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Assuring Food Security: Consumers' Ethical Risk Perception of Meat Substitutes

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Abstract: The world's growing population requires an adequate supply of protein to maintain food security, but animal protein production is limited by the finite resources of land, fresh water, and ocean capacity. Several meat substitutes offer protein alternatives that may improve food security in less-developed economies. However, perceptions of difference in the ethical risk associated with consumption of plant-based substitutes (PM) vs. cultured meat (CM) may affect purchases of these products. This study examined differences in ethical risk perception using online survey data gathered in 2020. An ordered logit technique yielded the probabilities of changes in ethical risk perception influenced by demographic attributes, views about the technology, and adequacy of industry regulations. The results show that consumers associated PM with low ethical risk. Educated consumers were more likely to agree that the ethical risks of CM are higher than PM and to regard PM products as safer than CM. Price sensitivity made consumers more likely to agree that the ethical risks related to CM are higher than those related to PM. Ingredient safety concerns increased the ethical risk perception of CM. Consumers perceiving the meat substitute classification to be unclear were more likely to assign a higher ethical risk to CM than PM. The perception of ethical risk associated with CM was greater than that associated with PM if meat substitute industry regulations were inadequate. The results suggest a need to provide verifiable information about each type of meat substitute as well as transparent and understandable standards and rules before these products can improve protein availability and food security.

Keywords: meat substitutes; ethical risk; plant-based meat; cultured meat; consumer perceptions

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1. Introduction

Meeting the world's food needs will require an increase in food production and food security to ensure access to nutritious food, including adequate protein intake. Meat remains the main global protein source [1], with animal protein demand expected to increase in the coming years [2]. In countries with large populations, like China, the demand for meat outpaces domestic supply and imports prevent shortages. In the European Union (EU), for example, about 42% of the protein consumed is derived from plants and the balance is derived from animal sources (meat, fish, eggs, and dairy products). Animal protein production is limited not only by energy and production costs and environmental factors [3,4], but also by animal welfare regulations and disease outbreaks, all of which pose risks to the meat supply [5,6]. Meat substitutes are alternatives to meat products obtained through nonlivestock production methods [7]. Meat substitutes can reduce the environmental burdens of the food production system [8–10], alleviate the imbalance between meat supply and demand [11], and support food security [10]. Additionally,

meat substitutes may reduce the use of grain in livestock production, a resource which is threatened by military conflicts such as the ongoing Russian invasion of Ukraine, both large exporters of grains and oilseeds.

Two types of meat substitutes were the focus of this study because they differently affect consumers and their expectations of the ethical risks associated with specific meat substitutes. These expectations now relate to real rather than hypothetical products and require examination because they influence purchasing decisions and products' commercial success.

1.1. Types of Meat Substitutes

Depending on different raw materials, meat substitutes include plant-based meat (PM) and cultured meat (CM) [12]. Plant-based meat (PM) is produced by modification of plant protein and cultured meat (CM) is the category of meat substitute grown from animal stem cells [13,14].

Consumers are concerned about ethical safety since both products have new food attributes. Demand for food emphasizes safety and nutrition [15–17]. Consumer doubts about meat substitutes include concerns related to product attributes and production technologies. Additionally, consumers face new psychological standards associated with meat substitutes [18]. To incorporate meat substitutes into their diets, consumers need to examine ethical, moral, and philosophical issues and the constraints of the development of the meat substitute industry. The solutions to these ethical challenges will determine the feasibility of the technology in improving food security and the product acceptability for consumers.

In recent years, several studies have researched consumer awareness of ethical risk in new foods, including meat substitutes [19–25]. Despite growing interest, consumers still lack confidence in meat substitutes and their ultimate market potential [18].

Some studies have suggested that the feasibility and practicality of CM products need thorough consideration [26]. Schaefer and Savulescu (2014) argue that ethical factors influence consumer acceptance of CM products [27], and concerns include the potential negative long-term effects of such products on human health [28–30]. Some consumers believe that meat substitutes, especially CM, are unnatural and likely to harm human health [21,31,32]. Mohorčich and Reese (2019) also believe that consumer response to CM may involve concerns about the products' nature and effects on humans [33].

However, existing studies on the ethical risk cognition and consumer acceptance of meat substitutes have often considered PM and CM products separately. The ethical risk of meat substitutes could include the intrinsic nature of their biological attributes, since the raw materials of PM and CM are plants and animals, respectively. The fundamentally different origins of the raw materials used in PM and CM manufacturing may affect consumer perceptions, especially if the nature of the raw material matters because of cultural preferences or philosophical beliefs. The type of protein in PM and CM products may matter to consumers with specific dietary preferences, ultimately affecting their consumption decisions. This study, rather than focusing on a single meat substitute, attempted to identify factors that distinguish PM and CM perceptions among potential consumers. The results indicate how various factors are relevant to meat substitute ethical risk perceptions, and this addresses a gap in empirical knowledge and in the literature [34]. Industry, policy makers, and regulators can all gain insights useful for addressing potential limitations to the enhancement of protein intake and food security. To empirically examine the issue of differences in PM and CM and their effects on consumers, this study used a unique dataset. Specifically, we conducted an online survey to gather data and analyzed the levels of ethical risk perception (hereinafter referred to as ERP) of PM and CM products and the differences in risk perception (C-P-ERP).

1.2. Meat Consumption in China

China has a large population and its rising meat demand will have a significant impact on the global meat market [35]. With the demand outpacing domestic production, China's meat imports have been increasing. For example, in the period of 20 months between December 2018 and July 2020, all meat imports increased by about 185% at an average monthly growth rate of 7.9% (General Administration of Customs P.R. China, 2021). The volume of consumed meat is expected to increase and meat substitutes offer a potential alternative. More importantly, PM meat can use domestic raw materials, while CM meat can possibly be exclusively based on domestic inputs.

In China, meat substitutes have already attracted wide attention from the domestic food sector in recent years [36–38]. A number of companies have produced PM products and introduced them to the market by collaborating with research institutions, such as the work of Beijing University of Technology and Industry and Hongchang in developing PM products in 2018 [38]. The companies currently supplying PM products include Beyond Meat and Impossible Foods. A total of more than 37,000 stores offer PM products. Other companies have also taken advantage of these opportunities, as reflected in products introduced by more than 100 brands, including some of the large fast food chains [36]. On 20 April 2020, KFC officially announced the public test launch of "planting and cultivating Golden Chicken Nuggets" in China, where the raw material was "vegetable meat". On 22 April 2020, Starbucks launched a meat substitute lunch menu offering PM "beef" and "pork" products in China [37].

CM meat has been developed at Nanjing Agricultural University [39]. The overwhelming majority of Chinese urban consumers have been shown to be unfamiliar with CM [25]. CM products have yet to meet the taste expectations of consumers and the manufacturing cost is high [40].

From a sustainability perspective, meat substitute production seems preferable over conventional meat [26,34,41]. Meat substitutes clearly require less land area and generate much lower levels of greenhouse gases (GHGs) [42]. Such production seems also better adapted to climate change, which can influence livestock production through, for example, higher temperatures resulting in lower feed conversion rates, reduced weight gain, and decreased reproduction [43]. The long-term advantage of CM may result from the availability of decarbonized energy [44].

Meat substitutes have already attracted wide attention from industry and markets in China; they could contribute to the reduction of meat consumption and have become a focus of the domestic food sector in recent years. The sustained demand for animal protein predicts a possible dietary protein shortage and a need to improve food security, but that perspective has received little attention in the literature. At the same time, there are concerns about the ethical risks of meat substitutes since consumers tend to be risk averse, especially in China, where several food safety incidents have been publicized in recent decades. This paper examines Chinese consumer ERP of meat substitutes and its novelty is the examination of the differences in consumer ERP of CM vs. PM. This study grouped factors into four categories: demographic characteristics, product information characteristics, technical level factors, and regulatory and policy factors. The ordered logit technique was used for estimation in a latent regression model to identify the influence of four categories of factors on the different perceptions of ethical risk associated with PM and CM products. Empirical results offer insights for the emerging meat substitute industry about the perceived ethical risk differences of the two meat substitutes and complement earlier studies focusing on, for example, the philosophical dimensions of in vitro meat [26].

2. Literature Review

2.1. Ethical Risk of Meat Substitutes: The Difference between PM and CM

The growing problems with meat production have boosted the development of meat substitutes [45]. As with many new technologies, meat substitutes have inevitably raised ethical questions [46]. The conflict between taste enjoyment and animal welfare causes

discomfort among some consumers [47], and consumers may seek ways to resolve this potential conflict [48]. The outcome of the moral debate on meat substitutes will determine their technical feasibility and acceptance of potential consumers [21].

PM substitutes are sustainable protein sources that can match the taste, texture, color, and nutrients of specific types of meat [40], but they are still a source of ethical dilemmas [49]. First, PM substitutes lack universal regulations on product naming, which may cause consumers to mistakenly regard the nutritional value of PM substitutes as equal to those of traditional meat [50]. For example, Australia, the United States, and the European Union (EU) have proposed bans on the use of the meat-related words and images which may imply that PM substitutes are the same as traditional meat [51]. There is also a lack of clear PM standards for manufacturers to observe. Whether meat substitutes offer natural nutrients equivalent to traditional meat has yet to be conclusively determined [52].

In a discussion prior to the commercial availability of CM, Welin and van der Weele (2012) [10] stressed the natural origin of this type of meat substitute and its expected environmental benefits, but not its possible role in improving food security by improving access to protein. Consumers have doubts about the potential advantages of CM, such as whether "CM helps to reduce the pain and exploitation of animals" or "CM can control costs" [26]. Welin and van der Weele [10] agree that the origin of CM, manufactured through tissue engineering using animal cells, is behind consumers' objections. An attempt to explore the technological promise of CM from a philosophical angle could inspire thinking about "new protein practices". Another study identified three moral profiles in the public debate on CM [41]. The authors inferred that the potential of CM could reflect consumption, if any, of various meats. Recognizing the potential of CM and the cultural and regulatory challenges it poses, [41] argued for increased funding of CM research, including promotion of public discussion about the technology and the societal implications stemming from the scientific and ethical considerations. The current study directly contributes to such discussions by exploring what differentiates CM from PM in consumer ethical risk perceptions. Philosophical approaches have dominated previous studies on CM ethics [34]. A number of consumer CM perception studies, applying various methodologies and conducted in Europe and the United States, countries where access and affordability generally do not constrain consumption of animal protein, showed a split in perceptions among those in favor, opposed, or having no opinion [34]. The authors [34] called for additional consumer studies since there is a potential for perceptions to change as new information becomes available. The current study, conducted in the most populous country in the world, updates scientific knowledge by examining not one (CM), but two meat substitutes, and identifying the differences in their ethical risk perception.

What is the difference in consumer perception of the ethical risks associated with PM vs. CM products? Current studies show that consumers consider the safety risk attributes of raw materials when choosing to buy meat substitutes. Elzerman et al. (2011) found differences in consumer product preference for different raw materials, and scored different product preferences and suitability for different meat substitutes with similar flavor and texture but different shapes (e.g., fragments and minced meat) [20]. Laestadius and Caldwell (2015) also found that most respondents believed the unnatural origin of CM would increase ethical risk [53]. Tarrega et al. (2020) concluded that consumers with weak meat preferences were more inclined to use a meat alternative containing plant protein [54]. Van der Weele and Driessen (2013) suggested that expanding the scope of identity in consumer ethics and fostering a process of integrating emotions, imagination, and rational thinking could encourage consumers to actively participate in this study [26]. All these factors need to create and guide the consumption environment for meat substitutes [55].

2.2. Factors Affecting Consumer Perceptions of PM and CM

Many articles have discussed the factors affecting consumers' ethical risk perceptions of PM and CM [30,40,56–58]. However, these past studies have focused on a single type of meat substitute and its product attributes, while the current study expands upon the

literature by explicitly recognizing the different origins of PM and CM. Moreover, this study complements the literature, since there has been a lack of focus on the differences in consumer risk perception (C-P-ERP) regarding these two meat substitutes. This study, to the extent permitted by the available data, sought knowledge about factors that distinguish unobserved preferences for either of the two studied meat substitutes. Specifically, the current study investigated the influence of demographics, product characteristic information, technical cognition, and regulations and policies on differences in consumer ethical risk perception of PM and CM products.

2.2.1. Demographic Characteristics

Varying consumer demographics affect cognition of the ethical risk of meat substitutes differently. Slade (2018) [59] and Tarrega et al. (2020) [54] found in hypothetical selection experiments that consumer willingness to buy PM and CM burgers was related to gender and age. Tilman and Clark (2014) [60] found that high levels of food source sustainability characteristics affect consumer behavior. Consumers in developing countries know little about meat substitutes like CM [61], and their ethical risk perceptions of meat substitutes may be influenced by income and age. Siegrist and Hartmann (2019) [62] and Verbeke et al. (2015) [30] found that education level affected willingness to consume meat substitutes. Meanwhile, Mancini and Antonioli (2019) [63], using a sample of Italian consumers, proposed that highly educated young people are potential consumers of meat substitute products such as CM. Zhang et al. (2020) [25] and Koch et al. (2019) [64] found that the consumers were not familiar with meat substitutes, but that highly educated young men were more likely to accept and try meat substitutes. Earlier, Hocquette et al. (2015) [12] reported that the consumer ethical risk perceptions of meat substitutes did not decrease as level of education attainment increased.

In recent years, researchers have recognized the importance of consumer ethical risk perceptions in dietary preferences. Consumer assessment of food safety is affected by individual values and lifestyle differences [65], and consumer cognition of the ethical risks of meat substitutes will affect dietary preferences [55]. Van Loo et al. (2020) [66] and Graça et al. (2015) [22] believe that vegetarians tend to have a stronger preference for meat substitutes than nonvegetarians. Profeta et al. (2021) [67] suggest that for consumers that are not interested in vegetarian alternatives such as meat substitutes, hybrid meats could be a low-threshold option for more sustainable food consumption behavior. Additionally, vegetarians seem to emphasize CM's role in protecting animal welfare [26]. The current study examined the influence of demographic characteristics such as gender, age, and education on the differences in consumer ethical risk perception of two meat substitutes.

2.2.2. Product Information Characteristics

Understanding of product characteristics may affect ethical risk perception. Informing consumers can change their attitudes towards unfamiliar objects [13,68]. Clear product-related information is an effective way to encourage the public to accept new products [25]. The raw materials used in meat substitutes are a major concern. Consumer risk awareness of meat substitutes made from different raw materials varies [69]. Regarding price, consumer meat or meat substitute choice is a philosophical issue [70]. Apparently, vegetarians are willing to pay higher prices than nonvegetarians for meat substitutes [71].

With improving living standards, consumers' increasing attention to safety and health concerns encourage the selection of meat substitutes. For example, Zhuang et al. (2020) [72] found that patients with hypertension, after learning that traditional meat can be harmful to health, would gradually choose to replace some foods with a meat substitute. In recent years, increased consumption of plant-based food has been considered healthy, and the use of meat substitutes as a protein source has drawn attention [73]. The nutritional effects of meat substitutes are not fully known and they may be viewed as potentially risky [74]. The current study examined the influence of perception of meat substitute safety and nutrition on differences in ethical risk perception.

2.2.3. Production Technology

Technology seems to determine consumer risk awareness of new foods, possibly explaining the low acceptance of meat substitutes [75]. The majority of the public knows very little about various new technologies [62,76]. Consumer perceptions of food manufacturing technology affect consumer risk awareness of meat substitutes [77]. Despite the huge potential of meat substitutes, their public acceptance is low [78]. Egolf et al. (2019) [79] believe that new technology can generate benefits, reduce the current level of resource consumption, and promote the efficient and sustainable development of the food system.

Previous studies have explored the relationship between consumer cognition of risk and product acceptance [34,80]. Verbeke et al. (2010) [17] believe that consumer attitudes towards meat substitute technology influence the development of the industry and that public support is associated with risk awareness. German consumers have expressed concerns about the global spread of CM [81]. While the vast majority of Chinese consumers are not familiar with meat substitutes, their risk assessment of such products is associated with their emotions and self-feeling [25]. Consumers have also expressed concerns about the use of specific ingredients, including pigments [19]. The current study examined the relevance of cognition of colorant use and the safety of ingredient origin on the ethical risk perceptions of two meat substitutes.

2.2.4. Regulations and Policy

Consumer anxiety arising from uncertainty about food safety is a persistent phenomenon [19]. Many countries have recognized the importance of policy and institutional reforms in shaping the emerging regulatory system of the meat substitute industry [82].

The process of formulating and modifying laws, regulations, and policies involves the standardization of the meat substitute product category. Ong et al. (2020) proposed criteria for meat substitutes applicable in promoting their benefits [78]. China's government implemented the Food Safety Law in 2009 as a result of food contamination by melamine, but relevant regulatory policies for the meat substitute industry need urgent implementation. Xiao and Gao (2017) maintain that legislative reform will lead large enterprises to supply product information to consumers on new product benefits [82]. This additional information could change consumer awareness and risk perception of the products.

3. Materials and Methods

3.1. Questionnaire Design

An online survey was implemented to collect the data used in this study. The questionnaire development consisted of three stages: preliminary design, pilot test and revision, and posting the final version of the questionnaire on a dedicated website. To address the research objectives, the questionnaire focused on soliciting responses about consumer awareness of PM and CM ethical risks, product information, technology cognition, regulations and policies, and sociodemographics. Ten randomly selected individuals were asked to complete the questionnaire and, as a result of the test, the questionnaire was revised to clarify response options. Subsequently, a pilot survey involving 100 participants showed the need for further changes. The additions included PM and CM pictures and a brief explanation at the beginning of the questionnaire to expand upon the limited consumer knowledge of meat substitutes.

3.2. Survey Implementation

The current study recruited respondents through a Chinese professional market survey company. The company sent the questionnaire to 2.6 million Internet users in 31 Chinese provinces and cities according to their population attributes. Three principles were applied to ensure the quality of the data: (1) preliminary screening of a potential respondent involved posing two questions that required careful answers before proceeding to the main questionnaire; (2) questionnaires completed in less than 300 s were checked to focus on how logical and reasonable the answers were, allowing for further filtering; (3) in the questions

applying a scale, if a respondent chose the same option for all questions, the staff marked the questionnaire as invalid and eliminated it from the sample.

The online data collection lasted two weeks (11–24 October 2020). A total of 1677 questionnaires were returned, and the sample consists of 1060 fully completed questionnaires (63.21%).

3.3. Estimation Approach

The objective of this study was to understand Chinese consumer perceptions of differences between PM and CM (C-P-ERP) and to identify of relevant factors. The coding of the variable of interest, C-P-ERP, suggested the use of a latent dependent variable model [83]. The choices presented to the respondents suggested the use of the ordered logit technique, since the response options represented ordered discrete values.

In the current study, the dependent variable, consumer C-P-ERP, had five levels. They were as follows: "CM ethical risk much lower than PM risk", "CM ethical risk somewhat lower than PM risk", "CM and PM ethical risks are about equal", "CM ethical risk somewhat higher than PM risk", and "CM ethical risk much higher than PM risk". The explanatory variables accounted for four groups of factors: demographic characteristics, product characteristics, technical cognition, and regulations. The selection followed the factors identified by earlier studies as relevant in the case of meat substitutes (Table 1).

Table 1. Explanatory variables relevant in the meat substitute studies identified in the literature.

Variable	Source
Gender	[55,59]
Income	[60,61]
Education	[12,25,30,62–64]
Age	[55,59]
Prefers meat	[22,26,65,66]
Regards PM as more nutritious	[74–76]
Regards PM as safer	[65,74,84,85]
CM more expensive	Consumer consumption choice for equivalent meat or meat alternatives is a philosophical choice [70].
Sensitive to safety of CM raw material acquisition	Cultured meat is meat substitutes grown with animal stem cells [13,14,86,87], also described as synthetic meat [86,88,89]. Consumers focus on the safety of raw material sources used in meat substitutes, especially CM, where nonstandardization is likely to have a harmful impact on human health [21,31,32].
Regards technology as immature	Technology seems to be a determinant of consumer risk awareness of new foods [25,62,77,79].
Regards colorant as nonstandard	Consumer concerns about technology manifest in the use of specific raw materials including pigments, preservatives, condiments, artificial sweeteners [19].
Views classification as unclear	Product regulation and policy standardization is important [50,82,85,90,91].
Views new food law as imperfect	Same as above.
Views technology standards as imperfect	Urgent need to promote widespread regulatory reform of the local, national and international food systems to develop the meat substitute industry [92,93]. It is important to improve the political system in the meat substitute industry and focus on creating new regulatory systems [82,94,95].

Note: TBD = to be empirically determined.

The general ordered logit model had the following form:

$$\ln(\mathrm{pk}) = \theta\mathrm{k} + \sum_{i=1}^{n} \beta_i X_i + \mu_i \ (i = 1,\ 2,\ \ldots,\ 14) \quad (1)$$

where pk indicates the probability that the consumer C-P-ERP is y = k, θk is the intercept of y = k (k = 1, 2, 3, 4, 5), β_i is the coefficient of each explanatory variable, and μ_i represents the estimation error (i = 1–14). Table 1 shows the explanatory variables.

4. Data

4.1. Sample Descriptive Statistics

Table 2 shows the descriptive statistics of the sample. Among the demographic characteristics, males accounted for 57%. Consumer income was reported in six categories, with a mean of 3.99, indicating that most respondents earn over 5000 RMB per month. Education was measured using seven levels, with a mean of 4.80. The mean education level indicates an educational attainment level above junior college.

Table 2. Definitions and sample descriptive statistics.

Variable	Definition	Mean	Std. Dev
Dependent variables			
C-P-ERP	1 = CMrisk much lower than PMrisk, 2 = CMrisk somewhat lower than PMrisk, 3 = risk about equal, 4 = CMrisk somewhat higher than PMrisk, 5 = CMrisk much higher than PMrisk	3.603	0.772
Independent variables			
Demographic characteristics			
Gender	1 = male, 0 = female	0.57	0.495
Income	1 = <1000 yuan; 2 = 1000–3000 yuan; 3 = 3001–5000 yuan; 4 = 5001–7000 yuan; 5 = 7001–10,000 yuan; 6 = >10,000 yuan	3.99	1.432
Education	1 = primary school or less; 2 = junior high school, or technical school; 3 = senior high school; 4 = junior college; 5 = undergraduate; 6 = master; 7 = Ph.D. or equivalent	4.795	0.77
Age	1 = ≤25 years old; 2 = 26–30 years old; 3 = 31–40 years old; 4 = 41–50 years old; 5 = >50 years old	2.412	1.107
Prefers meat	1 = no meat, vegetable only; 2 = mainly vegetable, some meat 3 = meat about same as vegetable; 4 = mostly meat; 5 = meat only	2.771	0.68
Product information characteristics			
Regards PM as more nutritious	1 = agree, 0 = otherwise	0.275	0.446
Regards PM as safer	1 = agree, 0 = otherwise	0.35	0.477
CM more expensive	1 = agree, 0 = otherwise	0.185	0.388
Technical level			
Sensitive to safety of CM raw material acquisition	1 = pays attention to CM raw material safety; 0 = otherwise	0.728	0.445
Regards technology as immature	1 = disagree absolutely, 2 = disagree, 3 = general, 4 = agree, 5 = agree absolutely	3.769	1.027
Regards colorant as nonstandard	Scale	3.651	0.992
Regulation and policy			
Views classification as unclear	Scale	3.475	0.973
Views new food law as imperfect	Scale	3.226	0.964
Views technology standards as imperfect	Scale	3.807	1.023

Preferences regarding food included five options. The mean preference value was 2.77, suggesting that the average respondent leaned towards vegetarianism. Among the 1060 respondents, 27.5% regarded PM as more nutritious, 35% regarded it as safer, and 18.5% believed that the price of meat substitutes is higher than that of conventional meat. In terms of factors associated with production technology, 72.8% cared about the safety of CM ingredients. The question about the maturity of meat substitute technology offered five options (negative) and the mean response was 3.77 (Table 1). This mean suggests that the average respondent regarded the current meat substitute technology as immature. Opinions regarding colorant additives also allowed a choice across five levels (negative), and had a mean response of 3.65. That is, the average respondent believed that the colorants currently applied to meat substitutes are defective. Regulatory and policy factors (i.e., product classification standards, new food laws, and technical standards) were each designated five levels, and had mean responses of 3.48, 3.23, and 3.81, respectively. The variation in the mean responses of the three factors suggests that the average respondent believed that the laws are inadequate.

The ethical risk perceptions of PM and CM were measured using a five-step Likert scale, where 1 = no ethical risk, 2 = low ethical risk, 3 = neither presence nor absence of ethical risk, 4 = high ethical risk, and 5 = very high ethical risk. More than half of the respondents regarded PM products as representing no or low ethical risk (23.68% + 35.19% = 58.87%). Only 2.45% viewed the ethical risks associated with the PM products as very high. However, consumer ethical risk perception of the CM products differed, with those viewing it as associated with high ethical risk accounting for 31.13% of respondents and another 9.62% of respondents perceiving the ethical risk as very high. Only 5.85% of the respondents thought that CM did not pose any ethical risk (Figure 1). Differences in raw materials could influence consumer ERP of meat substitutes, as suggested by the varying means of respondents' ethical risk perceptions of the PM and CM products, which were 2.33 and 3.19, respectively. The higher the mean, the higher the perceived ethical risk, with a value above 3 suggesting that some ethical risk exists.

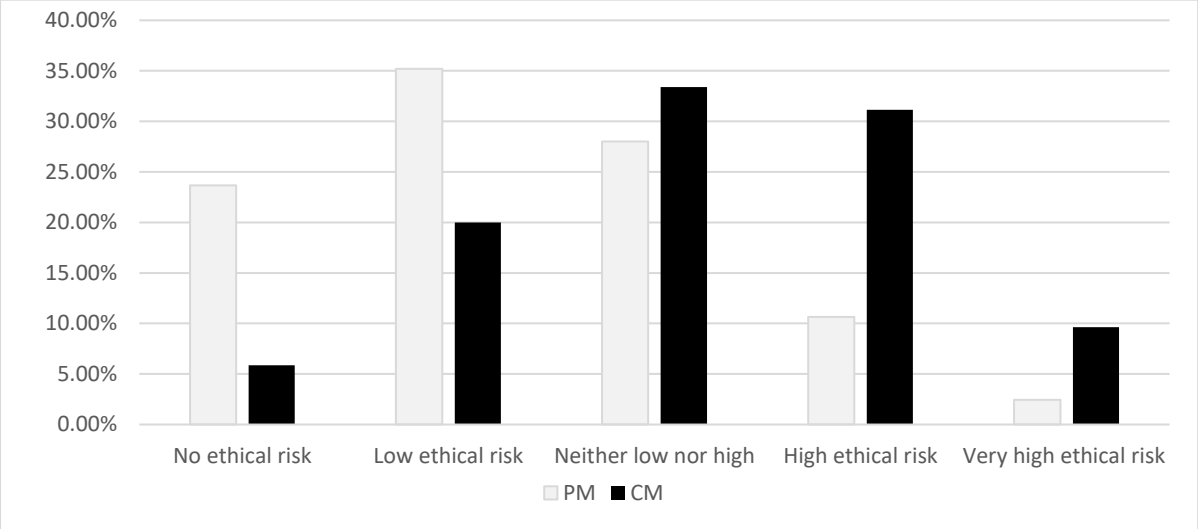

Figure 1. Percentages of respondents indicating perception of level of ethical risk associated with plant-based (PM) and cultured cell (CM) meat substitutes.

4.2. Consumer Ethical Risk Perception

To further focus on the differences in ethical risk perception, Table 3 shows the differences in consumer ethical risk perception of CM and PM by subtracting the two initial values associated with the CM and PM products. Given the five-step scale, this subtraction can generate eight possible outcomes: −3, −2, −1, 0, 1, 2, 3, and 4. The subtraction step indicated the number of respondents that perceived the PM and CM products as carrying

different levels of ethical risk. The number of observations associated with each difference value (from −3 to 4; Table 3) suggests a tapered distribution towards either end of the range. For the purpose of estimating an empirical relationship, several categories were combined to increase the number of observations.

Table 3. Tabulation of ethical risk perception of C-P.

C-P Ethical Risk Perception	Freq.	Percent	Cum.
−3	1	0.09	0.09
−2	11	1.04	1.13
−1	76	7.17	8.30
0	310	29.25	37.55
1	406	38.30	75.85
2	179	16.89	92.74
3	63	5.94	98.68
4	14	1.32	100.00
Total	1060	100.00	

Table 4 shows the five categories of ethical risk perception difference. The five categories display the shift from perceiving the ethical risks associated with CM products as "much lower" than those of PM products (coded as 1) to perceiving the CM ethical risk as being "much higher" than that of the PM product (coded as 5). The majority (62.45%) of the respondents regarded the ethical risk of CM as somewhat higher (55.19%) or much higher (7.26%) than that associated with PM (Table 4). Those considering the ethical risks to be equal for both meat substitutes accounted for 29.25%. Only 7.71% believed that the CM-ER was somewhat lower and another 1.13% thought it was much lower than the PM-ER.

Table 4. Tabulation of C-P-ERP.

Difference in Ethical Risk Perception between CM and PM (C-P-ERP)	Frequency	Percent
1 = CM-ER much lower than PM-ER	12	1.13
2 = CM-ER somewhat lower than PM-ER	76	7.17
3 = risk about equal	310	29.25
4 = CM-ER somewhat higher than PM-ER	585	55.19
5 = CM-ER much higher than PM-ER	77	7.26
Total	1060	100.00

5. Results

The ordered logit technique was used to estimate the empirical relationships of differences in ethical risk perception, i.e., CM vs. PM, (Stata 16.1, College Station, TX 77845, USA). The model fit and explanatory power were reasonable (Table 5). The Breusch–Pagan test for heteroscedasticity and the mean variance inflation factor (VIF) did not detect the presence of heteroscedasticity. The estimated coefficients in the ordered logit model could not be directly interpreted and were converted into the change in probability of an ethical risk perception difference falling into one of the five categories (Table 4) in response to a change in an explanatory variable. Table 6 shows the ordered logit estimation results and the calculated marginal effects. The following discussion refers to groups of explanatory variables as indicated in Table 2.

Table 5. Ordered logit estimation results of the equation modeling consumers' C-P-ERP.

C-P-ERP	Coef.	St. Error	*t*-Value	*p*-Value
Gender	0.014	0.124	0.12	0.907
Income	−0.005	0.051	−0.09	0.929
Education level	0.164 *	0.086	1.90	0.057
Age	−0.009	0.065	−0.14	0.891
Prefers meat	−0.145	0.091	−1.59	0.112
Regards plant-based meat as more nutritious	0.076	0.137	0.55	0.582
Regards plant-based meat as safer	0.389 ***	0.13	2.99	0.003
CM more expensive	0.294 *	0.16	1.84	0.066
Regards technology as immature	−0.02	0.069	−0.29	0.769
Regards colorant as nonstandard	0.175 ***	0.067	2.59	0.01
Sensitive to safety of cultured meat raw material acquisition	0.454 ***	0.135	3.35	0.001
Regards classification as unclear	0.177 ***	0.068	2.61	0.009
Views new food law as imperfect	0.322 ***	0.067	4.83	0
Views technology standards as imperfect	0.147 **	0.071	2.06	0.039
cut1	−1	0.671	.b	.b
cut2	1.102	0.619	.b	.b
cut3	3.114	0.622	.b	.b
cut4	6.371	0.647	.b	.b
Mean dependent var	3.603	SD dependent var	0.772	
Pseudo r-squared	0.044	Number of obs	1060	
Chi-square	104.617	Prob > chi2	0.000	
Akaike crit. (AIC)	2301.038	Bayesian crit. (BIC)	2390.426	

Note: Brant test value of 47.50 significant at $p > \text{chi}^2$ of 0.258 and confirms the parallel regression assumption. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table 6. Ordered logit results and marginal effects of consumers' C-P-ERP.

		dy/dx		Marginal Effects		
Variable Name	**Coefficient**	**CM-ER Much Lower than PM-ER**	**CM-ER Somewhat Lower than PM-ER**	**General Equal**	**CM-ER Somewhat Higher than PM-ER**	**CM-ER Much Higher than PM-ER**
Gender	0.014 (0.124)	−0.000161 (0.00138)	−0.000896 (0.00767)	−0.00205 (0.0175)	0.00215 (0.0184)	0.000952 (0.00815)
Income	−0.005 (0.051)	0.0000502 (0.000564)	0.000280 (0.00314)	0.000639 (0.00717)	−0.000672 (0.00754)	−0.000297 (0.00334)
Education level	0.164 * (0.086)	−0.00182 * (0.00109)	−0.0102 * (0.00543)	−0.0232 * (0.0121)	0.0244 * (0.0128)	0.0108 * (0.00578)
Age	−0.009 (0.065)	0.0000985 (0.000721)	0.000548 (0.00401)	0.00125 (0.00916)	−0.00132 (0.00963)	−0.000582 (0.00426)
Prefers meat	−0.145 (0.091)	0.00161 (0.00111)	0.00899 (0.00570)	0.0205 (0.0129)	−0.0216 (0.0135)	−0.00954 (0.00607)
Regards PM as more nutritious	0.076 (0.137)	−0.000842 (0.00155)	−0.00469 (0.00854)	−0.0107 (0.0195)	0.0113 (0.0205)	0.00498 (0.00906)
Regards PM as safer	0.389 *** (0.130)	−0.00434 ** (0.00190)	−0.0242 *** (0.00839)	−0.0552 *** (0.0183)	0.0580 *** (0.0193)	0.0256 *** (0.00891)
CM more expensive	0.294 * (0.160)	−0.00328 (0.00201)	−0.0182 * (0.0101)	−0.0417 * (0.0226)	0.0438 * (0.0238)	0.0194 * (0.0107)
Regards technology as immature	−0.020 (0.069)	0.000225 (0.000770)	0.00125 (0.00428)	0.00286 (0.00975)	−0.00301 (0.0103)	−0.00133 (0.00454)
Regards colorant as nonstandard	0.175 *** (0.067)	−0.00195 ** (0.000933)	−0.0108 ** (0.00431)	−0.0248 *** (0.00951)	0.0260 *** (0.0100)	0.0115 ** (0.00459)
Sensitive to safety of CM raw material acquisition	0.454 *** (0.135)	−0.00506 ** (0.00209)	−0.0282 *** (0.00881)	−0.0644 *** (0.0189)	0.0677 *** (0.0200)	0.0299 *** (0.00941)
Views classification as unclear	0.177 *** (0.068)	−0.00198 ** (0.000944)	−0.0110 ** (0.00434)	−0.0251 *** (0.00957)	0.0264 *** (0.0101)	0.0117 ** (0.00462)
Views new food law as imperfect	0.322 *** (0.067)	−0.00359 *** (0.00126)	−0.0200 *** (0.00456)	−0.0457 *** (0.00919)	0.0480 *** (0.00978)	0.0212 *** (0.00485)
Views technology standards as imperfect	0.147 ** (0.071)	−0.00164 * (0.000922)	−0.00913 ** (0.00451)	−0.0208 ** (0.0101)	0.0219 ** (0.0106)	0.00969 ** (0.00478)
Observations	1060					

Note: Brant test value of 47.50 significant at $p > \text{chi}^2$ of 0.258 and confirms the parallel regression assumption. Marginal effects; Standard errors in parentheses. (dy/dx) for discrete change of dummy variable from 0 to 1. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

5.1. Demographic Characteristics

The results show that the educational attainment level significantly affected the dependent variable. Neff et al. (2018) also indicated that education level affected consumer views on meat safety [93]. In the current study, as the respondent education level advanced to the next category, the probability of consumer perception that "CM-ER is somewhat higher than PM-ER" increased by 2.44%, and the probability of "CM-ER being much higher than PM-ER" increased by 1.08%. Better educated consumers can be expected to have more information and to be more likely to understand the bioethical issues involved in animal cell cultivation than the less educated. Consequently, the respondents perceived the CM products as carrying significantly higher ethical risk than PM.

5.2. Product Characteristics

Among product characteristics, safety and price significantly influenced the difference between the ethical risks associated with the two meat substitutes. The uncertain safety of a product affects consumer perception of risk [95–97]. Among the consumers who regarded PM as safe, the probability of perceiving that "CM-ER is higher than PM-ER" increased by 5.8%, and the probability of perceiving that "CM-ER is much higher than PM-ER" increased by 2.56%. Consumers can evaluate PM product safety based on their existing knowledge and some might have purchased PM products, but, at present, CM products are expensive and are not produced at a large scale. Consumer knowledge of CM safety depends only on limited information, since these products are not widely available. In terms of price, among consumers who regarded meat substitutes as more expensive, the probability of perceiving "CM-ER is somewhat higher than PM-ER" increased by 4.38%, and the probability of perceiving "CM-ER is much higher than PM-ER" increased by 1.94%. The more advanced commercialization of PM product manufacturing could be the reason for this, as consumer awareness of CM ethical risks still depends on limited scientific information [96].

5.3. Attributes of the Production Technology

The results showed that colorant use and the safety of ingredients used in CM significantly affected the consumer C-P-ERP. Increasingly negative views of colorant as standard resulted in an increase of the probability of "CM-ER is somewhat higher than PM-ER" by 2.60%, and of the probability of "CM-ER is much higher than PM-ER" by 1.15%. The early development of meat substitute technology faced great challenges in extracting plant additives [98]. Plant-based colorants extend the shelf life of meat and meat products and their natural origins alleviate consumer doubts [99]. However, the use of colorant additives in CM products often creates doubt in consumers, which may reflect broader distrust of the use of animal cells as a CM source. An increase in consumer sensitivity about the safety of CM raw materials raised the probability of perceiving that "CM-ER is somewhat higher than PM-ER" by 6.77%, and the probability of perceiving "CM-ER is much higher than PM-ER" by 2.99%.

5.4. Regulations and Policy

The clarity of meat substitute classification, adequacy of new food laws, and technical standards significantly affect consumer C-P-ERP. With increasing negative views about the clarity of meat substitute industry regulations, the probability of perceiving "CM-ER is somewhat higher than PM-ER" increased by 2.64%. However, the probability of perceiving that "CM-ER is much higher than PM-ER" increased by only 1.17%. With increasing negative views of new food laws, the probability increase associated with the view that "CM-ER is somewhat higher than PM-ER" was 4.80%. The probability increased by about half (2.12%) if a respondent perceived that "CM-ER is much higher than PM-ER". A negative appraisal of technology resulted in a 2.19% probability increase of the perception that "CM-ER is higher than PM-ER". The probability increase associated with the view that "CM-ER is much higher than PM-ER" was a meager 0.97%. Legislative reforms and regulatory changes have significantly impacted food-related industries in the past [85].

To promote the development of the meat substitute industry, there is a need for timely, wide-ranging regulatory reforms at the local, national, and international level to eliminate existing and potential safety risks [97], thus easing the ethical concerns of consumers.

6. Discussion

Consumers are the core stakeholders for the meat substitute industry and understanding the diversity of consumer perspectives has been underscored [100]. Developing strategies based on consumer risk preferences is crucial for the meat substitute industry. Both PM and CM products are important meat substitutes from the perspective of ensuring a sustainable global meat supply in the future, which highlights the relevance of the continued development of the meat substitutes industry. However, the use of different basic raw materials in meat substitute products (CM vs. PM) justifies extensive research and discussion of how to properly respond to consumer ethical risk perceptions of PM and CM.

Consumer cognitive differences in the ethical risk associated with PM and CM products can determine the purchase of meat substitutes, thus potentially affecting the commercialization of these products. The current survey results suggest that Chinese consumers are more concerned about CM ethical risks than PM ethical risks. Therefore, CM commercialization may be dependent on educating consumers with verifiable information. The study results suggest responses should be made in regard to four areas of concern represented by four groups of factors.

First, improving consumer knowledge of the science of meat substitutes is essential. Some consumers mistake meat substitutes for fraudulent meat products. Chinese consumers have extensive experience of consuming plant-based meat substitutes, such as tofu and bean skin. However, consumers regard CM products as posing ethical risks that are higher than those associated with PM products. Considering that Chinese consumers have expressed similar concerns about the acceptance of other new foods such as GMO foods, it is necessary to increase awareness of wholesomeness and safety of meat substitutes, supported by verifiable information. Frewer et al. (2011) proposed that in the early stages of product R&D [95], government and industry invite should public participation to promote the success of new foods [101,102]. If the meat substitute industry is to grow, there is a need for an open flow of relevant information, and for the media to play a role while experts help consumers understand what meat substitutes are and how they benefit consumers and the environment.

Second, several meat substitute attributes that are particularly important to consumers include nutrition, price, and safety. In terms of differences in ethical risk perception, the price and safety of PM products have been confirmed to cause less anxiety among consumers than those of CM products. Chinese households face budget constraints and the pricing of a meat substitute matters. At least initially, plant ingredients may permit the competitive pricing of PM products.

Third, it is necessary to assure consumers that the technology is safe. The production technology can significantly affect consumer ethical risk perception and eventually consumer willingness to buy meat substitutes. At present, the nutritional value, taste, and other attributes of meat substitutes are not identical to those of traditional meat products. Many companies are continuing to work to develop PM products with the taste, flavor, and nutritional value of natural meat [102,103]. CM production is still in the nascent stage. In the process of new technology development to improve appearance, taste, and nutritional value, companies must ensure the safety of the technology, with special consideration to ethical risks, and inform the public about these efforts.

Fourth, the formulation and revision of laws, standards, and policies related to the meat substitute industry has to be completed and communicated to the public. Because of the new production technology and the nonstandardized, novel nature of the products, consumers distrust meat substitutes [104]. There is an urgent need to establish clear classification and standards for meat substitutes and to determine whether plant-based (PM) and cultured meat (CM) substitutes qualify as agricultural food products or manufactured

foods. Adding some provisions related to meat substitutes to the China Food Safety Law (FSL), Agricultural Product Quality and Safety Law (APQSL), and other relevant laws and regulations is highly desirable, and will clarify regulatory authority and responsibilities with regard to meat substitutes. In terms of technical standards and specifications, the establishment of a meat substitute industrial association could be initiated by reputable scientific research institutes and leading companies. Such an association could formulate relevant technical standards and specifications. At the same time, relevant information should be released to the public in order to promote trust in the emerging meat substitute industry.

7. Conclusions and Limitations of the Study

Population growth occurs primarily in developing countries where food security is fragile and protein consumption is often inadequate. Animal protein supply in many countries has already inflicted environmental damage (see, for example, Zhang et al., 2014; Kairis et al., 2015; Yongo et al., 2021 [105–107]), while shocks to the food supply caused by military conflicts may reduce the availability of grain needed to raise livestock. The search for alternative supply sources has encouraged the emergence of the meat substitute industry. Meat substitutes can be produced using alternative technologies utilizing plant-based inputs and cell cultures.

This study investigated consumer perceptions of ethical risk associated with two meat substitute types, namely plant-based meat (PM) substitutes and those produced using animal cells (CM). Besides reporting on the ethical risk perceptions of each type of meat substitute of a sample of consumers, the study examined the differences in ethical risk associated with each product type, PM vs. CM.

The empirical modeling of consumer ethical risk perception difference between two meat substitute types (PM and CM) by applying an ordered logit technique was conducted using data collected through an online survey of 1060 Chinese consumers in 2020.

The results indicate that the ethical risk perception of PM products is lower than that of CM products. The majority of respondents regarded the ethical risks associated with CM as somewhat higher (55.19%) or much higher (7.26%) than those associated with PM products. Higher educational attainment level increased the probability that the respondents' perceived the risks of CM products to be higher than those of PM products. Current public attitudes towards the meat substitute industry and the awareness of the benefits of meat substitutes requires nonformal education, since the consumers surveyed were no longer of school age, but the content of the message must be verifiable and transparent to withstand the scrutiny of consumers. Consumer education campaigns may be necessary to reach those less educated, including via social media and visual means of communication.

Meat substitutes may increase access to protein in China, where consumers tend to be price-sensitive. This study showed that consumers are likely to view CM products as more expensive than PM products (4.38% somewhat higher and 1.94% much higher). Price determines a new food product's commercial success, and the emerging meat substitute industry has to recognize that the price will strengthen or weaken the ethical risk perceptions of specific meat substitutes in countries where consumers seek additional high-protein foods and simultaneously are constrained by their food budgets.

The perceived safety significantly affected the consumer ethical risk perception of the two meat substitutes. Consumers who regarded PM products as safer were more likely to agree that they posed less risk than CM products. Whether PM or CM, meat substitutes must ensure product safety and any ambiguity will likely discourage purchase.

The more consumers distrusted the safety of the raw materials used to produce CM, the higher was the probability of their viewing it as posing more ethical risk than PM products, and the probability change was relatively higher in this case than for other factors. In the process of developing new technologies that involve ingredients such as colorants which improve the appearance, taste, or nutrition characteristics of meat substitutes, the manufacturer must ensure the safety of these technologies. Distrust may

limit the acceptance of even a protein-rich meat substitute, despite its potential to improve food and nutrition security.

In terms of regulations and policies, if consumers regard product classifications as unclear because new food laws have loopholes and technical standards are imperfect, they are more likely to believe that CM products pose higher ethical risk than PM products. Establishing and improving the laws, regulations, and standards guiding meat substitute production will reduce consumers' reservations, especially those linked to CM product ethical risk. In countries with weak institutions, consumers may be more responsive to quality assurance from third parties, and the involvement of international NGOs or well-known corporations may be helpful in the process of strengthening food security through alternative protein sources.

Dynamic developments in the meat substitute industry and in the global food supply system may limit the implications of this study and require repeated future studies sampling a larger number of consumers and perhaps including other countries. Such an approach will allow differences in the type of meat consumed to be considered, and may even probe for consumption inclinations among those who refrain from meat consumption in general, but could accept PM products.

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