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Consumer preferences for aquaponics: A comparative analysis of Australia and Israel*

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Abstract

Aquaponics, the combined rearing of fish and hydroponic horticulture, has great potential for sustainable food production. Despite increasing research and investments in commercial scale systems, aquaponics is not yet a successful industry and most businesses report negative returns. Aquaponic produce is thought to contain added value to the consumer, and the environment. As most consumers are unaware of aquaponics and their benefits, little is known of its potential market. The present study addresses this gap by analysing willingness to consume aquaponic produce at different price levels in Israel and Australia. We used econometric tools to study the effects of pricing and other factors on revenues in each country. Cluster analysis was used to define groups of potential consumers. The results indicate that 17-30% of the population in both Israel and Australia would prefer to consume aquaponic produce once informed of their added value. Revenues at a given premium would be higher in Israel than in Australia, and higher for a leafy green, than for fish. Different segments of the population differed in their willingness to consume aquaponic produce, as well as in their stated motivations when purchasing food.

Conclusions highlight the importance of case-specific research on consumer preferences and economic considerations preceding commercial investment in aquaponics.

Key words: aquaponics; consumers; motivations; cluster analysis; market potential; willingness to consume.

1. Introduction

Aquaponics is a term that combines “aquaculture” and “hydroponics”. It refers to systems that integrate fish production in a closed system and soilless plant cultivation. Applying the ancient concept of integrated farming, aquaponics recirculates nutrient-rich effluent water from aquaculture to be used by plants that consume the nutrients. In this biological process bacterial cultures make nutrients available for plants and the water is thereby cleaned for reuse in the aquaculture tanks (Rakocy, 2012).

1.1 Aquaponics as a sustainable agricultural system

The ability to harvest both fish and plants from a closed system with little input other than fish feed, has a large potential in supplying growing food demands, especially in urban areas with short supply chains (dos Santos, 2016; Hindelang et al., 2014; Laidlaw and Magee, 2014), as well as rural areas, and developing countries (Somerville et al., 2014; Nichols and Savidov, 2011).

Aquaponics includes a variety of different production systems that can yield many types of edible plants and fish, thereby contributing to food security. Because of the chemical-free process that emulates the natural nutrient cycle, aquaponics is often referred to as an organic way of growing food (Goda et al., 2015; Gooley and Gavine, 2003).

The water efficiency of aquaponics is due to the recirculation of water in these systems, requiring only compensation for water losses due to transpiration and evaporation (Forchino et al., 2017; Tyson et al., 2011). Different system designs and climates lead to different levels of water efficiency when compared to soil-based cultivation, and range from 2.37 times (Love and Tokunaga, 2015) to 10 (McMurtry et al., 1997) times more efficient water use. With minimal water use and impact on the environment compared to conventional farming systems, it could play a significant role also in regions of high climate risk including arid areas (Goddek et al., 2015; McMurtry et al., 1997).

Reduced use of fertilisers for plant growth is achieved by utilising nutrients released in aquaculture effluents. There is generally a need to add limited amounts of minerals such as

calcium (Ca), potassium (K) and iron (Fe) to the aquaponic system, depending on the crops and growth stage but overall there is considerable reduction in fertiliser use (Rakocy et al., 1997; Tyson et al., 2011) as compared to conventional farming schemes.

Other proclaimed environmental benefits of aquaponic production are waste reduction, supporting urban farming, and climate change mitigation through energy efficiency (Goddek et al., 2015).

1.2 Technical and economic constraints on the development of commercial aquaponics

Despite its potential and interest by governments (Engle, 2015; Joly, Junge, and Bardocz, 2015) and international institutions, such as the European Union (König et al. 2018; Milliken, 2017) and the United Nations (Somerville et al., 2014, FAO 2019), the aquaponic industry has not spread widely and there are only a few commercial-scale aquaponic systems that make a profit from food production alone (Love et al., 2015; Villarroel et al., 2016).

Substantial research was conducted on aquaponics in the past decade (Junge et al., 2017), focusing mostly on the study of complex production systems, aimed to optimise the mechanical and biological aspects of aquaponics (Greenfeld et al. 2018). Several studies explored economic feasibility of current systems and reported a range of results from established profitability in the Virgin Islands (Bailey and Ferrarezi, 2017; Bailey et al., 1997; Rakocy et al., 2003), to marginal or partial profitability in other places (Bosma et al., 2017; Goodman, 2011; Love, Uhl, and Genello, 2015; Tokunaga et al., 2015).

A common conclusion from these economic assessments and reviews is that profitability can be enhanced by improving the public perception of aquaponics (Tyson et al., 2011). Unlike cost reduction, which has been explored in studies optimising production, few studies have addressed ways to increase revenue by improved marketing (Greenfeld et al., 2018). Several authors highlight the importance of consumer perception for the development of an aquaponics industry (Bosma et al., 2017; Goddek et al., 2015; Junge et al., 2017; Vermeulen and Kamstra, 2013) and for sustainable agriculture in general (Sage, 2012).

In the following section we present current understanding on the willingness of consumers to pay for the added value of aquaponics or products that have similar added value.

1.3 Consumer perspective and willingness to pay for added value of aquaponic products

Acceptance of aquaponic produce has been addressed in several countries. Positive attitudes were found amongst representative consumers in Alberta, Canada (Savidov, 2003),

Minnesota, USA (Short et al., 2017), Romania (Zugravu et al., 2016) and Malaysia (Tamin et al., 2015), where most respondents expressed intentions to consume produce from aquaponic systems once they were made available. In Berlin, Germany, on the other hand, most of the sampled population rejected the idea of aquaponics, and did not express an intent to consume aquaponic produce (Specht et al., 2016).

Studies that asked respondents about their reservations regarding aquaponic products, mainly reported on concerns about public health being negatively affected by aquaponics (Miličić et al., 2017; Savidov, 2003; Short et al., 2017; Specht et al., 2016).

Consumer views of products with added value have been studied extensively. It is commonly quantified as willingness to pay (WTP) for added value (Breidert, Hahsler, and Reutterer, 2006), or as willingness to consume (WTC) (Vanhonacker et al., 2013). The labelling of products, defining them as possessing added value such as “organic”, “locally grown” or “healthy” was found to increase WTP in many countries (Janssen and Hamm, 2012). Consumer surveys addressing WTP may be biased by referring to hypothetical consumption questions (Harrison and Rutström, 2008), but were found to be a good reflection of real-life choices and have yielded valid and similar demand curves (Miller et al., 2011).

There are hundreds of studies on WTP and WTC for organic produce and other health (Rödiger and Hamm, 2015) and environmental (Laroche, Bergeron, and Barbaro-Forleo, 2001) added values, but very few on aquaponic produce. Miličić et al. (2017) published the first quantitative analysis of consumers’ WTP for aquaponics. They found that most respondents would pay up to 40% more for aquaponic produce. As data for that survey were gathered using a network of aquaponic researchers and entrepreneurs (Milliken, 2017), it does not represent the general population, but does provide a good starting point for more specific studies of target populations in local and regional markets. Short et al. (2018) used an experimental approach and showed that consumers in the United States would not pay more for aquaponic lettuce. This study did not supply any information about benefits of aquaponics to participants, so it was effectively assessing consumer knowledge of aquaponics rather than WTP for its benefits.

Consumer willingness to pay a premium for the ‘green,’ ‘environmentally-friendly’ aspects of aquaponics is a recurrent topic in many studies. In Scandinavia, for example, the premium for such ‘green’ goods can be as high as 13-18% more (Bjørner, Hansen, and Russell, 2004).

Studies carried out in the 1990's described the typical population willing to pay a premium for green products as young, female, educated, and wealthy (Laroche et al., 2001; Straughan and Roberts, 1999). More recent research exploring consumer attitudes has found that consumer behaviour is a better way to classify consumers of green products than demographics (Chekima, Syed Khalid Wafa, Igau, Chekima, & Sondoh, 2016; Paul, Modi, & Patel, 2016; Rana & Paul, 2017). Despite the strong connection between environmental attitudes and WTP a premium for environmentally friendly food, the connection is not linear, as shown in a survey in Mexico by Husted et al. (2014). This is important since a small shift in attitude may be enough to generate a niche market, as suggested by Biswas and Mousumi (2016), who reported conceptual and contextual factors determining WTP for green products in India. Both can be enhanced by targeted education regarding the concepts of sustainable consumption.

Organic certification has been found to increase WTP and is predicted to boost returns on investment in aquaponics by about 5% (Tokunaga et al., 2015). In the European Union countries aquaponic produce cannot be marketed as "organic", because it was grown without soil and at high fish stocking densities (Junge et al., 2017), but can be regarded as "chemical/spray free". It is noteworthy that chemical-free food is attractive as such to many consumers and stakeholders (Blidariu and Grozea, 2011; Husted et al., 2014; Seo, Someya, and Dowaki, 2019).

There is limited information regarding the perceived taste of aquaponic produce. Aquaponic lettuce was found less appealing than soil-grown lettuce by most participants of a small sample experiment in Zurich (Graber and Junge, 2009), but reported to be preferred in Alberta (Savidov, 2003) and by chefs in Australia and Israel (Chef M. Andrew, Australia, personal communication November 2015; Chef T. Alleli, Israel, personal communication, October 2018).

1.4 Commercial aquaponics in Australia and Israel as case studies

In contrast to the progress made in commercial aquaponics in the USA and Canada, and growing interest in Europe, two countries that are unexpectedly behind are Australia and Israel. "Garden scale" or backyard aquaponics have been popular in Australia since the 1990's, with many growers involved in internet communities (Herbert and Herbert, 2008; Malcolm, 2005). Commercial scale aquaponics has been attempted in Australia as well (Gooley and Gavine, 2003), and pioneering research has been carried out, notably the work of Lennard (Lennard and Leonard, 2004, 2006; Nichols and Lennard, 2010). Israel has a strong agri-tech industry and

has contributed scientific and technological developments supporting modern aquaponics (Somerville et al., 2014; Kolkovski et al., 2003; Neori, 2007; Yogeve et al. 2017). In both countries, there are only a handful of operating commercial-scale aquaponic systems with little public support and without a professional framework to promote this industry. This is somewhat surprising, considering there is high awareness and WTP for both health and environmental benefits in Israel (Becker, Tavor, Friedler, & Bar, 2015) and Australia (Vince and Haward, 2017; Zander and Garnett, 2011). These facts seemingly make both these countries potentially suitable markets for aquaponic produce. However, to assess the willingness of consumers to pay a premium for aquaponic produce, direct observations are needed.

In this study we tested the underlying assumption that informed consumers will choose aquaponic produce and pay a premium for it based on its added value. We present results of consumer surveys in Australia and Israel as case studies for consumer WTC and the way it is affected by price and other factors. Beyond observations on the average consumer, we use the survey data to identify different segments within each potential market, differing in their WTC and factors effecting it.

2. Methods

2.1 Survey design and data collection

Potential consumer populations in Australia and Israel were surveyed from June to October 2017. A different data collection scheme was designed for each country to ensure that the sample was representative of the general population. In Israel, respondents were approached face to face in public places and asked to complete a questionnaire. This process was continued until the intended number of respondents was reached (n=200). In Australia, an online survey was distributed by a panel data service (Dynata, Sydney) to a representative sample of the population. After removing invalid respondents (such as those under 18, or unaware of household shopping habits) from our initial data-set, and “speeders” (participants submitting the online survey within less than 1/3 of the average completion time), following Greszki et al. (2014), we were left with the sample for Australia as n=321 and n=200 for Israel. Results of demographic variables were contrasted to means of the general population, to further ensure representativeness.

The survey consisted of an introduction describing aquaponics and its benefits to the environment and product qualities. Following this were questions divided into three sections:

(1) The first section of questions was designed to establish respondent's WTC. Willingness to consume is a form of Stated Preference that is less sensitive to the endogeneity problem than direct assessment of WTP (Martínez-Espiñeira & Lyssenko, 2011). Each respondent used a four-point Likert scale to assess the expected quantity to be consumed by their household of different products at different prices. Two food products were chosen, lettuce and fish that are commonly grown in aquaponic systems (Love et al., 2015; Villarroel et al., 2016). The most common fish species reared in aquaponic systems is tilapia. However, they are considered an invasive species in Australia and are thus not generally reared there. We therefore substituted trout for tilapia in the Australian questionnaire. The Likert scale for quantities used number of heads (0, 1, 2, ≥ 3) for lettuce and grams (0, 250, 500, ≥ 1000) for the fish. For each product, five scenarios were presented following Martínez-Espiñeira et al. (2015). The first question referred to conventionally grown (non-aquaponic) products at standard market price, and respondents were asked to select the amount they consumed weekly. This question provided a Revealed Preference benchmark for current consumption. The four following questions asked what quantity would be consumed of the same product produced in an aquaponic system, at a similar price and for three levels of premiums. These responses were used as Stated Preferences for a hypothetical product as aquaponic produce is not currently available to most consumers.

Further adjustments were required to adopt the survey for use in Israel and Australia. A Hebrew translation was used in Israel, and the prices given in questions on consumption were adjusted to reflect realistic consumption decisions in each country. In Australia, lettuce is normally sold at ~2.5 Australian Dollars (AUD)/head, and thus prices for aquaponic lettuce were set at 5, 4, 3.5 and 2.5 AUD. Prices for aquaponic trout were set at 35, 30, 25 and 20 AUD, being based on the price of whole trout commonly sold in Australia for ~20 AUD / kg. In Israel, lettuce is generally sold at ~3 Israeli Shekels (ILS)/head, and prices for aquaponic lettuce were set at 9, 7, 5, 4 and 3 ILS. Whole tilapia sells for 24 ILS/kg, and thus prices for aquaponic tilapia were set at 48, 40, 32 and 24 ILS/kg.

(2) Section two consisted of questions dealing with consumer motivations other than cost. Respondents indicated how much different motivations affect their decisions on food purchase on a scale from 1 (= no affect) to 5 (= highly affected). When selecting the motivations, care was taken to avoid parameter endogeneity by phrasing the questions in a general manner: *"To what extent does awareness to health and nutrition considerations influence your choice of food purchase?"* and did not refer to aquaponic produce specifically. Motivations referred to were: 1) health, 2) environment, 3) freshness, and 4) food taste.

(3) The third part consisted of socio-demographic questions to support the characterisation of potential consumers, referring to household size and income, and to respondents' age, gender and level of education. The question defining income levels differed between Israel and Australia for the listing of options below and above average household income. In Australia, net annual income was used as follows (AUD): 1 = less than \$49,000, 2 = \$49,000 to \$99,000, 3 = \$100,000 to \$149,000, 4 = \$150,000 to \$199,000, 5 = \$200,000 or more. In Israel the question referred to monthly income and the scale used was (ILS): 1 = less than 8,000 ILS, 2 = 8000-12,999 ILS, 3 = 13,000-17,999 ILS, 4 = 18,000-22,999 ILS, 5 = 23,000 ILS or more. Means of demographic variables were compared to national means, obtained from reports by the national bureau of statistics in each country (ABS, 2016; CBS, 2019), and adapted to the same scales used in the current survey. To supplement socio-demographic parameters, respondents were asked to indicate the extent of organic food consumption in their household, on a scale of 1 to 5 (0-5, 6-25, 26-50, 51-75, 76-100%). Respondents were also asked if they were members of an environmental organisation, and if they had heard of aquaponics prior to this study. Since each respondent referred to four or five different price scenarios, the number of observations for each product (N) was between 760-1096 (see Table 2).

2.2 Data analysis

Willingness to consume aquaponic produce at different price levels was used as the stated preference of consumers willing to consume aquaponic produce for their benefits (Mesías Díaz et al., 2012; Becker et al., 2015). In the regression analysis we used the quantity stated to be consumed at a given price (Q), as the dependent variable and the price, and demographic and motivational statements were used as explanatory variables (α_i see list of variables in Table 1). Since not all households consume fish or lettuce of any sort, a common response to WTC questions is zero unrelated to their acceptance of aquaponics. For this reason, we used tobit regression (Tobin, 1958), following Becker et al. (2015) and Schlup (2018). Tobit is a censored regression model on quantity consumed ($Q^* = \alpha_i z_i + e_i$) that accounts for the effects of the independent variables (z_i) only if the quantity is greater than zero ($Q^* > 0$). By using the specified parameters above, we developed the following model:

$$Q = [\sum \alpha_i z_i] + e_i = \alpha_0 + \alpha_1 HEALTH + \alpha_2 ENVIRONMENT + \alpha_3 TASTE + \alpha_5 GENDER + \alpha_2 AGE + \alpha_6 INCOME + \alpha_7 EDUCATION + \alpha_8 HOUSHOLD + \alpha_9 ORGANIC + \alpha_{10} ENVORGANIZATION + \alpha_{11} FARMILIARAQUAPONICS + \alpha_{12} PRICE + e_i$$

Tobit results were later used to plot a revenue curve for both products in Australia and Israel. All econometric analyses were performed using the Stata program, version 14.0 (Statacorp, USA). To establish a revenue function (TR , total revenue), we multiplied the price premium (p) by the associated quantity consumed (Q) after substituting the mean value of all explanatory variables (z_i) and multiplying them by their coefficients (α_i). This is given by:

$$TR = pQ = p [\sum \alpha_i z_i]$$

When presenting the price, we used the rate of premium as the percentage above the price of the conventional product to enable comparison among the different products.

The same survey data were used for cluster analysis to study the segmentation of potential consumers following Qannari et al. (2001) and Villarroel et al. (2016). These different methods of analyses complement one another and present a global coherence (Cariou and Qannari, 2018). We used factorial analysis to identify the main components and reduce the number of variables (see dos Santos, 2018; Field, 2013; Jaeger et al., 2017; Saba et al., 2018). Validation of factorial analysis was confirmed using the Kaiser–Meyer–Olkin measure of sampling adequacy and Bartlett’s test of sphericity (Gorton, Douarin, Davidova, & Latruffe, 2008).

To identify segments within potential consumers we formed homogeneous groups (clusters) using K-means clustering (Gil, Gracia, and Sanchez, 2000; Verain, Sijtsema, and Antonides, 2016) and cluster analysis (dos Santos, 2016; dos Santos, 2018). These were used since among the multivariate methods, cluster analysis and K-mean cluster analysis are most adequate for homogeneous groups with high internal consistency and for large external differences among groups (dos Santos, 2018; Gorton et al., 2008). These methods have been used extensively to study consumer attitudes (Cliceri et al., 2018; dos Santos, 2016; dos Santos, 2018; Miličić et al., 2017).

Multivariate techniques (cluster and factorial) were performed separately for the Israeli and Australian samples. The software used for all multivariate analyses was SPSS version 23 (SPSS Inc., USA).

3. Results

3.1 Descriptive statistics

The socio-economic characteristics and attitudinal statements about aquaponics for respondents in Australia and Israel are presented in Table 1. Slightly more than half of the

respondents were female in both countries, and the age of the sample population was younger than the corresponding average age of the population over 18 in both Australia (sample: 45.03, national mean: 47.18) and Israel (sample: 38.67.03, national mean: 45.68). The average annual income of respondents was slightly lower than the national mean household annual income in both Australia (sample: 2.23, national mean: 3.00) and Israel (sample: 2.19, national mean: 3.00), while education levels were higher in the sample in both Australia (sample: 3.51, national mean: 2.86) and Israel (sample: 3.44, national mean: 2.88). Household size in our sample is similar to national means in both Australia (sample: 2.78, national mean: 2.60) and Israel (sample: 3.62, national mean 3.72).

In Australia, 5% of the respondents claimed to belong to environmental organisations, while in Israel this value was just 3% of the sample. Organic products are consumed by about 8% and 23% of the population in Israel and Australia, respectively, and whereas 56% of the Australians asked were familiar with aquaponics before this survey, only 17% of the Israelis had heard of aquaponics.

Table 1. Descriptive characteristics of survey participants in Australia and Israel

Variable	Definition	Australia		Israel	
		Mean	SD	Mean	SD
Gender	m - Male or f - Female	44%(m)	56%(f)	42%(m)	58%(f)
Aquaponics	Previously familiar with aquaponics	56%		17%	
Age	Years	45.03	15.70	38.67	11.48
Household size	Number of people in participant's household	2.78	1.38	3.62	1.39
Education	Scale of 1 (=high school) to 4 (MSc/PhD)	3.51	1.14	3.44	0.94
Income	Scale of 1 to 5 (country-dependent)	2.23	1.15	2.19	0.82
Environmental Organisation	Members in an environmental organisation (%)	5.00	2.10	3.00	1.60
Organic	Consumption of organic products (%)	22.00	11.00	8.00	9.80
Health	Influence of health considerations on food purchase from 1 (=no affect) to 5 (=high affect)	4.01	0.93	3.56	1.10
Environment	Influence of environmental considerations on food purchase from 1 (=no affect) to 5 (=high affect)	3.35	1.03	3.09	1.14
Freshness	Influence of product freshness on food purchase from 1 (=no affect) to 5 (=high affect)	3.69	1.07	3.81	1.13
Taste	Influence of product taste on food purchase from 1 (=no affect) to 5 (=high affect)	4.31	0.85	4.25	0.95

3.2 Willingness to consume aquaponic produce

The proportion of respondents that would increase consumption was greater for fish (Australia: 19.63%; Israel: 30%) than for lettuce (Australia: 17.13%; Israel: 24%), and greater in Israel than in Australia. Most of the survey respondents in both countries said they would not increase their consumption of lettuce or fish if aquaponic produce were available even at a similar price as a non-aquaponic product. A small number of respondents (3-4.5%) in both countries said they would reduce their consumption of aquaponic products if these were sold at the same price as non-aquaponic products.

The regression results on the amount of produce respondents said they would purchase vs other variables (Table 2) show that, as expected, consumption was negatively correlated with product prices for lettuce and fish in both Israel and Australia.

In Australia, other factors found to significantly ($P < 0.05$) affect amounts of aquaponic fish that would be consumed were organic food consumption, membership in environmental organisations, importance of taste, income and household size; these all had a positive correlation with the amount that would be consumed. Similarly, although with some points of difference, lettuce consumption was positively correlated with organic food consumption, previous knowledge of aquaponics, importance of environmental motivations, and age and household size. Product prices were important factors negatively correlated with the amounts of both fish and lettuce that would be consumed.

In Israel, the amount of aquaponic fish and lettuce that would be consumed was positively correlated with organic consumption, age and household size, and environmental motivations. The amount of lettuce that would be consumed was affected by the same variables, except that it was correlated also with education and with the importance of taste rather than environmental factors.

Table 2. Tobit regression of variables affecting quantity of aquaponic produce that would be consumed at different prices in Australia and Israel.

Variable	Australia				Israel			
	Fish		Lettuce		Fish		Lettuce	
	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE
1. Health	-0.017	0.083	0.114**	0.045	0.044	0.065	0.011	0.036
2. Environment	0.123*	0.075	0.215***	0.041	0.187***	0.063	0.186	0.035
3. Freshness	0.066	0.063	-0.032	0.034	0.099*	0.056	0.013	0.032
4. Taste	0.28***	0.083	0.010	0.043	-0.071	0.067	0.085**	0.037
5. Gender	-0.118	0.126	0.001	0.070	-0.208*	0.123	0.036	0.069
6. Age	-0.022	0.046	0.110***	0.032	0.280***	0.073	0.071**	0.040
7. Income	0.214***	0.058	0.069	0.019	-0.001	0.035	-0.032	0.020
8. Education	-0.009	0.057	0.017	0.031	0.003	0.071	0.071**	0.040
9. Household size	0.160***	0.049	0.111***	0.027	0.196***	0.046	0.171***	0.015
10. Organic consumers	0.363***	0.060	0.150***	0.033	0.174***	0.066	0.142***	0.037
11. Environmental organisations	0.681**	0.318	0.052	0.163	-0.492	0.418	-0.045	0.229
12. Familiarity with aquaponics	-0.130	0.129	0.15**	0.071	0.141	0.168	0.097	0.094
13. Price	-0.10***	0.011	-0.501***	0.035	-0.058***	0.006	-0.20***	0.260
Constant	-2.61***	0.517	0.101	0.273	0.357	0.471	0.356	0.260
	N=1092		N=1096		N=780		N=974	
	LR χ^2 =183.22		LR χ^2 =293.04		LR χ^2 =154.06		LR χ^2 =294.33	
	P> χ^2 = 0.00		P> χ^2 = 0.00		P> χ^2 = 0.00		P> χ^2 = 0.00	
	LL = -1135.416		LL = -1234.287		LL = -1206.744		LL = -1255.273	
	Pseudo R ² =0.075		Pseudo R ² =0.106		Pseudo R ² =0.06		Pseudo R ² =0.11	

Variables 1-4 are the different motivations for buying food expressed by survey respondents, variables 5-9 are socio-demographic parameters and variables 10-12 represent additional personal information about the respondents. Each respondent estimated their consumption at several price levels, referred to here as variable 13. SE=standard error. Significance codes (*P* values) are < 0.01 *** ; < 0.05 ** ; and < 0.1 *

3.3 Establishing revenue curves from consumption at different premiums

Applying the revenue function on the different products in each country revealed that price affects revenue differently. In Israel, high premiums (~70% for fish and ~100% for lettuce on top of conventional product prices), would provide maximal revenue. In Australia on the other hand, maximising revenue would require lower premiums (~8% over conventional product price for fish and ~9.5% for lettuce). These results address revenue and do not reflect on profit as they ignore production costs that increase per unit. However, beyond the peak revenue it is not efficient, because revenue falls and production cost increases.

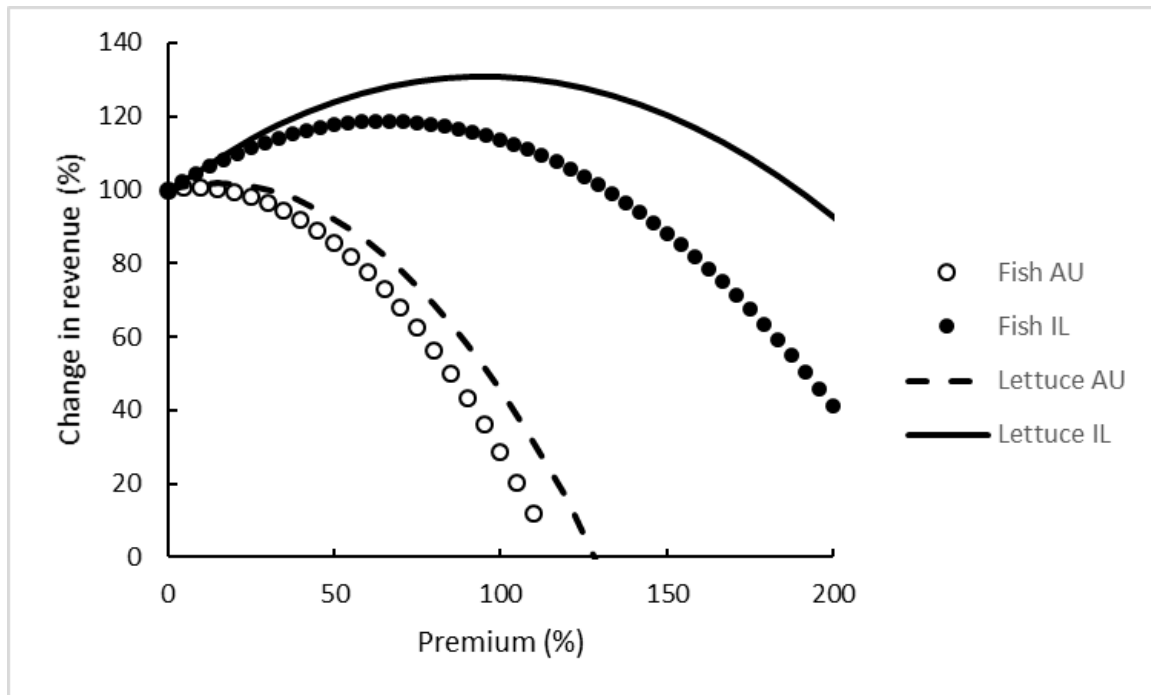


Fig 1. The effect of premium size (compared to conventional product price) of aquaponic fish and lettuce, on the predicted revenue based on the statements of the survey respondents in Australia (AU) and Israel (IL). Note that revenue does not account for change in net profit due to the increase in marginal production cost.

3.4 Identifying population segments by their consumption potential using multivariate techniques

K-means analysis results were confirmed using cluster analysis and results obtained were similar; we present here only the K-means clusters. The number of clusters was defined by average linkage (within group), minimising distances within clusters.

Most of the variables used contributed significantly to the segmentation of the Australian and Israeli potential consumers ($P < 0.1$), as did the results of the correlation matrix values. The data matrix was found to be highly correlated (Kaiser–Meyer–Olkin = 0.66, Bartlett’s sphericity $< 1\%$), indicating that the set of variables is appropriate for factorial analysis (Gorton et al., 2008). Variables that were highly correlated were eliminated from the cluster analysis: Variable 12, “familiarity with aquaponics” was highly correlated with Variable 11 “membership in an environmental organisation”. This variable was eliminated, since “familiarity with aquaponics” is seen by the authors as highly relevant for clustering consumers of aquaponic produce. The quantities consumed of a given aquaponic product at different prices

were highly correlated, so two variables were used for each product – a low premium and a high premium (Variables 14-15, 17-18, 20-21, 23-24). All clusters were defined, as shown in Table 3, by statements about consumption motivations (Variables 1-4), by socio-demographic conditions (variables 5-9), additional personal information (Variables 10-12) and WTC aquaponic produce (Variables 13--24).

Table 3. Clusters of Australian and Israeli populations (*I- IV*), based on the factorial and cluster analysis, with the mean parameter values for each cluster. Variables 5, 11 and 12 are given as %, and variables 1-4, 6-10 are ordinal scales on a range given in brackets (n-n). Prices (P) are in local currencies.

<i>Variable</i>	<i>Clusters in Australia</i>					<i>Clusters in Israel</i>				
	<i>Mean</i>	<i>I</i>	<i>II</i>	<i>III</i>	<i>IV</i>	<i>Mean</i>	<i>I</i>	<i>II</i>	<i>III</i>	<i>IV</i>
Size of cluster (%)		31.6	26.1	23.5	18.8		23.6	30.8	36.4	9.2
1. Health (1-5)	4.01	4.20	3.75	4.33	4.06	3.56	4.50	2.20	2.10	3.60
2. Environment (1-5)	3.35	3.33	3.37	2.95	3.36	3.09	4.30	2.10	3.30	1.80
3. Freshness (1-5)	3.69	3.75	3.35	3.67	3.66	3.81	4.10	3.50	2.50	4.45
4. Taste (1-5)	4.31	4.35	4.20	4.00	4.40	4.25	4.20	4.40	4.30	4.60
5. Gender (% of females)	0.56	0.75	0.45	0.83	0.49	0.58	0.58	0.45	0.62	0.65
6. Age (1-4)	3.12	3.43	2.61	3.34	3.11	2.83	1.85	2.82	3.80	3.70
7. Income (1-4)	2.23	2.19	3.64	2.11	3.74	2.19	2.90	3.70	2.50	3.10
8. Education (1-4)	3.51	2.11	3.60	3.30	3.70	3.44	3.50	2.44	1.90	2.50
9. Household size (1-4)	2.78	2.70	2.92	2.70	3.06	3.62	2.10	3.60	2.50	2.20
10. Organic consumers (0-4)	1.14	1.10	1.20	0.83	1.60	0.44	1.70	0.00	0.00	0.00
11. Environmental organizations (%)	0.05					0.03	0.11	0.01	0.02	0.00
12. Familiarity with aquaponics (%)	0.56	0.00	0.40	0.00	0.70	0.17	0.45	0.05	0.13	0.09
13. Non-aquaponic lettuce at P=2.5	1.05	0.99	1.17	1.05	1.21					
14. Aquaponic lettuce consumed at P=4	0.66	0.30	0.95	0.35	0.94					
15. Aquaponic lettuce consumed at P=5	0.46	0.01	0.83	0.02	0.79					
16. Non-aquaponic trout at P=20	1.06	0.88	1.50	0.75	1.17					
17. Aquaponic trout consumed at P=25	0.87	0.84	1.30	0.58	1.07					
18. Aquaponic trout consumed at P=30	0.61	0.28	1.05	0.31	0.77					
19. Non-aquaponic lettuce at P=3						1.66	2.37	0.78	1.37	1.10
20. Aquaponic lettuce consumed at P=7						0.92	2.10	0.65	0.66	0.55
21. Aquaponic lettuce consumed at P=9						0.80	1.87	0.32	0.68	0.34
22. Non-aquaponic tilapia at P=24						1.89	3.10	0.87	0.93	1.78
23. Aquaponic tilapia consumed at P=32						1.39	2.00	1.10	1.20	1.30
24. Aquaponic tilapia consumed at P=48						1.16	1.87	1.03	0.98	0.78

3.4.1 Australia

The results support dividing the population into four clusters (Table 4). The 2nd and 4th clusters (*II, IV*) represent a large minority of the population that are willing to consume aquaponic produce at a premium. They differ by one cluster that we named “Discerning-interested”, which included 26.1% of the sample and consisted of highly educated, young high-income families willing to pay a high premium for both fish and lettuce grown in aquaponics, mostly because of the health benefits. Another cluster, the ‘green consumers’ represented 18.8% of the sample. Members of this group were typically young, with small or no families that would be willing to pay a moderate premium for either aquaponic fish or lettuce. These two clusters define the natural market for aquaponics in Australia.

The 1st and 3rd clusters (*I, III*) represent most of the population (55.1%) that indicated unwillingness to pay any premium for aquaponics, or preferred the products grown conventionally. These clusters represent segments of the Australian population that are not potential consumers of aquaponic products and included mostly people who do not consume organic food and had not heard of aquaponics before. One of these clusters, the ‘discerning uninterested’, making up 31.6% of the sample, were older, mostly male, had smaller households, lower income and education, and mainly considered freshness and taste when shopping for food. The last cluster, ‘indifferent-uninterested’, making up 23.5% of the sample, included younger consumers with lower income and education, that did not attach special importance to any of the considerations presented in our survey except for product prices. The four clusters in the Australian sample are illustrated in Figure 2A.

Table 4. Clusters of potential consumers in the Australian sample based on cluster analysis of the survey sample (Table 3). Cluster names were chosen to represent their characteristics and willingness to consume aquaponics produce. This Table describes only those characteristics that contribute to the clustering; the variables that are near the population mean values are not mentioned in cluster description.

Cluster # and name	Cluster size	Cluster socio-economic and motivational characteristics	Willingness to consume aquaponic produce
<i>I</i> - Discerning-uninterested	31.6%	Older, with a female majority and smaller households. Do not consume organic foods. Lower income and education. Consider freshness and taste when buying food.	Not willing to consume aquaponic lettuce or fish.
<i>II</i> - Discerning-interested	26.1%	Higher income and education with bigger households. Consider health and taste when buying food.	Willing to consume aquaponic lettuce and fish for a large premium.
<i>III</i> - Indifferent-uninterested	23.5%	Younger and with a female majority. Do not consume organic foods. Lower income and education. Consider price when buying food, and not taste and freshness, nor health or the environment when buying food.	Not willing to consume aquaponic lettuce or fish at a premium.
<i>IV</i> - Green consumers	18.8%	Younger. Consume organic foods. Smaller households. Consider health and the environment when buying food.	Willing to consume aquaponic lettuce and fish at a moderate premium.

3.4.1 Israel

The cluster analysis of the Israeli sample supports dividing the population into four clusters (Table 5). All variables used in the four-segment clusters contributed significantly to the segmentation of the Israeli sample ($P < 0.1$), except membership in a green organisation ($P = 0.56$).

The 1st cluster (*I*) named “green consumers” represents a minority (23.6%) of the population that would consume aquaponics for a premium. They were typically young and consumed organic food regularly and consider health over price when purchasing food. Many of them had previous awareness of aquaponics and indicated that they would pay a high premium for lettuce for its environmental and health benefits. Fish would be consumed by this cluster but only for a small average premium, probably reflecting the fact that many of its members are vegetarian/vegan and do not consume fish at all.

The 3 other clusters represent a clear majority of the population sample (76.5%) that are currently not willing to consume aquaponic produce at a premium. When separating these clusters by their motivations and socio-demographics, they differ in their potential to consume aquaponics at lower premiums. The first cluster, ‘indifferent’ consumers, comprising 36.4% of

the sample, were older consumers that had not heard of aquaponics prior to the survey, did not consider highly any of the surveyed factors when purchasing food, but some were still willing to consume aquaponic produce. The second (smaller) cluster of 9.2%, termed ‘discerning interested’ consumers, received this category for being very mindful about product price, taste, health, freshness, and the environment when buying food. They were typically older with higher income and education and did not consume organic food regularly. Being motivated by considerations that are among the added values of aquaponics, this cluster can become more inclined to consume aquaponic produce by stronger marketing and consumer education. The ‘uninterested’ cluster of 30.8% represented small families with low income and education that are primarily concerned with product price and are not a potential target group for aquaponic produce sold at a premium. The four clusters in the Israeli sample are illustrated in Figure 2B.

Table 5. Clusters of potential consumers in the Israeli sample based on cluster analysis of the survey sample (Table 3). Cluster names were chosen to represent their characteristics and willingness to consume aquaponic produce. This Table describes only those characteristics that contribute to the clustering; the variables that are near the population mean values are not mentioned in cluster description.

Cluster	Cluster size	Socio-economics and cultural characteristics	Willingness to consume aquaponic produce
<i>I</i> - “green consumers”	23.6%	Younger. Some are members of ‘green organisations’. Consider health and environment when purchasing food. Many had heard of aquaponics before.	Willing to consume aquaponic lettuce for a high premium but most will not consume aquaponic fish at a premium.
<i>II</i> - “uninterested”	30.8%	Lower income and education. Smaller households. Do not consume organic food and are not familiar with aquaponics. Price is their major consideration when buying food.	Most are not willing to consume aquaponic fish or lettuce at a premium.
<i>III</i> - “indifferent”	36.4%	Older with larger households. Do not consume organic food and are not familiar with aquaponics. Do not consider price and taste nor health or the environment when buying food.	Most are not willing to consume aquaponic fish or lettuce at a premium.
<i>IV</i> - Discerning interested	9.2%	Older with higher income and education. Do not consume organic food and are not familiar with aquaponics. Consider price, taste, health, freshness, and the environment when buying food.	Most are not willing to consume aquaponic fish or lettuce at a premium.

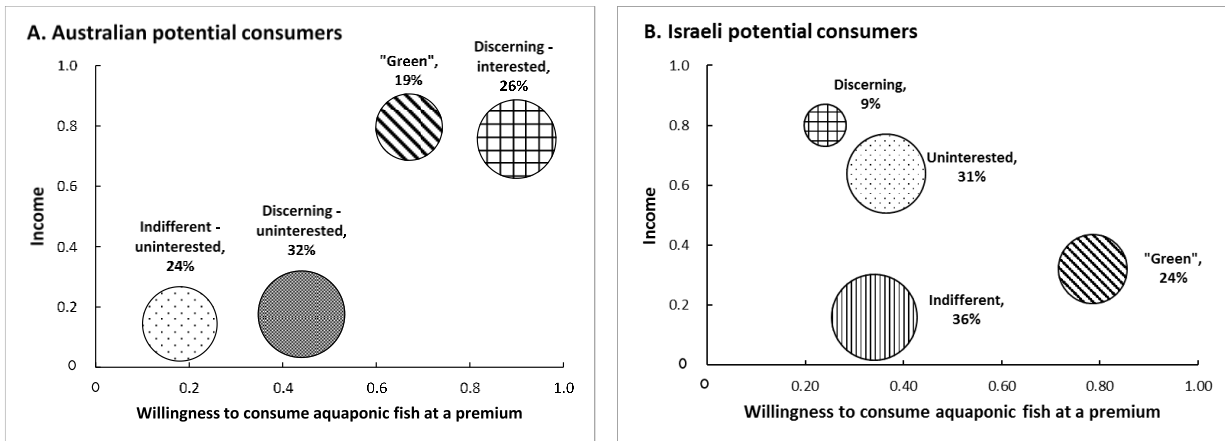


Fig. 2. Segmentation of populations into clusters in Australia (A) and Israel (B) following their motivations for food consumption, socio-demographic parameters, and willingness to consume aquaponic produce. Segmentation is illustrated here by plotting two of the clustering parameters: ‘income level’ and ‘willingness to consume aquaponic fish at a premium’ (note - scales are relative and do not reflect actual values). Circle sizes represent cluster sizes (indicated beside cluster name next to each circle).

4. Discussion and Conclusions

4.1 Factors affecting willingness to consume aquaponic produce

A considerable proportion of the population, 17-30% in both Australia and Israel, would prefer to buy aquaponic products, thereby acknowledging their added value. The majority of the respondents, however, were not convinced of consuming aquaponic over conventional produce even after learning of their added values. A small number of the surveyed respondents (3-4.5%) were biased against aquaponic produce, similar to the findings of a survey done in Europe (Miličić et al., 2017). The proportion of respondents willing to consume aquaponic produce represents the basis for the market. This finding is further emphasised by the cluster results, highlighting the characteristics of those segments of the population willing to consume aquaponic produce.

Product price was negatively correlated with WTC aquaponic produce for both countries and both products. The extent of organic consumption and household size was positively correlated with WTC across the board. As a generalisation, this would define the classic aquaponics consumers as being “families with organic diets”. The rest of the variables predicting WTC were different in each country and for each product. Household income, a common factor affecting organic food consumption (Rödiger and Hamm, 2015), was positively correlated only with WTC fish in Australia, suggesting higher income is not a major factor affecting most aquaponic consumption. Both personal (health, taste) and environmental

motivations affect the consumption decision process of aquaponics in both countries, but no single motivation stands out as a key factor.

As illustrated in Figure 1, aquaponic revenues are expected to be higher in Israel than in Australia, and higher for lettuce than for fish. The higher the premium, the fewer people will consume it, but in the Israeli market, price elasticity is lower, so demand is less sensitive to the price increase. In Australia, producers might achieve higher revenues with a smaller premium as price elasticity is high and WTC is more sensitive to price increase. It should be noted that these results do not necessarily correspond to profitability, since production costs are not considered here. Since the marginal cost of greater amounts is lower, selling large quantities for less might be a more beneficial strategy in Israel as well.

4.2 Who are the potential consumers of aquaponics?

As expected, populations in Australia and Israel cluster differently, since the connection between variables is strongly culture-dependent. By referring only to consumption at different revenues (Figure 1), it would seem that the Israeli market has greater potential for an aquaponics industry than the Australian market, since it could be sold at higher premiums to the average consumer. Nevertheless, once clusters were used to focus on smaller segments of the population, a more complex story is revealed, namely, that a larger proportion of the population in Australia (44.9%, clusters *II, IV*) would be willing to pay premiums for aquaponic produce, than in Israel (23.5%, cluster *I*). On the other hand, the population segments unwilling to consume aquaponics produce in Australia (clusters *I, III*) would be harder to persuade to become occasional consumers, as opposed to the unwilling segments of the Israeli population (clusters *II, III, IV*), who might be a large source of occasional consumption at low premiums.

4.3 Conclusions

The potential for aquaponics to become a large-scale sustainable food production industry is held back by both technical limitations and economic-administrative challenges. This study has addressed consumer acceptance of aquaponic produce. The assumption that aquaponic products can be sold at a premium to the general population was explored by surveying populations of two potential markets - Australia and Israel. It appears that even after consumers are provided information on aquaponics and its benefits, only a minority would consume its produce. Asking for a premium would further reduce consumption but with different flexibility for each product and each market. Consumer clustering revealed more specific characteristics of potential consumers in each country.

The ability to use surveys to study consumer acceptance of a new product is limited, since the consumers are making statements on consumption of a theoretical product rather than real-life decisions. This approach does, however, enhance our understanding of the basic trends and structure of potential consumer markets. It should be noted that limiting our discussion to consumer behaviour ignores the crucial role of other sustainable production stakeholders including producers, governments, and educational institutions (Xu et al., 2018). These stakeholders can all affect consumption directly and indirectly by reducing production costs in different ways, and positively influencing consumption by promoting environmental awareness.

Besides novel insights on the acceptance level and potential consumption of aquaponics in Israel and Australia, some general suggestions are proposed regarding the aquaponic industry worldwide: (1) If production prices of aquaponic produce are higher than existing alternatives, potential consumers can support a small niche market, and with a small premium. (2) Fish and leafy greens should be considered as separate products for distinctive consumer groups, requiring different marketing strategies. (3) As different markets and products elicit different consumer behaviours, it would seem prudent to conduct specific studies before entering industrial production, as their outcomes could have a major effect on business strategy. (4) Aquaponic produce has personal value (taste, health) as well as public value (e.g., environmental benefits). When only a few consumers are willing to pay for a societal benefit, market failure will occur, requiring public intervention. Stimulating willingness to consume such products would reduce the extent of the market failure, and in turn, the necessity for public intervention. Interventions such as subsidies for aquaponic produce, labelling of products signifying a public benefit, and public education are crucial for increasing the uptake of sustainable environmental options for food security. Future research will evaluate the public benefits of aquaponics by including these benefits in cost-benefit analyses of commercial-scale systems.

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