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Investigating consumers' views on foods from soilless farming systems: A review of the literature and discussion of implications and recommendations

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ABSTRACT

Increasing consumer demand for sustainable, locally produced, and fresh vegetables has prompted the crop industry to adopt new soilless farming systems (SFSs) to supply higher-yield, fresher, and more sustainable foods. To address the anticipated increasing and complex consumer demand for SFSs foods, it is essential to better understand the factors affecting consumer preferences for these new products. The scope of this review is threefold: (i) to identify the main factors influencing consumers' views on SFSs foods (e.g., hydroponics, aquaponics, and vertical farming); (ii) to discuss implications and recommendations for food industries and policymakers; and (iii) to identify potential research gaps for future research avenues. Results from 56 consumer studies showed that consumers' views of SFSs and related foods were mainly affected by product characteristics, as well as socio-cultural and psychological factors. Specifically, sensory properties, sustainability, growing conditions of SFSs, income, education, consumer knowledge, technology neophobia, and technology affinity were most frequently identified factors. Food industry and policymakers should better educate consumers about the characteristics and advantages of SFSs, which might potentially enhance consumer purchase intention toward these new products. Finally, future research avenues are outlined and discussed.

1. Introduction

The world population is expected to reach 9.7 billion by 2050 (United Nations, 2019), which challenges sustainable agricultural production for future generations (OECD & FAO, 2017). To feed the world population, one-third of the global land area is being used for agricultural production (FAO, 2022). However, there are several negative externalities increasingly associated with conventional agriculture production techniques (e.g., soil-based crop products), such as high environmental degradation, food loss, and land use, leading to unsustainable production practices (Meynard, Dedieu, & Bram Bos, 2012; Smith et al., 2014). To increase agricultural productivity, reduce pressure on land use, and provide solutions for more sustainable agricultural practices, new agriculture production technologies, such as biotechnology (Mafakheri & Kordrostami, 2020) and controlled environment agriculture (CEA) (Engler & Krarti, 2021), have expanded over the last few decades (Engler & Krarti, 2021). Meanwhile, consumers are increasingly aware of the environmental impact caused by food production and are becoming more concerned about sustainability when purchasing food products (Asioli, Aschemann-Witzel, & Nayga, 2020). Therefore, there is a significant need for alternative food production systems that balance high-yield performance with a lower environmental impact (FAO, 2015).

Among the new agri-food production systems, soilless farming systems (SFSs)—including the well-established hydroponics, aquaponics, aeroponics (Arumugam, Sandeep, & Maheswari, 2021; Engle, 2016) and the more recent vertical farming (VF) (SharathKumar, Heuvelink, & Marcelis, 2020) —are among the largely used technologies. Specifically, in hydroponics farming, plants are grown in a soilless, monitored, and controlled environment where roots are submerged in aqueous nutrient solutions with inert substrates, notably reducing water usage (Arumugam et al., 2021; Kannan, Elavarasan, Balamurugan, Dhanusiya,

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& Freedon, 2022). Aquaponics farming allows plants to grow hydroponically alongside fish within the same recirculating ecosystem, in which plants are supplied with nutrient-dense aquaculture water (Arumugam et al., 2021; Yep & Zheng, 2019). Another system that allows plants to grow in a soilless, monitored, and controlled environment is aeroponic farming, where roots are suspended in the air and misted with nutrient-dense water (Eldridge et al., 2020; Kumari & Kumar, 2019). In VF,[1] a novel, multilayer indoor plant production system is applied: "all growth factors, such as light, temperature, humidity, carbon dioxide (CO2) concentration, water, and nutrients, are precisely controlled to produce high quantities of high-quality fresh produce year-round, completely independent of solar light and other outdoor conditions" (SharathKumar et al., 2020). SFSs have been gradually expanding because of their high food productivity coupled with reduced land use (Birkby, 2016; Gonnella & Renna, 2021; Mok, Tan, & Chen, 2020). Indeed, the market for SFSs is expected to grow at a compound annual growth rate (CAGR) of 12.4 % from 2024 to 2030 for hydroponics (Grand view research, n.d.a), 9.6 % between 2024 and 2029 for aquaponics (Mordor Intelligence, n.d.), and 14 % between 2022 and 2028 for VF (Introspective market research, 2022).

Previous studies have identified several advantages of SFSs. Firstly, SFSs can significantly increase the crop yield compared to conventional soil farming due to the more efficient management of resources (Arumugam et al., 2021; Martin, Poulikidou, & Molin, 2019; Yep & Zheng, 2019) and optimal use of vertical space like VF (Banerjee & Adenaeuer, 2014). Secondly, SFSs reduce farmland usage by utilizing non-farmland areas or urban spaces such as rooftops and abandoned buildings (Arumugam et al., 2021; Gonnella & Renna, 2021; Yep & Zheng, 2019). Thirdly, the controlled environment of SFSs shields plants from unfavorable climate conditions and disruption caused by climate change, such as drought (Kannan et al., 2022). Fourthly, local and urban soilless farming contributes to a lower environmental impact by reducing carbon emissions from food transportation and decreasing the use of fossil fuels, water, and chemical pesticides on soil (Gonnella & Renna, 2021; Kannan et al., 2022; Yep & Zheng, 2019). These advantages, combined with the increasing consumer demand for sustainable food products (Li & Kallas, 2021), have prompted the industry to introduce several SFSs foods (e.g., leafy green vegetables, mushrooms, and tomatoes) that are currently available in various markets (Kalantari, Tahir, Joni, & Fatemi, 2018; Waiba, Sharma, Sharma, Chadha, & Kaur, 2020). In 2023, the global VF market was estimated at (USD) 6.92 billion and is expected to reach USD 24.95 billion by 2030 (Grand View Research, n.d.b). This is corroborated by the growing number of new startup businesses and companies (e.g., Planet Farms, PlantLab, and AeroFarm) that are investing significant financial resources in developing VF-grown products (Kalantari et al., 2018). Nevertheless, several drawbacks of SFSs have been identified, such as high investment costs, the necessity of preparing buildings for production, and high energy costs (Arumugam et al., 2021; Benis & Ferrão, 2018; Lubna, Lewus, Shelford, & Both, 2022).

Despite an increasing number of research investigating consumer views on SFS products, there is a lack of clarity regarding the factors affecting consumers' behavior, perceptions, acceptance, and preferences for SFSs foods. Recently, Csordás and Füzesi (2023) conducted a review on consumer acceptance of VF and found that their preferences are shaped by prior knowledge of VF technology and the sustainability of the production method. However, a broader understanding of the factors affecting consumer demand for SFSs foods, including different types of SFSs (i.e., hydroponics, aquaponics, and VF) is lacking. Exploring this topic can support and guide soilless farming practitioners in developing and marketing new foods and support policymakers in better understanding how to inform and educate consumers more efficiently.

To fill this void, the current review aims to (i) identify the main factors that influence consumer behavior, perception, acceptance, and preference for products cultivated from SFSs (i.e., hydroponics, aquaponics, and VF); (ii) discuss implications and recommendations for food industries and policymakers; and (iii) identify potential research gaps for future research avenues. It is important to note that VF and aquaponic farming techniques that use traditional soil to grow plants are not the focus of this study.

2. Methodology

A literature search was conducted in the following five online bibliographic databases: Web of Science, Scopus, Science Direct, AgEcon Search, and EconPapers. The following keywords and combinations of keywords were searched in titles, abstracts, keywords, or topic fields: ("vertical* farm*" OR "VF" OR "plant factory with artificial light*" OR "PFAL" OR "control* environment agricultur*" OR "CEA" OR "soilless*" OR "hydroponic*" OR "Nutrient Film Technique"[2] OR "NFT" OR "drip*"[3] OR "wick*"[4] OR "ebb*flow*"[5] OR "DWC" OR "deep water cultur*"[6] OR "aquaponic*" OR "aeroponic*" OR "fogponic*"[7]) AND ("consumer*") AND ("prefer*" OR "accept*" OR "attitud*" OR "percept*" OR "choice" OR "behavior*" OR "purchas*" OR "willing* to pay" OR "willing* to buy"). Specifically, keywords about SFSs and related variations of these terms (e.g., PFAL, CEA, and wick system) were included in the literature search. To construct and broaden the searched terms, Boolean operators (i.e., AND, OR) and wildcards were also used to ensure comprehensive coverage of the topic. Moreover, we reviewed relevant references for the included articles. No restrictions on publication date were set on the search, which included all published papers up to February 2024. The review was restricted to English-language and peer-reviewed articles investigating consumer behavior, perception, acceptance, willingness to pay (WTP), willingness to buy (WTB), and preferences for SFSs foods. Specifically, the included studies mainly targeted four types of SFSs: hydroponics, aquaponics, aeroponics, and VF.

Using the PRISMA method (Page et al., 2021), a total of 1465 articles were obtained from the first step of the search: 892 articles from Web of

[1] VF can be categorized into four different system structures (Butturini & Marcelis, 2020; Lloyd, 2018): (i) building-based vertical farm—plants are grown in an industrial building; (ii) in-store farm—plants are grown at the point of purchase or consumption (e.g., supermarket and restaurants); (iii) appliance farm—plants are grown at home or office room where the environment can be controlled by electronic devices (e.g., smartphones); and, (iv) deep farm—-plants are grown at refurbished underground tunnels or mine shafts where environmental conditions, such as temperature and humidity, can be kept constant and temperate (Lloyd, 2018). Compared to the small unit of VF (e.g., growing plants in-store and at home) a plant factory system with artificial lighting (PFAL) is often referred to as VF when large-scale plants are grown in abandoned industrial buildings (Gonnella & Renna, 2021; Jaeger, 2024).

[2] Nutrient film technique is a closed hydroponic system that allows plant to be placed and grown in a recycled and recirculated nutrient solution water channels (Arumugam et al., 2021).

[3] Drip hydroponic system is a two-layer system where the upper container grows plants and the lower container pumps a nutrient solution to the upper plants (Arumugam et al., 2021).

[4] Wick system is a hydroponic system that allows plants to absorb a nutrient solution from the roots without using a recycling system (Arumugam et al., 2021).

[5] Ebb and flow system is similar to drip hydroponic, consisting of two-layer containers, but the nutrient solution is flooded to the plant roots instead of using a water pump (Arumugam et al., 2021).

[6] Deep water culture is a hydroponic system that allows plants to grow on a floating or hanging support in a nutrient-rich container (Arumugam et al., 2021).

[7] Fogponics is an advanced version of aeroponics that allows plants to grow by suspended in air, with a nutrient solution ultrasonically transformed into a fog (Uddin & Suliaman, 2021).

Science, 480 articles from Scopus, 61 articles from Science Direct, 25 articles from AgEcon Search, and seven articles from EconPapers (Fig. 1). After subtracting duplicates, 1070 articles were left for further screening. Subsequently, the titles and abstracts were examined, this left 112 articles for in-depth review. Finally, sensory panel studies, non-consumer studies on SFSs, and studies that did not investigate influencing factors for consumer valuation of SFSs and related products were excluded, leaving 56 articles. The review and assessment of the included studies were completed by two authors. Disagreements were resolved through discussions between the authors. A full list of the included articles in this review is presented in Appendix A (Table A1).

Regarding the publication year, articles about consumer research on SFSs and related products were initially published in 1999. Most of the included articles were published over the last few years (2019–2023) (see Fig. 2).

In terms of geographical coverage, most of the studies were conducted in Western countries, such as North America (17 articles) and Europe (16 articles), followed by Asia (nine articles), South America (three articles), and Africa (one article). In addition, 10 studies were performed across continents. Regarding consumer research methods, most studies applied quantitative methods (24 articles), including surveys conducted online, face-to-face, or by telephone (21 articles), experimental auctions (two articles), and choice experiments (one article). Thirteen studies applied sensory testing, and 16 studies used mixed methods approaches (e.g., using both qualitative and quantitative techniques). Only three studies applied a qualitative method (i.e., in-depth interview and online qualitative study). Regarding the type of SFSs investigated, most studies focused on hydroponics (22 articles) and VF (19 articles), while fewer studies (9 articles) explored aquaponics. One study did not specify the type of SFS. The remaining studies (5 articles) included multiple types of SFSs (i.e., hydroponics, aquaponics, VF, and aeroponics). No consumer studies on fogponics were found. In terms of SFSs foods, most studies investigated vegetables (30 articles), with lettuce most frequently investigated, followed by tomatoes, basils, broccoli microgreens, carrots, and other salad greens. Several studies (14 articles) investigated a variety of food types, such as vegetables, crops, fruits, and fish. One study investigated hydroponic fruit (i.e., melon) while another mainly explored consumer valuation of aquaponic fish, which is one of two streams of aquaponic products (i.e. aquaponic vegetables and fish). The remaining studies (10 articles) did not specify the type of food products. The sample size of the included studies ranged from 18 to 2637.

Factors influencing consumer behavior, perception, acceptance, and preference for SFSs foods were identified and summarized in this review. Specifically, Mojet's model (Köster, 2009; Fig. 3) was applied to conceptualize, identify, and categorize the influencing factors and subfactors. This framework has been used to synthesize literature findings and describe drivers of consumer food choices for clean labels (Asioli et al., 2017a), and eggs (Rondoni, Asioli, & Millan, 2020).

3. Results

This section provides an overview of factors and subfactors influencing consumer behavior, perception, acceptance, and preference for SFSs foods through a review of the 56 articles introduced in the methodology section. Following Mojet's model (Köster, 2009), six categories of factors—product-related (intrinsic and extrinsic), sociocultural, psychological, situational, biological, and physiological factors—were identified as affecting consumers' views on SFSs foods (Fig. 4). However, it is important to acknowledge that the divisions between various factors may be blurred.

3.1. Product-related factors

Product-related factors consist of intrinsic[8] and extrinsic[9] product characteristics.

3.1.1. Intrinsic product characteristics

Five subfactors were identified as affecting consumer behavior, perception, acceptance, and preference for SFSs foods: *sensory properties*, *product safety and cleanliness*, *product type*, *nutrients*, and *product quality*.

Sensory properties are key drivers of consumer evaluations of SFSs foods. To illustrate, Padilla, Oberti, Boileau, Jabri, and Tekelioglu (2007) observed that consumers in Turkey were willing to buy hydroponic tomatoes, provided the sensory properties met their expectations. *Sweetness* or *reduced bitterness* were found to have a positive effect on consumer acceptance of VF vegetables in Denmark (Jaeger, Chheang, Roigard, & Frøst, 2023) and WTB hydroponic lettuces in the US (Holmes, Wells, Pickens, & Kemble, 2019), respectively. While some studies highlighted the significant role of taste in SFSs foods, they mainly focused on consumers' general sensory impressions of taste (Ercilla-Montserrat et al., 2019; Greenfeld, Becker, Bornman, dos Santos, & Angel, 2020; Padilla et al., 2007; Suarez-Caceres, Fernandez-Cabanas, Lobillo-Eguibar, & Pérez-Urrestarazu, 2021; Tan et al., 2020; Yano, Nakamura, Ishitsuka, & Maruyama, 2021). *Appearance*, *flavor,* and *texture* were other factors affecting consumer acceptance and purchase of hydroponic vegetables in China (Su, Wang, & Ow, 2020), Spain (Ercilla-Montserrat et al., 2019) and the US (Holmes et al., 2019; Tan et al., 2020; Xia, Mattson, Stelick, & Dando, 2022); consumer WTP for aquaponic products in the US (Short et al., 2018); and consumer attitude toward VF vegetables in Denmark, Germany, and the UK (Jaeger, Chheang, Roigard, & Frøst, 2023). For instance, de Souza et al. (2021) observed that the lighter *color* of hydroponic kale compared to soil-grown kale might decrease Brazilian consumers' purchase intention. It is noteworthy that concerns about *flavor* and *color* could be potential barriers to consumer preference for SFSs foods in Germany, the UK, and the US (Caputo, Rumble, & Schaefer, 2020; Jaeger, Chheang, Roigard, & Frøst, 2023; Short, Yue, Anderson, Russell, & Phelps, 2017). Although Caputo et al. (2020) applied a qualitative approach by interviewing British consumers, the results of consumer concerns about the SFSs foods flavor was supported by a quantitative consumer survey in the UK conducted by Jaeger, Chheang, Roigard, and Frøst (2023).

Food safety and *cleanliness* (including being free of pesticides) as another intrinsic subfactor positively affected consumer acceptance and WTB VF products in multiple countries (Ares, Chheang, & Jaeger, 2023; Ares, Ryan, & Jaeger, 2023; Huang, 2019; Jaeger, Chheang, & Ares, 2022; Jaeger, Chheang, & Ares, 2023; Jaeger, Chheang, & Bredahl, 2023; Wang, Onychko, Zubko, Wu, & Zhao, 2023; Yano et al., 2021). A qualitative study by Broad, Marschall, and Ezzeddine (2022) with a sample size of 45 US consumers, had results consistent with the quantitative results by Ares, Ryan, and Jaeger (2023). Similarly, if food was perceived as *safe*, *clean,* and *free of pesticides and pollution*, consumers were willing to eat and pay a premium price for aquaponic products in European and Latin countries (Miličić, Thorarinsdottir, Santos, & Hančič, 2017; Suarez-Caceres et al., 2021). However, concerns about *product safety* and *cleanliness* negatively affected consumer attitude VF vegetables (Caputo et al., 2020; Yano et al., 2021) and decreased

[8] Intrinsic product characteristics are food properties that cannot be changed or manipulated without changing the physical characteristics of a product, such as sensory properties and nutritional content (Asioli et al., 2017b; Olson & Jacoby, 1972).

[9] Extrinsic product characteristics are food properties that can be changed without changing the physical characteristics of a food product, such as brand and price (Asioli et al., 2017b; Olson & Jacoby, 1972).

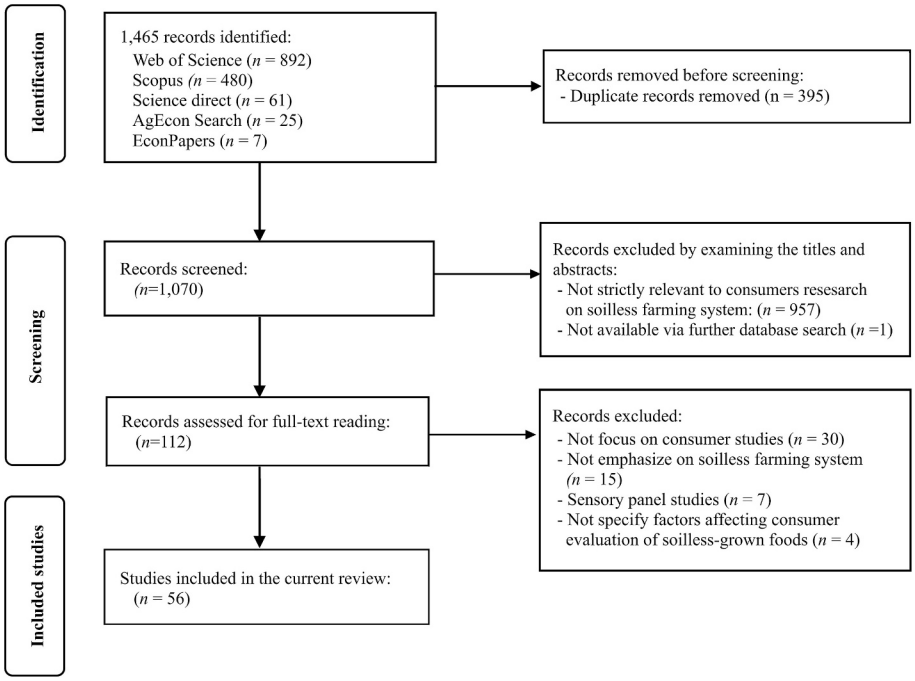

Fig. 1. PRISMA flow diagram for studies screening.

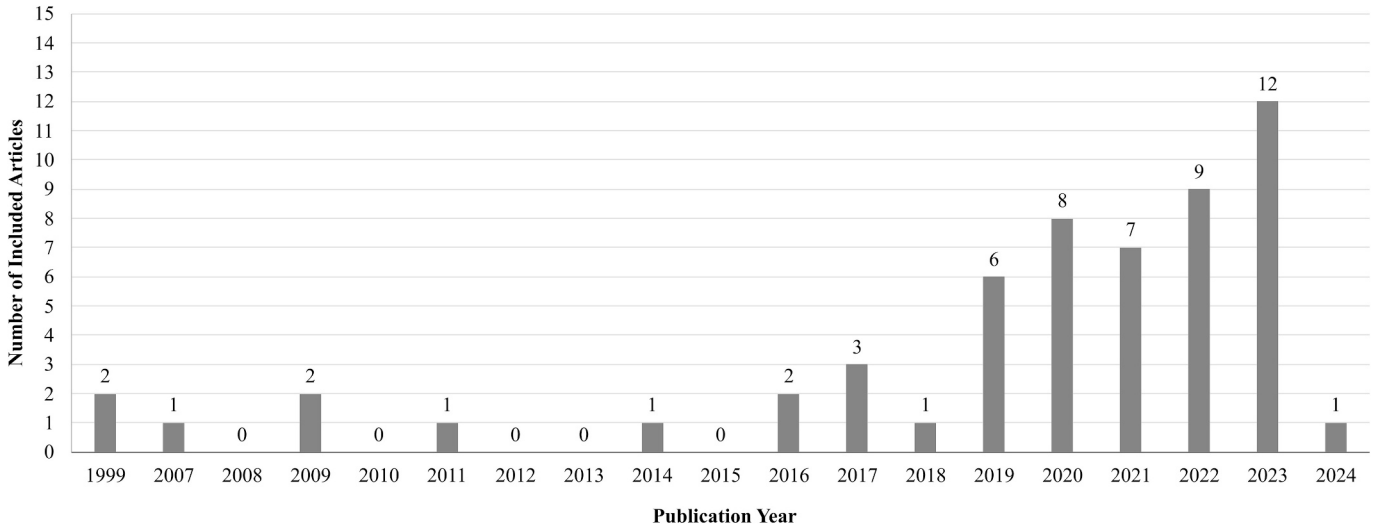

Fig. 2. Number of published articles related to consumer research on SFSs and related products since 1999.

consumers' WTB aquaponic products in the US (Short et al., 2017) and hydroponic products in the UK (Caputo et al., 2020). It is important to note that Caputo et al. (2020) adopted a qualitative interview design, which restricted the sample from being representative of the broader consumer population in the UK.

Consumer preferences for SFSs foods also depend on *product type*, such as food type and cultivar (Gichuhi, Mortley, Bromfield, & Bovell-Benjamin, 2009; Short et al., 2018; Sinesio et al., 2021; Yue et al., 2020; Zhou, Specht, & Kirby, 2022). For instance, Chinese consumers preferred to buy VF vegetables (e.g., spinach) and fruits (e.g., strawberries; Zhou et al., 2022) compared to other types of VF products (e.g., beans and fish). Moreover, US consumers assigned a higher value to aquaponically grown lettuces of their preferred cultivar type (Short et al., 2018).

Although Ares, Chheang, and Jaeger (2023), Jaeger, Chheang, and Ares (2023), and Wang et al. (2023) observed that *nutrients* could influence consumers' purchase of VF foods in Australia, China, Germany, Singapore, and the US, concerns about the nutrient properties of SFSs foods negatively affected Russian consumers' attitude toward VF vegetables (Yano et al., 2021) and US consumers' WTB aquaponic products (Short et al., 2017).

Furthermore, good *product quality* was found to positively affect consumer attitude toward VF products in Russia (Yano et al., 2021), consumers' WTB (Wang et al., 2023) and WTP (Zhou et al., 2022) regarding VF products in China, consumers' WTP for hydroponic products in Spain (Ercilla-Montserrat et al., 2019), and consumers' willingness to eat aquaponic products in Spanish-speaking countries (Suarez-Caceres et al., 2021).

3.1.2. *Extrinsic product characteristics*

Extrinsic product characteristics, including *sustainability*, *growing conditions, price, origin, fresh supply, naturalness, fish welfare, brand,* and

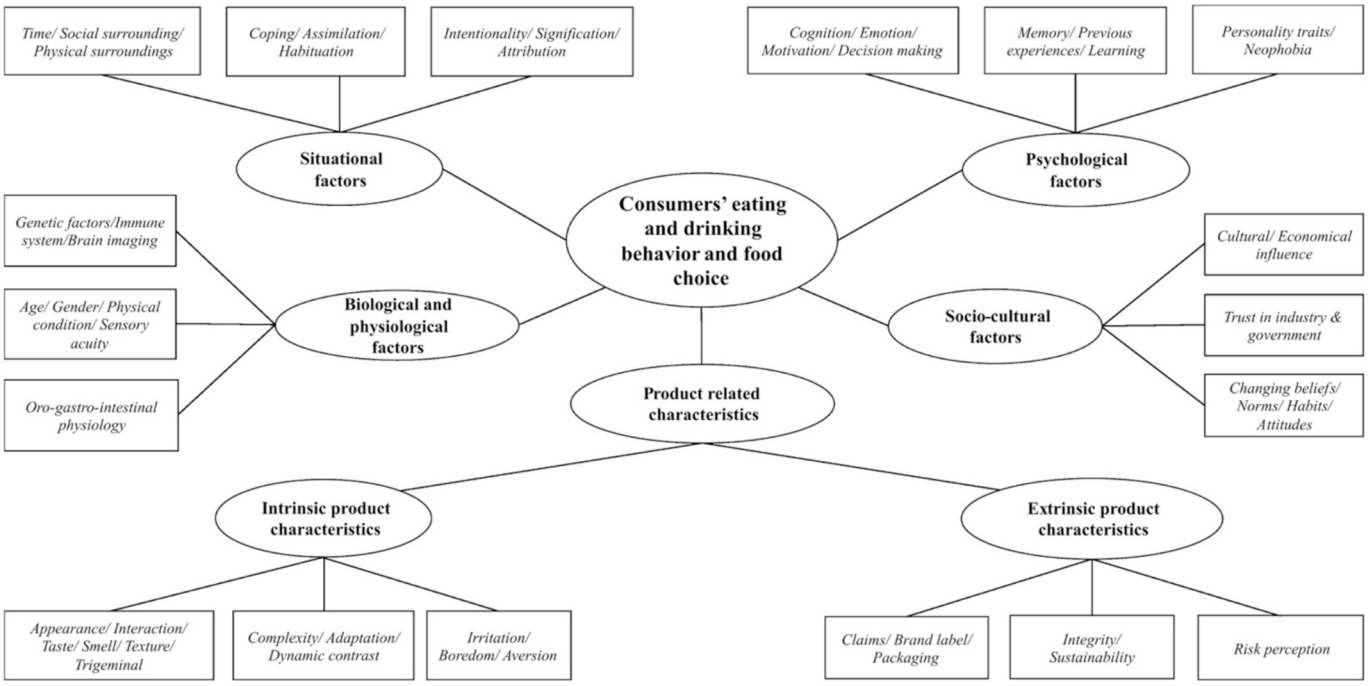

Fig. 3. Essential factors that influence eating, drinking behavior, and food consumer choice (adapted from Köster, 2009).

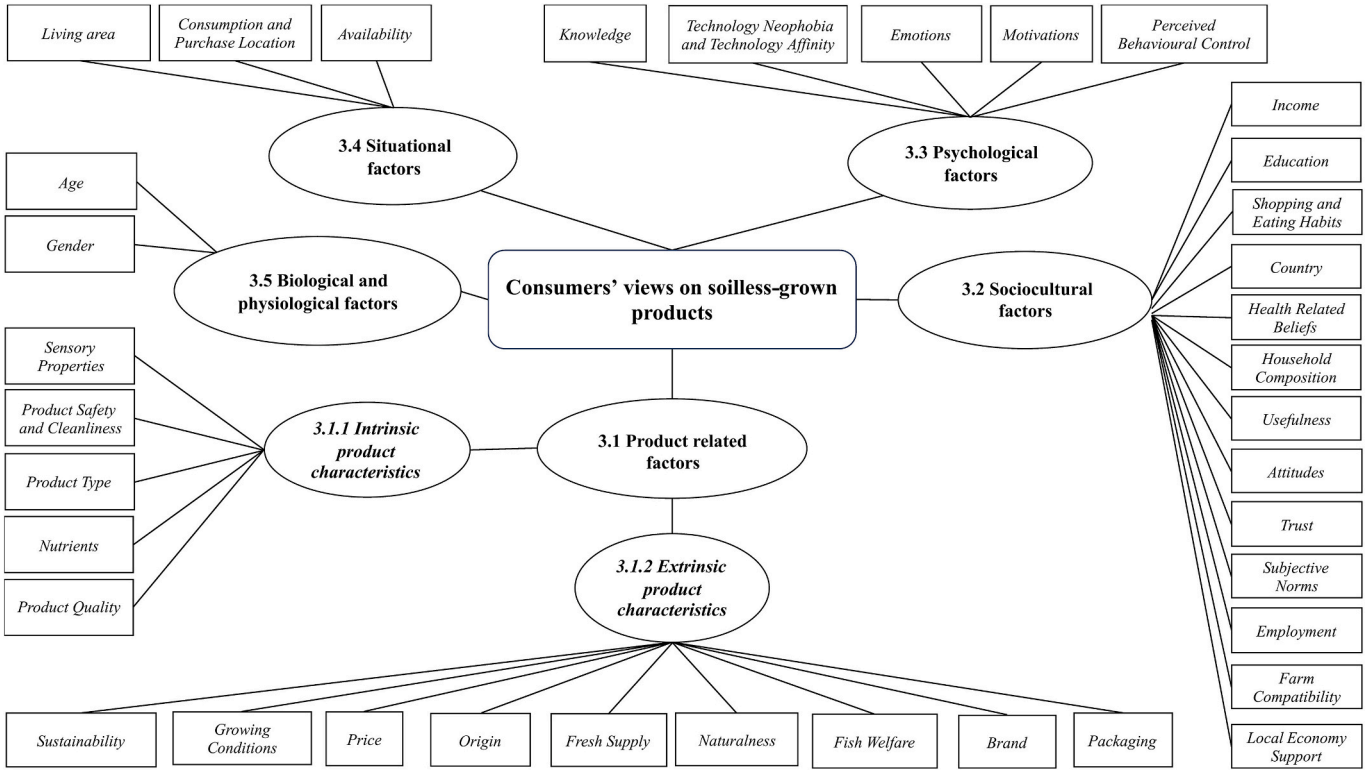

Fig. 4. Essential factors and subfactors affecting consumers' views on SFSs foods.

packaging were found to affect consumer behavior, perception, acceptance, and preference for SFSs foods.

Regarding the *sustainability* of SFSs foods, VF was more frequently investigated than hydroponics or aquaponics farming. Several studies found that consumers were positive toward VF (Ares, Chheang, & Jaeger, 2023; Ares, Ha, & Jaeger, 2021; Ares, Ryan, & Jaeger, 2023; Giacalone & Jaeger, 2023; Jaeger, Chheang, & Ares, 2023; Jaeger, Chheang, & Bredahl, 2023; Wang et al., 2023), hydroponic (Ercilla-Montserrat et al., 2019; Padilla et al., 2007), and aquaponic (Giacalone & Jaeger, 2023; Greenfeld et al., 2020; Miličić et al., 2017; Schröter & Mergenthaler, 2019) techniques due to their sustainability (e.g., lower carbon emissions and reduced use of farmland). Conversely, some consumers expressed concerns about the sustainability of SFSs (Broad et al., 2022; Huang, 2019; Padilla et al., 2007; Perambalam et al., 2021).

Specifically, these examples include climate burden (Huang, 2019; Jaeger et al., 2022), energy cost (Ares et al., 2021; Broad et al., 2022; Huang, 2019; Jaeger, Chheang, & Bredahl, 2023), the loss of rural towns (Jaeger, Chheang, & Ares, 2023), and unnatural growth method e.g., use of artificial lights (Broad et al., 2022; Perambalam et al., 2021). Consumers' conflicting perspectives regarding the sustainability of SFSs can also be found in the study by Broad et al. (2022). However, the US sample was not generalized to a broader sample as Broad et al. (2022) used a qualitative design. Notably, consumers' sustainability views on VF products varied across the included studies, which might be affected by their perceptions of different sustainability dimensions. Furthermore, consumers with higher environmental awareness in Austria (Eichhorn & Meixner, 2020), who were members of environmental organizations in Australia (Greenfeld et al., 2020), and who believed in climate change in Sweden (Spendrup, Bergstrand, Thörning, & Hultberg, 2024) were more accepting of aquaponic and hydroponic products than their counterparts. Conversely, US consumers who were members of environmental groups were less willing to pay for aquaponic products compared to those who were not members of environmental groups (Short et al., 2018). The quantitative study by Short et al. (2018) only included 90 consumers, and 88 % of sample were not members of environmental groups. The unbalanced sampling and the unclear environmental benefits of aquaponics for consumers may have contributed to the differing results compared to those of Greenfeld et al. (2020).

The *growing conditions* of SFSs, such as temperature, light color, height, nutrient solution, and farming type could affect consumer sensory preferences (Auerswald, Schwarz, Kornelson, Krumbein, & Brückner, 1999; Su et al., 2020; Walters & Lopez, 2022; Walters, Lopez, & Behe, 2021; Xia et al., 2022; Yam, Fan, Lin, Fan, & Lo, 2020; Yue et al., 2020), attitude (Ares, Ryan, & Jaeger, 2023; Ercilla-Montserrat et al., 2019; Spendrup et al., 2024), and purchase behavior regarding SFSs foods (Jürkenbeck, Heumann, & Spiller, 2019; Short et al., 2017; Su et al., 2020). For instance, Xia et al. (2022) observed that the increased NaCl (sodium chloride) concentration in the nutrient solution significantly decreased consumer liking of hydroponic salad greens in a sensory test. Spendrup et al. (2024) found that Swedish consumers were more positive toward hydroponics farming using food waste as fertilizers than those using mineral fertilizers as nutrient solutions. In Germany, Jürkenbeck et al. (2019) found that a greater number of consumers preferred to purchase VF products grown in in-store and building-based farms compared to those grown in appliance farms within a home environment. However, different growing conditions seemed to not always influence consumer preference for SFSs foods (Walters & Lopez, 2022; Yano, Maruyama, Lu, & Takagaki, 2023). For instance, presenting pictures of VF using different LED light colors did not significantly affect consumers' liking of the related products (Yano et al., 2023). Thus, consumer evaluations of SFSs foods might depend significantly on the specific growing conditions.

Price is another important extrinsic factor affecting consumer valuation for SFSs foods (Ares et al., 2021; Caputo et al., 2020; Coyle & Ellison, 2017; Greenfeld et al., 2020; Huang, Kan, & Fu, 1999; Jaeger et al., 2022; Jaeger, Chheang, & Ares, 2023; Jaeger, Chheang, & Bredahl, 2023; Short et al., 2017; Suarez-Caceres et al., 2021). Concerns about high production costs and high product prices negatively affected consumers' WTB hydroponic products (Caputo et al., 2020), consumers' consumption and WTB aquaponic products (Greenfeld et al., 2020; Short et al., 2017), and consumers' WTP and attitude toward VF products in several countries (Ares et al., 2021; Coyle & Ellison, 2017; Jaeger et al., 2022; Jaeger, Chheang, & Ares, 2023). While Caputo et al. (2020) collected data by qualitative interviews, the negative effect of price on consumers' purchasing of SFSs foods is supported by other quantitative results (Ares et al., 2021; Jaeger et al., 2022). If the prices of aquaponic and conventional soil-grown products are similar, Latin American and Spanish consumers were more willing to buy aquaponic products than conventional soil-grown products (Suarez-Caceres et al., 2021). Additionally, consumers in China were more willing to pay a premium price for hydroponic products if they did not consider price an important factor in food purchases (Huang et al., 1999).

Origin is another important factor influencing consumer preferences for SFSs foods from hydroponics, aquaponics, and VF (Broad et al., 2022; Caputo et al., 2020; Chen, Tong, Tan, & Kong, 2020; Ercilla-Montserrat et al., 2019; Jaeger, Chheang, & Bredahl, 2023; Miličić et al., 2017; Tan et al., 2020). In most cases (including two qualitative studies), consumers had positive attitude toward locally produced SFSs foods (Chen et al., 2020; Ercilla-Montserrat et al., 2019; Miličić et al., 2017; Tan et al., 2020).

Fresh supply positively affected consumers' attitude (Ares et al., 2021; Ares & Jaeger, 2022; Broad et al., 2022; Jaeger et al., 2022) and WTB (Wang et al., 2023) regarding SFSs products in many countries in Asia, Europe, and North America. It is not surprising that non-fresh hydroponic vegetables (i.e., after longtime storage) negatively affected Italian consumers' acceptance of hydroponic vegetables compared to soil-grown vegetables (Manzocco et al., 2011).

Naturalness was recognized as another factor affecting consumer responses to SFSs products (Broad et al., 2022; Caputo et al., 2020; Macht, Klink-Lehmann, & Hartmann, 2023; Schröter & Mergenthaler, 2019; Son & Hwang, 2023; Yano et al., 2021). For instance, Schröter and Mergenthaler (2019) found that consumers preferred aquaponics farming when they were exposed to visual information about aquaponics farming that valued naturalness compared to being exposed to visual information about aquaponics farming that exhibited a more technological concept. Some studies observed that European consumers expressed negative perceptions of *fish welfare* for aquaponics farming (Macht et al., 2023; Miličić et al., 2017). Besides, the *brand* of VF products affected Chinese consumers' preferences for VF products (Huang, 2019). For example, Huang (2019) revealed that consumers were willing to pay a premium price for VF products if the brand represented an academic institute or private corporation. Moreover, Son and Hwang (2023) discovered a significant interaction effect between *packaging* design and growing conditions on US consumer preference. Specifically, when packaging was designed using an image of lettuce, consumers' purchase intention for VF lettuce was lower compared to soil-grown lettuce. However, when products were packaged with an image of a male farmer, consumers' purchase intention for VF lettuce increased, becoming comparable to their purchase intention for soil-grown lettuce.

3.2. Socio-cultural factors

Numerous sociocultural factors, including *income*, *education*, *shopping and eating habits*, *country*, *health-related beliefs*, *household composition*, *usefulness, attitudes*, *trust*, *subjective norm, employment*, *farm compatibility, and local economy support* were found to influence consumer behavior, perception, acceptance, and preference for SFSs foods.

The effect of *income* on consumers' views on SFSs foods remains ambiguous. Specifically, high-income consumers were willing to pay more for hydroponic tomatoes (Ercilla-Montserrat et al., 2019; Narine, Ganpat, & Ali, 2014), expressed more interest in learning about aquaponics (Short et al., 2017), and had higher willingness to eat and WTP for aquaponic products (Greenfeld et al., 2020; Short et al., 2018; Suarez-Caceres et al., 2021) than low-income consumers in multiple countries such as Australia, Israel, Spain, the US, and countries in South America. Consistently, several studies observed that high-income consumers had higher acceptance and WTP for VF products than low-income consumers in Australia, the US, and many countries in Asia and Europe (Huang, 2019; Wang et al., 2023; Yano et al., 2021). Miličić et al. (2017) found that income did not significantly affect consumer attitude toward aquaponic products in many European countries; however, the study treated its entire European sample as one target group, without taking into account the context of country-specific incomes. Although Zhou et al. (2022) found that Chinese consumers' income was negatively correlated with their acceptance of VF, a weak relationship (*r*

= −0.113) was found and its significance was unknown. Overall, we found that high-income consumers' evaluation of SFSs foods was more positive than that of low-income consumers in most included studies.

High *educational* level positively influenced consumer eating frequency and WTP for hydroponic products (Huang et al., 1999; Narine et al., 2014; Nekesa, Njue, & Abong, 2023); consumer consumption, acceptance, and WTP for aquaponic products (Giacalone & Jaeger, 2023; Greenfeld et al., 2020; Short et al., 2018; Suarez-Caceres et al., 2021); and consumer acceptance of VF products (Ares et al., 2021; Wang et al., 2023) in various countries. Ercilla-Montserrat et al. (2019) observed that Spanish consumers who assigned a higher value to hydroponic tomatoes were mainly those with a high school education. However, a cluster analysis showed that consumers with a university education were more willing to pay a premium price for hydroponic tomatoes compared to other consumers.

In terms of *shopping habits*, consumers who preferred to purchase organic, local, fresh, environmentally friendly, or sustainable food products were more likely to accept and buy SFSs foods (Eichhorn & Meixner, 2020; Jaeger et al., 2022; Miličić et al., 2017; Short et al., 2018; Zhou et al., 2022). Various aspects of *eating habits* were found to affect consumer behavior and acceptance of SFSs foods (Giacalone & Jaeger, 2023; Greenfeld et al., 2020; Huang, 2019; Huang et al., 1999; Suarez-Caceres et al., 2021). For instance, Chinese consumers who dine out less were more willing to pay a premium price for hydroponic vegetables compared to those who frequently dine out (Huang et al., 1999). Flexitarian consumers and those with diverse dietary habits showed higher acceptance of aquaponics farming (Giacalone & Jaeger, 2023) and were more likely to pay a premium price for aquaponic products (Suarez-Caceres et al., 2021), respectively, compared to their counterparts. Furthermore, consumers with a high consumption of organic food were more likely to consume aquaponic products in Australia and Israel (Greenfeld et al., 2020) and showed higher WTP for VF vegetables (Huang, 2019) compared to their counterparts.

Consumer attitude and purchase intentions toward VF products were found to vary across different *countries* (Ares et al., 2021; Ares, Chheang, & Jaeger, 2023; Ares & Jaeger, 2022; Jaeger, Chheang, & Ares, 2023; Jaeger, Chheang, & Bredahl, 2023). For instance, Ares, Chheang, and Jaeger (2023) observed that German consumers were less likely to purchase VF lettuce while Singaporean consumers were more likely to purchase the same product when compared to Australian consumers. Regarding hydroponic products, Padilla et al. (2007) found that many French and German consumers considered the taste and quality of hydroponic tomatoes was not as good as that of soil-grown tomatoes, while Turkish consumers showed a positive attitude and high WTB hydroponic tomatoes if the products met their sensory expectations. Furthermore, Giacalone and Jaeger (2023) observed that consumers in Eastern countries showed high willingness to eat VF vegetables and aquaponic fish compared to those in Western countries. In summary, consumers in Eastern countries expressed more positive views on SFSs and related products compared to Western consumers in most of the studies (Ares et al., 2021; Ares, Chheang, & Jaeger, 2023; Giacalone & Jaeger, 2023).

Health-related beliefs also affected consumer valuation of SFSs foods. For instance, consumers' evaluations and purchase intentions of VF foods (Giacalone & Jaeger, 2023; Son & Hwang, 2023; Wang et al., 2023) and their willingness to eat aquaponic products (Greenfeld et al., 2020) were positively associated with their assessments of product healthiness in multiple countries. The belief that SFSs foods are unhealthy negatively affected consumer attitude toward hydroponic products in France and Germany, and consumers' WTP for VF products in the Republic of Trinidad and Tobago (Narine et al., 2014). Consumers' conflicting health-related beliefs regarding SFSs foods might be influenced by the message content presented when SFSs were introduced in various studies.

Consumer *household composition* was another factor affecting consumer consumption, acceptance, and preference for SFSs foods. Specifically, Ares, Chheang, and Jaeger (2023) found that consumers with small children showed higher purchase likelihood for VF vegetables in Australia, Germany, Singapore, and the US. Consistently, in China, these consumers were more willing to pay a premium price for hydroponic vegetables than their counterparts (Huang, 2019). In contrast, Short et al. (2018) observed that single US consumers without young children were willing to pay more for aquaponic products. However, 92 % of the consumers in Short et al. (2018) reported that they did not have young children, which might weaken the effect of household composition on consumers' WTP for aquaponic products. Moreover, household size was positively correlated with consumers' consumption of aquaponic products in Australia and Israel (Greenfeld et al., 2020). In most cases, consumers who had children and a large household size were willing to buy and pay a premium price for SFSs foods.

Subjective norms (i.e., friends, family, and/or colleagues supporting the purchase of VF-grown products) improved German consumers' perception of the *usefulness* of VF and consumers' attitude toward buying VF products, which further increased their purchase intentions toward VF products (Jürkenbeck et al., 2019). Similarly, usefulness positively affected Chinese consumers' acceptance of hydroponic products (Al Mamun, Naznen, Jingzu, & Yang, 2023; Wu & Kuo, 2016). Additionally, consumer *attitude* toward the purchase of VF products were found to be positively related to their sustainability perception and intentions to buy (Jürkenbeck et al., 2019) in Germany. However, a lack of interest in VF negatively affected Chinese consumers' acceptance of VF (Zhou et al., 2022). Moreover, Al Mamun et al. (2023) demonstrated that Chinese consumers' attitude toward diversity (e.g., openness to various sociocultural aspects such as beliefs and traditions) positively affected their acceptance of hydroponics farming.

Concerning *trust*, several studies identified its significant effect on consumer acceptance of SFSs foods in Asia and Europe (Miličić et al., 2017; Wu & Kuo, 2016; Yano et al., 2023). For instance, Wu and Kuo (2016) illustrated that Chinese consumers who trusted the quality of hydroponic vegetables perceived the use of LED light for hydroponic production as more useful. Miličić et al. (2017) found that European consumers who *distrusted* the benefits of aquaponic production had negative perceptions of the related products (Miličić et al., 2017).

Regarding *employment*, consumers with full-time employment in China and Singapore and those who worked in research institutions, universities, and government in China held more positive views and higher purchase intention for VF products (Ares et al., 2021; Wang et al., 2023) than others. Moreover, the *compatibility* (i.e., the alignment of innovation with potential users' value, needs, and prior experience) of hydroponics farming (Al Mamun et al., 2023) and the perceived benefits of aquaponics farming for *local economy support* (Macht et al., 2023) positively affected consumer acceptance in China and Germany, respectively.

3.3. Psychological factors

Psychological factors were found to affect consumer behavior, perception, and preference SFSs foods, including *knowledge, technology neophobia* and *technology affinity, emotions, motivations*, and *perceived behavioral control.*

Many studies identified that *knowledge* is an important factor influencing consumer responses to SFSs foods, but we found ambiguous results. Consumers who had knowledge of or had ever heard of SFSs held positive attitude toward foods produced from hydroponics (Al Mamun et al., 2023; Ercilla-Montserrat et al., 2019; Nekesa et al., 2023), aquaponics (Greenfeld et al., 2020; Macht et al., 2023; Short et al., 2017; Suarez-Caceres et al., 2021), and VF (Ares et al., 2021; Jaeger et al., 2022). In contrast, Spendrup et al. (2024) found that Swedish consumers who had no previous knowledge about hydroponics farming were more positive toward it than those with knowledge. Additionally, German consumers' subjective (self-reported) knowledge of VF positively influenced the perceived sustainability of VF production from appliance farms (i.e., within a home environment), but negatively affected the

perceived sustainability of VF production from in-store farms (Jürkenbeck et al., 2019). However, Miličić et al. (2017) did not find the effect of knowledge about aquaponics on European consumers' attitude and WTP for aquaponic products. Overall, the effect of knowledge on consumer views on SFSs foods varied across studies, highly depending on the type of SFSs and specific context in which SFSs were introduced. Many studies have found that the provision of information about SFSs could affect consumer responses to SFSs foods (Ares, Chheang, & Jaeger, 2023; Broad et al., 2022; Caputo et al., 2020; Coyle & Ellison, 2017; Gilmour, Bazzani, Nayga Jr, & Snell, 2019; Jaeger et al., 2022; Jaeger & Ares, 2022; Jaeger, Chheang, & Ares, 2023; Kralik et al., 2022; Schröter & Mergenthaler, 2019; Son & Hwang, 2023; Vidal, Ares, & Jaeger, 2022; Yano et al., 2023). For instance, when basic information about VF was presented to British consumers, they liked the fresh supply but disliked the VF technology feature and growing plants indoors. However, when additional advantages and disadvantages of VF were introduced to consumers, they favored the high yield, low farmland use, and reduced carbon emissions of VF, but disliked its high energy costs and premium prices (Jaeger et al., 2022). Informing consumers about the benefits of SFSs potentially increased their WTP for hydroponic products (US; Gilmour et al., 2019), healthiness perception and purchase of aquaponic fish (US; Kralik et al., 2022;), and acceptance of VF products (Japan; Yano et al., 2023). However, when comparing the production information about SFSs to that of other farming systems (e.g., soil-based farming systems), consumers' evaluations of SFSs foods were similar (Chen et al., 2020; Coyle & Ellison, 2017; Gilmour et al., 2019; Short et al., 2018) or lower (Manzocco et al., 2011; Son & Hwang, 2023) to other farmed products.

Regarding *technology neophobia,* some consumers showed an aversion toward the adoption of technology (e.g. IT systems, automation, and robots) for VF (Ares, Chheang, & Jaeger, 2023; Ares, Ryan, & Jaeger, 2023; Jaeger et al., 2022; Specht, Weith, Swoboda, & Siebert, 2016; Yano et al., 2023; Zhou et al., 2022) and aquaponics (Schröter & Mergenthaler, 2019; Specht et al., 2016), probably because of the potential risks and errors caused by technology as well as concerns about potential negative impacts on the labor market (Ares, Ryan, & Jaeger, 2023), intensive production (Specht et al., 2016), and artificiality (Schröter & Mergenthaler, 2019; Zhou et al., 2022). In contrast, some consumers expressed positive attitude toward the technology employed by SFSs, such as the controlled environment for plant growth and the use of robots (Ares et al., 2021; Ares & Jaeger, 2022; Ares, Ryan, & Jaeger, 2023; Jaeger, Chheang, & Ares, 2023) and innovativeness (Al Mamun et al., 2023; Miličić et al., 2017). Indeed, several studies found that consumers with high *technology affinity* (i.e., their relationship with the technology; Jürkenbeck et al., 2019; Yano et al., 2023) or low *technology neophobia* (Giacalone & Jaeger, 2023; Jaeger et al., 2022) felt positively about VF. A lack of comprehensive understanding of the risks and benefits of SFSs might result in consumers' diverse views about the adoption of these technologies for food production.

In addition, negative *emotions* (e.g., lack of interest and disgust) was identified as negatively correlated with European consumers' attitude toward aquaponics farming (Macht et al., 2023; Miličić et al., 2017), while positive emotion (e.g., enjoyment of eating) was found to be associated with Singaporean consumers' acceptance of VF (Jaeger, Chheang, & Bredahl, 2023) and German consumers' acceptance of aquaponics farming (Macht et al., 2023). Other psychological factors, such as *motivation* (i.e., altruistic factors such as less land use and self-centered motivations such as health) (Jaeger, Chheang, & Bredahl, 2023) and *perceived behavioral control* (i.e., beliefs about one's ability to perform a behavior) (Jürkenbeck et al., 2019) were observed to positively affect consumer acceptance of VF and purchase intention of VF products grown at home.

3.4. Situational factors

Situational factors, including *living area*, *consumption and purchase location,* and *farm availability* were found to affect consumer behavior, perception, and preference for SFSs foods.

Studies revealed that consumers' *living area* affected their acceptance and WTP for SFSs foods. Specifically, consumers living in the central region of the Republic of Trinidad and Tobago were more likely to pay a premium price for hydroponic tomatoes compared to those living in the northern and southern regions (Narine et al., 2014). As many farming communities and farmers' residences are concentrated in central Trinidad, consumers who lived in the central region might have more knowledge about SFSs, which might increase their WTP for hydroponic tomatoes (Narine et al., 2014). Russian consumers living in federal districts, such as the central and Volga districts, were less likely to accept VF-grown vegetables compared to those living in other districts, probably because they had easier access to fresh leafy vegetables and lived close to productive land (Yano et al., 2021). Similarly, Suarez-Caceres et al. (2021) found that Spanish consumers living in rural areas had a higher WTP for aquaponic products than those living in urban areas. Overall, it appears that the effect of living area on consumer acceptance and WTP for SFSs foods depends on the accessibility of products. However, Macht et al. (2023) illustrated that German consumers in regions transitioning toward a sustainable bioeconomy had lower acceptance of local aquaponics farming compared to the general acceptance of aquaponics farming (not emphasizing the local attributes). The potential direct threat posed by locating industry close to consumers' residential areas might explain why local aquaponics farming was less accepted compared to general aquaponic farming among consumers in transitional regions.

In terms of *consumption and purchase location*, a short distance between vertical farms and food stores might increase consumer acceptance of VF (Zhou et al., 2022). Similarly, Ercilla-Montserrat et al. (2019) observed that Spanish consumers preferred to eat hydroponic tomatoes at home rather than in a restaurant, and they preferred to buy them in a shop rather than at the production point. Regarding the location of consuming novel and interesting hydroponic vegetables, such as ice plants, restaurants were a frequent choice among US consumers (Xia et al., 2022).

Farm availability also influenced consumer acceptance of VF (Jaeger, Chheang, & Bredahl, 2023; Yano et al., 2023) and consumer consumption of hydroponic products (Orsini, Michelon, Scocozza, & Gianquinto, 2009). For instance, Brazilian consumers significantly increased their consumption of hydroponic vegetables if hydroponic farming was conducted in their communities (Orsini et al., 2009). Japanese consumers indicated that participating in tours and exhibitions of VF, as well as receiving information from the media, could increase their acceptance of VF (Yano et al., 2023).

3.5. Biological and physiological factors

Among the biological and physiological factors, *age* and *gender* were commonly identified as factors affecting consumer valuation of SFSs foods.

Studies have found conflicting effects of *age* on consumer views on SFSs foods (Giacalone & Jaeger, 2023; Greenfeld et al., 2020; Nekesa et al., 2023; Short et al., 2017; Spendrup et al., 2024; Suarez-Caceres et al., 2021; Wang et al., 2023; Zhou et al., 2022). Some studies revealed that younger consumers were more positive toward VF (Australia, India, Singapore, and the US) and aquaponics (US) compared to older consumers (Giacalone & Jaeger, 2023; Short et al., 2017; Wang et al., 2023; Zhou et al., 2022), Opposite results were found concerning consumer wiliness to eat (Sweden; Spendrup et al., 2024), frequency of consumption (Kenya; Nekesa et al., 2023) and WTP (Spain; Ercilla-Montserrat et al., 2019) regarding hydroponic products, and their willingness to consume (Australia, Israel; Greenfeld et al., 2020) and WTP (Latin America, Spain; Suarez-Caceres et al., 2021) for aquaponic products. The different types of SFSs and related products as well as the diverse ways of measuring consumer views in various countries might

account for these conflicting results. Additionally, Miličić et al. (2017) found that age did not influence European consumers' attitude toward aquaponics technology. It is important to note that the entire European sample in Miličić et al. (2017) was treated as one target group, lacking a comparison of the effect of age between countries.

Finally, *gender* was also found to affect consumer views on SFSs foods, but we found contrasting results. For instance, US females were more interested in learning about aquaponics in the US (Short et al., 2017) and Chinese females were more accepting of VF (Zhou et al., 2022) compared to males. However, a weak negative correlation between consumer acceptance of VF and gender (male) ($r = -0.117$) was found by (Zhou et al. (2022). In contrast, other studies observed that males were more positive toward aquaponic and VF products than females (Ares et al., 2021; Giacalone & Jaeger, 2023; Jaeger et al., 2022; Schröter & Mergenthaler, 2019; Short et al., 2018; Wang et al., 2023). Compared to females, males might be more interested in the high-tech attributes of SFSs (Schröter & Mergenthaler, 2019) and might have more relevant knowledge (Wang et al., 2023). In summary, female and male consumers' interests in SFSs foods varied in the context of how SFSs are introduced in various studies. Male consumers were more positive toward SFSs foods than female consumers in most investigated studies.

4. Discussion & conclusions

4.1. Consumer responses to SFSs foods

This review provides useful insights into consumer preference for SFSs foods. First, we observed that since 2019 there has been an increasing number of consumer studies investigating SFSs foods, concentrated mainly in high-income countries (i.e. the US and European countries). This can be attributed to the higher adoption levels of SFSs in high-income countries (Kalantari et al., 2018). Second, we found that most of the studies used quantitative research methods focused on vegetable products (e.g., lettuce and tomatoes). Third, we observed that many different intrinsic, extrinsic, sociocultural, psychological, situational, biological, and physiological factors affected consumers' responses to SFSs foods. This finding is corroborated by Rondoni et al. (2020) and Asioli et al. (2017a). Fourth, we found that product characteristics, sociocultural factors, and psychological factors are the most frequently investigated factors affecting consumer evaluations of SFSs foods. Fifth, intrinsic product characteristics, such as sensory properties, and extrinsic product characteristics, such as sustainability and growing conditions of SFSs, were frequently investigated factors influencing consumer views on SFSs foods. This aligns with previous research indicating that sensory properties, environmental impact, and production methods are key factors influencing consumer preferences for vegetables and fruits (Harker, Gunson, & Jaeger, 2003; Hoppu, Puputti, & Sandell, 2021; Pollard, Kirk, & Cade, 2002). In particular, the sustainability was the most frequently investigated extrinsic product factor affecting consumer valuation of SFSs foods, but we found ambiguous results. On the one hand, some studies (Ares et al., 2021; Broad et al., 2022) found that consumers were positive toward SFSs productions, probably because of reduced transportation and the associated lower CO_2 emissions as well as environmental preservation (Padilla et al., 2007). On the other hand, other studies (Jaeger et al., 2022) revealed consumer concerns about such production methods may be due to the potential climate burden and high energy costs (Ares et al., 2021; Jaeger et al., 2022). Sixth, concerning socio-cultural factors, we observed that higher income and education levels positively affected consumer preference for SFSs foods in most investigated studies. These findings are consistent with previous consumer studies on organic food (e.g., Rödiger & Hamm, 2015). This can be explained by the fact that higher-income and more educated consumers tend to pay more attention to the sustainability and environmental friendliness of food products. Seventh, regarding psychological factors, we found that knowledge of soilless production, technology affinity and neophobia affect consumer attitude toward SFSs foods. Generally, consumers' knowledge of soilless production positively affected their valuation of these products but food (technology) neophobia inhibited consumers from favoring SFSs foods. These findings corroborate with previous research showing that food (technology) neophobia typically leads consumers to reject unfamiliar food items and technologies (Asioli et al., 2019; Csordás & Füzesi, 2023; Siegrist & Hartmann, 2020). Eighth, we found that consumers preferred fresh SFSs foods produced locally. These findings are supported by previous studies identifying local food production as the main determinant of consumer choice (He, Shi, Gao, & House, 2020; Hempel & Hamm, 2016). Ninth, we found that areas lacking access to a fresh supply of vegetables and fruits may tend to impact consumer acceptance and purchase of SFSs foods.

4.2. Implications and recommendations for food producers and policymakers

Several implications and recommendations for producers of SFSs foods can be derived from this review. Firstly, since a diversity of factors were found to influence consumer response to SFSs foods, producers should take multiple factors into account in developing, marketing, and communicating about SFSs foods to consumers. Secondly, producers should consider meeting consumer expectations for SFSs foods by enhancing product taste, color, and flavor, and by ensuring food nutrient and safety. Transparently communicating scientific research findings about the sustainability of SFSs may mitigate consumer concerns about SFSs foods. Although price was not as frequently investigated compared to other factors, high prices negatively affected consumer purchases of SFSs foods. It is recommended that producer should price SFSs foods similar to conventional foods. Thirdly, it is suggested that producers provide local and fresh SFSs foods by building stores close to consumers who lack convenient access to vegetables or fruit. Producers need also carefully identify and analyze each specific consumer segment to more effectively target the market for these new products, given the differences in consumer preferences for SFSs foods. For example, highly educated and pro-environmental consumers might be the main target group for the promotion of VF foods. However, caution should be exercised when using demographic characteristics such as age and gender to target potential consumers of SFSs foods, considering their conflicting effects on consumer views. Fourthly, producers should communicate and inform consumers about SFSs in a transparent way to reduce their neophobia and concerns and promote the sustainability benefits of SFSs foods.

For policymakers interacting with producers, it is crucial to work toward a more homogenous definition and understanding of various SFSs and related foods. A uniform definition and regulation of the different types of SFSs and products available, including their environmental impact (e.g., carbon footprint) might promote a trend toward more sustainable food production. Furthermore, it is crucial that policymakers support producers in adopting transparent standards regarding the environmental impact of SFSs, enabling consumers to make more informed decisions through independent third-party certification (Southey, 2022). Given that consumer acceptance of new agri-food technologies is generally negatively affected by a lack of knowledge and a high degree of food (technology) neophobia (Lusk, Roosen, & Bieberstein, 2014) such as VF, providing information to consumers about the benefits of these novel production methods (i.e., SFSs) should be more effectively addressed (Csordás & Füzesi, 2023). Thus, both policymakers and producers might need to engage in public educational and communication campaigns about SFSs, including their characteristics and benefits.

4.3. Future research directions

This review has raised several questions about SFSs foods that merit

further investigation. First, future consumer studies could focus on developing countries that show high economic and income growth, or countries with climate disadvantages for producing conventional soil-based foods (Rawlinson, 2023), especially those with large cities where these new technologies may be more suitable. Second, in terms of research methodologies, additional qualitative research should be conducted to thoroughly explore in-depth consumer perception and preferences for SFSs foods. This would provide a deeper understanding of consumers' experiences, expectations, and needs regarding SFSs foods. Third, future research should investigate consumers' valuation for a larger number of new potential SFSs foods (e.g. leafy green vegetables, tomatoes, broccoli, fruits, and fish). Fourth, further research is suggested to optimize the method of communicating information about SFSs foods to consumers. For instance, studies could test how information channels and communication messages about the benefits of SFSs foods influence consumer decision-making. Fifth, future studies could estimate consumers' WTP and market shares for SFSs foods using more non-hypothetical research methods (Jaeger, 2024), such as experimental auctions (Lusk, 2007), real choice experiments (Alfnes & Rickertsen, 2011), or multiple price list experiments (Asioli, Mignani, & Alfnes, 2021) coupled with sensory tests (Asioli et al., 2017b) in real market settings (i.e., online and physical stores). Furthermore, it would be interesting to test whether the inclusion of various behavioral and psychological factors (e.g. risk preferences and personality) into economic models of consumer demand would improve their predictive power and, in turn, enhance understanding of consumers' decision-making processes for SFSs foods. Lastly, future reviews are suggested to broaden the research to a larger number of new sustainable farming technologies.

Author Statement

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CRediT authorship contribution statement

Xiao Zhou: Writing – review & editing, Writing – original draft, Validation, Methodology, Formal analysis, Data curation, Conceptualization. **Daniele Asioli:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Conceptualization. **Kristin Jürkenbeck:** Writing – review & editing, Writing – original draft.

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.

Data availability

No data was used for the research described in the article.

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Appendix A

Table A1
Overview of the selected articles ($n = 56$) about consumer behavior, perception, acceptance, and preference for soilless farming systems and related products.

NO.	AUTHORS	COUNTRY	SAMPLE SIZE	METHOD	SYSTEM	PRODUCT	MAIN FINDINGS
1	Al Mamun et al. (2023)	China	$n = 661$	Quantitative method (online survey)	Hydroponics	Not specified	• Tolerance of diversity (e.g., openness to various aspects of socio-culture such as beliefs and traditions), innovativeness of hydroponics, and knowledge about hydroponics significantly affected consumers' attitude toward hydroponic system. • Consumers' knowledge, attitude, perceived need for hydroponics, and compatibility of hydroponics significantly influenced their adoption intention and actual adoption of hydroponic system.
2	Ares, Chheang, and Jaeger (2023)	Australia, Germany, Singapore, and United States	$n = 2193$ (537 to 556 participants per country)	Mixed methods (online survey with closed-ended questions and text highlighting)	Vertical farming	Lettuces	• Consumers' in the "high" purchase likelihood group showed higher purchase likelihood for vertical farming (VF) lettuces when the benefits of VF production were introduced (e.g., same nutrition content as outdoor grown lettuces, pesticide-free, and sustainability) compared to the description of VF production such as the use of artificial light and robot. • Consumers who had children under 18 were more likely to be

(*continued on next page*)

Table A1 (*continued*)

NO.	AUTHORS	COUNTRY	SAMPLE SIZE	METHOD	SYSTEM	PRODUCT	MAIN FINDINGS
							represented in higher purchase intention group for VF lettuces than those who had no child. • German consumers were less likely while Singaporean consumers were more likely to be represented in higher purchase intention group than those from Australia.
3	Ares et al. (2021)	China, Singapore, United Kingdom, and United States	China: $n = 683$; Singapore: $n = 673$; United Kingdom: $n = 637$; United States: $n = 644$	Mixed methods (online survey with closed-ended questions and text highlighting)	Vertical farming	Not specified	• Increased yield, controlled plant growth environment, fresh supply, reduction of carbon emissions, secure food supply, environmental friendliness, and reduced use of farmland contributed most to the positive consumer attitude toward VF. • Premium price and high energy cost contributed most to the negative consumer attitude toward VF. • Consumer attitude toward VF varied across countries which were affected by different characteristics of VF. • Consumers with a positive overall attitude to VF were more likely to come from Singapore and China, among men with full-time job and higher educational level, and those who ever heard about VF.
4	Ares and Jaeger (2022)	China, Singapore, United Kingdom, and United States	China: $n = 683$; Singapore: $n = 673$; United Kingdom: $n = 637$; United States: $n = 644$	Mixed methods (online survey with closed-ended questions and text highlighting)	Vertical farming	Not specified	• Consumers' response of "like" or "dislike" to the information about VF varied across countries. • Consumers who were positive toward VF agreed with the statements about VF benefits such as the controlled environment, fresh supply, and the use of robot.
5	Ares, Ryan, and Jaeger (2023)	United States	$n = 624$	Mixed methods (online survey with open-ended questions and text highlighting)	Vertical farming	Not specified	• Consumer who was positive toward VF because of the use of nutrient-rich water, controlled growing conditions, and sustainable production. • Consumers regarded VF products as healthy, fresh, safe, and cheap because of the control environment with reduced use of pesticide. • Consumers were concerned about the use of robot and information technology system because of the potential technical errors and hacking issues, and negative effect on labor market. • Also, consumers were negative toward VF because of the high cost of water and energy.
6	Auerswald et al. (1999)	Germany	$n = 100$	Consumer sensory study	Hydroponics	Tomatoes	• Consumers preferred the external appearance of cultivar "Vanessa" to that of "Counter" when they grew at low and middle level of nutrition treatment, but they preferred the appearance of "Counter" to that of "Vanessa" when they grew at high level of nutrition treatment. • Consumers preferred the flavor, aftertaste, and mouthfeel of "Counter" to that

(*continued on next page*)

Table A1 (*continued*)

NO.	AUTHORS	COUNTRY	SAMPLE SIZE	METHOD	SYSTEM	PRODUCT	MAIN FINDINGS
							of "Vanessa" regarding each level of nutrition treatment.
7	Broad et al. (2022)	United States	$n = 45$	Qualitative method (interview)	Controlled environment agriculture (i.e., hydroponics, aeroponics, and aquaponics)	Not specified	• Consumers generally lacked the knowledge of controlled environment agriculture (CEA). • Consumers showed a tentative acceptance of CEA after knowing the positive and negative arguments. • Some consumers were positive toward CEA because of the efficiency of water use and yield, less transportation, fresh and local supply, and free of chemical pesticides and fertilizers. However, some consumers expressed their concerns about the sustainability of CEA because of the unnatural way of growing food such as the use of artificial light and the energy cost.
8	Caputo et al. (2020)	United Kingdom	$n = 35$ (vertical farming $n = 24$; hydroponics $n = 11$)	Qualitative method (interview)	Hydroponics, Vertical farming (a simple vertical frame of hydroponics using readily available materials)	Not specified	• The use of chemicals, price, food miles, and flavor were factors that affected consumers' WTB for hydroponic products. • Unnaturalness and the use of chemicals were consumers' main concerns about VF. • If consumers knew the cultivation method, they would reject to eat hydroponic products more than VF products.
9	Chen et al. (2020)	United States	$n = 150$	Consumer sensory study	Hydroponics	Broccoli microgreens	• Compared to commercial hydroponic broccoli microgreens, consumers had higher perceived benefits and WTB regarding local soil-grown broccoli microgreens and local hydroponic broccoli microgreens, but no significant difference of these measures was found between local soil-grown and local hydroponic broccoli microgreens.
10	Coyle and Ellison (2017)	United States	$n = 116$	Quantitative method (Experimental action)	Vertical farming	Lettuces	• Providing information about VF production did not change consumers' general evaluation of VF lettuces, but lowered consumers' perception of naturalness of such products, when compared to soil-farmed products. • Expectation about product cost was the main factor driving consumers' WTP for VF lettuces, especially when consumers were exposed to the information about the high yield of VF production. • Consumers expected to buy VF lettuces in premium store when they were unfamiliar with VF, but they indented to buy these products in supercenters or discount groceries when they learnt more about VF.
11	de Souza et al. (2021)	Brazil	$n = 65$	Consumer sensory study	Hydroponics	Kales	• The color of the hydroponic kales was less green than that of soil-grown ones, which might affect consumers' purchase intention.

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NO.	AUTHORS	COUNTRY	SAMPLE SIZE	METHOD	SYSTEM	PRODUCT	MAIN FINDINGS
12	Eichhorn and Meixner (2020)	Austria	$n = 315$	Quantitative method (face-to-face survey)	Aquaponics	Fish and vegetables	• Consumers' environmental awareness and habit of purchasing sustainable and environmentally friendly products directly affected their purchase intention and indirectly affected their WTP.
13	Ercilla-Montserrat et al. (2019)	Spain	$n = 238$	Mixed methods (survey with open-ended questions and closed-ended questions)	Hydroponics	Tomatoes	Response to close-end questions: • Income was positively correlated with consumer WTB rooftop hydroponic tomatoes. • Consumers with a high school education gave a better rating of the content and condition of rooftop hydroponic tomatoes compared to others. However, consumers who proposed a higher price for the rooftop hydroponic tomatoes were predominantly older, high-income consumers with university studies and a better valuation of the quality of the rooftop hydroponic tomatoes. • Consumers who valued the texture and taste of rooftop hydroponic tomatoes higher, had knowledge of rooftop hydroponic tomatoes, and perceived them as more environmentally friendly showed higher WTB than their counterparts. • Consumers regarded origin as an important factor influencing their consumption of rooftop hydroponic tomatoes. • Most consumers preferred to consume rooftop hydroponic tomatoes at home compared to other options such as restaurants. • More than half of consumers preferred to buy hydroponic tomatoes in a shop than the production point. Response to open-end questions: • Three consumers worried about the impact of air pollution in the city on the hydroponic tomatoes. • One consumer would like to know that if the contents of vitamins and nutrients from hydroponic tomatoes is the same as the soil-grown tomatoes.
14	Giacalone and Jaeger (2023)	Australia, India, Singapore, and United States	Australia: $n = 623$; India: $n = 615$; Singapore: $n = 627$; United States: $n = 629$	Quantitative method (online survey)	Vertical farming aquaponics	VF vegetables, aquaponic fish	• Consumers' intention for more sustainable diet was strongly associated with their responses to VF vegetables and aquaponic fish. • Consumers' healthy eating was strongly associated with their responses to VF vegetables. • VF vegetables and aquaponic fish were more acceptable by consumers in Eastern countries compared to consumers in Western countries in terms of willingness to consume the products. • Consumers who showed a higher acceptance level of VF

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NO.	AUTHORS	COUNTRY	SAMPLE SIZE	METHOD	SYSTEM	PRODUCT	MAIN FINDINGS
							and aquaponic farming (including other food technologies) were more likely to be represented as male, younger, flexitarian, had a university education, showed lower food technology neophobia, and expressed greater concern for the environment.
15	Gichuhi et al. (2009)	United States	$n = 96$	Consumer sensory study	Hydroponics	Carrots	• Consumers' liking of sensory attributes differed in different cultivars of hydroponic carrots.
16	Gilmour et al. (2019)	United States	$n = 198$	Quantitative method (non-hypothetical Choice Experiment)	Hydroponics	Lettuces	• Proving information about hydroponic benefits shifted consumers' WTP for the hydroponic lettuces, in comparison to soil-grown lettuces, from the negative to neutral. • Consumers' WTP for the hydroponic lettuces, in comparison to soil-grown lettuces, was similar when different information about hydroponic benefits was presented.
17	Greenfeld et al. (2020)	Australia and Israel	Australia: $n = 321$; Israel: $n = 200$	Quantitative method (online survey and face-to-face survey)	Aquaponics	Lettuces and fish	• Both Australian and Israelian consumers' willingness to consume aquaponic lettuces and fish were negatively correlated with product price, but positively correlated with household size and consumption of organic products. • Australian consumers' willingness to consume aquaponic fish was positively correlated with product taste, income, and if they were members from environmental organizations; their willingness to consume aquaponic lettuces was positively correlated with health and environmental considerations, age, and familiarity with aquaponics. • Israelian consumers' willingness to consume aquaponic fish was positively correlated with environment considerations and age; their willingness to consume aquaponic lettuces was positively correlated with product taste, age, and education level.
18	Holmes et al. (2019)	United States	$n = 50$	Consumer sensory study	Hydroponics	Lettuces	• Consumers' evaluation of sensory attributes of hydroponic lettuces varied in cultivars. • Scores of crispness, texture, flavor, and bitterness (higher score of bitterness indicated that the product was less bitter) were positively correlated with consumers' WTB hydroponic lettuces.
19	Huang (2019)	China	$n = 390$	Quantitative method (face-to-face survey)	Vertical farming	Vegetables	• While around half of consumers regarded VF foods as organic and safe, more than half of consumers were suspicious about VF foods and showed their concerns such as

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NO.	AUTHORS	COUNTRY	SAMPLE SIZE	METHOD	SYSTEM	PRODUCT	MAIN FINDINGS
							environmental pollution and energy cost. • Around half of consumers were willing to buy VF vegetables, mainly because of the free of pesticide. • Consumes who had higher income, had higher frequency of eating organic vegetables were more willing to pay for VF vegetables. • Consumers were more willing to pay a higher price for the VF vegetables if they were labeled with an allied brand of academic institutes and private corporations, compared to other types of brands.
20	Huang et al. (1999)	China	$n = 323$	Quantitative method (face-to-face survey)	Hydroponics	Vegetables	• Consumers who had small children, higher education level, lower frequency of eating out, and who did not consider price as important purchase factors were more likely to pay a premium price for hydroponic grown vegetables compared to their counterparts.
21	Jaeger and Ares (2022)	United Kindom	$n = 1466$	Mixed methods (online survey with text highlighting and closed-ended questions)	Vertical farming	Vegetables and fruits	• Consumers' response to the text highlight task depended on the contextual text of introducing VF. • Performing the text highlight task by reading the same VF information did not influence consumers' attitude toward VF.
22	Jaeger et al. (2022)	United Kindom	$n = 837$	Mixed methods (online survey with text highlighting and closed-ended questions)	Vertical farming	Vegetables and fruits	Consumers who were exposed to the basic information of VF: they liked the growing method and fresh supply but disliked the technology concept (e.g., IT system and robots) and cultivation in building. Female were more frequently shown in the negative attitude group toward VF than male. Consumers who were exposed to information about pros & cons of VF: they liked the growing condition of VF but liked more about less carbon emission, high yield, and return farmland to nature. Consumers still disliked the technology concept and cultivation in building but disliked more about the high energy cost and premium pricing. Consumers' income differences were found between groups of holding different attitudes toward VF. Regardless of the information format (i.e., including pros & cons of VF or not): • Consumers who were positive to VF agreed the advantages of VF (e.g., safe to eat) more than consumers who hold negative sentiment, while consumers who hold negative sentiments agreed the disadvantages of VF (burden of climate change) more than those in the positive group.

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NO.	AUTHORS	COUNTRY	SAMPLE SIZE	METHOD	SYSTEM	PRODUCT	MAIN FINDINGS
							• Consumers who were positive toward VF were those who ever heard of VF, who had lower food technology neophobias, and who had high frequency of purchasing organic vegetables and fruits.
23	Jaeger, Chheang, and Ares (2023)	Australia, Germany, Singapore, and United States	Australia: $n = 556$; Germany: $n = 537$ Singapore: $n = 547$; United States: $n = 553$	Mixed methods (online survey with text highlighting and closed-ended questions)	Vertical farming	Lettuces	• Consumers were positive toward VF in terms of food security, reduced land use, and decreased carbon emission, but they were negative toward the high price and the loss of rural towns by applying VF. • German consumers showed the least positive attitude and WTB regarding VF lettuces. • Nutrition, free of pesticide, and sustainability were positively associated with consumers' WTB VF lettuces while the use of robots and artificial lights were negatively associated with consumers' WTB VF lettuces. • Information related to the positive and negative aspects of VF influenced consumers' WTB VF lettuces.
24	Jaeger, Chheang, and Bredahl (2023)	Germany, Singapore	Germany: $n = 537$ Singapore: $n = 547$	Mixed methods: (hybrid-hard online laddering methodology)	Vertical farming	Vegetables	• Altruistic (e.g., food security, efficiency of production, food safety, no use of pesticide, environmental friendliness, less use of land, local production, and short transportation distance) and self-centered motives (e.g., healthy and availability of vegetables) were main factors affecting consumers' acceptance of VF. • German consumers: concerns about the price and high energy use were negatively associated with their views on VF. • Singaporean consumers: emotion of eating VF food was positively associated with their views on VF.
25	Jaeger, Chheang, Roigard, and Frøst (2023)	United Kindom, Germany, Denmark	Study 1: Germany, United Kingdom,: $n =$ 1000-1044 Denmark: $n = 1025$; Study 2: Denmark: $n = 81$. Study 3 Denmark: $n = 112$	Mixed methods: (quantitative online survey in Germany and the United Kingdom. Consumer sensory study in Denmark)	Vertical farming	Salad greens, herbs, and fruits	When only information of VF was presented (study 1): • British and German consumers' expectation of VF products was less positive than the organic counterparts. The sensory expectations of VF products were negatively evaluated compared to organic counterparts in terms of flavor, texture, color, and sweetness. Some of VF products were expected to be more ready to eat, more artificial, less wholesome, less rich in nutrition, less fresh, and less pure than organic counterparts. Some of VF salad green, and peas were expected to be less pure than organic counterparts. • For Danish consumers, VF products were expected to be paler in color and the basil was expected to be less fresh and intense than organic counterparts. VF products were

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NO.	AUTHORS	COUNTRY	SAMPLE SIZE	METHOD	SYSTEM	PRODUCT	MAIN FINDINGS
							expected to be less natural and less wholesome. Sensory tests among Danish consumers (study 2 and study 3): • VF products were not disliked by consumers. • Fresh appearance, sweet taste, juicy texture, and crispy texture significantly drove consumers' liking of all salad green and herds (including both VF products and organic products). In addition, identical product-specific flavor was associated with the average liking of VF products.
26	Jürkenbeck et al. (2019)	Germany	$n = 482$	Quantitative method (online survey)	Three types of VF for salads and herbs: vertical home farm[1]; in-store vertical farm[2]; indoor vertical farm[3]	Vegetables	• Around half of consumers would like to buy the products from in-store vertical farm, followed by indoor vertical farm and vertical home farm. • Subjective knowledge negatively influenced consumers' perception of sustainability regarding in-store VF, but positively affected their perceived sustainability of vertical home farm. • Attitude toward sustainability positively influenced consumers' perceived sustainability of indoor VF. • Perceived sustainability was the main driver of the consumers' perceived usefulness of all three VF systems, followed by subjective norms. Technology affinity only positively affected consumers' perceived usefulness of indoor VF. Then perceived usefulness positively influenced consumers' attitude toward buying products from all three VF systems and then further positively influenced their purchase intention. However, perceived behavioral control only positively influenced consumers 'purchase intention of the vertical home farmed products.
27	Kralik et al. (2022)	US	Sensory evaluation $n = 63$ consumer survey $n = 344$	Mixed methods (consumer sensory study and Quantitative online survey)	Aquaponics	Fish	• No significant difference of consumer sensory evaluation was found between aquaponic fish and conventional wild-caught fish. • Providing information about the production method, nutritional diet, and environmental benefits of aquaponics significantly increased consumers' healthiness perception and purchase intention of aquaponic fish compared to wild caught fish and traditional farm-raised fish.
28	Macht et al. (2023)	Germany	$n = 1989$	Quantitative method (online survey)	Aquaponics	Not specified	• Consumers' familiarity of aquaponics was positively related with their general acceptance and local acceptance of aquaponics. • Consumers in transition regions toward sustainable

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NO.	AUTHORS	COUNTRY	SAMPLE SIZE	METHOD	SYSTEM	PRODUCT	MAIN FINDINGS
							bioeconomy had lower acceptance of local aquaponic farming compared to consumers in non-transition regions. • Perceive benefits (e.g., support local economy and food production), risks (e.g., unnatural production and harmful for fish welfare) and affect significantly affected consumers' general and local acceptance of aquaponics (except the effect of perceived benefits on local acceptance of aquaponics among consumers in transition regions).
29	Manzocco et al. (2011)	Italy	$n = 200$	Quantitative method (survey)	Hydroponics	Lamb's lettuces	• When the images of vegetables were presented, consumers rejected the hydroponic products more than soil-grown counterparts, especially when the storage time of vegetables was extended.
30	Miličić et al. (2017)	16 European countries	$n = 635$	Mixed methods (online survey with open-ended questions and closed-ended questions)	Aquaponics	Vegetables & fish	Based on an introduction of aquaponic system: Responses to open-ended questions: • Consumers held positive attitude toward aquaponics in terms of innovativeness and sustainability. • The negative associations of aquaponics were negative emotions, bordering on disgust, negative perception of animal welfare and distrust of positive claims about aquaponics. Response to close-end questions: • If products were locally grown and free of antibiotics, pesticides and herbicides or not affected consumers' WTP for aquaponic products. • Consumers' attitude toward the aquaponic products were positively correlated with consumers' behavior of buying local and organic food, but not significantly influenced by gender, age, income, whether consumers were in charge of weekly food purchase nor consumers' knowledge about aquaponics.
31	Narine et al. (2014)	Republic of Trinidad and Tobago	$n = 405$	Quantitative method (face-to-face survey)	Hydroponics	Tomatoes	• Consumers who lived in central Trinidad were more likely to pay more for greenhouse-hydroponic tomatoes compared to consumers who lived in northern and southern Trinidad. • Consumer who had lower educational level and lower income, and those who believed greenhouse-hydroponic tomatoes were un-healthy were less likely to pay more for greenhouse- hydro-ponic tomatoes. • On average, consumers were willing to pay an average price of TT$ 6.74/pound for

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NO.	AUTHORS	COUNTRY	SAMPLE SIZE	METHOD	SYSTEM	PRODUCT	MAIN FINDINGS
							greenhouse hydroponic tomatoes.
32	Nekesa et al. (2023)	Kenya	$n = 310$	Quantitative method (face-to-face survey)	Hydroponics	Vegetables and fruits	• Age, educational level, and knowledge about the quality and safety of hydroponic vegetables and fruits significantly predicted consumers' frequency of eating such foods.
33	Orsini et al. (2009)	Brazil	$n = 289$	Quantitative method (face-to-face survey)	Hydroponics	Vegetables	• The adoption of community hydroponic garden in the community dramatically increased consumers' consumption of hydroponic vegetables.
34	Padilla et al. (2007)	Morocco Turkey Germany France	$n = 100$ per country	Mixed methods (qualitative interview, focus group, & quantitative survey)	Hydroponics	Tomatoes	Morocco and Turkey (interview and focus group): • Moroccan and Turkish consumers had poor knowledge of hydroponics and preferred tomatoes grown in soil, but Turkish consumers held a positive attitude of hydroponic tomatoes and showed WTB if the hydroponic products meet consumers' expectation of sensory properties. Germany and France (quantitative survey): • More French consumers had heard of hydroponic tomatoes than German consumers. • Near half of French and German consumers perceived hydroponic tomatoes as artificial and industrial product, and they were not very positive toward hydroponic production in term of health, environment preservation, taste, and quality.
35	Perambalam et al. (2021)	Denmark	Quantitative survey: $n = 111$, focus group: $n = 10$	Mixed methods (focus group & quantitative survey)	Vertical farming	Not specified	• VF was not widely accepted among young consumers (quantitative survey). • Perceived sustainability was an important factor affecting young consumers' acceptance of VF (quantitative survey and focus group).
36	Schröter and Mergenthaler (2019)	Germany	$n = 18$	Mixed methods (eye-tracking study with open-ended and closed-ended questions)	Aquaponics	Fish and vegetables	• Most consumers were positive toward aquaponic production because of the recirculating system, good prospects, and sustainability. • Most consumers preferred aquaponic farms when the graphic information presented natural attributes of aquaponics. Males preferred the aquaponic farms when the graphic information presented high-tech attributes of aquaponics. • When the graphic information was presented with high-tech attributes of aquaponics: more consumers were found to associate it with "innovative", "interesting", "artificial" and "factory farming", compared with consumers who were exposed to the graphic information presenting natural attributes of aquaponics.

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NO.	AUTHORS	COUNTRY	SAMPLE SIZE	METHOD	SYSTEM	PRODUCT	MAIN FINDINGS
							• When the graphic information was presented with natural attributes of aquaponics: more consumers were found to associate it with "natural" and "animal welfare", compared with consumers who were exposed to the graphic information presenting high-tech attributes of aquaponics. • Consumers' visual attention was associated with the graphic information of aquaponics and their perception of naturalness.
37	Short et al. (2018)	United States	$n = 90$	Quantitative method (experimental action)	Three cultivars of lettuces grown in soil, aquaponic warehouse (artificial light), aquaponic greenhouse (mix natural light with artificial light)	Lettuces	• Consumers' bids for aquaponic lettuces were not affected by learning about the production method. • Consumers had the highest WTP for aquaponic lettuces grown in warehouse, followed by soil-grown lettuces and aquaponic lettuces grown in greenhouse, but no significant difference was found. • Male, who had relatively higher income level (not including upper levels of income), higher educational level, higher frequency of shopping for fresh product, who were unmarried without young children at home, who were not a member of an environmental group, who liked the rex cultivar, and the sensory attributes of appearance, flavor, crispness, and texture would significantly increase their bids for aquaponic products.
38	Short et al. (2017)	United States	$n = 450$	Quantitative method (telephone survey)	Aquaponics	Fish and vegetables	• On average, consumers' responses to the description of aquaponics fell between neutral to agree, e.g., producing safe and clean foods with high nutritional value and positively impacting the environment. • Premium price and concern about safety and cleanliness were main barriers to consumers' WTB aquaponic products, followed by concern about flavor, the way of fish growth, concern about nutrition, and the way of plant growth. • Generation X were more likely to learn about aquaponics than Baby Boomers. • Women, who had the highest income level and ever heard of aquaponics, showed greater interest in learning more about aquaponics than consumer who had the opposite attributes.
39	Sinesio et al. (2021)	France (only include the study about hydroponic products)	$n = 103$	Consumer sensory study	Soilless farming	Tomatoes	• Cultivar affected French consumers' preference for soilless-grown tomatoes: modern varieties were more acceptable than traditional varieties.
40	Son and Hwang (2023)	United States	study 1: $n = 586$; study 2: $n = 719$; study 3: $n = 417$	Quantitative method (online survey)	Vertical farming	Vegetables and fruits	Study 1:

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NO.	AUTHORS	COUNTRY	SAMPLE SIZE	METHOD	SYSTEM	PRODUCT	MAIN FINDINGS
							• Consumers' evaluation, perceptions (naturalness and healthiness), and purchase intention of soil-grown foods were higher than VF foods. Study 2 and Study 3: • When the product packaging was designed with an image of regular food products, or a description of machine-made production, US consumers' evaluation and purchase intention for VF foods were significantly lower compared to soil-grown foods • When the product packaging was designed with a picture of a male farmer, ordinary woman, or a description of hand-made production, US consumers' evaluation and purchase intention for VF lettuces were high, but no significant differences were found between VF foods and soil-grown foods in terms of their evaluation and purchase intention. • Overall, the perceived naturalness and healthiness indirectly affected consumers' evaluation and purchase intention between VF foods and soil-grown foods.
41	Specht et al. (2016)	Germany	$n = 386$	Quantitative method (face to face survey)	VF and aquaponics	Not specified	• Most consumers had a low acceptance level of high-tech agriculture such as VF and aquaponic farming.
42	Spendrup et al. (2024)	Sweden	$n = 995$	Quantitative method (online survey)	Hydroponics (using food waste and mineral fertilizers as nutrients fertilizers)	Vegetables	• Older consumers who had no previous knowledge of hydroponics were more positive toward hydroponics compared to their counterparts. • Hydroponic foods were perceived as healthy, safe, modern, tasty, hygienic, and nutritious. • Hydroponic system that applied food waste as nutrients fertilizers was perceived as more positive (e.g., natural, environmentally friendly, and energy efficient) than that of using chemical mineral as fertilizers. • Believing in climate change was a significant predictor of consumers' willing to eat hydroponic vegetables, regardless of the fertilizer type. • Food neophobia and age were significant predictors of consumers' willingness to eat products grown from hydroponic system that using food waste as fertilizers.
43	Su et al. (2020)	China	$n = 30$	Consumer sensory study	Hydroponics	Vegetables: Italian lettuces, Shanghai Qing, Chinese flowering cabbage, and leaf celery	Sensory liking: • Consumers' sensory liking of hydroponic vegetables varied in the type of vegetables and the height of growing plants. Purchase intention:

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NO.	AUTHORS	COUNTRY	SAMPLE SIZE	METHOD	SYSTEM	PRODUCT	MAIN FINDINGS
44	Suarez-Caceres et al. (2021)	Spain and Latin America	$n = 636$	Quantitative method (online survey)	Aquaponics	Vegetables and fish	• Consumers have a strong intention to purchase vegetables grown in the top tank of hydroponic system. • Most consumers would buy the vegetables based on shape and color. • Good quality, taste and the absence of pesticides or chemical residues were main drivers for consumers to consume aquaponic products. • When the price was the same, consumers were more willing to buy aquaponic products than conventional soil-grown products. • The more variety regarding consumers' diet habit, the more they were willing to buy the aquaponic products. • Older consumers who had average and higher household income and higher educational level, who lived in rural area in Spain with more knowledge of aquaponics were willing to pay more for the aquaponic products compared to their counterparts.
45	Tan et al. (2020)	United States	$n = 150$	Consumer sensory study	Hydroponics	Broccoli microgreens	• Consumers' liking scores of smells, appearance, taste, and overall liking of hydroponic broccoli microgreens from the local farm were significantly higher than those from the commercial market, but as similar as soil-grown broccoli microgreens from the local farm. • Taste, smell, and appearance were strongly correlated with consumers' overall liking of hydroponic broccoli microgreens.
46	Vidal et al. (2022)	United States	$n = 1803$	Qualitative method (online survey)	Vertical farming	Fruits, vegetables, and grains	• Regarding consumers' responses to VF information stressing genetic engineering in VF: consistent topics were "buy" (related to the purchase of VF products or not), "vegetables and fruits availability", "indoor farming", "genetic engineering", and "plant vs meat". • Regarding consumers' responses to the VF information stressing urban production and reduced carbon emission by short transportation: consistent topics were "buy" related to the purchase of VF products or not, "food production", "local farming", "vegetables and fruits availability" and "environment".
47	Walters and Lopez (2022)	United States	$n = 86$	Consumer sensory study	Hydroponics	Basils	• Consumers' preference for specific sensory attributes (e.g., appearance, texture, color, and bitterness) of hydroponic basils was affected by the indoor temperature of growing environment. • Consumers' overall liking was not influenced by the indoor

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NO.	AUTHORS	COUNTRY	SAMPLE SIZE	METHOD	SYSTEM	PRODUCT	MAIN FINDINGS
							temperature of growing environment.
48	Walters et al. (2021).	United States	$n = 188$	Consumer sensory study	Hydroponics	Basils	• The radiation intensity of LED light used for hydroponic farming system affected consumers' overall liking and evaluation of sensory characteristics of hydroponic basils.
49	Wang et al. (2023)	China	$n = 729$	Quantitative method (face to face survey and online survey)	Vertical farming	Not specified	• Consumers were willing to buy VF products because they were clean and pollution-free, green, and healthy, fresh, nutritious, and high-quality. Cross-analysis: • Male, younger consumers who had higher educational level were more accepting VF products than their counterparts. • Male consumers who were middle-aged with higher educational level, higher income, and who came from scientific research institutions, universities, and government departments showed higher purchase intention for VF products compared to other consumers. • Male, middle-aged consumers had higher brand awareness for branded VF products compared to their counterparts. • Male consumers who were middle-aged with higher educational level and higher income were willing to pay higher price for branded VF products compared to their counterparts.
50	Wu and Kuo (2016)	China	$n = 306$	Quantitative method (survey)	Hydroponics	Vegetables	• Perceived usefulness and trust in hydroponic vegetables using LED lights positively affected consumers' usage attitude toward hydroponic vegetables using LED light.
51	Xia et al. (2022)	United States	$n = 115$	Consumer sensory study	Hydroponics	Vegetables (ice plant)	• Flavor determined consumers' overall liking of hydroponic vegetables. • Increased NaCl concentration in the nutrient solution during hydroponic production significantly decreased consumers' overall liking and evaluation of sensory characteristics such as flavor and taste. • Consumers preferred to have hydroponic ice plant used in salads and in restaurants.
52	Yam et al. (2020).	China	$n = 58$	Consumer sensory study	Hydroponics	Melon	• Precise management of nitrogen and potassium in a hydroponic system can affect consumers' sensory preference and overall liking of hydroponic melons.
53	Yano et al. (2023)	Japan	$n = 961$	Quantitative method (online survey)	Vertical farming	Lettuces	• Different LED light colors did not significantly affect consumers' liking of VF. • Providing additional evidence-based information about the vegetables growth under artificial light significantly increased consumers' liking of

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NO.	AUTHORS	COUNTRY	SAMPLE SIZE	METHOD	SYSTEM	PRODUCT	MAIN FINDINGS
							VF when the light color was dark, red-purple. • Participation in tours and exhibitions of VF, getting information from the mass media, and trust in food safety significantly increased consumers liking of VF. • Food technology neophobia negatively affected consumers' liking of VF. • Consumers who reported a preference for physics (preferred the field of electricity and mechanics) showed higher liking of VF compared to others.
54	Yano et al. (2021)	Russia	$n = 289$	Mixed methods (online survey with open-ended questions and closed-ended questions)	Vertical farming	Leafy vegetables	• Consumers who lived in federal districts were less favorable for VF vegetables compare to those lived in area with limited access to vegetables production. • Consumers who had higher income level were more favorable for VF vegetables compared to those who had lower income level. • Consumers' positive attitude toward VF vegetables were closely related with their perceived food safety, good taste, and good quality. • Consumers' negative attitude toward VF vegetables were closely related with the perception such as unnatural, less nutritious, unhealthy, and unsafe.
55	Yue et al. (2020)	United States	$n = 105$	Consumer sensory study	Hydroponics; Aquaponics	Basils	Cultivar preference: • Overall liking, flavor liking, texture liking and flavor intensity of Nufar cultivar were rated higher by consumers than that of other cultivars. Growing condition preference: • Consumers generally liked basils grown in the soilless medium and aquaponic greenhouse more than basils grown in the aquaponic warehouse.
56	Zhou et al. (2022)	China	$n = 713$	Quantitative method (paper-based survey: expert interview is not considered)	Vertical farming	Multiple type of foods: e.g., vegetables fruits, bean, and fish	• Consumers who lived near food store, who were at younger age, who had lower income, and females were more likely to accept vertical farm. • Consumers were most willing to buy vertical farmed vegetables and fruits (e.g., tomatoes, spinach, strawberries), compared to other food products (e.g., beans, fish) and they were willing to pay higher price for VF products if the products were organic with good quality. • Preference in conventional farming, perceived artificiality of VF and lack of interest in VF were the most frequently mentioned reasons by consumers who would not accept VF.

NOTE. CEA: controlled environment agriculture; VF: vertical farming; WTB: willingness to buy; WTP: willingness to pay; [1]vertical home farm: VF applies smart phone to control the growth of products at home; [2]in-store vertical farm: VF set at store where consumers can watch the production growth and choose their preferred products; [3]indoor vertical farm: products grown at indoor environment with no direct contact with consumers.

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