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Consumer reaction to indoor farming using LED lighting technology and the effects of providing information thereon

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A R T I C L E I N F O

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A B S T R A C T

Indoor vertical farming using artificial light has gained popularity as one solution to food problems. However, prior studies have shown that some consumers have a negative impression that crops are grown in an artificial environment. The increased use of purple Light-Emitting Diode (LED) lighting, which would make the growing environment look more artificial, may exacerbate that negative perception, leading to low acceptance of vertically farmed produce. Given that consumers are increasingly seeing indoor vertical farming directly, for example, in supermarkets and office buildings, it is important to understand how they perceive the use of purple LED lighting to grow crops and whether these perceptions can be improved by learning more about the scientific basis for artificial light cultivation. This study aimed to determine whether purple LED lighting reduces consumers' perceptions of indoor vertical farming compared to traditional white lighting, and to examine whether providing information on plant growth and artificial light changes those perceptions. We administered a web-based questionnaire to 961 Japanese respondents, and analyzed the response data using analysis of variance and an ordered probit model to explore the factors that define the likability for indoor vertical farming. The results revealed that the color of LED lighting had a limited influence on consumers' perceptions of indoor vertical farming, whereas explaining the principle of plant growth under artificial light improves their perceptions. Additionally, personal factors, such as resistance to novel food technology, trust in food safety, and awareness of indoor vertical farming, had a significant impact on the perceptions. It is crucial to expand opportunities for people to interact with artificial light cultivation and disseminate information about its scientific mechanisms.

1. Introduction

With the increase in global population and growing concern about climate change in recent years, indoor vertical farms (IVFs) (also known as plant factories using artificial lighting), which allow crops to be grown regardless of season or location, have been attracting attention [1,2]. IVF uses artificial light and multilevel growing racks in a closed environment to control plant growth and efficiently produce high-quality crops year-round [3,4]. Various types of IVFs, from large to small, have been developed so far, and recently they are increasingly installed in locations close to consumption areas, such as supermarkets, restaurants, and office buildings (see Appendix A for pictures of IVFs). The spread of IVFs is expected to enable a stable supply of fresh vegetables and fruits in urban areas

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where land is limited.

However, because crops are grown using only artificial light and no sunlight in IVFs, some consumers perceive such foods as unnatural and even nutrient-poor [5–8]. One reason for this is that many consumers do not know the scientific basis for artificial light cultivation. Moreover, although many facilities use Light-Emitting Diode (LED) to grow plants under purple light to increase production efficiency and quality [9–12], such a special light color appears to be extremely unnatural to consumers who value the naturalness of food and may increase the number of consumers who have a negative perception of IVF (i.e., consumers may not value it appropriately). This may cause further misunderstanding that vertically farmed produces are unhealthy and can lead to low acceptance of such foods.

Considering that general consumers are increasingly seeing indoor vertical farming using LEDs in person or on TV and the Internet, it is important to understand how consumers perceive colored LED light cultivation and whether these perceptions can be improved by learning more about the scientific basis for artificial light cultivation. At the same time, it is also necessary to carefully consider how consumers' values, as shaped by years of learning and experience, influence their perceptions.

Previous studies have shown that the color of lighting used for display affects consumers' perceptions of vegetables and fruits because it changes their surface color. Hasenbeck et al. [13] and Yang et al. [14] found that study participants' perceptions of the food and their motivation for consumption were higher under yellow and white lighting than under blue, red, and green lighting. These findings indicate that when food is exposed to light colors that are not commonly seen in everyday life, its surface color becomes unfamiliar, and people's perception of the food depreciates. Similarly, the use of purple LED lighting, which is unfamiliar to consumers, may have a negative effect on consumers' perceptions of IVF and its produce (e.g., leafy greens). However, to the best of our knowledge, no studies have verified this aspect.

The impact of providing information about emerging food technologies on consumers' perceptions, attitudes, and acceptance has been extensively studied, but no consistent results on its effects have been obtained [15,16]. However, Bruhn [17], Brunner et al. [15], Deliza et al. [18] and Fell et al. [19] found that listening to consumers' queries and providing evidence-based information about the technology may improve consumers' perceptions and increase acceptance. In the case of IVF, explaining why vegetables grow well under artificial light may also help to resolve consumers' doubts and improve perceptions. Furthermore, because the color of LEDs used in IVF has scientific support and offers benefits to consumers (e.g., increased biomass growth and quality), such information may be more effective when vegetables are grown under special lighting. However, to the best of our knowledge, no studies have examined the relationship between information about the growing environment using artificial light and changes in perceptions.

The objectives of this study are (1) to determine whether unfamiliar purple LED lighting reduces consumers' perception (likability) for IVF compared to conventional white lighting, (2) to examine whether explaining the principle of vegetable growth under artificial light (LED lighting) increase consumers' likability for IVF, and (3) to investigate whether the effectiveness of the information provided above differs depending on the LED light color. To accomplish these objectives, the study conducts an online survey of 961 Japanese subjects and explores the factors that define the likability for indoor vertical farming using analysis of variance (ANOVA) and an ordered probit model.

Based on the findings of previous studies, this study assumes the analytical framework depicted in Fig. 1 for the determinants of perception (likability) toward IVFs. The LED light color directly impacts likability; if the color is unfamiliar, likability is likely to be lower. In addition, we assume that providing information about artificial light cultivation positively affects likability, and that the effect depends on the light color. Furthermore, because it is generally known that personal factors, such as food technology neophobia (resistance to new food technologies), trust in efforts to ensure food safety, awareness of science and technology, and demographic factors, influence consumer attitudes toward novel food technologies [16,20–24], we assume that these factors also affect likability toward IVF.

The results of this study will provide useful insights into how consumers view IVFs using colored LED lighting, the effectiveness of the information about the scientific basis for artificial light cultivation, and the personal factors affecting consumers' perceptions. Hence, the study will contribute to the development of the effective communication and marketing strategies of IVFs.

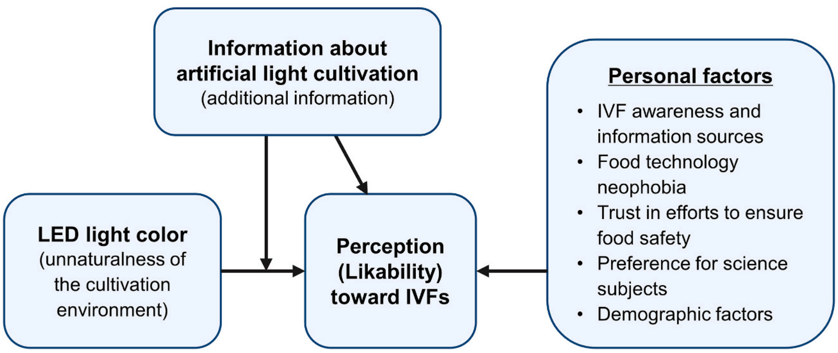

Fig. 1. Analytical framework: Determinants of perception (likability) toward IVFs.

2. Materials and methods

2.1. Questionnaire design

The online questionnaire comprised four major components: (1) IVF awareness and information sources, (2) providing information and likability ratings, (3) food technology neophobia, trust in efforts to ensure food safety, and preference for science subjects, and (4) basic attributes. The full questionnaire is available as a supplementary file.

2.1.1. IVF awareness and information sources

We asked participants about their awareness of IVFs and sources of information. Specifically, we asked the following: "In IVFs, vegetables such as lettuce are grown indoors using artificial light. Have you ever seen this around town or in the media?" Then, the respondents were asked to choose between "Yes, I have seen it" and "No, I have not seen it."

Next, those who answered "Yes, I have seen it" were asked "Where have you seen any information about IVF?" and were asked to check all that applied from the following options: "Internet sites and social media," "TV and magazines," "In buildings such as restaurants and shopping malls," "IVF tours and exhibitions," and "Other."

2.1.2. Light color, providing information, and likability assessment

After the abovementioned questions, information about IVF and photos of lettuce being grown under LED lighting were presented, and the subjects were asked to rate their likability. In this study, six different survey forms were created according to the combination of the color of LED lighting (three patterns: white, light red-purple [LRP], and dark red-purple [DRP]) and the information provided (with or without additional information) (Table 1). For group (G) 1, G2, and G3, basic IVF information and photos of the LED growing environment were included (see Appendix B for details). In addition to the basic information and photos, information on "why vegetables grow well under artificial light," was also included and provided in G4, G5, and G6 (see Appendix C for details). The LED lighting color was white in G1 and G4 (Fig. 2 (a)), LRP in G2 and G5 (Fig. 2 (b)), and DRP in G3 and G6 (Fig. 2 (c)). In this study, an NK-type artificial climate chamber (MNLH14067) was used as the LED light source, and the LED wavelength distribution was adjusted so that white was 49% red (R) + 14% green (G) + 37% blue (B), LRP was 78% R + 13% G + 9% B, and DRP was 60% R + 2% G + 39% B.

After the information was provided, a photograph of the same LED growing environment was presented again, and the subjects were asked, "Based on the above, how do you feel about vegetables grown in such an environment?" and to rate their likability on a 7-point scale with "(7) favorable - (1) unfavorable" at two extremes (a high score indicates a positive impression). A score of 4, the middle point of the scale, was set as "neither."

2.1.3. Food technology neophobia, trust, and favorite science subjects

The Food Technology Neophobia Scale (FTNS), developed by Cox and Evans [25], consists of 13 items and has been used to measure food technology neophobia (the fear of novel food technology and the tendency to avoid foods made with such technology) [26]. This scale was shortened to 9 items by Schnettler et al. [27,28] namely, Abbreviated Food Technology Neophobia Scale (AFTNS). In this study, the Japanese version of the abbreviated scale was used (Table 2). The response format for each item was a 5-point scale: 1: "Strongly disagree," 2: "Somewhat disagree," 3: "Neither agree nor disagree," 4: "Somewhat agree," and 5: "Strongly agree." The higher the score, the higher the food technology neophobia tends to be.

Regarding trust in efforts to ensure food safety, the subjects were asked to rate two items using the same 5-point scale used for the measurement of food technology neophobia. The two items were as follows: "I trust the efforts of the government, food business operators, and others to ensure food safety in principle" and "I trust the information disseminated by scientists and engineers."

For the subjects' favorite science subject, they were asked, "Which science subjects do you enjoy?" and were asked to check all that apply from the following options: "mathematics," "physics," "chemistry," "biology," "other," and "I do not like any science subjects." This classification of subjects is generally familiar to Japanese people.

2.1.4. Background

Regarding background, respondents were asked about gender, age, place of residence, family structure, and annual household income. For annual household income, respondents were also provided the option of "Not intend to answer/not sure."

Table 1
The color of LED lighting and the information provided for each group (G).

		G1	G2	G3	G4	G5	G6
Basic IVF information		✓	✓	✓	✓	✓	✓
LED Color	White	✓			✓		
	Light red-purple (LRP)		✓			✓	
	Dark red-purple (DRP)			✓			✓
Additional information about vegetable growth under LED lighting					✓	✓	✓

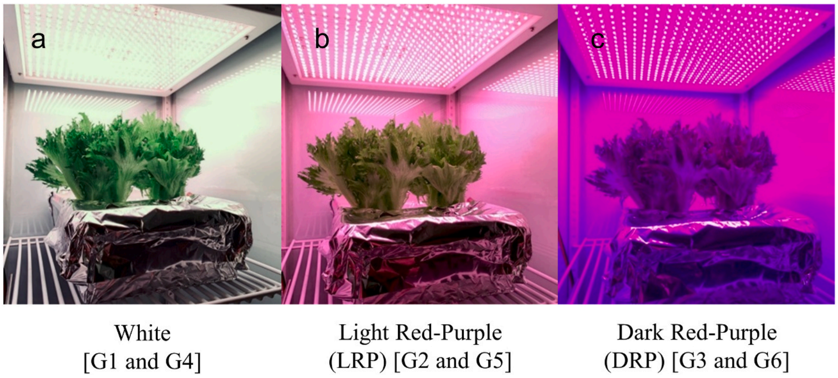

Fig. 2. The color of LED lighting: a) white, b) light red-purple, c) dark red-purple

Table 2
Items of the abbreviated food technology neophobia scale (AFTNS) (n = 961).

No.	Item	Mean	Std. Dev.
1	New foods are not healthier than traditional foods.	2.73	0.68
2	The benefits of new food technologies are often grossly overstated.	3.41	0.73
3	There are plenty of tasty foods around so we do not need to use new food technologies to produce more.	2.63	0.80
4	New food technologies decrease the natural quality of food.	2.91	0.74
5	New food technologies are unlikely to have long term negative health effects.[a]	2.96	0.71
6	New food technologies may have long term negative environmental effects.	2.98	0.74
7	It can be risky to switch to new food technologies too quickly.	3.22	0.82
8	Society should not depend heavily on technologies to solve its food problems.	2.93	0.80
9	There is no sense trying out high-tech food products because the ones I eat are already good enough.	2.69	0.73

[a] Indicates reversed scored items. For all items, "strongly agree" = 5, …"strongly disagree" = 1.

2.2. Data collection

The survey was conducted on December 6–9, 2019 via an online questionnaire distributed to men and women aged between 20 and 79 years residing in Japan. The design sample size was set to150 for each of the six patterns of the survey instrument, yielding a total of 900. INTAGE Inc., the largest marketing research company in Japan, was contracted to distribute and collect the questionnaires. The registered monitors were divided into 12 categories based on gender and six age groups. The distribution targets were randomly selected from each group and distributed equally. Online surveys are prone to bias in terms of respondent gender and age [29], and the

Table 3
Definition of the independent variables.

Variable	Description
Light color of LED	
LRP (Light red-purple)	1 if a picture of a growing environment with LRP LED was presented; 0 otherwise
DRP (Dark red-purple)	1 if a picture of a growing environment with DRP LED was presented; 0 otherwise
Additional information	
Information	1 if information about artificial light cultivation was presented; 0 otherwise
Awareness	
Mass_Media	1 if the respondent has seen IVF in mass media; 0 otherwise
Internet	1 if the respondent has seen IVF on the Internet; 0 otherwise
Building	1 if the respondent has seen IVF in a building; 0 otherwise
Tour	1 if the respondent has seen IVF at a tour or exhibition; 0 otherwise
Food Technology Neophobia	
FTN	The score for the first principal component (using three items No.1, No.4, and No.6 of the AFTNS in Table 2)
Trust in food safety	
Trust	1 if the average score of two items regarding trust in efforts to ensure food safety as described in subsection 2.1.3 exceeds 4; 0 otherwise
Preference for science subjects	
Physics	1 if the respondent likes physics; 0 otherwise
Chemistry	1 if the respondent likes chemistry; 0 otherwise
Biology	1 if the respondent likes biology; 0 otherwise
Demographic variables	
Female	1 if female; 0 if male
Age	Years
Kanto	1 if the respondent lives in the Kanto (metropolitan) region; 0 otherwise

equal distribution to each stratum was intended to eliminate such problems as much as possible. Informed consent was obtained from all participants who agreed to participate in the survey.

In addition, the title of the questionnaire was changed to "Questionnaire on Lifestyles" to avoid bias in the respondents' interest in the survey subject matter. Nevertheless, although the possibility of bias remains because the respondents are Internet users and voluntarily registered for monitoring [30], the questionnaire was designed to be suitable for conducting a large-scale nationwide survey by assigning different LED lighting color combinations for each group, providing additional information, and administering the questionnaire online. This method also has the advantage of making it easy to create branching questions and randomize the order in which items are presented.

2.3. Analysis method and variable definition

This study aimed to determine how the LED lighting color and the availability of information on artificial light cultivation affect consumers' likability for IVF. For this purpose, we first tested whether there is a difference in the likability scores among the six groups listed in Table 1 using analysis of variance (ANOVA) and multiple comparison methods. Subsequently, to comprehensively identify the factors that define the likability for IVF, we conducted an analysis using an ordered probit model, which is used when the dependent variable (here, likability) is an ordinal variable (see Appendix D for model details).

For likability, ratings were obtained on a 7-point scale ranging from (7) favorable to (1) unfavorable. However, as described below, the percentages of responses for both (1) and (2) were $<$2%, and almost 50% of the responses were "(4) neither" (in the middle). Therefore, (1), (2), and (3) were integrated into "1: unfavorable," (4) into "2: neither," and (5), (6), and (7) into "3: favorable." Thus, the dependent variable is a three-level ordinal variable ($M = 3$).

Table 3 summarizes the definitions of the independent variables.

The light color of LED illumination: *LRP* and *DRP* are dummy variables that were set to a value of 1 when a picture of a growing environment with LRP and DRP LED illuminations, respectively, was presented. The red-purple color was used for the following reasons. First, a preliminary survey of 817 consumers was conducted immediately before this study. The results showed that LRP was rated similarly to light blue or green, and DRP was rated similarly to the single color red or blue. Based on these results and the fact that the red-purple color (a combination of red and blue, which is effective for plant growth) is common in IVFs using LED lighting, we decided to use LRP and DRP lighting.

Additional information: *Information* is a dummy variable that was set to 1 when the additional information was presented. In this study, we also estimated a model including a cross term with the light color dummy (i.e., *Information*LRP* and *Information*DRP*) to test whether the effect of providing information varies depending on the color of LED lighting.

Awareness of IVF and information sources: *Mass_Media*, *Internet*, *Building*, and *Tour* are dummy variables that were set to a value of 1 when the respondent has seen IVF (vegetables grown under artificial light) in mass media such as television, on the Internet, in a building such as a restaurant or shopping mall, and at a tour or exhibition, respectively. It is known that most consumers obtain information about new food technologies from the mass media and Internet, which significantly impacts their attitudes toward these technologies [31–33]. In the case of IVF, dummy variables were created for each of these information sources as consumers may see them installed in buildings such as malls or when they attend tours or exhibitions.

Food Technology Neophobia: A principal component analysis was performed using data from the nine items of the AFTNS, which resulted in a low contribution rate of 0.37 for the first principal component. Therefore, each item in Table 2 was entered into the model as a variable, and No. 1, No. 4, and No. 6 became statistically significant. However, because the problem of collinearity remained, a composite variable (first principal component) was created by combining these three items in a principal component analysis and named *FTN* (*Food Technology Neophobia*). The contribution of the first principal component was 0.61, and Cronbach's alpha coefficient of reliability was 0.683. Previous studies have found that food technology neophobia has a negative impact on consumers' acceptance of foods developed using novel food technologies, such as genetic modification [27,34], nanotechnology [34,35], cloning technology [27], 3D printers [15], IVF [36]. Similarly in this study, we predicted that *FTN* would have a negative effect on the perceptions of IVF.

Trust in food safety: *Trust* is a dummy variable that was scored 1 if the average score of two items regarding trust in efforts to ensure food safety as described in subsection 2.1.3 exceeds 4 (i.e., the average score is "Somewhat agree" or higher). Previous studies have shown that increased trust in the food industry, government, and science & research tends to reduce risk perception of and to increase willingness to purchase foods produced using various technologies [22,23,37–39]. Similarly, trust is expected to have a similar positive effect on likability for IVF.

Preference for science subjects: *Physics*, *Chemistry*, and *Biology* were dummy variables set to 1 if the respondent answered that they like physics, chemistry, and biology, respectively. Several studies have found that those exposed to science (e.g., those who took courses related to natural sciences in college) have more positive attitudes toward genetically modified foods than those who were not [40,41]. Yang and Hobbs [42] showed that attitudes toward science and technology influence consumer acceptance of genetically modified produce. However, no study has shown the influence of attitudes toward each science subject on attitudes toward food technology. We examined the impact of likes and dislikes of each natural science subject on the level of likability for IVF.

Demographic variables: *Female* was a dummy variable equal to 1 if the respondent was a woman, *Age* was the respondent's age, and *Kanto* was a dummy variable that was equal to 1 if the respondent lived in the Kanto (metropolitan) area. To preface this, many studies have found that women have a more negative attitude toward new food technology [16,19,31,43]. However, the findings of previous studies on the effect of age on it have been inconsistent [15,19]. Furthermore, a dummy variable was created to account for the possibility that more people in areas close to metropolitan regions would better understand indoor cultivation in office buildings, underground, shopping malls, etc., than in other areas.

3. Results and discussion

3.1. Questionnaire responses

Responses were accepted until the number of respondents for each pattern of the questionnaire exceeded the design sample size of 150, resulting in a total of 961 respondents. The breakdown was 160, 158, 161, 163, 159, and 160 for G1, G2, G3, G4, G5, and G6, respectively, all of which were used for data analysis as valid responses. Note that given this sample size, an effect size (Cohen's f) of 0.12 or greater can be detected at a significance level of 5% and a power of 0.8.

3.1.1. Representativeness of data

Table 4 shows the distribution of respondents' backgrounds. In this section, we compare the composition of the sample to that of the total population (20–70 years) as calculated from census data to ascertain the representativeness of the data. Data on gender, age, area of residence, marital status, and presence of children living together were obtained from the 2015 Population Census of Japan [44], and data on annual household income were obtained from the Summary Report of Comprehensive Survey of Living Conditions 2018 [45].

First, there was little difference between the sex ratio in the census and that in the questionnaire survey. The age distribution of respondents tended to be slightly lower among those in their 20s and relatively higher among those in their 60s and 70s, but the difference among the other age groups was only 1%–2%, which was generally close to the actual distribution. The distribution of residential areas also tended to be slightly higher in the Kanto region and lower in the Kyushu region but was consistent with the actual distribution of the population. Furthermore, compared with the census, the marriage rate was slightly higher and the cohabitation rate of children was slightly lower but not significantly skewed. These findings suggest that the representativeness of backgrounds was generally maintained, although household income could not be compared owing to a substantial number of "do not want to answer/not sure" responses.

3.1.2. Awareness and sources of information

Table 5 presents respondents' awareness of IVF cultivation system and sources of information. Among the respondents, 60.7%

Table 4
The distribution of respondents' backgrounds (n = 961).

Characteristic	Frequency	%	Census %
Gender			
Male	471	49.0	49.4
Female	490	51.0	50.6
Age			
20 to 29	76	7.9	13.2
30 to 39	141	14.7	16.6
40 to 49	166	17.3	19.6
50 to 59	163	17.0	16.4
60 to 69	242	25.2	19.3
70 to 79	173	18.0	14.9
Region			
Hokkaido	50	5.2	4.2
Tohoku	61	6.3	7.1
Kanto (Metropolitan area)	361	37.6	33.8
Chubu	141	14.7	16.9
Kansai	184	19.1	17.7
Chugoku	55	5.7	5.9
Shikoku	28	2.9	3.0
Kyushu	81	8.4	11.4
Marital Status			
Married	643	66.9	62.4
Unmarried	318	33.1	37.6
Presence of Children			
Yes	347	36.1	43.0
No	614	63.9	57.0
Income			
Less than 3 million yen	159	16.5	33.4
Between 3 and 5 million yen	228	23.7	23.8
Between 5 and 7 million yen	106	11.0	16.1
Between 7 and 9 million yen	77	8.0	10.4
Greater than 9 million yen	73	7.6	16.3
Prefer not to answer/not sure	318	33.1	N/A

Census information on gender, age, region, marital status and presence of children was obtained from the 2015 Population Census of Japan, whereas income information was from the 2018 Comprehensive Survey of Living Conditions. One million yen = 7285 USD (8/22/2022). N/A = not available.

Table 5
Respondents' awareness and sources of information.

Variable	Frequency	%
Awareness (n = 961)		
Yes	583	60.7
No	378	39.3
Sources of information (n = 583)		
Internet sites and social media	49	8.4
TV and magazines	551	94.5
In buildings such as restaurants and shopping malls	39	6.7
Indoor vertical farm tours and exhibitions	24	4.1
Other	1	0.2

answered that they had "seen" artificial light cultivation in IVFs in real life or in the media. Of the responses, "TV, magazines, and other media" was the most common source of information at 94.5% (57.3% of the total), followed by "websites, blogs, and social media on the Internet" at 8.4%, "inside buildings such as restaurants and shopping malls" at 6.7%, and "tours and exhibitions at IVFs" at 4.1%. These results indicate that about 40% have never seen IVF at all and of those who have seen IVF, most had seen it in cultivation when it was introduced on TV or other media, and few have yet to see it in person.

3.1.3. Likability rating

The distribution of likability scores for the IVF showed some differences among the groups, but the trend was that respondents who provided positive evaluations of (7) favorable, (6), and (5) together accounted for about 40% of the total (Table 6). On the other hand, negative evaluations of (1) unfavorable, (2), and (3) together accounted for around 10% of the total, but (4) neither accounted for about 50% of the total, indicating that many respondents were either unsure of their decision or unable to make a decision due to insufficient knowledge. The tendency to have a few extreme opinions and many neutral opinions was similar to that reported in another study on other novel food technologies [19]. It became clear that more than half of the respondents had a less positive attitude toward LED lighting, regardless of the light color or additional information provided. A comparison of average likability between groups is discussed in more detail in section 3.2.

3.1.4. Food technology neophobia, trust, and favorite science subjects

The average scores for each item on the FTNS are shown in Table 2. No. 1, No. 3, and No. 9 had low average scores, with a relatively small percentage of respondents believing that foods produced using new technology are unnecessary or unhealthy. In contrast, No. 2 and No. 7 had high average scores, and relatively more respondents believed that new technology was overestimated and that its rapid introduction was not good. The other items had an average value of close to 3, indicating that opinions were divided. In all items, "neither" accounted for around 50% of the responses, indicating that many were unsure of their decision.

Table 7 reports the responses to the questions about trust in food safety. Regarding trust in efforts of the government and food business operators to ensure food safety, only 0.9% answered "Strongly agree," while 27.6% answered "Somewhat agree," 52.8% answered "Neither agree nor disagree," 16.2% answered "Somewhat disagree," and 2.5% answered "Strongly disagree." Similarly, 1.5% of respondents answered "Strongly agree," 27.7% answered "Somewhat agree," 57.8% answered "Neither agree nor disagree," 12.3% answered "Somewhat disagree," and 0.8% answered "Strongly disagree" to the question asking whether you can trust the information disseminated by scientists and engineers. There were slightly more positive than negative responses, but ambiguous responses were also evident.

Table 8 shows respondents' favorite science subjects. The largest percentage of respondents (34.0%) answered that their favorite subject was "mathematics," followed by "biology" (24.6%), "chemistry" (15.1%), and "physics" (13.0%). In addition, about 40% of the respondents answered "no favorite science subject." This indicates that relatively few respondents like science (or science-related) subjects, particularly chemistry and physics.

3.2. Intergroup comparison of likability scores

Fig. 3 compares the average likability scores for each of the groups from G1 to G6. The error bars show the mean ± 2 standard error. A one-way analysis of variance was performed to verify whether there was a difference in means between groups. A significant

Table 6
Distribution of responses across seven categories of likability by groups.

Group	1 = Unfavorable	2	3	4	5	6	7 = favorable	n
G1	1.9%	2.5%	3.8%	58.1%	13.8%	11.9%	8.1%	160
G2	2.5%	0.0%	8.9%	48.7%	19.6%	7.6%	12.7%	158
G3	1.9%	3.1%	8.7%	52.2%	17.4%	9.9%	6.8%	161
G4	0.6%	1.2%	4.3%	47.9%	20.9%	11.7%	13.5%	163
G5	0.6%	3.1%	7.5%	54.1%	15.7%	10.1%	8.8%	159
G6	1.9%	0.0%	4.4%	48.8%	14.4%	15.0%	15.6%	160

Table 7
Respondents' trust in food safety (n = 961).

Question	Strongly Disagree	Somewhat Disagree	Neither	Somewhat Agree	Storngly Agree
I trust the efforts of the government, food business operators, and others to ensure food safety in principle.	2.5%	16.2%	52.8%	27.6%	0.9%
I trust the information disseminated by scientists and engineers.	0.8%	12.3%	57.8%	27.7%	1.5%

Table 8
Respondents' favorite science subjects (n = 961).

Subject	Frequency	%
Mathematics	327	34.0
Physics	125	13.0
Chemistry	145	15.1
Biology	236	24.6
Other	20	2.1
No favorite science subject	381	39.6

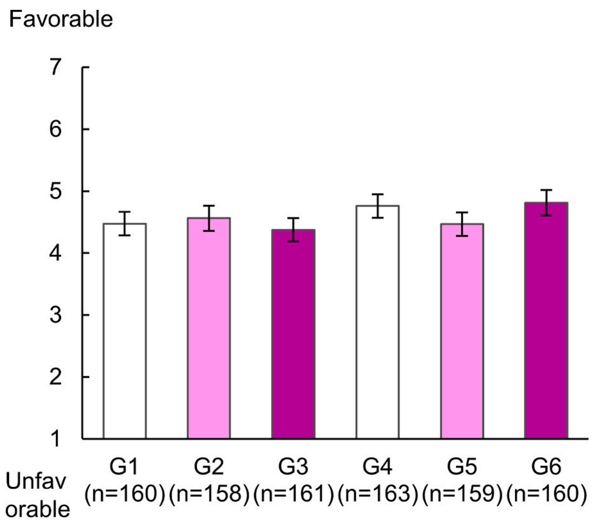

Fig. 3. The average likability scores for each of the groups (Error bars show the mean ± 2 standard error).

difference was found between any of the groups as a whole (F (5, 955) = 3.27, $p < 0.01$). To confirm whether there was a difference between any of the groups, multiple comparisons between the groups were performed. There was a difference only between G3 and G6 in the direction of higher mean likability scores for G6 ($p < 0.05$ for all of Bonferroni, Sidak, and Holm). This result indicated no difference in the likability scores with the LED illumination color. Furthermore, when additional information was presented, the difference in average likability scores was noted when the light color of the LED illumination was DRP.

3.3. Estimation results of the ordered probit model

Table 9 shows the estimation results of the ordered probit with likability for IVF as the dependent variable. Model 1 did not include the cross term between additional information and the light color dummy, but Model 2 did. For each Model, the estimation results for the full model, including all independent variables and the model with variable selection using the stepwise method, are shown. Comparing the results of Models 1 and 2, the variables and coefficients that were significant except for the cross term were comparable. However, the Akaike information criterion (AIC) of Model 2 was smaller, and the McFadden's pseudo R-squared was higher. The average variance inflation factor (VIF) and the condition number (CN) calculated as indicators for the multicollinearity diagnosis were smaller when the stepwise method was used, meaning that the possibility of a problem was also lower (the average VIF was close to 1, and the CN was <5). In general, multicollinearity should be suspected when the CN exceeds 20 [46]. Considering these results, the results obtained by estimating Model 2 with a stepwise variable selection method are presented below.

First, none of the coefficients for the light color dummies (*LRP* and *DRP*) were statistically significant, indicating that the special light color of LEDs did not affect the likability. This finding was contrary to expectations based on the findings of Hasenbeck et al. [13]

Table 9
Estimation results and marginal effects of the ordered probit model (n = 961).

	Model 1 (w/o cross terms)				Model 2 (w/cross terms)				Marginal Effects		
	Full Model		Stepwise Selection		Full Model		Stepwise Selection		Model 2 Stepwise Selection		
	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	$y = 1$ Unfavorable	$y = 2$ Neither	$y = 3$ Favorable
LRP	−0.139	0.09			−0.001	0.13					
DRP	−0.071	0.09			−0.155	0.13					
Information	0.208 **	0.08	0.198 **	0.08	0.240	0.13	0.297 **	0.09	−0.043 **	−0.051 **	0.095 **
*Information*LRP*	–	–	–	–	−0.271	0.19	−0.290 *	0.12	0.042 *	0.050 *	−0.093 *
*Information*DRP*	–	–	–	–	0.176	0.19					
Mass_Media	0.351 **	0.08	0.354 **	0.08	0.348 **	0.08	0.352 **	0.08	−0.051 **	−0.061 **	0.112 **
Internet	0.165	0.20			0.170	0.20					
Building	−0.078	0.25			−0.071	0.25					
Tour	0.738 **	0.28	0.746 **	0.27	0.735 **	0.28	0.747 **	0.28	−0.109 **	−0.129 **	0.238 **
FTN	−0.367 **	0.04	−0.367 **	0.04	−0.370 **	0.04	−0.368 **	0.04	0.054 **	0.064 **	−0.117 **
Trust	0.386 **	0.13	0.382 **	0.13	0.380 **	0.13	0.381 **	0.13	−0.055 **	−0.066 **	0.121 **
Physics	0.340 **	0.13	0.357 **	0.12	0.334 **	0.13	0.360 **	0.12	−0.052 **	−0.062 **	0.115 **
Chemistry	0.149	0.11			0.153	0.11					
Biology	0.108	0.10			0.115	0.10					
Female	0.099	0.08			0.093	0.08					
Age	−0.004	0.00			−0.003	0.00					
Kanto	0.186 *	0.08	0.161 *	0.08	0.174 *	0.08	0.153	0.08	−0.022	−0.026	0.049
1st threshold	−1.22	0.16	−1.06	0.09	−1.20	0.17	−1.07	0.09			
2nd threshold	0.66	0.16	0.81	0.08	0.69	0.17	0.81	0.08			
Pseudo R-squared	0.14		0.14		0.15		0.14				
Wald Chi-square	194 **		183 **		203 **		190 **				
AIC	1570		1564		1569		1560				
Mean VIF	1.12		1.03		1.67		1.09				
Condition number	13.19		4.33		14.33		4.50				

*$p < 0.05$, **$p < 0.01$.

and Yang et al. [14] which have suggested that unfamiliar light colors used for display, such as blue or red, negatively influence consumers' perceptions. This inconsistency may be due to the fact that the current study focused on purple lighting, which previous studies did not use, and that respondents were asked about their impressions of the LED growing environment rather than their impressions of the food itself.

Next, the additional information dummy (*Information*) generally had a significant positive effect on the likability. This means that explaining the scientific basis for vegetable growth under artificial light can increase consumers' perception for IVF. This finding was in accord with previous studies indicating that providing evidence-based information about the technology can improve consumers' perceptions [15,17–19]. However, the results differed for those presented with a LRP light (purple slightly closer to white). It was found that the explanation of the color strengthened the perception of the purple color more than the white color, resulting in the emergence of an effect (negative effect) that reminded them of the unnaturalness of the color, which in turn nullified the positive effect.

As for variables related to IVF awareness and information sources, the *Mass_Media* and *Tour* coefficients were positive and significantly higher than other variables. This may be because IVF has been positively featured in TV news programs in Japan, and the benefits of IVF have been communicated to the public. The marginal effects indicated that participation in tours and exhibitions particularly increased the probability of a "favorable" response. However, this result may reflect the participants' original level of interest and knowledge. On the other hand, *Internet* and *Building* were not significant. This may be because the Internet does not necessarily provide information that positively influences likability, and it is difficult to convey the benefits of IVF and the mechanism of plant growth under artificial light by simply observing the growing environment inside a building. Overall, participants who had previously heard about IVF were more likely to show a positive attitude toward it, which matched Ares et al. [43] and Jaeger et al. [36].

The coefficient of *FTN* was negative and significant, confirming that respondents with higher resistance to new food technology expressed a lower preference for IVF. This result is consistent with those of previous studies in that food technology neophobia negatively affects the acceptance of foods developed using novel food technologies [15,25,27,34–36]. The *Trust* coefficient was positive and significant, indicating that respondents with high trust in food safety initiatives and information have a high likability toward IVF. This result is consistent with those reported by Roosen et al. [37], Siegrist et al. [38], Siegrist [23], and Sodano et al. [39]. Furthermore, the *Physics* coefficient was positive and significant, indicating that respondents who reported a preference for physics tended to show high likability toward IVF. Because IVF uses advanced industrial technology, respondents who are inclined toward fields related to electricity and mechanics likely showed a high likability. Furthermore, the demographic variables *Female*, *Age*, and *Kanto* were not significant at a 5% significance level. The finding regarding gender of the current study differs from that of the previous research indicating that women have a more negative attitude toward emerging food technologies in general [16,19,31,43].

3.4. General discussion

In summary, the color of LED lighting does not affect consumers' likability for IVF; instead, "resistance to new food technology," "trust in efforts to ensure food safety," and "recognition of the technology," which are generally reported as factors affecting perception and acceptance of novel food technology, have a significant impact on the likability for IVF. It was also suggested that providing information on why vegetables can grow well under artificial light can improve the likability for IVF on average. Furthermore, it was found that among the natural sciences, those who liked "physics," which includes contents such as mechanics and electricity, rather than subjects such as chemistry and biology, showed a high preference for IVF.

These findings provide valuable insights for developing the effective communication and marketing strategies of IVFs. When setting up IVFs in restaurants and retail stores or posting IVF images and videos on the Internet, the light color of LEDs should not be an issue; rather, it is important to carefully communicate the scientific basis underlying vegetables growing well even under artificial light. In stores, it may be effective to provide such information using promotional tools, such as point of purchase (POP) displays. When providing information, it should be as concise as possible to avoid bias due to information overload. It may also be necessary to create opportunities for individuals to become familiar with cultivation methods using artificial light, thereby reducing resistance to the novel technology used in IVF while also providing answers to questions about safety and nutritional value. For example, using small LED hydroponic kits for school education, etc., and teaching students the process and mechanism of vegetable growth under LED lighting and using liquid fertilizer, as well as having them eat the vegetables they grow, may be effective in improving their perception of IVF. Furthermore, promoting information dissemination by distributing press releases, as well as interactive communication with consumers through workshops and social media may be effective in building mutual understanding and trust.

4. Conclusion

This study examined whether the use of purple LED lighting affects consumers' perception for IVF compared to conventional white lighting and whether providing information on the principle of the artificial light cultivation techniques changes those perceptions. We conducted a comprehensive analysis, including factors influencing consumers' perception and acceptance of novel food technologies that were identified in previous studies.

The results revealed that the use of purple LED lighting did not have an effect on the perceptions of IVF, whereas factors such as food technology neophobia, trust in food safety assurance, and awareness of IVF through mass media reports and tours had a significant impact on these perceptions. While the results also indicated that providing information on the principle that plants can grow well under artificial light was effective in increasing the likability for IVFs, the effect was not higher for the special light color LED lighting (purple LED) than for conventional white lighting.

Our findings provide valuable insights into the factors affecting consumers' perceptions of IVFs using colored LED lighting, and have important implications on the development of the effective communication and marketing strategies of IVFs. The use of purple LED lighting should not be an issue even if consumers see IVFs in stores or other places. To improve perceptions of IVF, it is important to explain the scientific basis for the effectiveness of artificial light use carefully while also reducing resistance by familiarizing individuals with cultivation methods using artificial light. Promoting small IVFs in educational facilities and offices will further enhance opportunities for people to come into contact with artificial light cultivation systems. Adding explanations about the scientific mechanisms related to artificial light and plant growth will deepen their understanding of IVF. Public relation activities, such as the distribution of press releases as well as the dissemination of information through sales promotion tools, such as in-store POP (electronic and handwritten POP materials), flyers, and product packaging, could be made more effective by including information that can help consumers resolve their queries. Furthermore, interactive communication through social media and workshops would also be effective in building mutual understanding and trust. In summary, increasing opportunities to learn about artificial light cultivation, regardless of the color of the lighting, is crucial to improving the perceptions of IVFs.

Finally, the limitations of this study and future perspectives are discussed herein. First, the survey in this study did not ask respondents to observe LED cultivation in person and rate their impressions. It would be necessary to set up a small IVF at the venue and conduct a survey in which respondents could see and evaluate the actual product. Second, the current study only included Japanese respondents, which may limit its applicability to other cultures. Future research should include a survey targeting consumers in other countries. Third, although we attempted to eliminate self-selection bias by devising the title of the questionnaire, the problem of bias that occurs in online surveys remains. Data should also be collected in ways other than online surveys. In addition, the sample size used in this study was insufficient to detect effect sizes smaller than Cohen's $f = 0.12$ at a significance level of 5% and a power of 0.8. Future studies should increase the sample size to overcome this problem. Finally, this study did not take a problem of information overload into consideration, which is an issue for future research.

Ethics statement

Ethical review and approval for this study were waived by the Ethics Committee of the Graduate School of Horticulture, Chiba University, because the data was voluntary and anonymous with no information regarding physiological and deep psychological indices. The informed consent was obtained from all subjects involved in the study.

Author contribution statement

Yuki Yano: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Atsushi Maruyama: Analyzed and interpreted the data; Wrote the paper.

Na Lu: Performed the experiments; Contributed reagents, materials, analysis tools or data.

Michiko Takagaki: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data.

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Data availability statement

Data will be made available on request.

Additional information

Supplementary content related to this article has been publish online at [URL].

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2023.e16823.

Appendix A. Pictures of indoor vertical farms

Figure A.1 shows interior view of the IVF using LED lighting in Fukushima, Japan. Consumers can see the inside of this type of IVFs in the media, such as TV, newspaper and Internet, or at exhibitions and tour.

Fig. A.1. Interior view of the indoor vertical farm using LED lighting, Fukushima, Japan.

In recent years, consumers are increasingly seeing indoor vertical farms using LED lighting directly in stores, office buildings, and other places. Figure A.2 shows an indoor vertical farm used in supermarket in Japan.

Fig. A.2. Indoor vertical farm installed in a supermarket (by Planet Co. Ltd., Japan). Notes: Reprinted from the Figure 15.9 in Chapter 15 of the book “Plant Factory Basic, Applications, and Advances,” [47].

Appendix B. An example of basic IVF information and photo

An example of a photo of the LED growing environment and basic information about IVF presented to respondents are shown in the following figure (Figure B.1: White LEDs).

- IVF allows for the systematic production of lettuce and other vegetables by computerized control of the growing environment, including light, temperature, humidity, CO2 concentration, water, and nutrients indoors.
- Recently, research has been conducted to cultivate high-quality vegetables using LED lighting, as shown in the image.

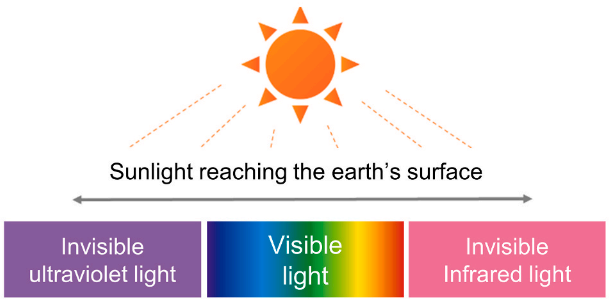
Fig. B.1. Example of a photo of the LED growing environment and basic information about IVF presented to respondents.

Appendix C. Additional information

Information about the scientific basis for artificial light cultivation presented to respondents is shown in the following figure (Figure C.1).

Why crops grow well under artificial light

- Sunlight includes visible and invisible light, as shown in the figure, but not all of it is used for plant growth.



- Recent research has shown that visible light is necessary for plant growth, especially **red and blue light**.
- Attempts are being made to use **LED technology** to grow nutrient-rich vegetables in a short time by exposing them to red, blue, or purple light.

Fig. C.1. Information on why vegetables grow well under artificial light.

Appendix D. : Ordered probit model used in this study

Because the rating scale method was used to measure likability in this study, it is a categorical variable with an order relationship. In general, an ordinal variable with M categories is defined as follows (Eq. (1)):

$$y_i = 1, 2, \ldots, M \ (0 < 1 < 2 < \ldots < M) \quad (1)$$

In the ordered probit model, assuming that the dependent variable (ordinal variable) y_i corresponds to a continuous latent variable y_i* (where the latent variable represents the magnitude of likability), we consider the following linear model:

$$y_i^* = x'_i \beta + \varepsilon_i \ (i = 1, 2, \ldots, n) \tag{2}$$

Where, x_i is the vector of independent variables ($K \times 1$), β is the vector of unknown parameters to be estimated ($K \times 1$), and ε_i is the error term. The subscript i represents the ith respondent. Considering the category selected for each respondent as determined by the size of the latent variable, we define the relationship between the ordinal and latent variables as follows:

$$y_i = 1 \text{ if } y_i^* \le \alpha_1$$

$$y_i = 2 \text{ if } \alpha_1 < y_i^* \le \alpha_2 \tag{3}$$

$$\vdots$$

$$y_i = M \text{ if } \alpha_{M\text{-}1} < y_i^*$$

Where α_1, α_2, …, $\alpha_{M\text{-}1}$ are the threshold parameters. Assuming that ε_i follows a normal distribution, from Eqs. (2) and (3), the conditional probability of the dependent variable can be expressed as follows (Eq. (4)):

$$\Pr(y_i = 1 | x_i) = \Phi(\alpha_1 - x'_i \beta)$$

$$\Pr(y_i = 2 | x_i) = \Phi(\alpha_2 - x'_i \beta) - \Phi(\alpha_1 - x'_i \beta) \tag{4}$$

$$\vdots$$

$$\Pr(y_i = M | x_i) = 1 - \Phi(\alpha_{M\text{-}1} - x'_i \beta)$$

Where $\Phi(\bullet)$ is the cumulative probability density function of the standard normal distribution. Thus, for any given respondent i, the log-likelihood function is determined as follows (Eq. (5)):

$$\log L_i(\beta, \alpha_1, \alpha_2, \ldots, \alpha_{M\text{-}1}; y, x) = \sum_m z_{im} \log\{\Phi(\alpha_m - x'_i \beta) - \Phi(\alpha_{m\text{-}1} - x'_i \beta)\} \tag{5}$$

Where z_{im} is the indicator function and takes the value 1 when $y_i = m$ and 0 otherwise, and $\alpha_0 = -\infty$ and $\alpha_M = \infty$. In the ordered probit model, the parameters are estimated to maximize the sum of this log-likelihood function for each respondent (i.e., $\sum_i \log L_i$). StataSE15.1 software (StataCorp., College Station, TX, USA) was used for the statistical analysis, and a two-tailed p value of <0.05 was considered statistically significant.

The estimated parameter β does not directly represent the marginal effect of the independent variable on the dependent variable. The marginal effect of the independent variable on the probability of category m is expressed as follows (Eq. (6)):

$$\partial \Pr(y_i = m \mid x_i) / \partial x_{ki} = \{\varphi(\alpha_{m\text{-}1} - x'_i \beta) - \varphi(\alpha_m - x'_i \beta)\} \beta_k \tag{6}$$

Where $\varphi(\bullet)$ is the standard normal density function. Because marginal effects depend on the coefficients and the vector of independent variables, it is common practice to calculate the average effect. There are two ways to evaluate marginal effects: averaging the marginal effects for each respondent or using the sample mean of the variables. The former method is used in this study.

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