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Consumer attitudes to vertical farming (indoor plant factory with artificial lighting) in China, Singapore, UK, and USA: A multi-method study

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ABSTRACT

Major changes are needed both with regard to what we eat and how food is produced. The latter is the focus of the present research, specifically the rise of controlled environment agriculture. In this context, empirical research is presented on consumer attitudes to vertical farming (VF) (i.e., indoor plant factory with artificial lighting), conducted in four countries (USA, UK, Singapore, and China) using online surveys (637–683 participants per country with matched gender and age group distributions). A multi-method research approach was used, including a novel methodology of text highlighting, which requires that participants read a descriptive text about VF with mentions of pros and cons and use highlighter functions to select aspects of the text that they 'like' and 'dislike'. Based on the information provided in the text, attitudes towards VF were largely positive in the four countries. The characteristics of VF that aligned with the United Nations Sustainable Development Goals were identified as key drivers of positive attitudes (i.e., higher yield, reduction of carbon emissions, and securing access to food). On the other hand, high energy use and premium prices contributed to negative attitudes about VF. Although the majority of participants responded to the text with an overall positive attitude towards VF, there were smaller groups of participants in every country who expressed a negative or neutral/ambivalent attitude. These between-segment differences were larger than cross-cultural differences, although the latter did exist, particularly for selected aspects of VF. For example, Chinese participants tended to be the least negative about the use of robots to help planting and harvesting. Future research is needed to understand consumer responses to aspects VF not covered in the text (e.g., powering VF with renewable energy, product range), and consumer insights about VF should be sought in other countries.

1. Introduction

Seventeen Sustainable Development Goals (SDGs) form the central pillar of the United Nations 2030 Agenda for Sustainable Development and serve as a "shared blueprint for peace and prosperity for people and the planet" (United Nations, 2015). Since being adopted, these goals have directed many public initiatives, company policies, educational efforts, research activities, etc. The present research is no exception and is situated in the context of food security and ensuring food supply for growing world populations. Major changes are needed both with regard to what we eat – less animal-based and more plant-based – and how food is produced (Willett et al., 2019). The latter is the focus of the present research, specifically the rise of controlled environment agriculture.

Vertical farming (VF) and other methods of controlled environment agriculture represent changes to current food systems that can improve global food supply and security (e.g., Avgoustaki & Xydis, 2020; Benke & Tomkins, 2017; Kalantari, Tahir, Joni, & Fatemi, 2018; O'Sullivan et al., 2020). On the controlled environment agriculture spectrum of technologies, 'low-tech' approaches include conventional greenhouses without cooling and heating, while VF classifies as control-intensive and high-tech (Niu & Masabni, 2018).

While the term VF can encompas a wide range of technologies and production systems (Beacham, Vickers, & Monaghan, 2019) the present research is focused on indoor plant factories with artificial lighting. In the pursuit of greater crop yield per area of land (Beacham et al., 2019), this type of VF grows crops indoors in vertically stacked layers under controlled conditions that optimise use of nutrients, water, energy, and space (e.g., De Oliveira, Ferson, & Dyer, 2021). Hydroponic systems are

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very popular (Beacham et al., 2019) either with aqueous solutions or substrates such as glue plugs, coco peat pellets or stone wool to support plant roots (e.g., den Besten, 2019). Other characteristics include year-round harvests and consistent quality since the crops are protected from extreme weather conditions. Being inside buildings, the plants are also protected from pests and diseases, which can reduce the need for pesticides/fungicides. VFs range from small in-home units through in-store farms and mobile units to large commercial operations located in repurposed or newly constructed buildings (e.g., Butturini & Marcelis, 2020). VFs tend to be located in or around cities (e.g., Kalantari et al., 2018), which may contribute to the fresh supply of perishable products for urban populations. This also minimises the distance between food production and consumption, which conserves energy (Kalantari et al., 2018; Specht et al., 2014).

As a young industry, VF is in constant evolution, seeking ways to overcome three key challenges: standardisation, environmental sustainability, and profitability (De Oliveira et al., 2021). Another critical challenge is the need to expand the range of crops – to date largely leafy greens and herbs – to other types of fruits and vegetables (F&V) that contribute more substantially to global food security (O'Sullivan et al., 2020). Yet, there is the risk that these challenges are overcome, but to little avail because consumers are sceptical of VF and its produce. This is not an improbable scenario considering concern about novel technologies for food production among consumers (e.g., Bruhn, 2007; Cardello, Schutz, & Lesher, 2007; Cox & Evans, 2008; Deliza & Ares, 2018; Siegrist & Hartmann, 2020). It is therefore important to understand consumers' perceptions of VF, including aspects they consider favourably and unfavourably.

A body of consumer insights regarding VF and related controlled environment agriculture technologies already exists, including Grebitus, Chenarides, Muenich, and Mahalov (2020); Jansen, Cila, Kanis, and Slaats (2016); Jürkenbeck, Heumann, and Spiller (2019); Specht, Siebert, and Thomaier (2016); Specht et al. (2019); Yano, Nakamura, Ishitsuka, and Maruyama (2021); and Coyle and Ellison (2017). In various ways it illuminates the mix of potential advantages and disadvantages of VF to consumers including improved security in food supply, shorter supply chains, all-year crop production, higher yields, and less pesticide and herbicide use (advantages), but high energy use and premium pricing, concerns over health risks and concerns over fully automated IT systems (disadvantages). Stakeholder insights have also been keenly sought, often through depth interviews and/or case studies (e.g., Milestad, Carlsson-Kanyama, & Schaffer, 2020; Specht et al., 2019; Sanyé-Mengual, Specht, Grapsa, Orsini, & Gianquinto, 2019; Specht & Sanyé-Mengual, 2017; Broad, 2020).

A shortcoming of this growing literature is the lack of exploration of attitudes to and perceptions of VF in cross-cultural settings (see Sanyé-Mengual et al. (2019) for an exception). Such undertakings are pertinent considering that the challenges VFs seek to overcome affects people globally. In this regard consumer attitudes in Asia are particularly relevant because of the region's population density and its many mega cities.

1.1. Uncovering consumer attitudes towards vertical framing

Attitudes can be regarded as affective associations that predispose consumers to evaluate a specific concept as positive or negative (Conrey & Smith, 2007; Fazio, 2007), and attitude measurement is fundamental to understanding consumer behaviour (Conrey & Smith, 2007).

Explicit measurements relying on participants' responses to Likert-type scales are the most common approach for measuring attitudes towards a specific topic (Fazio, 2007) and consist of participants being asked to indicate their degree of agreement with a series of statements using rating scales. Despite their popularity, concerns over the reliability and validity of Likert-type scales in cross-cultural research have been raised due to cultural differences in response style (e.g., Ares, 2018; Baumgartner & Steenkamp, 2001; Liamputtong, 2008). For example, extreme responding (i.e., the tendency to respond using extreme endpoints on rating scales) is more common among Asians (e.g., Batchelor & Miao, 2016), and acquiescence (i.e., the tendency to respond with agreement/affirmation) has been linked with collectivist cultural orientation (e.g., Johnson, Kulesa, Cho, & Shavitt, 2005; Smith & Fischer, 2008).

One way to overcome the limitations of rating scale is to use scale-free methods, and in the context of cross-cultural research both ranking (Fischer, 2004; Harzing et al., 2009) and best-worst scaling (Finn & Louviere, 1992; Louviere, Flynn, & Marley, 2015) are advantageous. The latter extends the method of paired comparison (Thurstone, 1927) to multiple choices by requiring participants to choose both the most and the least attractive item/object from a set of 3 or more items/objects. In the context of attitude measurement, this means presenting multiple statements and asking participants to select those statements that they agree or disagree with, respectively, most and least. From such repeated choice tasks, a metric scaling of agreement/disagreement with each statement can be derived.

Another scale-free method for attitude research is text highlighting, which was recently introduced by Jaeger, Chheang, and Ares (2022). The task simply requires that participants read a piece of text and make use of highlighter functions to indicate information in the text that they feel positive and negative about. There are no further requirements and participants can focus on whatever aspects of the text that suit them and decide how much/little text to highlight. Jaeger et al. (2022) showed the validity of text highlighting in a case study about VF with adult consumers from the UK and reported that the method allowed the identification of desirable and undesirable aspects of VF, as well as consumer segments with different overall attitudes towards VF. Using the text about VF from the present research as exemplar, Fig. 1 shows the text highlighting task following completion by a (hypothetical) participant.

1.2. Research contribution

In the context of VF – here defined as indoor plant factories with artificial lighting – the present research contributed new consumer insights by conducting a cross-cultural investigation to uncover aspects of VF that consumers find acceptable or unacceptable. Consumer attitudes were obtained in direct response to researcher-provided information about VF – what it is, and some of its advantages / disadvantages. Four countries were included in the research – the United States of America (US), the United Kingdom of Great Britain (UK), the Republic of Singapore (SG) and the People's Republic of China (CN) – and insights were sought both for individual countries and based on consumer segments with different overall attitude to VF (Positive, Negative or Neutral/Ambivalent).

According to market intelligence from Markets and Markets (2020), the global VF market by crop type was valued at USD 1.57 billion in 2019 and is predicted to grow at an annual rate (CAGR) of 42.3% between 2020 and 2025, reaching an expected value of USD 11.55 billion by 2025. By value, the market is currently largest in the North America, Europe and Asia-Pacific regions (Markets and Markets, 2020) and the countries included in the study were selected to represent these. All four countries have commercial and research interests linked to VF (e.g., Al-Chalabi, 2015; Kalantari et al., 2018; Zhang, Asutosh, & Hu, 2018). Although the US market in 2020 was the largest for a single country by value (USD 470 billion), the growth rate is higher for China (23.5% CAGR), and projected to be larger by value than USA by 2025 (USD billion 1050 vs. 953) (Markets and Markets, 2020).

2. Methodology

2.1. Participants

All participants had self-registered with an ISO-accredited web panel (online survey) provider (Lightspeed) and were eligible to take part if

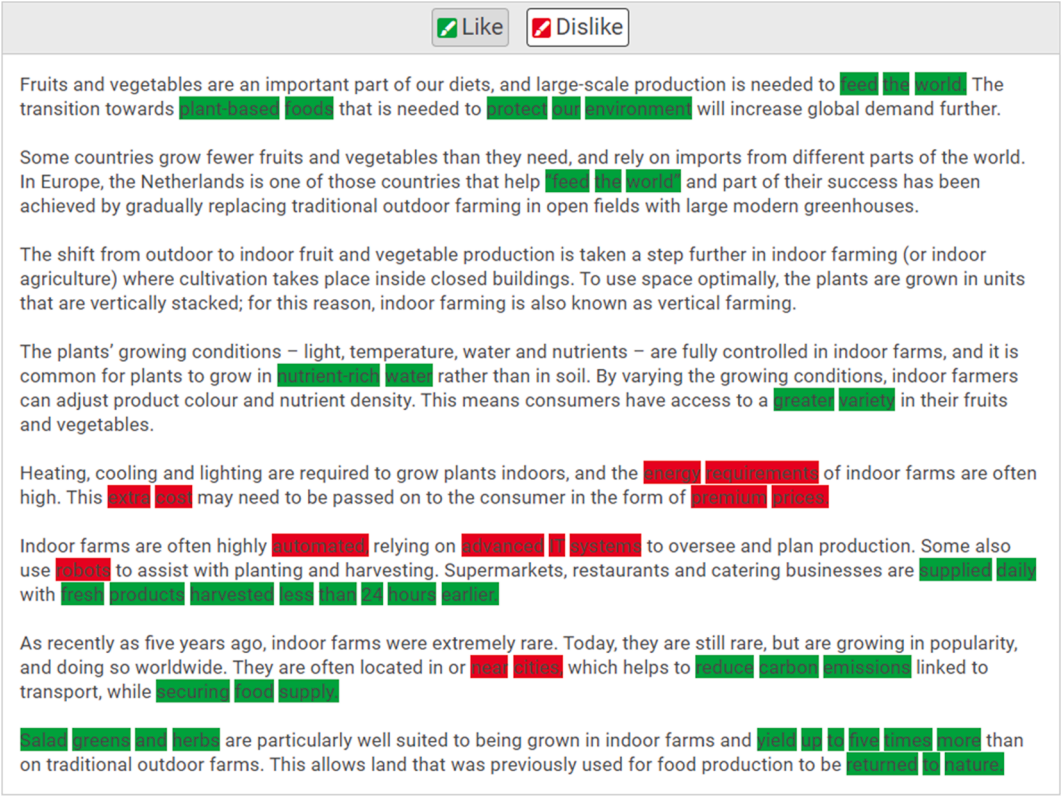

Fig. 1. Text highlighting task. Participants were instructed to read the text and use the highlight functions to indicate text that they that they like / feel positive about and text that they dislike / feel negative about. To illustrate what participants responses could look like, illustrative highlights are added.

they identified English (UK, US, SG) or Mandarin (CN) as their primary language and were regularly involved in the household grocery shopping and food preparation (more than once per week). Full data were obtained from 2637 people as follows: n = 637 (UK), n = 644 (US), n = 673 (SG) and n = 683 (CN).

To ensure that the samples from each country were as comparable as possible, interlocking quotas were imposed based on male/female and two age groups (18–39 years old and 40–56 years old), and the distribution of these four groups was not statistically different in the four countries ($p = 0.62$ and $p = 0.70$ for age and gender, respectively). In all countries, the participants were geographically diverse, and corresponded to regional distributions for place of living. Part 1 of Supplementary Material has further participant details.

2.1.1. Human ethics statement

The research was covered by a general approval for sensory and consumer research from the Human Ethics Committee at The New Zealand Institute for Plant and Food Research Limited (PFR). Participants were assured that their responses would remain confidential and gave voluntary consent to participate. As compensation, participants earned reward points and promotional offers.

2.2. Multi-method responses

A multi-method approach was used to enhance robustness, and the empirical strategy was to combine direct attitude questions with two scale-free methods, one of which was the novel text highlighting methodology. The other was inspired by best-worst scaling to create a simple choice task.

2.2.1. Text highlighting

The text used in the highlighting task comprised 19 sentences, where the first four sentences was about global changes happening in F&V production, including a shift from outdoor to indoor agriculture. This served as a lead-in to the VF-centric part of the text where key aspects of VF were explained to the reader together with possible benefits and disadvantages (Sentences 5 to 19). Although VF to date is mostly used to grow lettuce, kale, herbs, and microgreens (Benke & Tomkins, 2017), we broadened the scope to fruits and vegetables to increase participant relevance and align with technological progress and longer-term aspirations (Markets and Markets, 2020; O'Sullivan et al., 2020). Hydroponics, although common in VF, was not mentioned, and this omission was linked to Jaeger et al. (2022) having previously addressed this aspect of VF technology. Furthermore, efforts were made to keep the text from becoming too lengthy as recommended by Jaeger and Ares (2022).

The text was written in English by the authors and revised following feedback from colleagues and a full-time science editor with a PhD in biological sciences. The intent was that it would be suitable for use with a lay audience, while factual and credible. For this reason, we used the terminology 'indoor farming' and 'indoor farms', which is also common in the extant literature (e.g., Beacham et al., 2019; Gobble & Headrick, 2019; O'Sullivan et al., 2020) and was regarded as more consumer friendly, especially if participants had never before heard about controlled environment agriculture.

In addition to Fig. 1, which shows the full text with exemplar highlights, Part 2 of Supplementary Material shows the task as it appeared to participants before they began adding highlights. Part 3 of Supplementary Material contains the text in English and the Mandarin version (simplified characters). A bilingual consumer researcher with previous relevant experience performed the translation using Google Translate for assistance. The text was further revised in discussion with another bilingual speaker. The final version was agreed between these two people.

Task implementation was very similar to Jaeger et al. (2022) and Jaeger and Ares (2022), and participants were instructed to read the text and use the highlighter functions to select content they liked and

disliked. On screen, the text was shown with left alignment, without indentation for the start of a new paragraph, and with a blank line separating different paragraphs (Fig. 1). The only significant change, based on the suggestion of Jaeger and Ares (2022) was to include prompts to use both 'like' and 'dislike' highlights. Specifically, if a participant only used 'like' highlights, the following message appeared on screen: "We noticed you only selected text which you like/feel positive about. Please also select text which you dislike/feel negative about, or press continue if you do not dislike/feel negative about any of it." If only the 'dislike' function had been used, respondents were similarly prompted to select 'like' text or confirm that they did not want to make further text selections. The software used to implement the highlighting task was accessed through the online survey provider.

2.2.2. Attitudinal statements

Immediately following the text highlighting task participants saw seven attitude statements relating to different characteristics of VF (pros and cons): 1) "The fact that the growing conditions in indoor farms are fully controlled appeals to me," 2) "It worries me that indoor farms use a lot of energy, " 3) "I like that robots can be used for planting and harvesting in indoor farms, " 4) "One of the things that excites me about indoor farming is that fruits and vegetables will be available in shops less than 24 h after being harvested, " 5) "I'm against indoor farms being located in or near cities, " 6) "For me, it is an argument in favour of indoor farms that they help to secure global food supply, " and 7) "I see no need to return land used for food production to nature."

The questions were preceded by the instruction: "Please consider fruits and vegetables from indoor farms, then indicate your level of agreement or disagreement with each of the following statements." Responses were obtained on fully labelled 7-pt Likert scales from 'disagree strongly' (1) to 'agree strongly' (7). The text about VF used in the highlighting task was available for participants to read again if they needed to and accessed by clicking a hyperlink. Within country and question type (general, specific), statement presentation order was randomised. The statement wordings were developed by the authors and revised following feedback from colleagues.

2.2.3. Choice task

The purpose of the choice task was to probe participants' overall opinion about VF and the aspects of VF that shaped their opinion. They were shown seven statements that each described a different aspect of VF, and in a parallel to best-worst scaling instructed to select the aspect that was most important in shaping their overall opinion about VF, and the one aspect that was least important in shaping your overall opinion. Repeated choices were not performed, and the responses could not be analysed to derive a scaling of the importance of the individual aspects. The decision to not do so sought to reduce overall survey length and participant burden.

The statements describing the different aspects of VF were: 1) "Indoor farms can yield up to five times more than traditional outdoor farms, " 2) "Growing fruits and vegetables in indoor farms can help to reduce carbon emissions," 3) "Supermarkets are supplied daily with freshly harvested fruits and vegetables," 4) "Energy requirements are often high due to heating, cooling and lighting needs," 5) "Plants grow inside buildings under fully controlled conditions," 6) "Fruits and vegetables from indoor farms will likely sell at premium prices," and 7) "Indoor farms often rely on automation, robotics and advanced IT systems." Within countries, the presentation order of statements was randomised across participants. The statements describing aspects of VF were developed by the authors and revised following feedback from colleagues. It was consumers' responses to these statements that was of interst, rather than the validity of the statements themselves.

2.3. Data collection

The survey language was English in US, UK, and Singapore (US spelling in US, UK spelling in UK and Singapore) and Mandarin in China. Since English is the *lingua fraca* in Singapore, it was appropriate to use as the survey language in that country. The English version of the survey was translated to Mandarin (simplified characters) by the research provider. This was reviewed and revised by one bilingual consumer researcher with relevant past experience, and disagreements were solved by discussion to reach the final version.

Participants completed the online survey in a location of their choosing using a desktop or laptop computer (tablets and mobile phones were restricted since reduced screen size could interfere with ability to perform the text highlighting task). Data collection took place in April and May 2021 following careful revision of test links and evaluation of responses from 10% of the total sample in each country to ensure that the survey performed as expected.

Participants performed the three tasks in the order: i) text highlighting, ii) attitudinal statements and iii) choice task. For supporting information, participants were asked if they had previously heard about VF, and about their fruit and vegetable consumption habits. Demographic and socio-economic questions were asked at the end of the survey. The overall survey included sections linked to other projects that were unrelated to this research (not considered further).

2.4. Data analysis

The data from each country were analysed separately using the same procedures. All analyses were performed using R software version 3.6.1 (R Core Team (2020)). A 5% significance level was considered.

2.4.1. Text highlighting

Participants overall attitude toward VF was determined through their highlighting responses. For each sentence, categorical coding was used to record whether a participant selected words/logograms as 'like' (+1), 'dislike' (−1), or did not make a selection (0). Sentiment scores for sentences were calculated as the average of all individual scores multiplied by 100, which is equivalent to the difference between the percentage of participants highlighting at least one word within the sentence as 'like' and the percentage of participants highlighting at least one word within the sentence as 'dislike'. The scores could range between −100 and 100, with the former representing that all participants only used 'dislike' highlighting in the sentence and the latter representing that all participants used 'like' highlighting. Positive scores represented a generally positive sentiment toward the information in a sentence, and negative scores represented a generally negative sentiment toward the provided information. For example, a sentence for which 50% of participants used 'like' highlighting and 10% used 'dislike' highlighting would have a sentiment score of 40, indicating an average positive sentiment towards the information it contained. On the contrary, a sentence for which 15% of participants used 'like' highlighting and 40% used 'dislike' highlighting would have a sentiment of −25. Kruskal-Wallis test was used for evaluating significant differences among participants in the four countries in the sentiment of each of the sentences. Dunn's test was used for post-hoc comparisons considering Bonferroni's correction.

2.4.2. Consumer segmentation based on text highlighting

Considering only the sentences in the VF-centric part of the text (Sentences 5 to 19), an overall sentiment score for participant was calculated and segmentation was performed using these scores to create a three-way consumer segmentation: i) *VF Positive* cluster for participants with sentiment scores higher than 0 (indicating an overall positive sentiment towards the VF-centric text), ii) *VF Neutral/Ambivalent* cluster for participants with sentiment scores equal to 0 (indicating a neutral/ambivalent overall sentiment towards the VF-centric text), and iii) *VF Negative* cluster for participants with sentiment scores lower than 0 (indicating an overall negative sentiment towards the VF-centric text). The three VF sentiment clusters were compared in terms of their socio-

demographic characteristics and responses to the different parts of the questionnaire (attitudinal statements and choice task). Chi-square test and Kruskal-Wallis tests were used to assess the statistical significance of the comparisons between the clusters.

2.4.3. Attitude statements

For each of the attitudinal statements, the mean scores of the Likert-scales were calculated. Kruskal-Wallis test was used for evaluating significant differences among participants in the four countries. When differences were significant, Dunn's test was used for post-hoc comparisons considering Bonferroni's correction.

2.4.4. Choice task

Categorical coding was used to record whether each participant selected each of the aspect of VF as most important (1), least important (-1) or did not select it (0) in the choice task. Drawing on a standard approach for the analysis of best-worst data (Louviere et al., 2015), a B-W score for each aspect of VF was calculated as the average score across participants multiplied by 100. Average positive B-W scores indicate that a relative importance higher than average, whereas average negative B-W scores indicate a relative importance lower than average. The scores provided by participants in the four countries were compared using Kruskal-Wallis. When differences among countries were significant, Dunn's test was used for post-hoc comparisons considering Bonferroni's correction.

3. Results

Results from attitudinal statements (i.e., standard approach in attitude measurement) are presented first, progressing to text highlighting and the choice task, focusing on the country-specific results and their similarities/differences. To end, a consumer segmentation analysis based on sentiment scores from the VF-centric text across countries is presented.

Table 1
Average degree of agreement or disagreement[#] with seven statements related to vertical farming (VF) for participants in the United Kingdom (UK, n = 637), USA (US, n = 644), Singapore (SG, n = 673) and China (CN, n = 683). Values of standard deviation are shown in brackets.

Attitude statement[*,**]	UK	US	SG	CN
1. The fact that the growing conditions in indoor farms are fully controlled appeals to me	4.7^{c} (1.4)	5.2^{b} (1.4)	5.2^{b} (1.2)	5.6^{a} (1.2)
2. It worries me that indoor farms use a lot of energy	5.1^{a} (1.5)	$4.9^{a,b}$ (1.7)	$4.9^{a,b}$ (1.4)	4.6^{b} (1.6)
3. I like that robots can be used for planting and harvesting in indoor farms	4.1^{d} (1.7)	4.7^{c} (1.8)	5.1^{b} (1.4)	5.5^{a} (1.2)
4. One of the things that excites me about indoor farming is that fruits and vegetables will be available in shops less than 24 h after being harvested	5.1^{c} (1.5)	$5.5^{a,b}$ (1.4)	5.4^{b} (1.2)	5.7^{a} (1.2)
5. I'm against indoor farms being located in or near cities	3.5^{b} (1.7)	3.8^{a} (1.9)	3.5^{b} (1.6)	3.8^{a} (1.7)
6. For me, it is an argument in favour of indoor farms that they help to secure global food supply	5.0^{c} (1.3)	5.2^{b} (1.4)	5.2^{b} (1.2)	5.6^{a} (1.2)
7. I see no need to return land used for food production to nature	3.6^{b} (1.8)	3.9^{a} (2.0)	$3.7^{a,b}$ (1.7)	3.9^{a} (1.8)

Notes: [#]) Responses obtained on 7-pt scales from 1='disagree strongly' to 7='agree strongly.' *) The terminology "indoor farming" was used in data collection in preference to VF, to enhance appropriateness for consumers. **) Values with different letters within a row are significantly different according to Dunn's test for a significance level of 0.05 considering Bonferronni's correction.

3.1. Attitude statements

Table 1 shows average agreement/disagreement scores for the seven attitudinal statements in each of the four countries. Statements worded to convey a positive attitude towards VF, respectively, controlled growing conditions, fresh products, and global food supply (Statements 1, 4, 6) received average scores close to 5 ('agree slightly') in all four countries. Statements worded to convey negative attitudes regarding location of VFs in/near cities and VFs enabling land to be returned to nature (Statements 5 and 7, respectively) received scores that were slightly lower than 4 (between 'slightly disagree' and 'neither agree nor disagree') in all four countries. For Statement 3, which described the use of robots in VF for planting and harvesting, average scores ranged between 4.1 (UK) and 5.5 (China). There was modest agreement with Statement 2 relating to worries about high energy requirements in VF (4.6–5.1). Collectively, these results pointed to cross-cultural consensus regarding a dominantly positive attitude toward VF among consumers in UK, US, Singapore, and China.

There were significant differences between countries for all statements, and in general the highest average scores were observed in China, while the lowest average scores were observed in the UK (Table 1).

3.2. Text highlighting

Sentiment scores for the 19 sentences in the highlighting text are shown in Table 2, where sentences are sorted from most positive sentiment (top) to most negative sentiment (bottom) based on average values across all counties. Overall, the sentence "Fruits and vegetables are an important part of our diets, and large-scale production is needed to feed the world" had the most positive sentiment score, although the average score for China was lower than in the other three countries ($p < 0.001$), and only ranked as the 4th most positive sentence in this country.

Regarding VF, the highest sentiment scores were found for sentences related to increased yield for salad greens and herbs (Sentence 18), controlled growing conditions in nutrient-rich water (Sentence 7), supply of fresh products harvested less than 24 h earlier (Sentence 14), location in/near cities to reduce of transport-related carbon emissions and secure food supply (Sentence 17), protection of the environment (Sentence 2) and returning agricultural land to nature (Sentence 19) received the highest sentiment scores overall. However, significant differences between countries were found, which often contrasted China to the other countries. For example, the positive sentiment for the sentences about plants growing under controlled conditions in nutrient-rich water (Sentence 7) and reliance in VFs on automated and advanced IT systems (Sentence 12) was highest in China, followed by Singapore. Chinese consumers also responded more positively to the sentence about adjusting growing conditions in VFs to vary product colour and nutrient density (Sentence 8). Conversely, sentiment scores for sentences describing environmental aspects of VF (Sentences 17, 2, 19) were lowest in China. Notable other differences included the higher sentiment in Singapore towards optimal use of space through vertical stacking (Sentence 6), and for Sentence 17 which described VFs being located in/near cities to reduce transport emissions while securing food supply, the average sentiment was more positive in the UK and Singapore than in the US and China.

At the opposite end of the sentiment continuum, cross-cultural agreement was observed on the most negative aspects of VF mentioned in the text: possible premium pricing (Sentence 11) and high energy requirements (Sentence 10). However, the strength of average negative sentiment differed significantly by country for both sentences. Consumers in UK and Singapore were more negative toward premium pricing than consumers in US and China, while consumers in the UK were considerably more negative toward high energy requirements of VFs than consumers in the other three countries.

For two sentences (13 and 3), the sign of the sentiment scores varied

Table 2
Sentiment scores (-100 to 100) for Sentences 1 to 19 following the text highlighting task by participants in the United Kingdom (UK, n = 637), USA (US, n = 644), Singapore (SG, n = 673) and China (CN, n = 683).

Sentence*,**, ***	UK	US	SG	CN
1. Fruits and vegetables are an important part of our diets, and large-scale production is needed to feed the world.	46[b]	55[a]	40[b]	19[c]
18. Salad greens and herbs are particularly well suited to being grown in indoor farms and yield up to five times more than on traditional outdoor farms.	27[a]	23[a]	25[a]	23[a]
7. The plants' growing conditions – light, temperature, water and nutrients – are fully controlled in indoor farms, and it is common for plants to grow in nutrient-rich water rather than in soil.	17[b]	19[b]	21[a,b]	27[a]
14. Supermarkets, restaurants and catering businesses are supplied daily with fresh products harvested less than 24 h earlier.	21[a]	21[a]	21[a]	20[a]
17. They are often located in or near cities, which helps to reduce carbon emissions linked to transport, while securing food supply.	25[a]	17[b]	21[a,b]	17[b]
2. The transition towards plant-based foods that is needed to protect our environment will increase global demand further.	15[b,c]	27[a]	22[a,b]	11[c]
19. This allows land that was previously used for food production to be returned to nature.	24[a]	16[b]	20[a,b]	1[b]
4. In Europe, the Netherlands is one of those countries that help "feed the world" and part of their success has been achieved by gradually replacing traditional outdoor farming in open fields with large modern greenhouses.	18[a]	24[a]	22[a]	9[b]
6. To use space optimally, the plants are grown in units that are vertically stacked; for this reason, indoor farming is also known as vertical farming.	12[b]	14[b]	22[a]	17[a,b]
9. This means consumers have access to a greater variety in their fruits and vegetables.	16[a]	15[a]	16[a]	16[a]
5. The shift from outdoor to indoor fruit and vegetable production is taken a step further in indoor farming (or indoor agriculture) where cultivation takes place inside closed buildings.	6[b]	13[a]	16a	11[a,b]
12. Indoor farms are often highly automated, relying on advanced IT systems to oversee and plan production.	1[b]	6[b]	18[a]	19[a]
8. By varying the growing conditions, indoor farmers can adjust product colour and nutrient density.	4[b]	7[b]	8[b]	20[a]
16. Today, they are still rare, but are growing in popularity, and doing so worldwide.	5[a,b]	9[a]	5[a,b]	1[b]
13. Some also use robots to assist with planting and harvesting.	−3[b]	2[a,b]	5[a]	8[a]
15. As recently as five years ago, indoor farms were extremely rare.	4[a,b]	7[a]	0[b]	1[b]
3. Some countries grow fewer fruits and vegetables than they need, and rely on imports from different parts of the world.	−4[b]	4[a]	−6[b]	5[a]
10. Heating, cooling and lighting are required to grow plants indoors, and the energy requirements of indoor farms are often high.	−17[b]	−4[a]	−5[a]	−6[a]
11. This extra cost may need to be passed on to the consumer in the form of premium prices.	−32[a,b]	−17[c]	−35[a]	−25[b,c]

Notes: *) Sentences are listed in the order from average highest to average lowest sentiment scores across all countries. Numbers indicate placement in text from start (Sentence 1) to end (Sentence 19). **) The terminology "indoor farming" was used in data collection in preference to VF, to enhance appropriateness for consumers. ***) Values with different letters within a row are significantly different according to Dunn's test for a significance level of 0.05 considering Bonferroni's correction.

across the four countries, pointing to more major cross-cultural differences in the valence attached to specific characteristics of VF. Although average sentiment scores were close to zero in the four countries, consumers in the UK felt negatively about VFs often relying on highly automated and relying on advanced IT systems to oversee and plan production (Sentence 13). There was also negative sentiment in UK and Singapore (vs. positive sentiment in US and China) to the sentence describing how some countries grow fewer fruits and vegetables than they need to feed their own populations (Sentence 3).

3.3. Choice task

In the choice task, seven aspects of VF were described, and participants indicated which was most/least important in shaping their overall opinion about VF. The results are shown in Table 3, where increased yield, reduction of carbon emissions and availability of fresh F&V (Aspects 1, 2 and 3) received the highest scores, suggesting that they were regarded as most influential in shaping participants' overall opinion about VF. This result was consistent across countries, with no significant differences in the average importance scores.

Premium prices and reliance on robotics and IT systems (Aspects 6 and 7) were regarded as the least important for shaping overall opinion about VF (Table 3). Significant differences between countries in the relative importance of these two aspects of VF were found, and compared to participants in the other three countries, Chinese participants attached less relative importance to use of robotics and IT systems and more relative importance to premium prices.

3.4. Cross-cultural consumer segmentation based on overall sentiment scores from text highlighting

The great majority of participants (n = 2469, 99.4%) highlighted words within the VF-centric text (Sentences 5 to 19). This enabled the calculation of overall sentiment toward VF of each participant, and, in turn, group participants with, respectively, a positive, neutral/ambivalent, or negative attitude toward VF based on text highlighting responses. The majority of participants (n = 1559, 63%) showed a positive attitude towards the VF-centric text (*VF Positive* cluster), whereas 17% showed a neutral sentiment (*VF Neutral/Ambivalent* cluster, n = 411) and 20% showed a negative sentiment (*VF Negative* cluster, n = 499).

Table 4 profiles the participants in the three VF sentiment clusters. They were statistically significantly different in their distribution

Table 3
Average scores of the seven aspects of vertical farming (VF) included in the choice task (-100 to 100) for participants in the United Kingdom (UK, n = 637), USA (US, n = 644), Singapore (SG, n = 673) and China (CN, n = 683).

Statements describing aspects of VF*,**, ***	UK	US	SG	CN
1. Indoor farms can yield up to five times more than traditional outdoor farms	11[a]	13[a]	12[a]	15[a]
2. Growing fruits and vegetables in indoor farms can help to reduce carbon emissions	12[a]	15[a]	11[a]	11[a]
3. Supermarkets are supplied daily with freshly harvested fruits and vegetables	11[a]	7[a]	11[a]	5[a]
4. Energy requirements are often high due to heating, cooling and lighting needs	2[a]	−1[a]	0[a]	−2[a]
5. Plants grow inside buildings under fully controlled conditions	−6[a]	−9[a]	−9[a]	−4[a]
6. Fruits and vegetables from indoor farms will likely sell at premium prices	−10[a]	−11[a]	−5[a]	−22[b]
7. Indoor farms often rely on automation, robotics and advanced IT systems	−20[b]	−15[b]	−20[b]	−3[a]

Notes: *) Statements are listed in the order from average highest to lowest importance scores across all countries. **) The terminology "indoor farming" was used in data collection in preference to VF, to enhance appropriateness for consumers. ***) Values with different letters within a row are significantly different according to Dunn's test for a significance level of 0.05 considering Bonferronni's correction.

Table 4
Characterisation of participants by consumer group, shown for the three groups with different overall sentiment to vertical farming (VF) based on text highlighting responses to the VF-centric text. The groups have, respectively, positive overall sentiment (*VF positive*, n = 1559), neutral/ambivalent overall sentiment (*VF Neutral/Ambivalent*, n = 411) and negative overall sentiment (*VF Negative*, n = 499). Within variables, group distributions are compared using chi-squared (χ^2) tests.

Participant variable	VF Positive	VF Neutral/ Ambivalent	VF Negative	χ^2 (p-value)
Country				37.7 (<0.001)
UK	22	23	31	
US	22	26	29	
Singapore	28	24	21	
China	28	27	19	
Gender				7.0 (0.03)
Female	52	45	48	
Male	48	55	52	
Age group (years)				1.9 (0.38)
18–39	43	39	42	
40–56	57	61	58	
Education level				10.6 (0.005)
Lower than university degree	29	28	36	
University degree or higher	71	72	64	
Working status				23.7 (0.02)
Working full time	80	75	74	
Working part time	6	11	10	
No-paid work/ home duties	3	4	5	
Student	2	2	2	
Unemployed	6	5	6	
Retired	1	1	1	
Other	2	2	2	
Number of people in the household				11.9 (0.16)
1	9	10	13	
2	17	18	18	
3	36	36	34	
4	26	25	22	
5 or more	12	11	13	
Grocery shopping				3.5 (0.17)
I do all or most of the grocery shopping for my household	84	80	84	
I do some of the grocery shopping for my household	16	20	16	
Knowledge about VF				29.2 (<0.001)
Yes	70	59	57	
No	29	38	40	
Don't know	2	3	3	
Consumption frequency of fruits and vegetables				26.0 (0.054)
Never	1	1	1	
Less than once a month	4	3	4	
1–3 times per month	6	5	7	
Once a week	7	7	7	
2–4 times per week	17	22	20	
5–6 times per week	13	17	15	
Once a day	20	24	19	
2–3 times per day	26	18	23	
4 or more times per day	6	3	4	
Percentage fruits and vegetables consumed that is organic				8.4 (0.39)
0%	20	23	22	
1–24%	33	32	34	
25–49%	27	30	26	
50–74%	15	12	13	
75–100%	5	3	5	

according to country, gender, educational attainment and working status. The cluster with a positive overall attitude to VF (*VF Positive*) comprised a higher proportion of participants from Singapore and China, more men and more full-time workers with higher educational attainment than the other two clusters. No statistically significant differences were found in the distribution of the three VF sentiment clusters according to age group and household composition. The clusters were also not different with respect to involvement in household grocery shopping or F&V consumption. Participants in the *VF Positive* cluster were more likely to have previously heard about VF, which 70% had compared to 57–59% in the *VF Negative* and *VF Neutral/Ambivalent* clusters.

A comparison of average sentiment scores for the three consumer segments (Fig. 2) primarily showed that the *VF Positive* cluster was more positive towards VF advantages and less negative towards VF disadvantages. In this group of participants, a negative sentiment score was only found for the sentence about possible premium pricing (Sentence 11). Conversely, in the *VF Negative* cluster the average sentence sentiment scores were always negative, except for the sentence describing how VF allows land previously used for food production to be returned to nature (Sentence 19). The sentence sentiment scores in the *VF Neutral/Ambivalent* cluster varied between positive and negative, pointing to a mix of perceived advantages or disadvantages of VF. Sentence 11 which described how there could be a possible price premium for F&V from VF differed from other sentences in a more negative sentiment score. The differences between clusters in average sentiment was sentence specific and larger for some sentences than others. The biggest cluster differences were observed for those sentences describing key characteristics of VF or its pros/cons (Fig. 2).

The insights regarding similarities and differences between the three VF consumer segments gained from the attitudinal statements and the choice task largely resembled those from text highlighting, and, for parsimony, are presented in the Supplementary Material (Part 4).

4. Discussion

4.1. Consumer insights about VF

Results from the present work – which were obtained in response to the researcher-provided text about VF (Fig. 1) – showed a generally positive attitude to VF in the four countries. This fits with top-line findings in the extant literature, for example, Grebitus et al. (2020); Jaeger et al. (2022); Jürkenbeck et al. (2019); Specht et al. (2019); Yano et al. (2021); Coyle and Ellison (2017); Broad, Marschall, and Ezzeddine (2021). Insights regarding specific characteristics of VF were also obtained, as discussed below.

The contributions of VF to the United Nations Sustainable Development Goals (United Nations, 2015) were identified, as expected (e.g., Jürkenbeck et al., 2019; Broad et al., 2021, Jaeger et al., 2022), as key drivers of positive attitudes towards this technology. Results from the three methodologies showed that the large majority of the participants positively perceived higher yield, reduction of carbon emissions, and secure access to food. It was not surprising, for example, that consumers responded positively to information about reduced carbon emissions considering the media attention (e.g., Painter & Gavin, 2016; Smith & Joffe, 2009), and past food-related consumer research has also shown concern regarding this aspect of food production and supply, and some willingness to change behaviour to reduce one's carbon footprint (e.g., Canavari & Coderoni, 2020; Rondoni & Grasso, 2021). Concerns over food insecurity are widespread (e.g., Kirshenbaum & Buhler, 2018) and have gained prominence during the COVID-19 pandemic, both at individual and national levels (e.g., Crush & Si, 2020; Niles et al., 2020). The pandemic as a scenario of possible future developments has tangibly exposed food insecurity in urban centres because of disruption to food supply chains, and VF alongside other forms of urban agriculture can contribute to resilient food systems (e.g., Grebitus, 2021; Lal, 2020;

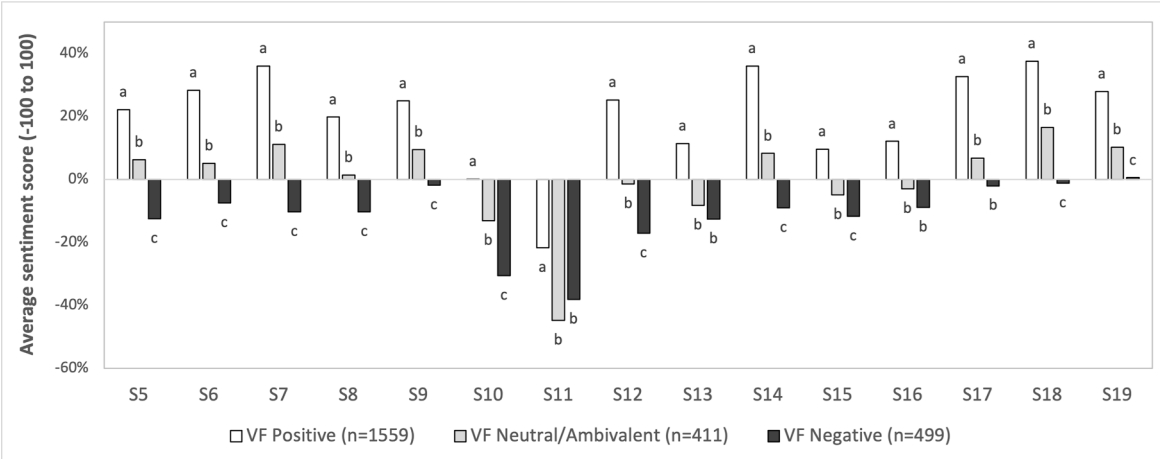

Fig. 2. Average sentiment scores participants in cross-cultural consumer segments with positive, neutral/ambivalent, and negative sentiment towards vertical farming (VF) following the text highlighting task. Scores (-100 to 100) pertain to the VF-centric text only (Sentences 5 to 19, Table 2), and values with different letters within sentences are significantly different among groups according to Dunn's test for a significance level of 0.05 considering Bonferroni's correction.

Specht et al., 2019; Sanyé-Mengual, Anguelovski, Oliver-Solà, Montero, & Rieradevall, 2016). Moreover, the notion that urban agriculture (including some forms of VF) is not well accepted by European consumers "since food security is not currently perceived as a problem in most European cities" (p. 376) (Ercilla-Montserrat et al., 2019) may, therefore, be undergoing revision.

Consumers regard product freshness as a benefit of VF and related technologies (e.g., Jaeger et al., 2022; Yano et al., 2019; Ercilla-Montserrat et al., 2019; Grebitus et al., 2020), and the present findings were no exception. Reports of the importance consumers attach to freshness when deciding that F&V to buy and eat resonate with this finding (e.g., Gunden & Thomas, 2012; Petrescu, Vermeir, & Petrescu-Mag, 2020). Like other participants, those in the *VF Negative* cluster also responded positively to VF's freshness benefit (Part 4 of Supplementary Material). Interestingly, however, the sentiment score in this cluster was negative for Sentence 14, which mentioned that shops, as well as restaurants and catering businesses would be supplied daily with fresh produce (Fig. 2). It is possible that this additional information drew attention to the burden of product distribution from VFs to vendors, which, could then have spurred negative affect because transportation to ensure daily deliveries of F&Vs would be accompanied by CO_2 emissions and air pollution. In turn, this explanation point to the possibility of environmental and sustainability factors being important for VF rejection in the cluster with overall negative sentiment. This aligns with Jürkenbeck et al. (2019), who found that perceived sustainability was a major driver of VF acceptance among consumers. In a similar vein, Broad et al. (2021) concluded that expansion of the VF industry would depend on its ability to "convince value-oriented food consumers that the products meet the triple-bottom-line of economic, social, and environmental sustainability goals" (p. 1). Assessments of sustainability attributes from operating VFs have confirmed this potential but also noted that that it is scale dependent (e.g., Milestad et al., 2020).

The characteristics that are key to defining VF – indoors cultivation with artificial lighting under fully controlled conditions, plants growing in nutrient rich substrates instead of soil and being vertically stacked for optimal space use (e.g., Kalantari et al., 2018) – were generally perceived more positively than negatively by the participants (Tables 1 and 2, Fig. 2 and Part 4 of Supplementary Material), which aligned with results from Specht et al. (2019) and Jaeger et al. (2022). Considering further that the importance of these characteristics for shaping overall opinion about VF were below average (Table 3, Part 4 of Supplementary Material), it seems that controlled indoor agriculture in itself is not a major concern to consumers. This even held for the *VF Negative* cluster, where the fact that plants grow inside buildings under fully controlled conditions was least important in shaping overall opinion about VF (Part 4 of Supplementary Material). This result was interesting in light of reports that consumers perceive VF as somewhat unnatural and artificial (e.g., Specht & Sanyé-Mengual, 2017; Jürkenbeck et al., 2019; Yano et al., 2021), which may stem from conflicts with images of traditional agriculture and a predisposition for accepting F&V grown outdoors (Specht et al., 2019; Specht, Siebert, & Thomaier, 2016). Likely, this rejection may lessen for many consumers as familiarity with VF increases.

The general acceptance of the controlled growing conditions in VF may reflect awareness among consumers that much food production is already industrialised and regulated, which they accept because it conveys benefits including food safety, regular supply and consistent product quality (e.g., Specht et al., 2019). It also seems likely that consumers are relatively aware that F&Vs are grown commercially in greenhouses (e.g., Sirieix, Salançon, & Rodriguez, 2008; Coyle & Ellison, 2017), and with this as a point of reference, a transition to VF and fully indoor production may not be perceived as a transformative change. Tentative, if consumers knew how high-tech some greenhouses are, with features that resemble VFs (e.g., Niu & Masabni, 2018; Zhou, Meinke, Wilson, Marcelis, & Heuvelink, 2021) they may regard the two production methods as more similar than different.

Access to a greater variety of F&Vs was positively perceived by consumers in all four countries (Table 2), and only in the *VF Negative* cluster was the average sentiment for Sentence 9 slightly below zero (Fig. 2). This finding resonated well with the importance given to product innovation in the food sector, including F&Vs (Stasi, Colelli, & Garini, 2019). Considering that the average sentiment scores for Sentence 8 ("By varying the growing conditions, indoor farmers can adjust product colour and nutrient density") were closer to zero, it may be relevant to more fully describe how the VF environment can be regulated to grow cultivars with novel features. For example, the focal sentence could be explicit about varying lighting, temperature or nutrient composition in order to grow lettuce in different shades of green and purple and with different phytochemicals for functional health benefits (e.g., Bian, Yang, & Liu, 2015). Such knowledge may reassure consumers, and, if appropriate, it could also be noted that plants are not genetically modified/gene edited, since this has been a major worry linked to foods and beverages (e.g., Zhang, Wohlhueter, & Zhang, 2016) although possibly of decreasing concern when applied in plant breeding (Yang & Hobbs, 2020).

Premium pricing was of below average importance for overall opinion about VF (Table 3, Part 4 of Supplementary Material), which suggested that the price products sell for is, in and of itself, of little

importance for acceptance/rejection of this novel technology. However, consumers in all four countries were negative about the prospect that F&Vs from VFs would sell at higher prices, suggesting that price could have a significant impact on uptake. The negative attitude aligned with Coyle and Ellison (2017), who reported lower willingness to pay for lettuce from VF than lettuce from greenhouses or grown outdoors. Similarly, Broad et al. (2021) warned that premium pricing may alienate many potential buyers with potential consequences for the industry's ability to expand. Yet, it is important to interpret the negative attitude to possible premium pricing in the context of the information participants were given (Fig. 1), which explicitly linked possible premium pricing to the high energy requirements of VF. Tentatively, if premium prices had been justified as a consequence of transitioning to sustainable food production which is necessary for reversing the global climate crisis (Willett et al., 2019), negative sentiment may have been fully/partially reduced. Other studies show that some consumers, if key choice criteria like taste are fulfilled are willing to pay somewhat higher prices for products that contribute to these altruistic goals (Li & Kallas, 2021; Renner, Sproesser, Strohbach, & Schupp, 2012). Consumers may also be willing to pay premium prices for improved/novel product benefits relating to flavour, convenience, health, etc. (e.g., Casini et al., 2019; Pappalardo & Lusk, 2016).

Information about reliance on advanced IT systems, automatization, and robots in VF had below average importance in shaping overall opinions about VF (Table 3, Part 4 of Supplementary Material), but elicited negative attitudes. Rapid improvements in the capabilities of industrial robots is fuelling concerns that they will replace jobs (De Vries, Gentile, Miroudot, & Wacker, 2020), and this belief could be particularly widespread in the UK where robot adoption is significantly lower than in other advanced economies (Kariel, 2021). Industrial robots are expected to have disruptive effects on employment – both replacing routine manual task-intensive jobs while also creating new ones, albeit with sector-specific impacts, and for agricultural industries and the food and beverage sectors minor overall employment effects are predicted (De Vries et al., 2020). With regard to reliance on advanced IT systems to plan and oversee production (Sentence 12) the results resembled those found for robots. In future research it could be relevant to provide consumers with more information about the benefit of such IT systems, for example to ensure a constant supply of fresh produce or optimising the growing environment, including monitoring water and nutrient use. An alternative is to more directly embrace the notion of VF delivering techno-local foods, which are simultaneously "real" and technologically optimized and fully transparent for the public (Broad, 2020).

The profiles of participants in the three VF segments (Table 4) mostly differed in expected ways. There were no segment differences for age group distributions, which matched Yano et al. (2021). Grebitus, Printezis, and Printezis (2017) also reported similar results in relation to community gardens/urban agriculture. In these two studies, gender was reported as not being linked to degree of consumer acceptance. However, the present study found a small, but significant, difference, with more men in the *VF Positive* segment. The most significant difference between the VF segments was for level of educational attainment, which was higher in the *VF Positive* segment. This matched Ercilla-Montserrat et al. (2019) and Miličić, Thorarinsdottir, Santos, and Hančič (2017). The latter reported a more positive attitude for aquaponic F&V, reflected in greater willingness to pay, among people with higher incomes (generally serves as proxy for income). The finding that consumers in the *VF Positive* segment were more likely to previously have heard of VF fitted with previous findings. Ercilla-Montserrat et al. (2019) studied consumer perceptions of tomatoes grown in a soilless rooftop greenhouse and found that past knowledge increased consumer acceptance.

4.2. Cross-cultural similarities and differences in consumer attitudes towards VF

Consumers in the four countries were more similar than different in their overall opinion about VF (Tables 1–3). However, differences between countries did exist. In general, participants from China and Singapore exhibited the most positive attitudes towards VF.

Some differences in attitudes towards specific characteristics of VF were identified. Results from the text highlighting task pointed to UK participants perceiving two key characteristics of VF less positively than consumers in the other three countries: VF plants grown indoors under fully controlled conditions and vertically stacked for optimal space use (Table 1 – Statement 1; Table 2 – Sentences 5 and 7). Tentatively, this cross-cultural difference was linked to an idealised/stereotyped associations with traditional agriculture/farming, which may be inaccurate relative to current practices in the UK (e.g., Cox et al., 2008; Yiridoe, Bonti-Ankomah, & Martin, 2005). Only a small proportion of British people (<2%) currently live on farms (DEFRA, 2020) and as the population continues to shift from rural to urban areas, people likely become more removed from agricultural practices. A similar situation applies to the USA (Kirshenbaum & Buhler, 2018).

Attitudes towards the use of automation and robots in VF were more positive in China compared to the other countries. This could be explained by the changing demographic profiles that are reducing the workforce (e.g., Banister, Bloom, & Rosenberg, 2012). For Japan, this has been suggested as an explanation for openness towards automation and robotics (Trujillo & Holt, 2020).

Chinese participants attached less importance to premium prices than those in the other three countries. Tentatively, this could be related to a positive perception of controlled production, which may be associated with increased food safety, something which many Chinese consumers demand (e.g., Liu, Gao, Snell, & Ma, 2020).

The text about VF (Fig. 1) mentioned that in transitioning from outdoor to indoor agriculture, land that was previously used for food production can be returned to nature. Participants responded positively to this benefit of VF, particularly in the UK (Table 3 – Sentence 19). This points to cross-cultural differences, which may be influenced by past history with famine, available land for agriculture and the value placed on nature (e.g., Lindemann-Matthies, Keller, Li, & Schmid, 2014; Revelle, 1976; Smil, 1999).

4.3. Limitations and suggestions for future research

Vertical farms, in the form of indoor plant factories with artificial lighting, remain novel, or even unknown to many people (e.g., Broad et al., 2021; Jürkenbeck et al., 2019; Coyle & Ellison, 2017). This implies that information about VF need to be given to research participants when studying consumer attitudes to VF. Such provision of information is not uncommon in consumer research about novel food technology (e.g., Bhatt, Ye, Deutsch, Ayaz, & Suri, 2020; Behrens, Barcellos, Frewer, Nunes, & Landgraf, 2009; Hoek et al., 2011; Lee, Lusk, Mirosa, & Oey, 2015; Lusk, McFadden, & Wilson, 2018; Verbeke, 2005; Miličić et al., 2017) – including VF (e.g., Coyle & Ellison, 2017; Jürkenbeck et al., 2019; Broad et al., 2021) – and creates a frame of reference to interpret the results against. The present study is no different, and the findings should be interpreted in the context of the provided information, a.k.a. Fig. 1. Results regarding attitudes to VF would have been different if other facts about VF had been presented to participants, or if the text had been written in a manner to bias towards or against this new production method. This is supported by previous research linked to novel food technologies, including genetic modification, high-pressure processing, irradiation and micro encapsulation. Such studies have shown that information given to consumers shape their responses (e.g., Siegrist & Hartmann, 2020; Teisl, Fein, & Levy, 2009), and that consumer attitudes are more positive if the provided information focuses on benefits and more negative if the provided information focuses on risks and

disadvantages (e.g., Smart & Ensley, 1988; Stuart, Shimp, & Engle, 1990). Thus, the current results are directly linked to the provided information and should not be generalised beyond it, and this is also the case for most other studies on consumer perception of novel technologies in food production and supply.

Therefore, it directly follows that the effects of varying information about VF on consumers attitudes is a relevant topic for future research with many avenues to pursue. Researchers could create informational texts that are particularly focused on a few aspects of VF that have their particular interest (e.g., how energy demands are met or how operations remain 100% pesticide free), or the information provided to participants could remain generic but be more detailed (e.g., that VF yield increases compared to in-field cultivation are crop dependent). Considering the common reliance on hydroponics in VF (Markets and Markets, 2020), this growing system would be relevant to mention or describe in more detail than done by Jaeger et al. (2022). An applied angle would be to develop persuasive texts and determine which VF aspects are the most influential for consumers. This could be used to support marketing and advertising initiatives for commercial or public purposes.

To help advance the transition to a more sustainable food system, the aspects of VF that were associated with negative sentiment represent a worthwhile topic for future research, and more information could be given about benefits of industrial robots (e.g., less physically demanding, and safer working environments) and advanced IT systems (e.g., how machine learning and artificial intelligence capabilities ensure optimum data capture to identify continuous optimisation of the growing environment where the fewest resources are used). These innovations are slowly finding their way into other parts of food manufacturing also (e.g., Bader & Rahimifard, 2018, 2020). Negative sentiment could also be counteracted by addressing concerns that consumers express in relation to VF, for example, their energy use (e.g., Broad et al., 2021). This could be done through reference to renewable sources of energy and energy-efficient LED lights. In addition, consumers' attention could be drawn to comparisons with traditional greenhouses which are one of the most energy-intensive sectors of the agricultural industry (Iddio, Wang, Thomas, McMorrow, & Denzer, 2020).

Alternatively, consumer benefits of VF could be emphasised more, including how light at specific wavelengths may enhance biomass growth (Pennisi et al., 2019), sensory fruit quality (Kim et al., 2020) and phytonutrient contents of leafy greens (Wong, Teo, Shen, & Yu, 2020). Information could also be given about the fact that water and nutrient use in hydroponic systems is greatly reduced (70–90%) compared to traditional agriculture (Sharma, Acharya, Kumar, Singh, & Chaurasia, 2018), and that pesticide and herbicide use in such systems can be eliminated completely. In the context of F&V from aquaponic farming Miličić et al. (2017) reported that consumes viewed this positively, and Jürkenbeck et al. (2019) expects this will also be the case for VF.

Consumer segmentation in attitudes towards VF also deserves further exploration. Further to differences linked to demographic and socio-economic factors, it could be relevant to extend this to psychographics which exert a big influence on consumer attitudes (Symmank et al., 2017). In relation to VF, this may be driven by differences in individuals' connectedness to nature (Mayer & Frantz, 2004), which may modulate whether returning past agricultural land to nature (i.e., rewilding) is seen as more or less positive. Aspects that may be particularly salient in some countries could be further addressed, say food security which has a high profile in Singapore (e.g., Yong, 2017), and a topic that may be of increasing importance for the UK since Brexit (Lang, Lewis, Marsden, & Millstone, 2018). It would also be relevant to understand if there are systematic differences between Eastern and Western countries in consumer acceptance of VF and for what reasons.

5. Conclusions

The present research explored consumer attitudes to VF among consumes in the UK, USA, Singapore, and China who completed an online survey. Using a novel methodology of text highlighting, where consumers were provided with information about VF (incl. some pros and cons), the majority of consumes in all countries indicated a positive sentiment to VF. There were smaller groups of consumers, in all countries, with neutral/ambivalent or negative VF sentiment. A multi-method approach was used and extended the attitudinal insights with opinions about what specific aspects of VF were more/less important for overall opinion. Future research is needed, with extensions to other countries and different information about VF being presented to consumers. An advantage of the text highlighting methodology was the ability to present participants with targeted information about VF and obtain their attitudinal reactions to specifics aspects of this food production system. This deepened consumer insights about specific features of VF that are positively and negatively perceived.

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CRediT authorship contribution statement

Gastón Ares: Conceptualization, Methodology, Formal analysis, Writing – original draft, Writing – review & editing. **Birgit Ha:** . **Sara R. Jaeger:** Conceptualization, Methodology, Writing – original draft, Writing – review & editing.

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.

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Appendix A. Supplementary material

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