Consumer Perceptions of Aquaponic Systems

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Summary. **Aquaponics, an integrated system with both hydroponic plant production and aquaculture fish production, is an expanding alternative agriculture system. Many key questions about the overall feasibility of aquaponic systems remain unanswered. Of particular concern for start-up and established producers alike are consumer perceptions and willingness to pay for aquaponic produce and fish. This study reports results and analysis of a consumer survey about perceptions and preferences for aquaponic-grown products that was conducted in Minnesota during Feb. 2016. Probit and ordered probit models are used to evaluate the probability of different consumer demographic segments having various levels of knowledge and perceptions about aquaponics. About one-third of respondents had previously heard of aquaponics, and upon learning more about the system through the survey, respondents tended to be generally neutral or favorable to aquaponics. Price might be an issue for many consumers, but many tend to believe that aquaponics can impact the environment in a positive way. The results represent a first step toward building knowledge about the potential consumer base for aquaponics, which is a critical piece in the system's potential overall profitability. It appears that consumer education and marketing will be key for the expansion of the market.**

Aquaponics is an integrated system with both hydroponic plant production and aquaculture fish production. Methods of operation and system design can vary greatly depending on the environment and the production goals. Typically, water with fish waste flows to a biofilter for solid removal and oxidation of inorganic nitrogen compounds by nitrifying bacteria (*Nitrospira* sp., *Nitrobacter* sp., and *Nitrosomonas* sp.). The plant roots use the resulting nitrate, and nutrient-free water returns back to the fish. Given the right conditions, aquaponics has the potential to be a sustainable system of food production that can be implemented at a variety of different scales and at locations not traditionally suited for agriculture (Somerville et al., 2014). The opportunities and challenges regarding the sustainability of aquaponic systems have been well documented (Tyson et al., 2011).

A recent technical report from the Food and Agriculture Organization of the United Nations (FAO) details some of the possible benefits of aquaponic systems compared with conventional agriculture and fisheries. These include the potential to take pressure off land conversion, increase the world supply of fish without depleting wild stocks, produce food in areas with minimal water supply, and enable food production by urban residents (Somerville et al., 2014). When grown in a controlled environment like a greenhouse or warehouse, products can be harvested year-round, making locally grown produce available even in cold climates during winter (Savidov, 2004); however, many key questions about the overall feasibility of aquaponic production remain unanswered. Of particular concern for start-up and established producers alike are the consumer perceptions and willingness to pay for aquaponic produce and fish.

A small number of studies have examined the economic feasibility of aquaponic production systems (Bailey et al., 1997; Baker, 2010; Rupasinghe

Table 1. Proportional representativeness of 450 aquaponic survey respondents compared with the Minnesota adult population ages 18+ years (Minnesota State Demographic Center, 2015).

	N	Proportion in survey (%)	Proportion in Minnesota (%)
Generation[z]			
Baby Boomers	185[y]	41	36
Generation X	158	35	34
Millennials	106	24	30
Gender			
Male	207	46	49
Female	242	54	51
Household income			
Less than $30,000	66	15	24
$30,000–$49,999	85	19	18
$50,000–$74,999	82	18	19
$75,000–$99,999	74	16	14
$100,000 or more	88	20	26
Region in Minnesota			
Twin Cities Metro	337	75	58
Southeast	33	7	12
Southwest	11	2	6
West Central	23	5	11
Northwest	12	3	6
Northeast	34	8	7
Race			
Other	52	12	15
White	398	88	85

[z]Baby Boomers (55+ years), Generation X (35–54 years), Millennials (18–34 years).
[y]Not all participants answered all demographic questions resulting in some category totals that are less than 450 (i.e., 100%).

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and Kennedy, 2010; Tokunaga et al., 2015) and even fewer studies have investigated consumer perceptions and marketing potential for fish and produce grown with aquaponic production methods (Savidov, 2004; Tamin et al., 2015; Zugravu et al., 2016).

More studies exist on consumer perceptions of other alternative agriculture production methods such as local, organic, and hydroponics. Feldmann and Hamm (2015) provide a review of 73 publications examining consumer perceptions and preferences for local food with a major finding that unlike organic food, local food is not perceived as expensive, but consumers will also pay more for local foods. For local foods, consumers are motivated to purchase by perceptions of freshness and safety as well as a desire to support the local economy (Yue and Tong, 2009).

Organic foods also command a premium price, although the proportion of consumers who will pay a premium decreases as the premium level increases (Yiridoe et al., 2005). Reasons consumers buy organic products include their perceptions of healthfulness, environmental friendliness, taste, freshness, and quality of the food, as well as a desire to avoid genetically modified ingredients (Demeritt, 2002). The price premiums for organic foods also tend to increase with combinations of preferred attributes (Yiridoe et al., 2005). In a review of the literature on consumer perceptions and preferences for organic foods compared with conventionally grown food, Yiridoe et al. (2005) found that the demand is more dependent on the price differential between organic and conventional food than the actual price of the organic food (Yiridoe et al., 2005).

It is possible that consumers' perceptions of aquaponic products might contain some of the same appealing attributes as organic and local production; however, studies focused on choices consumers make at farmers' markets have revealed that consumers expect lower prices and better quality of these local products (Brown, 2002, 2003). As the collection of the aforementioned studies show, the connection between preferences, perception, and willingness-to-pay is not straightforward and depends on a number of factors including specific combinations of attributes and the price and availability of alternatives.

Regarding hydroponic production, a Nashville, Tennessee market analysis found limited potential for hydroponic lettuce (*Lactuca sativa*), although the prospects for hydroponic cucumber (*Cucumis sativus*) and tomato (*Solanum lycopersicum*) were better. The study concluded that hydroponic lettuce producers would need to establish a wholesale relationship and use a "push strategy"

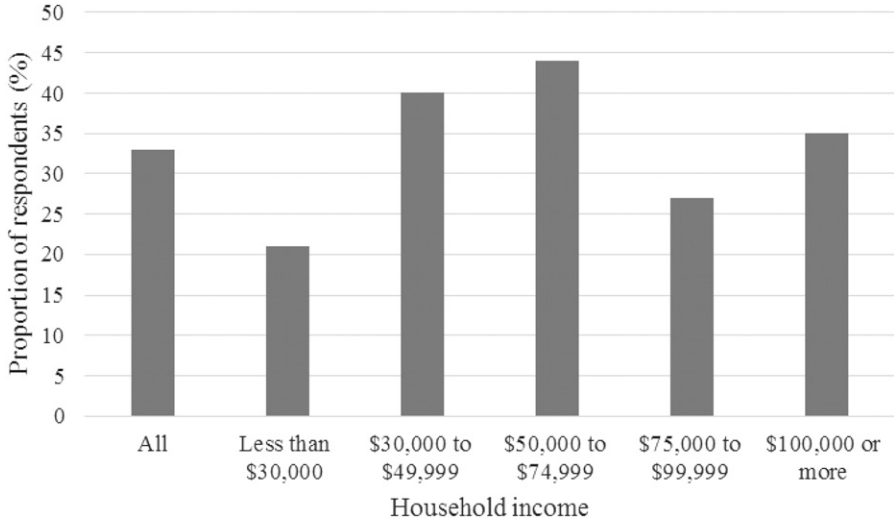

Fig. 1. Aquaponic survey respondents (out of 386 Minnesota consumers) who had heard of the term "aquaponics" broken down by income category.

Table 2. Probit MLE and marginal effects of 386 aquaponic survey respondents on if they have ever heard of the term "aquaponics."

	Probit coefficient	SE	Marginal effect[z]	SE
Generation[y]				
Baby Boomers	—	—	—	—
Generation X	–0.184	(0.161)	–0.064	(0.056)
Millennials	–0.119	(0.177)	–0.042	(0.062)
Gender				
Male	—	—	—	—
Female	–0.082	(0.138)	–0.029	(0.048)
Household income				
Less than $30,000	—	—	—	—
$30,000–$49,999	0.568**[x]	(0.232)	0.190**	(0.074)
$50,000–$74,999	0.685***	(0.236)	0.234***	(0.076)
$75,000–$99,999	0.216	(0.249)	0.065	(0.074)
$100,000 or more	0.434*	(0.237)	0.140*	(0.074)
Region in Minnesota				
Twin Cities Metro	—	—	—	—
Southeast	0.115	(0.240)	0.042	(0.090)
Southwest	—[w]		—	
West Central	–0.728**	(0.353)	0.215***	(0.080)
Northwest	–0.613	(0.460)	–0.188*	(0.114)
Northeast	–0.062	(0.262)	–0.022	(0.093)
Race				
Other	—	—	—	—
White	–0.141	(0.204)	–0.050	(0.074)
Constant	–0.521*	(0.278)		

MLE = maximum likelihood estimation; SE = standard error.
[z]Marginal effects show change in probability of $Y = 1$ for each demographic category (all else equal), compared with the base group (—).
[y]Baby Boomers (55+ years), Generation X (35–54 years), Millennials (18–34 years).
[x]***$P < 0.01$, **$P < 0.05$, *$P < 0.10$.
[w]Estimation for Southwest region was dropped because of insufficient number of responses to this question.

to develop a customer base (Huang et al., 2002). A more recent study found that consumers in Trinidad were, on average, willing to pay a 4% premium for greenhouse-hydroponic tomatoes (Narine et al., 2014). Among those willing to pay more (51% of their sample), the average was a 30% premium over conventional field-grown tomatoes. Those not willing to pay more for greenhouse-hydroponic tomatoes (49%) required an average discount of ≈24% of the conventional price to be persuaded to purchase. The split among those willing/not willing to pay a premium in the Trinidad study (Narine et al., 2014) is similar to the split found in the Canadian aquaponics survey (Savidov, 2004) and has important implications for the industry moving forward.

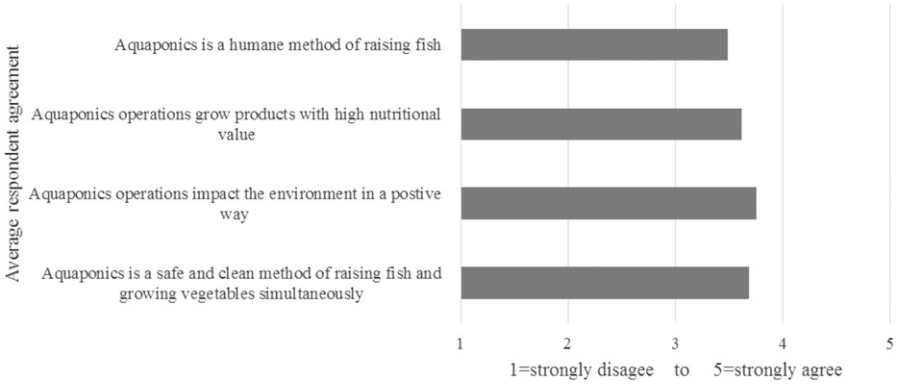

Fig. 2. Aquaponic survey respondents' average agreement to statements about aquaponics (directly after being read the short definition) on a scale of 1 to 5, where 1 = strongly disagree and 5 = strongly agree (384 Minnesota consumers answered the humane method of raising fish question, 383 Minnesota consumers answered the nutritional value question, 394 Minnesota consumers answered the environmental impact question, and 381 Minnesota consumer answered the safe and clean method question).

Methods

In Feb. 2016, we conducted a one-time, cross-sectional survey on Minnesota adults to assess the market potential for aquaponic products by gathering data on consumer product awareness, receptivity of aquaponic products, and their preferred information sources ($n = 450$). The survey was conducted by telephone, with the sample randomly

Table 3. Ordered probit MLE and marginal effects of 387 aquaponic survey respondents on their interest in learning more about aquaponics on a scale of 1 (not at all interested) to 5 (very interested).

			1		2		3		4		5	
	Probit coefficient	SE	Marginal effect[z]	SE	Marginal effect	SE	Marginal effect	SE	Marginal effect	SE	Marginal effect	SE
Generation[y]												
Baby Boomers	—	—	—	—	—	—	—	—	—	—	—	—
Generation X	0.241*[x]	0.130	–0.065*	0.035	–0.018*	0.010	–0.009	0.006	0.026*	0.015	0.065*	0.035
Millennials	0.179	0.142	–0.049	0.039	–0.013	0.011	–0.006	0.006	0.021	0.016	0.047	0.038
Gender												
Male	—	—	—	—	—	—	—	—	—	—	—	—
Female	0.247**	0.111	–0.066**	0.03	–0.018**	0.009	–0.009*	0.005	0.027**	0.013	0.067**	0.030
Household income												
Less than $30,000	—	—	—	—	—	—	—	—	—	—	—	—
$30,000–$49,999	0.109	0.184	–0.034	0.058	–0.006	0.011	0.001	0.003	0.016	0.027	0.024	0.041
$50,000–$74,999	0.284	0.184	–0.084	0.056	–0.019	0.012	–0.003	0.006	0.038	0.026	0.069	0.044
$75,000–$99,999	0.503***	0.188	–0.138***	0.053	–0.037**	0.015	–0.017	0.011	0.057**	0.024	0.135***	0.050
$100,000 or more	0.453**	0.183	–0.126**	0.053	–0.033**	0.014	–0.013	0.009	0.054**	0.024	0.119**	0.047
Region in Minnesota												
Twin Cities Metro	—	—	—	—	—	—	—	—	—	—	—	—
Southeast	0.043	0.200	–0.011	0.051	–0.003	0.015	–0.002	0.009	0.004	0.020	0.012	0.057
Southwest	0.513	0.382	–0.107*	0.061	–0.042	0.032	–0.042	0.043	0.026***	0.009	0.166	0.137
West Central	–0.147	0.237	0.041	0.070	0.010	0.015	0.004	0.004	–0.017	0.03	–0.038	0.058
Northwest	–0.300	0.326	0.089	0.105	0.019	0.017	0.003	0.007	–0.039	0.048	–0.072	0.069
Northeast	–0.010	0.223	0.003	0.060	0.001	0.017	0.000	0.009	–0.001	0.024	–0.003	0.061
Race												
Other	—	—	—	—	—	—	—	—	—	—	—	—
White	–0.094	0.171	0.025	0.046	0.007	0.013	0.004	0.007	–0.010	0.018	–0.026	0.047
Heard of aquaponics												
No	—	—	—	—	—	—	—	—	—	—	—	—
Yes	0.300**	0.119	–0.080**	0.032	–0.022**	0.009	–0.012**	0.006	0.031**	0.013	0.082**	0.032

MLE = maximum likelihood estimation; SE = standard error.
[z]Marginal effects show change in probability $\Upsilon = n$ (n = 1, 2, 3, 4, 5) in each demographic category (all else equal), compared with the base group (represented by —).
[y]Baby Boomers (55 + years), Generation X (35–54 years), Millennials (18–34 years).
[x]***$P < 0.01$, **$P < 0.05$, *$P < 0.10$.

Table 4. Ordered probit MLE and marginal effects of 381 aquaponic survey respondents on how credible they find grocery stores or restaurants as an information source about aquaponics on a scale of 1 (not at all credible) to 5 (very credible).

			1		2		3		4		5	
	Probit coefficient	SE	Marginal effect[z]	SE	Marginal effect	SE	Marginal effect	SE	Marginal effect	SE	Marginal effect	SE
Generation[y]												
Baby Boomers	—	—	—	—	—	—	—	—	—	—	—	—
Generation X	0.000	0.129	–0.000	0.019	–0.000	0.017	–0.000	0.014	0.000	0.020	0.000	0.029
Millennials	–0.009	0.141	0.001	0.021	0.001	0.018	0.001	0.015	–0.001	0.022	–0.002	0.032
Gender												
Male	—	—	—	—	—	—	—	—	—	—	—	—
Female	0.464***[x]	0.111	–0.068***	0.018	–0.063***	0.017	–0.049***	0.014	0.076***	0.020	0.103***	0.025
Household income												
Less than $30,000	—	—	—	—	—	—	—	—	—	—	—	—
$30,000–$49,999	0.151	0.181	–0.025	0.031	–0.020	0.024	–0.011	0.013	0.027	0.033	0.030	0.036
$50,000–$74,999	0.355*	0.183	–0.053*	0.029	–0.047*	0.025	–0.036*	0.019	0.057*	0.031	0.079*	0.040
$75,000–$99,999	0.196	0.188	–0.032	0.031	–0.026	0.025	–0.016	0.015	0.034	0.033	0.040	0.038
$100,000 or more	0.230	0.182	–0.037	0.030	–0.031	0.024	–0.020	0.016	0.039	0.032	0.048	0.037
Region in Minnesota												
Twin Cities Metro	—	—	—	—	—	—	—	—	—	—	—	—
Southeast	0.272	0.205	–0.032	0.021	–0.034	0.025	–0.038	0.033	0.034	0.021	0.070	0.058
Southwest	0.350	0.380	–0.039	0.033	–0.044	0.044	–0.051	0.067	0.041	0.028	0.093	0.115
West Central	–0.167	0.236	0.027	0.041	0.022	0.032	0.015	0.016	–0.029	0.043	–0.035	0.046
Northwest	–0.428	0.326	0.080	0.076	0.056	0.040	0.021**	0.009	–0.080	0.066	–0.077*	0.046
Northeast	–0.217	0.219	0.036	0.040	0.029	0.029	0.017	0.013	–0.038	0.041	–0.044	0.040
Race												
Other	—	—	—	—	—	—	—	—	—	—	—	—
White	–0.130	0.169	0.019	0.025	0.017	0.022	0.014	0.018	–0.020	0.026	–0.029	0.038

MLE = maximum likelihood estimation; SE = standard error.
[z]Marginal effects show change in probability $Y = n$ (n = 1, 2, 3, 4, 5) in each demographic category (all else equal), compared with the base group (—).
[y]Baby Boomers (55 + years), Generation X (35–54 years), and Millennials (18–34 years).
[x]***$P < 0.01$, **$P < 0.05$, *$P < 0.10$.

drawn from 17,800 landline and cellular phone numbers. The telephone survey method was used to be able to screen participants and potentially minimize self-selection among respondents. Inclusion criteria stated that all participants must be at least 18 years old and visit restaurants and grocery stores or both, but are not employed at either type of establishment. Each participant was first asked if he/she had ever heard of the term "aquaponics," then all participants were read a definition of the term and asked a series of questions regarding aquaponics based on what they had just heard. The definition was "Aquaponics produces both fish and vegetable products. It is a closed, water-circulating system in which the waste produced by the fish supplies nutrients for the plants, which in turn purifies the water. It can be done in a greenhouse or warehouse." In addition to the questions about aquaponics, the survey instrument contained questions regarding fish-purchasing habits and preferences. The questions used for this paper are listed in Supplemental Appendix A.

Several questions used the format of choosing a rating of agreement, credibility, or level of interest to statements regarding aquaponics on a scale of 1 to 5, where 1 means strongly disagree/not credible at all/not at all interested and 5 means strongly agree/very credible/very interested. All the rating questions of this type had the additional option for respondents to answer "unsure/I don't know," which is why the number of responses varies slightly from question to question. For instance, respondents were asked to rate their agreement with the statement, "aquaponics operations impact the environment in a positive way," and could choose 1–5 or "unsure/I don't know."

Probit models were used to analyze the yes/no questions and ordered probit models were used to evaluate the questions where respondents chose a scale ranking for their answers. The probit model estimates the probability of outcomes of a binary response variable:

$$P(Y = 1|X) = \Phi(X'\beta)$$

where P denotes the probability that Y equals 1 conditional on X, a vector of demographic characteristics, and Φ is the cumulative distribution function of the standard normal distribution.

The parameter β is estimated by maximum likelihood. Ordered probit is a generalization of probit to more than two outcomes of an ordinal response variable. Both models can be characterized by a latent choice framework where y^* is unobserverd, but categories of response are observed. For instance,

$$Y = 0 \text{ if } y^* \leq 0, \text{and } Y = 1 \text{ if } y^* > 0$$

The probit and ordered probit estimation will use the observations of Y which can be thought of as censored versions of y^* to fit the parameter β given the vector X (Greene, 2012).

Table 5. Ordered probit MLE and marginal effects of 385 aquaponic survey respondents on how credible they find universities as an information source about aquaponics on a scale of 1 (not at all credible) to 5 (very credible).

			1		2		3		4		5	
	Probit coefficient	SE	Marginal effect[z]	SE	Marginal effect	SE	Marginal effect	SE	Marginal effect	SE	Marginal effect	SE
Generation[y]												
Baby Boomers	—	—	—	—	—	—	—	—	—	—	—	—
Generation X	–0.185	0.135	0.016	0.012	0.013	0.010	0.027	0.020	0.011	0.009	–0.068	0.049
Millennials	0.124	0.150	–0.008	0.010	–0.008	0.009	–0.018	0.022	–0.012	0.016	0.047	0.057
Gender												
Male	—	—	—	—	—	—	—	—	—	—	—	—
Female	0.346***[x]	0.116	–0.027**	0.011	–0.024**	0.009	–0.052***	0.018	–0.026**	0.010	0.129***	0.043
Household income												
Less than $30,000	—	—	—	—	—	—	—	—	—	—	—	—
$30,000–$49,999	0.179	0.185	–0.020	0.022	–0.015	0.016	–0.027	0.027	–0.001	0.005	0.063	0.065
$50,000–$74,999	0.272	0.186	–0.029	0.021	–0.022	0.016	–0.041	0.028	–0.006	0.008	0.097	0.066
$75,000–$99,999	0.724***	0.200	–0.055***	0.021	–0.049***	0.017	–0.108***	0.031	–0.058**	0.023	0.270***	0.071
$100,000 or more	0.513***	0.189	–0.046**	0.021	–0.038**	0.016	–0.078***	0.029	–0.028*	0.016	0.189***	0.068
Region in Minnesota												
Twin Cities Metro	—	—	—	—	—	—	—	—	—	—	—	—
Southeast	0.186	0.219	–0.011	0.011	–0.011	0.012	–0.028	0.032	–0.021	0.029	0.071	0.084
Southwest	–0.555	0.379	0.062	0.061	0.045	0.035	0.080*	0.047	0.008	0.024	–0.195*	0.118
West Central	–0.479*	0.249	0.050	0.036	0.038	0.023	0.071**	0.034	0.012	0.012	–0.171**	0.082
Northwest	–0.299	0.332	0.027	0.037	0.022	0.028	0.045	0.049	0.015**	0.007	–0.110	0.117
Northeast	–0.295	0.222	0.027	0.024	0.022	0.019	0.045	0.033	0.015**	0.007	–0.109	0.079
Race												
Other	—	—	—	—	—	—	—	—	—	—	—	—
White	0.138	0.177	–0.011	0.014	–0.009	0.012	–0.021	0.026	–0.010	0.014	0.051	0.065

MLE = maximum likelihood estimation; SE = standard error.
[z]Marginal effects show change in probability $\Upsilon = n$ (n = 1, 2, 3, 4, 5) in each demographic category (all else equal), compared with the base group (represented with —).
[y]Baby Boomers (55 + years), Generation X (35–54 years), and Millennials (18–34 years).
[x]***$P < 0.01$, **$P < 0.05$, *$P < 0.10$.

Results

SOCIODEMOGRAPHIC BACKGROUND OF RESPONDENTS. In total, 450 consumers participated in the survey (Table 1) with varying demographic backgrounds including generation ("Baby Boomers" includes ages 55+ years, "Generation X" includes ages 35–54 years, and "Millennials" includes ages 18–34 years), gender, household income, region of residence across the state of Minnesota (Twin Cities Metro, Southeast, Southwest, West Central, Northwest, Northeast), and race. Not all participants answered all demographic questions, which is why not all categories in Table 1 total 450 (i.e., 100%). Forty-six percent of the respondents were male. Respondents' income level distributes fairly even across the five income categories with 20% having $100,000 or more annual income and 15% having less than $30,000 annual income. The majority of respondents (75%) are from the metropolitan area of Minneapolis and St. Paul, MN (Twin Cities Metro), whereas the rest are distributed across the remaining five regions of Minnesota which are defined as the state's emergency management regions (Southeast, Southwest, West Central, Northwest, Northeast). Eighty-eight percent of respondents are Caucasian. Forty-one percent of respondents are categorized as Baby Boomers, 35% are Generation X, and 24% are Millennials. Table 1 also shows that the relative proportions of each racial category in the sample are, in general, aligned with the state population proportions. There are some differences in other categories such as an undersampling of people in the highest and lowest income categories and Millennials, and an oversampling of people in the Twin Cities Metro area and Baby Boomers (Minnesota State Demographic Center, 2015).

KNOWLEDGE OF AQUAPONICS. Among all respondents, 33% had heard of the term "aquaponics" (Fig. 1). When this probability of survey respondents having heard of the term was divided into income level, 44% of those making $50,000–$74,999 had heard of the term, making that the income range with the highest probability. Respondents with income less than $30,000 have the lowest probability: only 21% had heard of the term (Fig. 1).

Based on probit estimation results (Table 2), respondents with income in the $30,000–$49,000 range were 19% more likely to have heard of the term than those in the lowest category, and respondents in the $50,000–$74,999 income range were the most likely to have heard of the term as stated before (Fig. 1), with a 23% greater probability than the lowest income class. These results are significant at the 95% confidence level, with the results for the $50,000–$74,999 income class being significant at the 99% confidence level (Table 2). Results for the $75,000–$99,999 income class were not significantly different from the baseline, but respondents in the income class of $100,000 or more were 14% more likely to have heard of the term than the lowest income class with significance at the 90% confidence level.

Table 6. Ordered probit MLE and marginal effects of 381 aquaponic survey respondents on how credible they find the government as an information source about aquaponics on a scale of 1 (not at all credible) to 5 (very credible).

			1		2		3		4		5	
	Probit coefficient	SE	Marginal effect[z]	SE	Marginal effect	SE	Marginal effect	SE	Marginal effect	SE	Marginal effect	SE
Generation[y]												
Baby Boomers	—	—	—	—	—	—	—	—	—	—	—	—
Generation X	0.005	0.129	–0.001	0.024	–0.001	0.016	–0.000	0.008	0.001	0.026	0.001	0.022
Millennials	0.337**[x]	0.142	–0.051**	0.021	–0.041**	0.018	–0.036**	0.018	0.059**	0.025	0.069**	0.031
Gender												
Male	—	—	—	—	—	—	—	—	—	—	—	—
Female	0.268**	0.111	–0.045**	0.019	–0.032**	0.014	–0.023**	0.01	0.050**	0.021	0.050**	0.021
Household income												
Less than $30,000	—	—	—	—	—	—	—	—	—	—	—	—
$30,000–$49,999	0.010	0.181	–0.002	0.037	–0.001	0.022	–0.000	0.007	0.002	0.039	0.002	0.027
$50,000–$74,999	0.022	0.181	–0.004	0.037	–0.003	0.022	–0.001	0.007	0.005	0.039	0.003	0.027
$75,000–$99,999	0.529***	0.189	–0.079**	0.031	–0.064***	0.024	–0.058**	0.023	0.092***	0.035	0.109***	0.040
$100,000 or more	0.309*	0.181	–0.053	0.033	–0.038*	0.023	–0.026	0.016	0.060*	0.036	0.056*	0.033
Region in Minnesota												
Twin Cities Metro	—	—	—	—	—	—	—	—	—	—	—	—
Southeast	0.115	0.201	–0.017	0.028	–0.014	0.024	–0.013	0.025	0.020	0.033	0.024	0.044
Southwest	–0.498	0.379	0.105	0.100	0.058	0.039	0.014	0.019	–0.104	0.083	–0.073*	0.040
West Central	–0.440*	0.244	0.090	0.060	0.052*	0.027	0.017*	0.010	–0.092*	0.054	–0.067**	0.029
Northwest	–0.276	0.329	0.051	0.071	0.034	0.039	0.017*	0.010	–0.056	0.071	–0.047	0.047
Northeast	–0.216	0.215	0.039	0.043	0.027	0.026	0.015	0.011	–0.043	0.045	–0.038	0.034
Race												
Other	—	—	—	—	—	—	—	—	—	—	—	—
White	–0.128	0.170	0.022	0.029	0.015	0.020	0.011	0.015	–0.024	0.032	–0.024	0.032

MLE = maximum likelihood estimation; SE = standard error.
[z]Marginal effects show change in probability $Y = n$ (n = 1, 2, 3, 4, 5) in each demographic category (all else equal), compared with the base group (represented with —).
[y]Baby Boomers (55 + years), Generation X (35–54 years), and Millennials (18–34 years).
[x]***$P < 0.01$, **$P < 0.05$, *$P < 0.10$.

Beliefs about aquaponics. Figure 2 shows the average agreement of survey respondents to four statements regarding aquaponics on a 1–5 scale. On average, respondents fall between neutral (3) and agree (4) for all questions. "Aquaponics operations impact the environment in a positive way" had the most favorable rating (Fig. 2).

Coefficients from the estimations regarding beliefs about aquaponics and standard errors (SEs) are reported in the first two columns of Tables 3–7. Marginal effects were calculated for each different answer choice and are reported along with SEs in the remaining columns of Tables 3–7. Marginal effects allow for easy interpretation of the probability of respondents' selecting different answer choices.

Among the reasons people might not be willing to purchase aquaponic products (Fig. 3), price and safety or cleanliness concerns are cited by the highest proportion of respondents (36% for each). Flavor concerns and "how the fish were raised" were cited next as potential issues by 20% and 19% of respondents, respectively (Fig. 3). Nutrition was a concern for 17% of respondents, and "how the plants were grown" ranked as the least concerning out of all reasons with only 12% of respondents citing it as a reason they might not purchase aquaponic products (Fig. 3). These findings, in particular, seem to be in line with conclusions from the Savidov (2004) Canadian survey, which implied that finding the right price and ensuring consumers are confident in the safety of aquaponic products should be top priorities of the industry.

Potential interest in learning more about aquaponics. The results and marginal effects from an ordered probit regression assessing respondents' interest in learning more about aquaponics are reported in Table 3. On a 1–5 scale, respondents in Generation X are 6.5% less likely to choose 1 (not at all interested) and more likely to choose 5 (very interested) for their interest in learning about aquaponics than Baby Boomers at the 90% confidence level (Table 3). Women are generally more interested in learning more about aquaponics than men, with significance at the 95% confidence level (Table 3). Women are ≈6.6% less likely to choose 1 (not at all interested) than men and 1.8% less likely to choose 2. Women are 2.7% more likely to choose 4 and 6.7% more likely to choose 5 (very interested) (Table 3).

Significant effects regarding interest in learning more about aquaponics are also found for the two highest income categories at the ≥95% confidence level (Table 3). Respondents in the $75,000–$99,999 income category have a 13.8% lower probability of selecting 1 (not at all interested) and a 13.5% higher probability of selecting 5 (very interested) than those in the lowest income category. Similar results are found for the $100,000 or more category with a 12.6% lower probability of selecting 1 and an 11.9% probability of selecting 5.

Table 7. Ordered probit MLE and marginal effects of 385 aquaponic survey respondents on how credible they find aquaponics growers as an information source about aquaponics on a scale of 1 (not at all credible) to 5 (very credible).

			1		2		3		4		5	
	Probit coefficient	SE	Marginal effect[z]	SE	Marginal effect	SE	Marginal effect	SE	Marginal effect	SE	Marginal effect	SE
Generation[y]												
Baby Boomers	—	—	—	—	—	—	—	—	—	—	—	—
Generation X	0.294**[x]	0.130	–0.046**	0.021	–0.045**	0.021	–0.023**	0.011	0.047**	0.021	0.067**	0.030
Millennials	0.440***	0.143	–0.063***	0.021	–0.067***	0.023	–0.041**	0.017	0.063***	0.021	0.108***	0.037
Gender												
Male	—	—	—	—	—	—	—	—	—	—	—	—
Female	0.285***	0.110	–0.041**	0.017	–0.043**	0.018	–0.026**	0.011	0.041**	0.017	0.069**	0.027
Household income												
Less than $30,000	—	—	—	—	—	—	—	—	—	—	—	—
$30,000–$49,999	0.160	0.181	–0.023	0.026	–0.024	0.027	–0.015	0.017	0.022	0.025	0.040	0.044
$50,000–$74,999	0.056	0.181	–0.008	0.028	–0.008	0.027	–0.005	0.015	0.008	0.027	0.013	0.043
$75,000–$99,999	0.092	0.188	–0.014	0.028	–0.014	0.028	–0.008	0.016	0.013	0.027	0.022	0.045
$100,000 or more	0.012	0.181	–0.002	0.028	–0.002	0.027	–0.001	0.014	0.002	0.028	0.003	0.042
Region in Minnesota												
Twin Cities Metro	—	—	—	—	—	—	—	—	—	—	—	—
Southeast	0.291	0.202	–0.036*	0.021	–0.043	0.029	–0.033	0.028	0.033*	0.018	0.079	0.060
Southwest	0.357	0.374	–0.042	0.034	–0.052	0.051	–0.043	0.055	0.037	0.023	0.099	0.117
West Central	0.213	0.247	–0.028	0.028	–0.032	0.036	–0.023	0.031	0.026	0.025	0.056	0.070
Northwest	–0.301	0.323	0.055	0.069	0.045	0.046	0.015**	0.007	–0.052	0.062	–0.061	0.056
Northeast	–0.055	0.214	0.009	0.034	0.008	0.032	0.004	0.016	–0.008	0.034	–0.013	0.048
Race												
Other	—	—	—	—	—	—	—	—	—	—	—	—
White	–0.021	0.171	0.003	0.025	0.003	0.025	0.002	0.015	–0.003	0.024	–0.005	0.042

MLE = maximum likelihood estimation; SE = standard error.
[z]Marginal effects show change in probability $Y = n$ (n = 1, 2, 3, 4, 5) in each demographic category (all else equal), compared with the base group (represented with —).
[y]Baby Boomers (55+ years), Generation X (35–54 years), and Millennials (18–34 years).
[x]***$P < 0.01$, **$P < 0.05$, *$P < 0.10$.

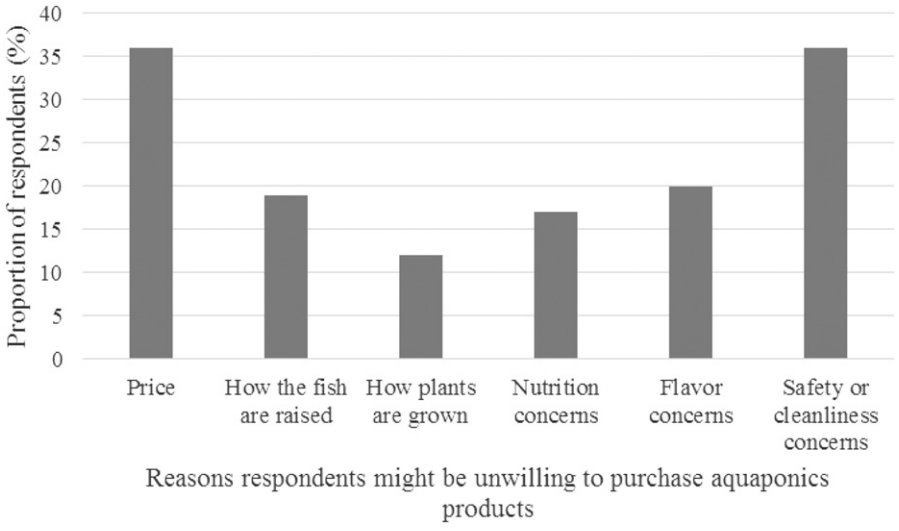

Fig. 3. Aquaponic survey respondents who indicated that they would be unwilling to purchase aquaponics products for the following reasons: price, how the fish are raised, how the plants are grown, nutrition concerns, flavor concerns, or safety or cleanliness concerns; multiple choices were allowed.

Having previously heard of aquaponics is also positively associated with an interest in learning more about aquaponics (95% confidence level). Participants in the sample who had heard about aquaponics were about 8% less likely to choose 1 (not at all interested) and more likely to choose 5 (very interested) (Table 3).

Regarding how people would potentially like to learn more about aquaponics, Fig. 4 shows the preferred information sources for aquaponics. "In a news report" is the most preferred source, selected by 52% of respondents, whereas "At the grocery store" is next, selected by 38% of respondents. Social media is preferred by 28% and e-mail the least, 24% (Fig. 4).

Credibility of information sources regarding aquaponics. Ordered probit estimation results and marginal effects for the question "How credible would you consider the following to be as a source of educational information about aquaponics?" from four sources are shown in Tables 4–7: grocery store or restaurant (Table 4), university (Table 5), government (Table 6), and aquaponics grower (Table 7). Women in the sample have a higher probability of finding sources credible than men across all information sources. Compared with men, women in the sample are 10.3% more likely to rank grocery stores/restaurants "very credible"

[ranking 5 (Table 4)] and 12.9% more likely to rank university sources "very credible" (Table 5). Government (Table 6) and aquaponics growers (Table 7) also have a higher probability of being found "very credible" by women over men with increased probabilities of 5% and 6.9%, respectively.

Respondents in the two highest income categories, as compared with the lowest income category, have a higher probability of finding a university as a credible source of information (Table 5) compared with those in the lowest income category (27% higher probability of finding university a "very credible" source for respondents whose income level is $75,000–$99,999, and 18.9% higher probability for respondents whose income level is greater than $100,000).

Millennials were more likely to rate government as "very credible" than Baby Boomers (6.9% more likely), as were people in the income category $75,000–$99,999 with a 10.9% increased probability (Table 6). People in both the Millennial and Generation X generations have a higher probability than Baby Boomers of finding information from aquaponics growers as credible (Table 7); Generation X has a 6.7% increase in probability and Millennials have a 10.8% increase in probability compared with the Baby Boomers.

Although news reports were the preferred information source, they have the lowest credibility rating of all sources (Fig. 5). The ordered probit regression for this information source produced results that were not likely to have any significance from the sociodemographic variables and, thus, are not reported.

Discussion

Aquaponics is an emerging production system with significant potential (Savidov, 2004). Industry understanding of consumer perceptions and willingness to pay are critical to the development of marketing strategies and long-term economic sustainability. Our telephone survey results found that only about one-third of respondents had heard of aquaponics, although we do not know if they knew about the specifics of the system. Upon learning more about the system through the survey, respondents tended to be generally neutral or favorable to aquaponics, although food safety and price are important factors for some consumers.

The statement, "Aquaponics operations impact the environment in a positive way," had the most favorable rating among participants on average (Fig. 2). This could be a good sign for the potential of the industry to market itself as an environmental-friendly agricultural technology, although the sustainability of aquaponics systems is not guaranteed (Tyson et al., 2011), and the actual environmental impact of different aquaponic systems will vary and should be taken into consideration.

Price might be an issue for many consumers as predicted previously (Narine et al., 2014; Savidov, 2004). As noted in other studies, many consumers are indifferent to production method and are therefore not willing to pay a premium price over conventional products (Savidov, 2004; Tamin et al., 2015; Zugravu et al., 2016). The market results for aquaponics, therefore, could differ from what has been observed with organic and local production systems, and

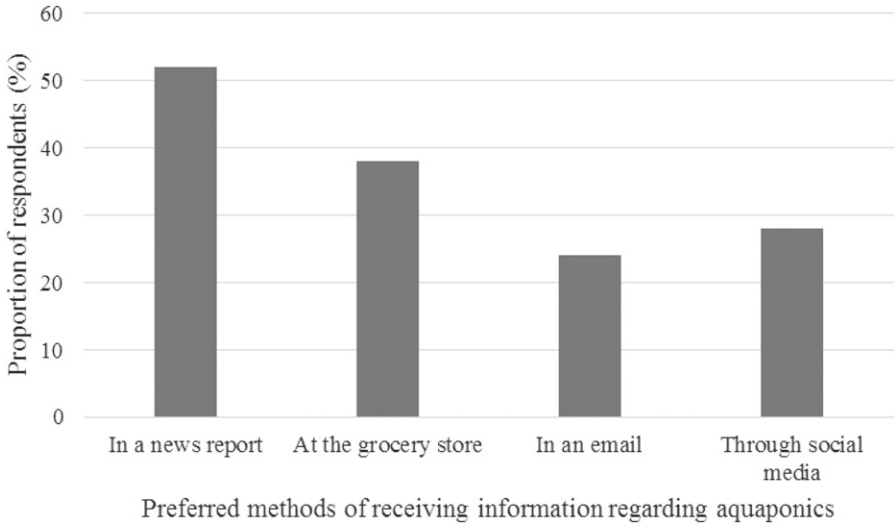

Fig. 4. Aquaponic survey respondents who indicated that they would prefer to receive information regarding aquaponics from the following sources: in a news report, at the grocery store, in an e-mail, or through social media; multiple choices were allowed.

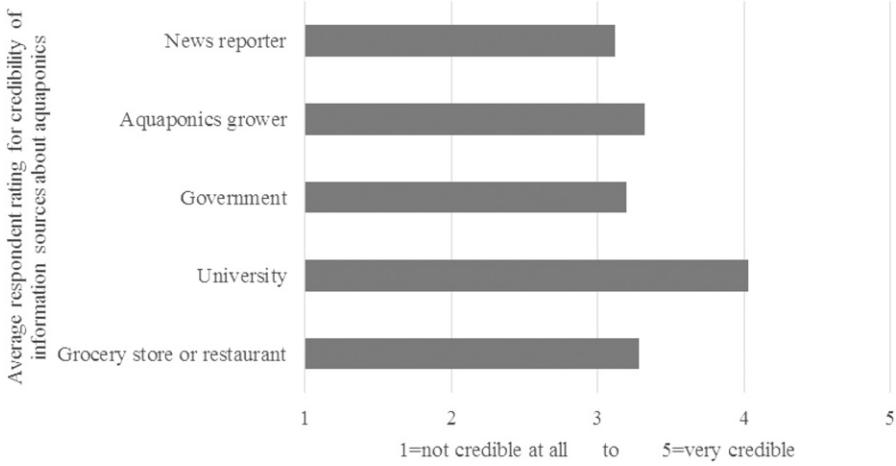

Fig. 5. Aquaponic survey respondents' average credibility rating on a scale of 1 (not at all credible) to 5 (very credible) for the following potential information sources about aquaponics: news reporter, aquaponics grower, government, university, and grocery store or restaurant.

producers should not automatically expect that people will pay a premium for aquaponic products.

These survey results provide the first step toward understanding consumer perceptions and the market availability for aquaponic products in Minnesota. Further research is needed to gather information about consumers nationwide, consumer willingness to purchase and willingness to pay, as well as more detailed demographic information about the potential target consumer base.

Our results have important implications for producers because economic feasibility might hinge on investing in large production systems and receiving a premium price (Tokunaga et al., 2015). We recommend that the aquaponics industry devote effort toward educating and building a consumer base at the same time as production capacity grows. The high level of credibility from university sources could potentially be paired with the preferred information source of news reports through earned media on aquaponics research activities. By doing further consumer research and targeting education or marketing materials toward those most likely to be receptive, producers could increase the consumer base who would be willing to pay a premium. Women and consumers in the highest income categories showed the strongest interest in learning more about aquaponics compared with men or the lowest income category, which indicate that targeting these interested groups as the potential primary consumer base could be a good starting point.

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Supplemental Appendix A.
Survey questions utilized in this study.

Russell Herder
Strategy wins.

AQUAPONICS SURVEY

Good morning/afternoon/evening. This is _____ from _____, a professional research firm. We're conducting a survey today with Minnesotans who go to restaurants and/or grocery stores. We are not selling anything; we are simply interested in your opinions. The survey will take approximately eight minutes. Would you like to participate?

Great! This is survey of randomly selected individuals for research purposes; we obtained your contact information by purchasing a list of phone numbers in your area. This is an anonymous survey, meaning that you will not be identified in the results.

[Callers: Responses to questions if asked by the individual.]

* *How long will this take?* Our discussion should only last about eight minutes.
* *Who is sponsoring this survey?* A research organization affiliated with the University of Minnesota.
* *Why are you calling me?* Your phone number was randomly selected. I do not know anything about your household other than your phone number and name.
* *If respondent mentions the National Do Not Call List, read:* Because this survey is a legitimate research study, the National Do Not Call List does not apply. We are not selling anything.

Screening Information

First of all, just to confirm, are you 18 years of age or older?

☐ Yes [Continue]
☐ No [Is an adult available?]

Are you, or is any member of your household, employed by a restaurant or grocery store?

☐ Yes [Thank and end call]
☐ No [Continue]

7. Have you ever heard of the term "aquaponics"?

☐ Yes
☐ No

8. To clarify, aquaponics produces both fish and vegetable products. It is a closed, water-circulating system in which the waste produced by the fish supplies nutrients for the plants, which in turn purifies the water. It can be done in a greenhouse or warehouse. Based on what you just heard, I am going to read you a list of statements and would like you to tell me whether you agree or disagree with each, or if you are unsure. Please use a scale of 1 to 5, where 5 means strongly agree and 1 means strongly disagree. [Read list; check one for each.]

	Strongly agree				*Strongly disagree*	*Unsure*
	5	*4*	*3*	*2*	*1*	*DK*
Aquaponics is a safe and clean method of raising fish and growing vegetables simultaneously.	☐	☐	☐	☐	☐	☐
Aquaponics operations impact the environment in a positive way.	☐	☐	☐	☐	☐	☐
Aquaponics operations grow products with high nutritional value.	☐	☐	☐	☐	☐	☐
Aquaponics is a humane method of raising fish.	☐	☐	☐	☐	☐	☐

9. Do you know if Minnesota has any aquaponics operations?

☐ Yes
☐ No

11. Is there any reason you may be unwilling to purchase aquaponics products? [Do not prompt; attempt to categorize responses.]

☐ Price
☐ How the fish are raised
☐ How the plants are grown
☐ Nutrition concerns
☐ Flavor concerns
☐ Safety or cleanliness concerns
☐ Other (please list):_____

14. How interested would you be in learning more about aquaponics? Please rate on a scale of 1 to 5, with 5 meaning very interested and 1 meaning not at all interested. [Read list; check one for each.]

Very interested				*Not at all interested*	*Unsure*
5	*4*	*3*	*2*	*1*	*DK*
☐	☐	☐	☐	☐	☐

[If answer 1 on above, skip to question 16.]

15. Where would you prefer to receive information regarding aquaponics? [Read list; check all that apply.]

☐ In a news report
☐ At grocery store or restaurant
☐ In an email
☐ Through social media
☐ Other (please list):_____

16. How credible would you consider the following to be as a source of educational information about aquaponics? Please use a scale of 1 to 5, where 5 means very credible, and 1 means not at all credible or helpful. [Read list; check one for each.]

	Very credible				*Not at all credible*	*Unsure*
	5	*4*	*3*	*2*	*1*	*DK*
Grocery store or restaurant	☐	☐	☐	☐	☐	☐
University	☐	☐	☐	☐	☐	☐
Government	☐	☐	☐	☐	☐	☐
Aquaponics grower	☐	☐	☐	☐	☐	☐
News reporter	☐	☐	☐	☐	☐	☐

All of your responses will be kept strictly confidential and are for classification purposes only.

17. Which of the following categories best represents your age? [Read list; check one.]

☐ 18 to 24
☐ 25 to 34
☐ 35 to 44
☐ 45 to 54
☐ 55 to 64
☐ 65 or older
☐ [Do not read] Refused

18. I am required to ask this question. What is your gender? [Read list; check one.]

☐ Male
☐ Female
☐ [Do not read] Other
☐ [Do not read] Refused

19. Please specify your race/ethnicity [Please check all that apply]

☐ Hispanic or Latino
☐ Black or African American
☐ White
☐ Native American or American Indian
☐ Asian/Pacific Islander
☐ Other (please list):_____

20. Which of the following best describes your annual household income? [Read list; check one.]

☐ Less than $30,000
☐ $30,000 to $49,999
☐ $50,000 to $74,999
☐ $75,000 to $99,999
☐ $100,000 or more
☐ [Do not read] Refused

21. Which county do you currently reside in? [Drop-down menu of counties]_____

That is all the questions I have; thank you for your time. If you have any follow-up questions or concerns, you can contact Carol Russell, our lead researcher for this project, at carol@russellherder.com