health and environmental values that can influence food choice (Ghvanidze et al., 2017). The present study provides a useful platform for exploring other approaches to target these broader values, such as utilizing economic experimentation with market levers that may attract or incentivise (motivate) people to purchase eggs derived from the more sustainable gene marking approach that might also influence perception of risk and potential mental trade-offs in the decision-making process. It would be interesting to understand that self-justification or rationalization process that people engage in if they hold conflicting beliefs about animal welfare and GM technology risk. There is a clear tension here between choosing to purchase eggs laid through current, traditional food production methods where male chicks are culled, and purchasing higher welfare eggs laid by hens involved in the gene marking process. It is also possible that people may consider that the presence of risks (or rather being concerned about these risks) should not preclude further *development* of the technology, but rather the actual *implementation* of the technology. The distinction is subtle; however, some people may consider that the technology development process would be scientifically robust and cautious, necessarily including a proper evaluation of risks and long-term effects. Further qualitative research would be needed to better understand the concerns that people hold regarding risks and long-term effects, and their expectations of how risks are considered as part of the technology development process. Such qualitative work would also usefully reveal to technology developers and implementers, what the public expects when it comes to safeguards and risk management measures/methods.

The role of social influence is another consideration when understanding public acceptance of novel technologies and is observed in the way people typically rely on important others to guide their own attitudes and behaviors. This is particularly so in situations of low knowledge, such as that presented by novel synbio applications (Mankad et al., 2020). While the relationship between norms and support for gene marking technology was not as influential as other psychosocial factors in the model, and indeed as other research may have found in other research on technology acceptance (e.g., Venkatesh and Davis, 2000), the effect was still significant. A possible explanation for the relatively weaker influence of both subjective and personal norms is perhaps because of the novelty of the proposed solution and—in some regards—low awareness of the chick culling problem. Two out of three participants indicated little or no awareness of chick culling in the egg-laying industry. It is quite likely that this problem is not well discussed in the public domain, which may limit the extent to which individuals have a sense of the prevailing social norms and associated moral issues (Bruijnis et al., 2015; Danovich, 2021). Thus, individuals may not know for sure whether others would support the technology, and whether there is a moral expectation or imperative to support it. It is possible that other social norms concerning GM, sustainability, or animal welfare may be more established and therefore more pervasive; this could be explored in future studies to determine the impact of social influence on consumer support for, and engagement with, the technology. Nevertheless, we may still surmise that commercial-scale chick culling would generally be perceived as an emotive and troubling issue (e.g., Australian Broadcasting Company, 2016) and; finding a solution for this problem is deeply rooted in fundamental concerns pitting human consumption priorities against those of animal welfare.

We observed that positive emotions were strongly associated with support for development of the technology and had greater predictive power than negative reactions toward the technology. This supports past research on public acceptability of synthetic biology innovation, where positive emotions have been found to be more influential in predicting support than negative emotions (e.g., Mankad et al., 2020). Perhaps framing the use of gene marking technology to deliver a higher welfare end product for consumers elicits positive sentiments toward the technology as well as meeting public expectations that new technologies ought to be inherently good and improve the human condition (Pew Research Center, 2014). Although we did not explicitly measure emotional reactions to the problem statement or affective reactions occurring in relation to the anticipated outcome (e.g., purchasing an egg derived from a GM process), we can conclude that the strength of emotions as predictors of support in this study reflects the importance of emotions in dynamic decision making and ultimately for "brand success" (Garcia-Garcia, 2020). The results also justify our decision to focus on presenting "intended benefits" of the gene marking technology in this study, rather than also presenting hypothetical risks of the technology. Including the latter may, at face value, appear a more balanced examination. However, the constructed problem of chick culling for human food production is highly emotive and likely elicited internalized queries of morality, ethical responsibility, and a desire to exercise personal control over remedial actions such as sustainable food choices (Mankad et al., 2019; Reithmayer, 2020). To further include a presentation of risks would have obscured the unique contribution of our predictors as they relate to decision-making. As Baumeister et al. (2001) argue, "bad" impressions and stereotypes are not only quicker to form but are also more difficult to "disconfirm." We argue that this is even more so the case with GM food technologies, where there is a history of public mistrust and strong anti-GM sentiment likely to elicit a negativity bias (Sikora and Rzymski, 2021). That is not to say that an examination of risks of gene marking technology is not warranted, just that a more efficacious approach is needed.

The preferred method for assessing perceived risk in the present study was to query more general concerns about the introduction of the gene marking technology. Concerns regarding how the consequences of the technology would be managed (i.e., perceived risks) was directly related to willingness to purchase eggs. The presence of a direct, rather than indirect, relationship between perceived risk and willingness to purchase, in this instance, is possibly because the risks lay squarely within the implementation environment—that is, when the technology is already integrated into business-as-usual egg production processes and resultant eggs are available to purchase. In other words, the point of purchase (and imminent *consumption*) of the egg is where people may perceive the greatest risk. Thus, prior to implementation of the end consumer product derived from gene marking technology, it will be important to allay concerns—real or perceived—about consuming the end product and how identified risks will be mitigated and/or managed at this point in the process.

The global egg industry is aware that chick culling is a risk to business and production, and that the practice is a known concern for major supermarket retailers, who represent the major outlet for table eggs and egg products. Current solutions being introduced in Europe (e.g., endocrinological procedures, hyperspectral imaging, and MRI) are driven by legislative requirements and come at a significant cost to industry (in machinery, materials, incubation time and concomitant production losses). Questions remain whether such solutions will appreciably improve sustainability and address key ethical issues. While the gene marking technology presented to participants in this study may result in sustainable outcomes, there are challenges associated with communicating this new technology to consumers. Not only would such communication require raising public awareness of existing culling practices, but it would also mean communicating about a GM process (albeit one that produces a non-GM whole-food product). Industry risk perceptions in relation to low consumer tolerance of GM processes in food production may be additionally fuelled by previous public opposition to agricultural biotechnologies. The costs to individual operators and larger commercial entities associated with adoption of new technology, manufacturing processes, and infrastructure is also a key consideration for future investment. A social perspective is therefore useful to explore, even at the early stages of technology development, because it provides insight into consumer perceptions and acceptance of the new technology. From an industry perceptive, it is important to know whether consumers will support the technology, and whether their egg purchasing preferences will change (and if so, how). Industry will then be able to undertake an informed assessment about whether this technology is a valuable addition to the egg production process, or is an unnecessary investment destined for insufficient uptake.

CONCLUSION

Alternative technologies which have the potential to make improvements to intensive food production processes, including a reduction in lower-welfare practices such as culling, are broadly aligned with current industry aspirations for sustainability. Innovations such as gene marking for sex selection also address an increasing public demand for more ethical supply chains and transparency in food provenance. These coalescing factors, along with efficiencies such as improved resource use and less waste, present multiple opportunities for industry consideration of innovative synthetic biology technologies globally (Capper, 2020). The use of gene marking, while currently being developed via gene editing, can utilize synthetic biology techniques to scale up potential and provide a commercially viable solution to culling which results in a non-GM consumer product, and more sustainable commercial egg production. However, communicating this complex sex-selection innovation to general publics may require an introduction and explanation of current culling practices, which in the short term may raise industry anxiety. Key sector engagement including social research into the perceptions, attitudes and expectations of industry and supply chain actors will therefore be important next steps in ascertaining industry and supply chain preparedness. From a consumer perspective, this study suggests that everyday consumers are supportive of innovation and willing to change their purchasing habits should the right solution come along for a perceived moral and ethical problem.

DATA AVAILABILITY STATEMENT

The summarised data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by CSIRO Human Research Ethics Committee. The participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

AM: conceptualization, data curation, formal analysis, funding acquisition, investigation, methodology, project administration, resource visualization, supervision, validation, roles/writing—original draft, and writing—review and editing. EH: conceptualization, data curation, formal analysis, investigation, methodology, project administration, resource visualization, validation, roles/writing—original draft, and writing—review and editing. LC: conceptualization, resource visualization, writing—original draft, and writing—review and editing. MT: resource visualization, writing—original draft, and writing—review and editing.

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