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RESEARCH

Bridging the gap: exploring consumer knowledge, perceptions, and willingness to pay for aquaponics products across the UK

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Abstract

Aquaponics (a sub-field of integrated agri-aquacultural practices (IAAS)) has emerged as a novel approach to combat global food security, reduce soil erosion and nutrient loss, and mitigate agronomic greenhouse gas (GHG) emissions. However, little remains known of potential consumer markets. Despite recent research throughout Europe, Central America, Australia, and the Middle East, this work represents the first large-scale evaluation of UK consumer understanding, assessment, and willingness to pay (WTP) for aquaponic products. Following analysis of 588 survey responses, we identify environmental awareness and green consumption, recognition of common UK eco-labels and sector-specific certification schemes, and consumer perceptions of aquaponics compared to conventional, locally sourced, and organic food production. Initially, 44% of survey respondents were familiar with aquaponics, with familiarity positively influenced by age and level of education. After presenting a definition of aquaponics (detailing its use and commonly cited socio-environmental benefits), consumer perceptions were mixed, with respondents broadly favourable to the practice despite uncertainty. Over 43% of consumers were willing to pay an associated price premium for aquaponic produce (valued, on average, as a 23% price increase over conventional alternatives). This willingness to pay was statistically in line with the organic market premiums and independent of prior familiarity with aquaponics as a food production system. These findings suggest a sizable consumer market for aquaponic produce and public interest in its sustainability benefits. Tailored marketing strategies could position aquaponic produce competitively alongside organic and environmentally friendly alternatives (irrespective of certification/eco-labelling), ensuring the long-term economic viability of the emerging aquaponics industry.

Keywords Aquaponics · Aquaculture · Food security · Consumer perceptions · Consumer acceptance · Willingness-to-pay

Abbreviations

EAGC Environmental awareness & green consumption

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RAS	Recirculating aquaculture systems
IAAS	Integrated agri-aquacultural systems
GHG	Greenhouse gas
UAO	Understanding & awareness of organic food production
UAA	Understanding & awareness of aquaponic food production
WTP	Willingness to pay
FA	Familiarity with aquaponics
SCS	Sustainability certification schemes

Introduction

In the face of rapid anthropogenic change, urbanisation, and resource scarcity, current agricultural and fisheries practices are insufficient in combatting global food insecurity (Viana et al. 2022; Pawlak and Kołodziejczak 2020). In seeking alternatives, aquaponics has emerged as a novel approach to overcoming numerous sustainability challenges across the agricultural sector (Goddek et al. 2019; Yep and Zheng 2019), connecting recirculating aquaculture systems (RAS) with hydroponic horticulture. In this way, aquaponics has gained momentum as an agri-aquacultural innovation that maximises yield under limited resource input (Obirikorang et al. 2021), mitigates soil erosion and carbon emissions (Yang and Kim 2020), facilitates cultivation across peri-urban and urban environments (David et al. 2022; Wizra and Nazir 2021); and supports diversified socio-economic opportunities (Proksch et al. 2019).

Over recent years, aquaponics has evolved from its initial vision of small-scale, integrated farming to an industrial enterprise verging on widespread commercialisation (Verma et al. 2023; Yep and Zheng 2019). Nevertheless, despite theoretical promise and decades of research, the success of the aquaponics industry in practice remains mixed, especially throughout the EU and UK (Cammies et al. 2021). Unlike the US and Australia, few large-scale EU/UK aquaponic ventures have managed to showcase economic viability: hampered by barriers to adoption and development, including a lack of definitional clarity (Baganz et al. 2022), complex legislative and regulatory frameworks (Fruscella et al. 2021), current exclusion from agri-environmental subsidies, ineligibility for organic certification (Araújo et al. 2021; Lobillo-Eguibar et al. 2020) and limited knowledge of consumer markets (Greenfeld et al. 2020; Eichhorn and Meixner 2020; Miličić et al. 2017). Historically, much of the scientific literature on aquaponics has centred on understanding the development, technical application, and operational efficiency of varying system designs (Krastanova et al. 2022; Pattillo et al. 2022; Palm et al. 2018). More recently, research has begun challenging the economic, regulatory, and socio-political barriers to engagement and widespread adoption (Cammies et al. 2021; Turnšek et al. 2020). Nevertheless, comparatively little attention has been paid to characterising consumer awareness, perceptions, and willingness to pay (WTP) for aquaponic produce (for relevant examples, consult Tadesse 2023; Kralik et al. 2022; Awal and Bonnici 2021; Suárez-Cáceres et al. 2021; Eichhorn and Meixner 2020; Miličić et al. 2017; Short et al. 2017).

Consumers are becoming increasingly conscious of socio-environmental issues and individual responsibilities, particularly regarding food purchasing decisions (Mughal et al. 2021; Barker et al. 2019). Yet, for widespread 'green consumerism' to translate into commercial benefits, individuals must be both willing to accept novel technologies and front the cost of sustainability (Giacalone and Jaeger 2023; Sachdeva et al. 2015): given the price premiums often associated with environmentally friendly, locally sourced, and organic produce (Nguyen et al. 2019; Sigmon 2019). Despite demand, the market share of sustainable food products remains low, and assessment of the drivers for change in consumer perceptions, purchase intention, and WTP often prove inconclusive (Camilleri et al. 2023; Eyinade et al. 2021; Eichhorn and Meixner 2020). In this context, economic and regulatory challenges for commercial aquaponic systems are further compounded by a lack of public awareness (Cammies et al. 2021; Suárez-Cáceres et al. 2021; Turnšek et al. 2020). Early research findings typically demonstrate low consumer recognition for aquaponics, alongside poor knowledge of food assurance, sustainability, and welfare certification schemes beyond the organic label. Thus, current EU/UK regulations prohibiting aquaponics from organic certification hamper the ability to obtain higher prices for aquaponic produce and, as such, the long-term future economic viability of commercial systems (Fruscella et al. 2021; Miličić et al. 2017). Whilst early market analyses across Europe, Central America, Australia, and the Middle East have been positive in terms of the potential for consumer acceptance of aquaponic produce (Eichhorn and Meixner 2020; Greenfeld et al. 2019, 2020), no large-scale assessment has been conducted across the UK.

This study addresses this gap by evaluating consumer understanding, assessment, and WTP for aquaponic produce across UK consumer markets. Through quantitative analysis of survey data, we assess: (i) consumer recognition of common UK food safety, sustainability, and welfare-orientated certification labels; (ii) post-definition consumer understanding and acceptance of aquaponics, noting how the technology is viewed against conventional and organic methods of food production once provided with information regarding its potential benefits; (iii) evaluate potential markets and future consumer profile, via assessment of consumers' willingness to pay (WTP) price premiums for sustainable food products. In doing so, this research seeks to characterise UK consumer attitudes towards aquaponics: providing insights for developing effective marketing strategies to improve public awareness, influence policy decisions, and ensure the long-term success of commercial aquaponics in the UK and further afield.

Methodology

Survey design & data collection

The potential UK consumer population was cross-sectionally surveyed across a two-month period (1st February – 1st April 2022). The research questionnaire was primarily distributed online through social media networks (Facebook, LinkedIn, NextDoor, Twitter, WhatsApp), email chain links, and QR codes embedded in research flyers. However, supplementary in-person data collection was also conducted to build upon online responses and target consumer groups otherwise inaccessible to the above sampling methods. Here, participants were approached across the Greater Bristol Area and asked to partake via smartphone or paper copy. As such, the research population resulted from the non-probabilistic convenience and snowball sampling of UK adults (i.e., > 18 years old) with basic proficiency in English and, where relevant, access to the internet.

Following consultation with academic professionals and industry experts, the survey was designed to gather exploratory data on consumer perceptions of aquaponics in comparison to conventional, local, and organic models of food production. The resulting questionnaire was composed of 13 main questions (Appendix A). The questionnaire included numeric answers, closed and semi-closed-ended questions, and multi-item Likert scales ranging from 'strongly disagree' (1) to 'strongly agree' (5): through which respondents were asked to select the value that best reflected their position, opinion, or behavioural pattern. Following pilot testing, an additional 'unsure' response option was included, given the hypothesised lack of knowledge surrounding key terminology—coded as (0) upon analysis.

All participants were provided with an introductory passage and ethics statement explaining the research, its intended purpose, and key information regarding participant confidentiality, data management, analysis, and reporting. Upon subsequently agreeing to take part, the questionnaire was divided into four main sections:

1) The first section centred around the basic socio-demographic assessment of age, education level, and household income: to provide reference points for statistical analysis and comparison to broader population averages.
2) The second section focused on background consumer knowledge and purchasing behaviour. To do so (as utilised by Miličić et al. 2017), a six-item Likert scale was used to assess environmental awareness and green consumption (EAGC), alongside participant recognition of common UK sustainability, welfare, and food safety certification/assurance schemes and eco-labels.
3) The third section identified consumer perceptions towards organic food production. An eight-item Likert scale was utilised to ascertain understanding and assessment of organic food production (UAO) prior to subsequent questioning on resulting WTP for common organic vegetable and organic meat/fish produce types.
4) The final section applied a similar framework to explore consumer perceptions of aquaponics. A direct binomial (yes/no) question was provided to measure respondents' prior familiarity with aquaponics. Irrespective of initial responses, a brief definition was provided to ensure all participants were conceptually aware of the practice and its potential benefits. A final six-item Likert scale identified post-definitional understanding and assessment of aquaponic food production (UAA). Again, respondents were then asked to specify their WTP for typical aquaponic produce. When questioned on WTP, the distinction between vegetable and meat/fish produce was made to avoid biasing results based on common dietary choices.

The questionnaire concluded with statements for future research and contact. Respondents were asked to specify their willingness to: (i) engage in further research through semi-structured interviews; (ii) remain informed of future research outcomes; (iii) and/or enter a randomly allocated prize draw (to receive financial remuneration via online gift card).

Data treatment & analysis

Data management and visualisation were performed via Microsoft Excel 2022. In turn, quantitative statistical analysis of survey data was conducted using IBM SPSS Statistics 28 (SPSS Inc, USA). Prior to analysis, a series of reliability assessments were undertaken to ensure the validity and inter-item consistency of Likert scale responses (EAGC, UAO, and UAA). Exploratory Factor Analysis (EFA) was used to assess one-dimensionality and, where applicable, remove items insufficiently correlated with the desired construct(s) (Appendix B). Kaiser–Meyer–Olkin (KMO) measure of sampling adequacy, Bartlett's test of sphericity, and factor values were consulted for verification. Throughout, all variables were coded in the same direction. That is, any negatively balanced variables were reverse-coded so that the highest scores possible mean the same thing, wherein (1 = 5, 2 = 4, 3 = 3, 4 = 2, 5 = 1) (Suárez-Álvarez et al. 2018). Where valid, this explanation is valid for every statement with *.

Following interpretation, EAGC and UAA were identified as one-dimensional (principally explained by a single component). Whereas, UAO was identified as a multi-dimensional construct. To ensure construct validity, three individual Likert items (UAO5, UAO6, and UAO7) were removed when calculating mean participant scores. Taken further, all Likert response options relating to consumer 'understanding & awareness of organic food production' (UAO) were then removed from subsequent analysis, reporting, and production of summary figures. Values are, however, retained within the appendices to ensure transparency and aid in the external validation of research findings. Indicator reliability and internal consistency were considered across the revised constructs via Cronbach's α and composite reliability scores (Appendix B). Following normality testing and graphical visualisation to verify relevant assumptions, a series of statistical tests were conducted to determine key relationships between variables of interest and highlight potential differences in WTP. Thus, any result quoted as statistically significant has minimally satisfied the 95% confidence interval ($p < 0.05$).

Research ethics & informed consent

This research formed part of a broader, mixed-methods analysis of stakeholder and consumer awareness and initial perceptions of aquaponics. All research received full ethical approval from the University of Bristol Ethics of Research Committee (Reference ID: 10240).

Results

Demographic profile

Overall, 588 survey responses were recorded across the study period. Table 1 provides the demographic profile of research participants in contrast to the overall UK consumer population obtained via the UK Data Service (see Annual Population Survey 2021 (via Office for National Statistics Social Survey Division, 2023); OECD 2021; Family Resources Survey 2019–20 (via Office for National Statistics NatCen Social Research, 2021)). Chi-Squared Tests of Goodness-of-Fit were performed to contrast the study samples' socio-demographic distribution (age, education level, household income) against broader UK populational estimates.

Based on this characterisation, the sampled age is statistically different to the general population ($X^2 = 1727.19$, $df = 6$, $p = 0.000$), with greater numbers of 18–24, 45–54, 55–64-year-olds, whilst fewer numbers of the remaining age groups. The data also indicate a statistical difference in average education level. The surveyed population are, on average, more highly educated ($X^2 = 254.51$, $df = 6$, $p < 0.001$), with 72.1% of the sample educated to at least a degree level (compared to the 41.8% of the general population). A statistical difference was also identified between the surveyed population and wider populational estimates, with regard to approximate household income. Here, the sample population consists of greater numbers of higher earners ($X^2 = 1321.53$, $df = 6$, $p < 0.001$). In summary,

Table 1 Socio-demographic profile of research participants, viewed against wider (UK) populational averages

Description	Survey respondents (*n* = *588*)		Population averages
	Frequency	Percentage (%)	UK Average (%)
Age			
18 – 24	134	22.8	**10.6**
25 – 34	56	9.5	**17**
35 – 44	71	12.1	**16.1**
45 – 54	128	21.8	**16.9**
55 – 64	115	19.6	**15.8**
65 +	80	13.6	**23.6**
Prefer not to say	4	0.7	**/**
Education			
No formal education	9	1.5	**9.4**
GCSE's (or equivalent)	59	10.0	**23.8**
A levels (or equivalent)	87	14.8	**25.1**
Undergraduate degree	255	43.4	**25.6**
Postgraduate degree	139	23.6	**11.9**
Doctorate (PhD)	30	5.1	**2.0**
Prefer not to say	9	1.5	**2.2**
Annual household income			
Up to £12,500	33	5.6	**10.2**
£12,501—£25,500	86	14.6	**28.8**
£25,501—£50,000	167	28.4	**32.6**
£50,001—£75,000	131	22.3	**15.2**
£75,001—£100,000	59	10.0	**6.6**
£100,001 +	56	9.5	**6.2**
Prefer not to say	56	9.5	**0.4**

Data obtained from the UK Data Service, with education data acquired from the Annual Population Survey 2021 (See Office for National Statistics Social Survey Division, 2023); Household Income estimates obtained via the Family Resources Survey 2019–20 (See Office for National Statistics NatCen Social Research, 2021), and percentages values for percentage of UK population with Doctorate (PhD) level training taken from OECD 2021

consumers of all ages, levels of education, and household incomes are captured and well-represented within this survey; however, there remains an overall bias towards higher earning, more educated potential consumers, and lesser representation of consumers within the age groups of 25–44, and 65 or older.

Background environmental awareness & eco-labelling

Before explicitly addressing perceptions of aquaponic production, respondents' broad levels of environmental awareness and green consumption (EAGC) were analysed via the multi-dimensional assessment of consumer knowledge, behavioural patterns, and

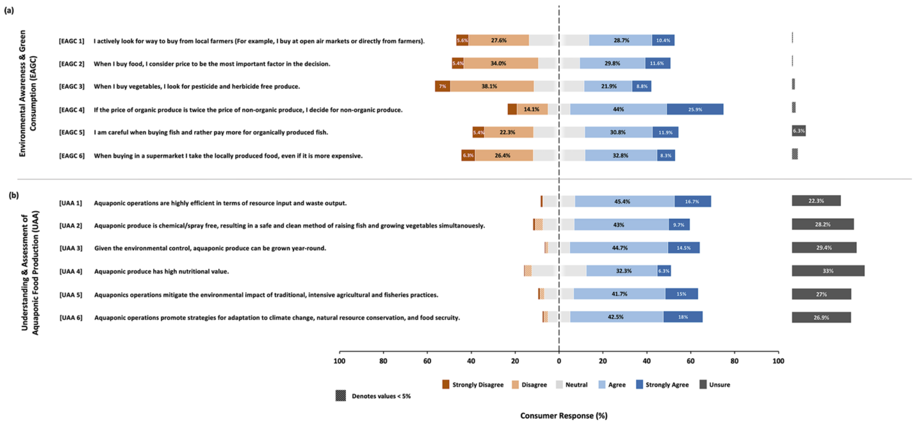

Fig. 1 Percentage consumer responses to Likert-scale questioning of key research constructs: **A** Environmental Awareness & Green Consumption (EAGC) and (**B**) Understanding & Assessment of Aquaponic Food Production (UAA). From left to right, the values provided represent the relative percentage of responses for 'strongly disagree' (brown), 'disagree' (orange), 'neutral' (grey), 'agree' (light blue), 'strongly agree' (dark blue), and 'unsure' (black)

purchasing attitudes towards predominantly environmentally friendly and sustainable produce, such as those 'locally sourced', 'spray free', or 'organic' (Fig. 1—A).

Of those surveyed, 39% of respondents actively sought ways to source local produce: from regional markets or farmers. Specifically, 30.7% actively sought pesticide and herbicide-free produce when buying vegetables. When buying fish, 42.7% would rather pay more for organically produced produce. Similarly, 41.1% claimed to select locally produced food items when shopping in supermarkets, even at an increased cost. Conversely, 41.4% of the surveyed population claim they consider price the most important factor during food purchasing, and 69.9% of participants opted for non-organic produce if the organic price was double that of conventional alternatives. To access the complete breakdown of percentage frequencies for Likert item responses, consult Appendix C. Spearman's correlation was conducted to determine the relationship between respondents' summated mean EAGC scores and key socio-demographic parameters. There was a medium, positive correlation between EAGC and age (r_s (588) = 0.366, $p < 0.001$); in addition to weak, positive correlations between EAGC and education (r_s (588) = 0.167, $p < 0.001$), and household income (r_s (588) = 0.081, $p < 0.049$); all of which were deemed statistically significant.

Consumer recognition of common UK certification/assurance schemes is presented in Fig. 2. Notably, most respondents (< 51.9%) recognised at least 50% of the logos displayed. Of those included, the most recognised were Fairtrade (96.9%), Red Tractor (81.6%), and Rainforest Alliance Certified (58%). By contrast, the least recognised across the study sample were eco-labels associated with Best Aquacultural Practices (BAP) (9.2%), The Wholesome Food Association (17.3%) and the EU organic logo (23.5%).

Consumer familiarity, understanding & assessment of aquaponic food production

Prior to research engagement, over half of respondents surveyed (56.1%) were unfamiliar with aquaponics. Binary logistic regression was carried out to identify the effect of key parameters (age, education level, household income, and general environmental awareness

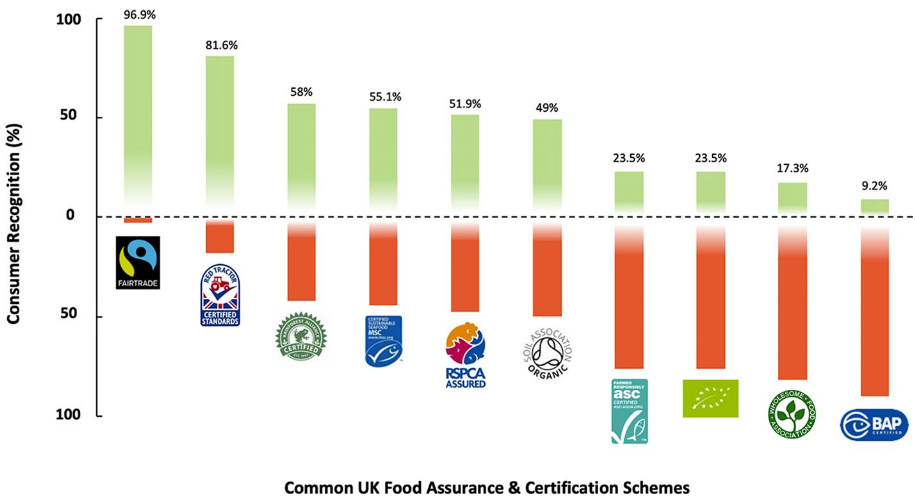

Fig. 2 UK consumer recognition of 10 food safety, sustainability, and welfare certification labels. From left to right, the values provided represent the relative percentage recognition of Fairtrade, Red Tractor, Rainforest Alliance Certified, Marine Stewardship Council (MSC), RSPCA Assured, Soil Association Organic, EU Organic, Aquaculture Stewardship Council (ASC), EU Organic, Wholesome Food Association, and Best Aquacultural Practices (BAP). Green bars (above midline) represent successful recognition of a given logo, whereas red bars (below midline) display the relative percentage of respondents that did not successfully recognise the logo displayed

and green consumption (EAGC)) on the likelihood of prior familiarity with aquaponics. The overall model was statistically significant when compared to the null model *(X_2* (19) = 65.023*, $p < 0.001$):* explained 14% of the variation in familiarity (Nagelkerke R^2); and correctly predicted 63.3% of cases. Upon consulting the predictor variables, age ($p = 0.003$) and education level ($p < 0.001$) added significantly to the model, with greater age and higher education level both associated with increased familiarity with aquaponics. In contrast, EAGC ($p = 0.125$) and household income ($p = 0.351$) did not add significantly to the model. When performing linear regression to obtain multi-collinearity diagnostics, the results indicate correlations between EAGC and education (medium), age (small), household income (tiny), and VIF values ranging from 1.024 to 1.201. Overall, respondents' age and education level significantly influenced likely prior familiarity with aquaponics (with older, more highly educated survey respondents increasingly likely to be familiar with the practice).

Following an initial definition of aquaponics (including the commonly cited benefits regarding sustainability, stocking densities, alongside reductions in pesticide, herbicide, and fertiliser use), survey respondents were presented with statements regarding aquaponic practices and resulting produce (Fig. 1—B). Responses indicated a generally favourable response to the definition, with many highly favouring aquaponics and its proposed socio-environmental value. Most respondents agreed that aquaponic operations are highly efficient (62.7%), allow for year-round cultivation (59.2%), and that resulting aquaponic products are chemical/spray-free, resulting in a safe and clean method of raising fish and growing vegetables simultaneously (52.7%). Additionally, 60.5% of participants believe aquaponics operations promote strategies for adaptation to climate change alongside mitigating the environmental impacts of intensive agricultural and fisheries practices (56.7%). However, with 'unsure' response options ranging from 22–33%, the definition alone was insufficient to adequately convince/explain the benefits to all parties. A Mann–Whitney U test illustrates a significant difference (U ($N_{familiar}=258$, $N_{unfamiliar}=330$) = 30,938.50, z = -5.710, $p<0.001$) in the mean understanding & assessment of aquaponics (UAA) scores of respondents already familiar with aquaponics; in comparison to those who were unfamiliar with the practice, prior to research engagement. Overall, the mean rank score for those familiar with the practice was 339.10, compared to 259.63 for those with no prior familiarity, suggesting those with prior experience of, and engagement with aquaponics, are more likely to understand its benefits and were more strongly aligned to its positive characteristics.

Willingness to pay (WTP)

Consumer WTP for common organic and aquaponic produce types is detailed in Fig. 3. Overall, 61.9% of the surveyed population expressed a willingness to pay more for organic produce when compared to conventionally farmed alternatives. In comparison, 43.2% of respondents would be willing to pay a premium for aquaponic produce. Thus, consumers are more likely to pay premium prices for organic produce when compared to the increasingly novel aquaponic produce entering the market.

To determine whether the proportion of WTP was equally distributed across all produce types, a Chi-Square Goodness-of-Fit test was performed. To conclude, WTP was not equally distributed across the produce types ($X^2=90.832$, $df=3$, $p<0.001$). Post-hoc, Chi-Square Tests of Independence were then utilised to assess consumer WTP between and across produce types. Of those surveyed, consumers are more likely to pay increased

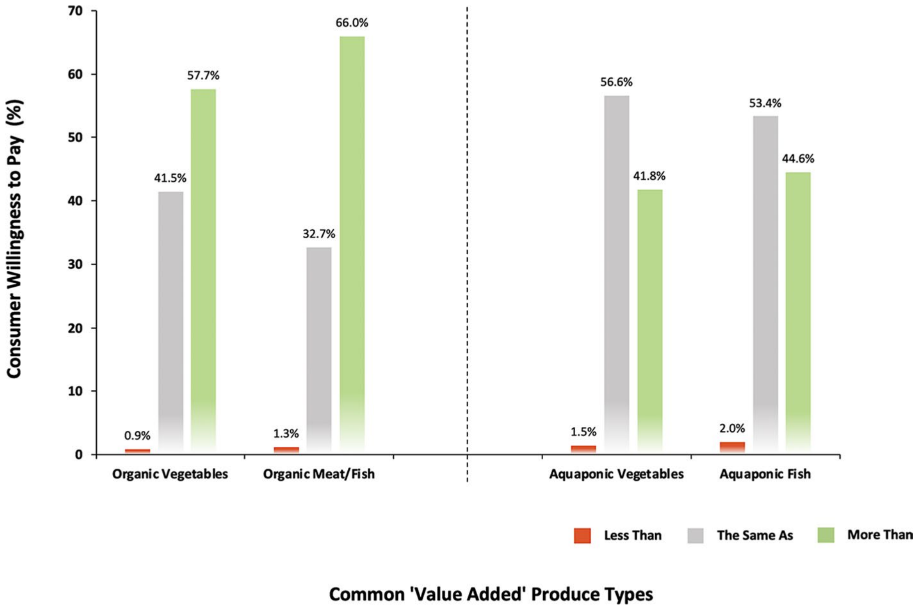

Fig. 3 Consumer willingness to pay (WTP) for organic (vegetable and meat/fish) produce; contrasted against same-sample WTP for aquaponic (vegetable and fish) produce. From left to right for each produce type, values presented are WTP 'less than' (red), 'the same as' (grey), or 'more than' (green) conventionally farmed alternatives. Total percentages are provided as outside data labels

prices for organic meat/fish produce than organic vegetable produce (*X^2 = 8.650, df = 1, p = 0.003*). On the contrary, consumers were equally willing to pay the premium cost associated with aquaponic fish and aquaponic vegetable products (*X^2 = 0.887, df = 1, p = 0.346*). Notably, consumers were most willing to pay increased prices for organic meat/fish: when compared across all potential cross-comparisons (i.e., organic vegetable, aquaponic vegetable, and aquaponic fish produce).

Further Chi-Square Tests of Independence were performed to assess the relationship between consumer WTP (for organic and aquaponic produce), against prior familiarity with aquaponics (FA) as a food production system. For aquaponic produce, there was a significant relationship between the two variables (*X2 = 5.135, df = 1, p = 0.023*). Similarly, a significant relationship existed between consumer WTP for organic produce and FA (*X^2 = 9.151, df = 1, p = 0.002*). As such, consumers familiar with aquaponics before this research were, on average, increasingly willing to pay the price premiums often associated with both organic and aquaponic produce.

Willingness to pay (WTP) – relative % increases

Where relevant, survey respondents were requested to specify the relative percentage increase in WTP for organic and aquaponic produce compared to conventionally farmed alternatives. Following descriptive analysis, the average increase in willingness to pay for organic produce was valued at 24.1% (vegetables = 22.5%; meat/fish = 25.7%), whilst for aquaponic produce, the average price increase was 22.5% (vegetables = 21.3%; fish = 23.6%).

A Kruskal–Wallis H test showed that there was a statistically significant difference in average increased consumer WTP between the different produce types; $\chi^2(3) = 9.675$, $p = 0.022$, with a mean rank increased WTP of 584.42 for organic vegetables, 633.52 for organic meat/fish, 547.96 for aquaponic vegetables, and 594.32 for aquaponic fish. Post-hoc, pairwise comparisons (Dunn's test with Bonferroni adjustments) indicated that increased consumer WTP for Organic Meat/Fish were observed to be significantly different from those of Aquaponic Vegetables ($\chi^2 = 85.555$, $p = 0.002$, adjusted $p = 0.014$). No other differences were deemed statistically significant. As such, whilst consumers were more likely to be initially willing to pay increased prices for organic produce than aquaponic produce (compared to conventional alternatives—see above), of those willing to pay a premium, there were no statistically significant differences in relative percentage price increase between organic and aquaponic produce. Mann–Whitney U tests illustrate a series of non-significant differences in the mean WTP percentage increase between those familiar with aquaponics as a food production system and those who (prior to research involvement) were unfamiliar: across organic vegetable (U ($N_{familiar} = 176$, $N_{unfamiliar} = 153$) = 12,627.500, $z = -0.985$, $p = 0.325$), organic meat and fish (U ($N_{familiar} = 194$, $N_{unfamiliar} = 176$) = 16,339.000, $z = -0.720$, $p = 0.471$), as well as aquaponic vegetable (U ($N_{familiar} = 122$, $N_{unfamiliar} = 116$) = 6769.500, $z = -0.586$, $p = 0.558$) and aquaponic fish produce ($N_{familiar} = 122$, $N_{unfamiliar} = 116$) = 7831.000, $z = -0.041$, $p = 0.968$), respectively. As such, the comparable percentage price increases observed across organic and aquaponic produce are not influenced by, or contingent, on prior familiarity with aquaponics.

Lastly, Spearman's correlations were conducted to determine the relationship between respondents' summated mean EAGC scores and relative percentage increases in willingness to pay for various organic and aquaponic produce. There were small, positive correlations between EAGC and WTP for organic vegetables (r_s (329) = 0.238, $p < 0.001$), organic meat/fish produce (r_s (370) = = 0.236, $p < 0.001$), in addition to further, small positive correlations between EAGC and WTP for aquaponic vegetable (r_s (238) = 0.267, $p < 0.001$), and aquaponic fish produce (r_s (251) = 0.248, $p < 0.001$): all of which were deemed statistically significant. Individuals with higher environmental consciousness were more likely to be willing to pay the premium cost(s) associated with green produce.

Willingness to pay (WTP) – consumer profile

The socio-demographic profile of those willing to pay associated price premiums for organic and aquaponic produce is presented in Table 2. On average, 55–64-year-olds, respondents educated to PhD level, and those in an income bracket of £25,501—£50,000 were responsible for the greatest price premiums observed. Overall, when considering WTP percentage increases across each key grouping (age, education, and household

Table 2 Socio-demographic profile of consumer Willingness to Pay (WTP) 'More Than' Conventionally farmed alternative, for varying organic and aquaponic produce types across key socio-demographic parameters (age, level of education, and approximate household income)

	Relative proportion of consumers willing to pay 'more than' (%)			
	Organic veg	Organic meat/ Fish	Aquaponic veg	Aquaponic fish
Age				
18–24	56.7	61.2	38.1	43.3
25–34	48.2	60.7	39.3	44.6
35–44	62	66.2	49.3	50.7
45–54	54.7	63.3	40.6	41.4
55–64	55.7	67.8	36.5	36.5
65 +	72.5	80	55	60
Prefer not to say	/	50.0	/	/
Education				
No formal education	22.2	44.4	44.4	44.4
GCSE's (or equivalent)	47.5	54.2	39	45.8
A Levels (or equivalent)	51.7	59.8	40.2	37.9
Undergraduate degree	56.5	67.1	43.1	48.6
Postgraduate degree	69.1	73.4	41	39.6
Doctorate (PhD)	66.7	70	50	53.3
Prefer not to say	44.4	66.7	22.2	33.3
Household income				
Up to £12,500	48.5	66.7	36.4	51.1
£12,501—£25,500	51.2	55.8	41.9	38.4
£25,501—£50,000	53.9	65.3	44.9	47.9
£50,001—£75,000	63.4	64.1	42	45
£75,001—£100,000	57.6	74.6	30.5	33.9
£100,001 +	66.1	69.6	51.8	53.6
Prefer not to say	62.5	75.0	37.5	41.1

income), there are relatively constant variations across varying age and income brackets—with no single response options skewing results, or strong positive/negative trendline. Here, education has the greatest effect on WTP percentage increases, rising, on average, by 23.2% from those with no formal qualifications, to those PhD educated.

Discussion

This study assessed consumer understanding, assessment, and WTP for aquaponics across the UK. Key findings indicate (1) a low prior familiarity with aquaponics (43.9%) despite generally high levels of environmental awareness and green consumption (EAGC) in the sampled population. (2) Consumer recognition of common food certification schemes/eco-labels was mixed, with most respondents recognising at least half of all logos displayed. There was a marked contrast in average consumer recognition between the widely publicised accreditations/welfare standards (i.e., Fairtrade, Red Tractor, Rainforest Alliance), and increasingly, niche, sector-specific, and/or locally-bound certification schemes (i.e., Wholesome Food Association, Best Aquacultural Practices) with the notable exception of the EU organic label (which was poorly recognised). (3) Post-definition, consumer perceptions of aquaponics were largely positive indicating receptiveness to aquaponic produce as a sustainable food alternative. (4) over 43% of surveyed consumers were WTP an associated price premium for aquaponic produce (valued, on average, as a 23% increase over conventional alternatives). Lastly, (5) the absence of statistically significant differences in relative percentage increases between organic and aquaponic produce suggests a comparable market position for both, setting the stage for a 'value-added' marketing strategy for aquaponic fish and vegetable products.

Accessibility of information and initial perceptions play essential roles in mediating consumer purchasing behaviour (Zhao et al. 2014; Testa et al. 2020). Thus, for aquaponics to become a commercially viable enterprise capable of delivering upon its proposed benefits, an understanding of initial consumer perceptions, prior knowledge, and broader consumer preferences is needed in developing future marketing strategies (Eichhorn and Meixner 2020; Greenfeld et al. 2019). Here, analysis of purchasing attitudes towards 'green' (locally sourced, spray-free, and organic) produce indicates varying levels of environmental awareness and green consumption (EAGC) in the UK. These findings reflect the diverse range of individual priorities, dispositions, and constraints commonly found across highly developed consumer markets. As the variety of agri-food products expands, consumers are increasingly conscious of the social, environmental, and ethical impacts of food systems (Siegrist and Hartmann 2020) and are willing to pay more for products that align with these values (Cecchini et al. 2018; Zander and Feucht 2017). Such findings are reflected in this present study, with many consumers indicating a WTP for the environmental benefits of aquaponics. Cost was also found to significantly impact purchase intent alongside socio-demographic factors (age, level of education, and approximate household income), which, in turn, positively correlate with EAGC. However, cost is just one of many factors that influence consumer perceptions of novel agri-food technologies, alongside broader issues of habitual purchasing and convenience, limited alternatives, and individual differences arising from food neophobia and cultural values (Cachero-Martinez 2020; Eldesouky et al. 2020; Kim 2018).

This study underscores the importance of education and outreach in increasing consumer awareness and understanding of aquaponics. Despite early innovation and outreach activities by pioneer farmers, prior consumer familiarity with aquaponics in the UK remains low (43.9%). Whilst in line with early European assessments (Miličić et al. 2017), recent work demonstrates increased variation across international markets and greater consumer awareness of aquaponics across Australia, Spain, and Latin America (Suárez-Cáceres et al. 2021; Greenfeld et al. 2020). This variation in consumer acceptance and understanding may be due to research design and distribution differences; or may also indicate broader underlying factors that impact commercial aquaponics' establishment and long-term success. As such, there is no 'one-size-fits-all' approach to maximising consumer understanding, acceptance, and prospective future buy-in. Outcomes will vary given levels of education and accessibility, given complex system designs and technological innovation, alongside regional bio-physical, economic, socio-cultural, and policy environments (Eichhorn and Meixner 2020; Pollard et al. 2017). Furthermore, although post-definition perceptions of aquaponics were generally favourable, lingering uncertainty and scepticism were evident, given the relative percentage of 'unsure' response options (ranging from 22–33% of surveyed respondents) for statements surrounding aquaponic food production, suggesting the need for more detailed information dissemination to build consumer trust in the benefits of integrated agri-aquacultural food production. As the health benefits and nutritional value of aquaponic produce remain largely unknown, such information was not included in the definition used. Consequently, respondents displayed notably high levels of uncertainty and scepticism to this statement, indicating they had not unthinkingly bought into the notion of aquaponics as a panacea to all environmental and sustainability challenges without considering both the definition and subsequent statements provided.

Ultimately, these findings suggest that, at present, novel aquaponic products (promoted as sustainable food alternatives) entering the market are likely to be highly accepted by environmentally aware and ethically conscious consumers (Eichhorn and Meixner 2020; Mauracher et al. 2013) – provided they are educated about the technology. Given that current consumer familiarity with aquaponics remains low, this highlights the need for information exchange, education, and outreach to increase consumer awareness and understanding (Greenfeld et al. 2019) as an essential prerequisite for long-term commercial success. For consumers to pay the price premiums required for industry expansion, knowledge of aquaponics' perceived socio-environmental advantages should be plainly stated to build understanding, and impact purchase intention (Suárez-Cáceres et al. 2021; Risius et al. 2017). This can be achieved, for example, via consumer-friendly front-of-pack labelling as a potentially cost-effective way of influencing consumer behaviour (Duckworth et al. 2022), highlighting commonly cited benefits, including the absence of pesticides/herbicides, limited food miles, high ethical standards, and efficiency in terms of resource input(s) and waste output(s) (Eichhorn and Meixner 2020). Improved communication measures could be further supported by holistic information and outreach marketing schemes highlighting early adopters and existing projects—online, in-store, and in-person—via demonstration farms, thematic workshops, and product tastings to decisively impact consumer willingness to purchase (Cammies et al. 2021; Eichhorn and Meixner 2020).

To date, aquaponic operations are economically viable only when there is market differentiation from conventionally produced food products (Gregg and Jürgens 2019). As such, early practitioners have had to diversify (on-farm and across supply chains), maximising profitability through food accreditation and certification schemes—market-orientated mechanisms designed to encourage pro-environmental behaviour via the provision of information regarding product sustainability and values (Brenton 2018; Sønderskov and Daugbjerg 2010). To this end, numerous authors have theoretically discussed the potential for marketing aquaponic produce as 'value added' (Miličić et al. 2017; Villarroel et al.

2016; Goddek et al. 2015). However, with the rapid emergence of novel sustainability certification schemes (SCS) and eco-labels, consumers face numerous, conflicting, and often ambiguous food labels (Sirieix et al. 2012). This growth and divergence in metrics have resulted in widespread controversy, and questions have been raised as to the effectiveness and adaptability of such schemes in a constantly changing market that highlights the need for increased regulation and reform (Sigurdsson et al. 2022; Mori et al. 2016). Herein, consumer recognition of common UK food assurance and certification schemes was highly variable. Whilst most recognised well-established, international standards such as Fairtrade (96.1%) and Rainforest Alliance (58%), alongside long-standing UK-wide, assured food standards including Red Tractor (81.6%), average consumer recognition for organic (i.e., Soil Association (49%), EU organic (23.5%), and Wholesome Food Association (17.3%) labels), and aquaculture-specific (i.e., Aquaculture Stewardship Council (23.5%) and Best Aquacultural Practices (9.2%), respectively) was, generally, far lower. Together, such findings suggest that across the UK market, many accreditation schemes may not be influencing consumer decision-making processes as intended (as key determining factors in food purchasing); and that food safety, sustainability, and welfare certification labels associated with sector-specific agricultural and fisheries practices may be ineffective, have little reach, or are saturated within the market to a degree that results in generalised consumer impact.

Almost half of surveyed respondents (48.6%) maintain that organic accreditation/labelling is an important factor in food purchasing decisions. With the growing popularity of organic products (Zhao and Dou 2019; Nechaev et al. 2018) and increased profitability of aquaponic systems if organic prices can be generated for resulting produce (Quagrainie et al. 2018), this represents a noteworthy conclusion in that: under EU Commission Regulation 2018/848, aquaponic produce is currently excluded from organic certification, and (2) despite UK departure from the European Union and resulting legislative overhaul of post-CAP agri-environmental regulations and subsidies, the adoption of an organic, or in turn, aquaponic-specific certification scheme for soil-less and Recirculating Aquaculture Systems appears unlikely to change under new environmental land management schemes (ELMS) (Cammies et al. 2021; Fruscella et al. 2021; Kledal et al. 2019). Here, a significant percentage of surveyed consumers (43.2%) were willing to pay an associated price premium for aquaponic produce entering the market (valued, on average, as a 23% increase over conventional alternatives, and statistically comparable to WTP increases for organic produce). Collectively, these findings indicate a potentially sizeable market for future 'value-added' aquaponic fish and vegetable products: capable of achieving price premiums equal to that of the longer standing and well-established, organically certified produce, and offers practitioners an avenue (irrespective of certification) to reimburse the high capital investments typically associated with commercial systems (Kledal et al. 2019). It should, however, be noted that WTP is not a universally applied phenomenon. Several individual, economic, psychological, and market-specific factors impact its influence, including price sensitivity and perceived value, product differentiation, and initial consumer perceptions (Chen et al. 2020, 2021; Suárez-Cáceres et al. 2021; Greenfeld et al. 2020). Moreover, it is also necessary to consider any potential thresholds in consumer WTP, as the proportion of consumers willing to pay the cost(s) associated with aquaponic and environmentally sustainable produce ultimately decreases as the price increases, as observed in this work (Short et al. 2017).

To this end, we advocate for a concerted marketing and education campaign for aquaponic produce to enable products to be sold at a premium in packaging that clearly advertises pro-environmental characteristics (i.e., lack of pesticides/herbicides, low stocking densities, minimal waste). Nevertheless, challenges remain. Not least, there remains a need for clarity regarding the certification status of aquaponic practices and resulting produce to offset the high capital costs associated with initial production (Fruscella et al. 2021; Gregg and Jürgens 2019; Kledal et al. 2019). However, with the poor levels of consumer recognition shown for existing food certification labels, an aquaponics-specific accreditation standard or food label is likely to fail—without comprehensive marketing efforts. In fact, given the current size of the UK aquaponic industry, there may be insufficient financial backing to achieve the scale of marketing required. As such, while external funding centred on exploring avenues for improving food security or sustainability may have considerable success, a suitable alternative may be the inclusion of aquaponics under existing organic labels that are broadly well-recognised and have an established price premium. As consumers educated on aquaponics are prepared to pay comparable price premiums, they may be well accepting of aquaponics under the organic label (Cammies et al. 2021; Fruscella et al. 2021; Gregg and Jürgens 2019; Miličić et al. 2017).

Limitations

Further research is necessary to solidify the claims made in this report and build upon its findings. Notably, this work represents the understanding and attitudes of consumers in one highly developed and specific food market. Therefore, echoing the claims made across the broader literature, greater insight is needed into consumer preferences and perceptions of aquaponics across different socio-cultural and international markets (Eichorn and Meixner 2020; Greenfeld et al. 2020). Despite efforts to ensure equal representation across key socio-demographic parameters of interest (age, level of education, and approximate household income), the research population resulted from non-probabilistic, convenience and snowball sampling. As such, those surveyed do not fully reflect the broader UK consumer landscape: varying markedly from populational estimates (somewhat younger, more highly educated, and on average, of a higher household income), thus limiting the transferability of subsequent results. That said, recruitment strategies centred on convenience/snowball sampling remain popular and valid options for achieving high levels of participant uptake (at low cost and given short sampling periods) and were chosen given full consideration of potential limitations (Suárez-Cáceres et al. 2021; McRobert et al. 2018). In utilising surveys to assess consumer acceptance of novel products, decisions are often made on a theoretical basis rather than real-life purchasing trends: centred on individual technologies in isolation, rendering cross-comparisons difficult (Giacalone and Jaeger 2023). Crucially, in sharing a favourable, albeit brief, consensus definition of aquaponics, any post-definitional consumer understanding and acceptance must be considered given the potentially leading 'benefits' cited, surrounding sustainability, stocking densities, and reductions in chemical inputs – which may have primed respondents to perceive aquaponics in a positive light and, in turn, potentially skew their subsequent responses. Similarly, the use of Likert-scale assessment tools raises broader issues of social desirability and central tendency biases. Participants may have felt inclined to provide responses that align with socially desirable attitudes or exhibit a tendency to select neutral or moderate responses, irrespective of their true opinions. Despite these methodological considerations, the approach employed in the study offers valuable insights into potential consumer market trends and structures: relevant in real-world contexts. Notably, the study reflects a common scenario where consumers are presented with limited or biased information when making purchasing decisions. Therefore, understanding how participants responded under such conditions provides valuable insights into real-world behaviours and decision-making processes. Furthermore, the dataset reflects a diverse range of response values across all Likert-scale categories, indicating a comprehensive representation of participant perspectives whilst providing a solid foundation for understanding consumer attitudes and preferences towards aquaponics. Nevertheless, these findings do also highlight the importance of providing comprehensive and neutral information to individuals to elicit informed consumer responses. Future research is recommended to supplement online sampling with conventional methods that more heavily capitalise on respective benefits (Lamm and Lamm 2019), utilise increasingly detailed methods of inquiry, and extend the conversation to consider additional actors along the whole value chain, including producers, practitioners, and end purchasers, alongside local government, extension and advisory services, and educational institutions (Greenfeld et al. 2020; Hao et al. 2020).

Conclusions & future perspectives

In summary, this research emphasises the pivotal role of consumer familiarity, understanding, and WTP in shaping the market potential for aquaponic produce. It presents the case for a potentially sizeable future UK market, achieving comparable price premiums to organic produce. Crucially, the study demonstrates that education and outreach are necessary to ensure long-term commercial viability—facilitated through improved communication measures and marketing strategies that increase public acceptance, combat potential uncertainty/scepticism (especially amongst consumer demographics unfamiliar with the practice), and emphasise aquaponics' inherent socio-ethical benefits and reduced environmental burden (Ibrahim et al. 2023; Greenfeld et al. 2021; Eichhorn and Meixner 2020; Rizal et al. 2018).

Challenges selling aquaponic produce at a premium despite potential consumer appetite align with, and emphasise, the need for broader economic, regulatory, policy, and labelling reform in creating a favourable landscape for the commercial expansion of commercial agri-aquacultural practices (as outlined herein). With such reforms, aquaponics has the potential to become an economically viable model of agri-food production in developed food markets, resonating with environmentally aware and ethically conscious consumers (Cammies et al. 2021; Miličić et al. 2017). As the future of food production increasingly centres on environmental sustainability and diversification, achieving commercial success for aquaponics hinges on cross-collaboration and investment throughout the supply chain, effectively bridging the gap between practitioners, producers, and end purchasers. To this end, this study provides insight into the current state of consumer perceptions and offers suggestions of a roadmap for integrating aquaponics into mainstream food production systems.

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Author contributions C.C and R.C conceived the initial idea. J.D, F.S, R.C, C.C and R.M developed the idea and methodology. J.D and F.S collected all the data. J.D and C.C analysed the data with input from F.S, R.C and R.M. J.D wrote the manuscript with input from C.C, R.C and R.M. J.D produced the figures with input from F.S, R.C, R.M and C.C.

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Data availability No datasets were generated or analysed during the current study.

Declarations

Ethics statement This research received full ethical approval from the University of Bristol Ethics of Research Committee (Reference ID: 10240). To this end, assurances were made to ensure that all data collection, analysis, and storage complied with General Data Protection Regulations (GDPR) and relevant UK legislation.

Competing interests Rosemary Crichton and Christopher Cammies have non-commercial relationships with Bioaqua Farm, an aquaponics company based in Somerset, UK. Rosemary Crichton is Director of the not-for-profit Bristol Fish Project CIC. The authors declare that the research was conducted in the absence of any further known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper or be constructed as a potential conflict of interest.

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