Title: From Water to Table: A Multidisciplinary Approach Comparing Fish from Aquaponics with Traditional Production Methods

Brittany Kralik[1]
Fei Weisstein[2]
Jeffrey Meyer[2]
Kevin Neves[3]
Dawn Anderson[1]
Jonathan Kershaw[1]*

[1]Department of Public and Allied Health, Bowling Green State University, 111 Health and Human Services Building, Bowling Green, OH 43403, USA

[2]Department of Marketing, Bowling Green State University, 240 Maurer Center, Bowling Green, OH 43403, USA

[3]Department of Biological Science, Bowling Green State University, 217 Life Sciences Building, Bowling Green, OH 43403, USA

*Corresponding author: jkersha@bgsu.edu

Abstract

Global fisheries are insufficient to meet the rising seafood demand of a rapidly growing population. Aquaponics – the co-production of fish and produce in a water-circulating system where fish naturally fertilize the plants, which in turn filter the water for the fish – offers a potential solution to sustainable aquaculture. Despite the ecological promise of aquaponics, relatively little is known about the impact of this novel production method on fish composition, sensory properties, and consumer acceptance. In this research, we offered a unique, interdisciplinary perspective to examine the market potential of aquaponics by conducting a series of multidisciplinary studies to compare yellow perch (*Perca flavescens*) from a combined Recirculating Integrated Multitrophic Aquaculture System (RIMTAS) with fish from traditional production methods (i.e., wild-caught and farm-raised). Our quality parameter and macronutrient analyses showed that aquaponic perch were comparable to their wild-caught and farm-raised counterparts in texture, moisture content, total fat, and total protein. We also demonstrated that aquaponic perch were as liked as wild-caught perch in a consumer sensory evaluation. Furthermore, in a consumer perception and acceptance study, we found that providing information about the environmental benefits of aquaponics significantly increased consumer tastiness perception, healthiness perception, and purchase intention to a level at or exceeding that of wild-caught perch. With proper messaging strategies, aquaponic fish can compete in the market with wild-caught fish. Our findings offer insights to stakeholders in the aquaculture value chain as they explore and establish RIMTAS aquaponics as an environmentally and economically sustainable seafood production source.

Keywords: IMTA, sustainability, sensory evaluation, consumer perception, purchase intention

1. Introduction

Innovative food production practices are needed to sustainably support an expanding global population. According to the United Nations' Food and Agricultural Organization, 60% more food will be needed to support the projected 2050 population of 9.3 billion (Graziano da Silva, n.d.). Seafood production, in particular, represents a sector where innovative practices are needed to sustainably meet growing demand. The majority of wild fisheries are already being fished at capacity or unsustainable rates (FAO, 2020). Although open-ocean aquaculture has increased significantly to meet growing seafood demand and avoid overfishing, these aquaculture methods may introduce other environmental concerns (Srithongouthai & Tada, 2017). Numerous other ecological harms of traditional aquaculture have been extensively documented, including high production of greenhouse gas emissions, destruction of coastal habitats, the introduction of invasive species, and overfishing of wild populations needed to produce aquaculture feed (Klinger & Naylor, 2012; Tilman & Clark, 2014). Although novel techniques can increase seafood production while minimizing harm to the environment, these practices can only ultimately be successful if they are also economically viable. Consumer acceptance of products sourced from innovative food systems is key to supporting sustainable food production.

Aquaponics, a combination of hydroponics and a recirculating aquaculture system (RAS), is a state-of-the-art, environmentally friendly alternative to conventional seafood production methods. In a traditional aquaponic system, nutrient-rich fish wastewater is circulated to bacteria sources, which convert the ammonia from waste into nitrates. The nitrates are then circulated to the plants, which use them as a natural food source while simultaneously cleaning the water before it is recirculated to the fish for reuse (Forchino et al., 2017). Furthermore, incorporating an integrated multitrophic aquaculture (IMTA) approach to aquaponics provides additional environmental benefits. In IMTA, species from different trophic levels, such as plants, fish, shrimp or other detritivorous shellfish, and bacteria, are nourished by the co-products of other species in the system (dos Santos, 2016). A Recirculating IMTA System (RIMTAS) could include shellfish to consume uneaten feed and solid fish waste. Thus, RIMTAS aquaponics supports sustainable aquaculture because it minimizes biological waste, requires fewer inputs, and uses less land and water than other aquaponic methods (Greenfeld et al., 2019; Love et al., 2014). In addition to the environmental benefits of RIMTAS aquaponics, these integrated systems also provide economic benefits to producers because they yield multiple products (dos Santos, 2016).

While aquaponics has the potential to provide the growing population with consumable fish and fresh produce in a sustainable way, whether fish from an aquaponic system differ in quality parameters from fish sourced from wild-fisheries or conventional fish-farming methods is largely unexplored. Fish quality is determined by compositional and sensory measurements and is the most important factor in consumers' seafood purchase decisions (FMI, 2021; González et al., 2006). Fish quality (both actual and perceived) is a complex concept and influenced by many factors such as price, trendiness, presentation of product, and country of origin (Gaviglio & Demartini, 2009). Furthermore, factors such as production method (flow-through vs. recirculating system), fish diet (lipid content), living environment (freshwater vs. marine), and amount of exercise or dissolved oxygen may also contribute to the differences in product quality (Lefevre & Bugeon 2008). Due in part to varying conditions within a given production method, it is unclear whether fish quality parameters differ consistently based on the production method alone. For example, there are reports of both higher and lower lipid content in farmed fish compared with wild-caught fish (Alam et al., 2012; González et al., 2006; Parma et al., 2019). Although compositional differences between farm-raised and wild-caught fish have been studied extensively (Fuentes et al., 2010; Kaya & Erdem, 2009; Manthey-Karl et al., 2016; Verbeke et al., 2007), no studies to our knowledge have sought to quantify the potential quality parameter differences in fish from an aquaponic system. In addition to quality, the health benefits of fish, especially as a good source of protein and healthy fats, are becoming increasingly important to consumers (Conte et al., 2014; FMI, 2021; Banovic et al. 2021). Given the importance of actual and perceived quality and nutritional content to consumer acceptance (Conte et al., 2014), there is a need to examine the impact of aquaponic production on these factors to ensure its market success.

Although objective measurements of fish composition are useful for quality control and production purposes, it is ultimately the consumer's sensory experience that will most influence their evaluation of product acceptability. Indeed, taste is consistently considered the top criteria for consumer fish selection (Bronnmann & Hoffmann, 2018; Weir et al., 2021). Although some studies suggest that production method can alter sensory characteristics (González et al., 2006; Parma et al., 2019), others have found no difference between farmed and wild-caught fish of various species (Sveinsdóttir et al., 2010; Farmer et al., 2000). In numerous other taste evaluations where participants were unaware of the fish source, farmed fish have been rated superior to wild-caught fish (Claret et al., 2016; Kole et al., 2009; Luten et al., 2002; Rickertsen et al., 2017). Despite the evidence that farm-raised fish are accepted as much as wild-caught fish in blind studies, many consumers believe that wild-caught fish are better in taste (Bronnmann & Hoffmann, 2018; Claret et al., 2014). Given aquaponics is a new and emerging practice, little is known how sensory acceptance of aquaponic fish compares with wild-caught ones. Thus, it is critical to generate evidence and messages that demonstrate the sensory parity and acceptance of aquaponic fish to effectively support and promote the commercialization of aquaponics.

Consumers not only hold a taste bias favoring wild-caught fish, but also perceive farm-raised fish as lower in nutritional value, artificial, and less fresh, all of which contribute to decreased quality perceptions (Bronnmann & Hoffmann, 2018; Claret et al., 2014; Kole et al., 2009; Rickertsen et al., 2017; Verbeke et al., 2007). Importantly, lower quality perception of farm-raised fish contributes to a lower willingness-to-pay relative to wild-caught fish (Bronnmann & Asche, 2017; Davidson et al., 2012; Roheim et al., 2011). Because consumers are increasingly seeking sustainably-caught seafood, environmentally-friendly messaging is one promising strategy to improve farm-raised fish perception (Bronnmann & Asche, 2017; FMI, 2021; Uchida, Onozaka, et al., 2014; Uchida, Roheim, et al., 2014). Although studies reporting attitudes toward fish from an aquaponic system are sparse, evidence from studies of marine IMTA systems provides relevant insights. In general, knowledge of IMTA among consumers is low; however, after learning more about IMTA, most consumers view it favorably (Barrington et al., 2010; Knowler et al., 2020; Yip et al., 2016). Due to perceived environmental benefits, IMTA can elicit a 10 to 39% higher willingness-to-pay than fish from conventional aquaculture, particularly when the eco-benefit is clearly labeled (Barrington et al., 2010; Shuve et al., 2009; Yip et al., 2016). Because RIMTAS aquaponics has a number of unique environmental benefits, clear sustainability messaging may be a promising strategy to improve perceived quality of this novel, farm-raised production method.

To address gaps in evidence regarding quality and consumer perception of aquaponic fish, we conducted three studies from multiple disciplines to assess the market potential of fish from an aquaponic system. In study one, we quantified the quality parameters and total fat and protein of yellow perch raised in an aquaponic system compared with wild-caught and farm-raised yellow perch. In study two, we compared consumer sensory acceptance of aquaponic fish with wild-caught fish. In study three, we conducted a consumer experiment to evaluate how information on fish production methods affects consumer perception of tastiness, healthiness, and purchase intention. By integrating findings from our multidisciplinary studies, this research provides a foundation to promote aquaponics as an environmentally and economically sustainable solution to fish production.

2. Methods

2.1. Aquaponics system

Aquaponic fish were sourced from the existing RIMTAS aquaponic system located in a research greenhouse at a midwestern public university in the United States. The system was comprised of three 750-L polyethelene tanks connected to a common side drain line; the first two tanks contained yellow perch (*Perca flavascens*) and the third contained calico crayfish (*Orconectes immunis*) (Figure 1). The drain line gravity-fed a 1.5 x 6.1 m raceway via 1.3 cm polyvinyl chloride (PVC) valves to ensure even distribution of water. The raceway was constructed from a plywood frame and a custom-made vinyl pool liner and contained tomato (*Solanum lycopersicum*) seedlings suspended using 5 cm foam discs set within a 5 cm thick styrofoam sheet. Plants were spaced 0.6 m apart and suspended from the roof of the greenhouse using twine. A drain at the end of the raceway led to a sump composed of polyethylene rain barrels. The water was pumped from the sump to the tanks via a ½ HP centrifugal pump. A Delta Star DS-7 inline air-cooled ¾ HP chiller, on a separate loop, was used to keep the water temperature between 20-26° C. No artificial lighting was used during these trials. All water quality was monitored in accordance with Standard Methods set forth by the American Public Health Association (APHA et al., 1998). Temperature, oxygen (HI 9147, Hanna Instruments, Smithfield, RI), and pH (HI 98108, Hanna Instruments, Smithfield, RI) were measured twice daily. Once weekly, ammonia, nitrite, and nitrate were measured from each tank, the sump, and the raceway using a colorimeter (HR 900, Hach, Loveland, CO).

Juvenile yellow perch, chosen due to their regional popularity, were fed twice daily to apparent satiation with a commercially available diet (Zeigler Silver; 40% protein, 10% fat, Zeigler Bros Inc. Gardners, PA). Aquaponic yellow perch were compared with yellow perch available on the market, namely farm-raised yellow perch (raised in ponds; obtained from Millcreek Perch Farm, Marysville, OH) and wild-caught yellow perch (caught from Lake Erie by study personnel in September of 2020). All three perch samples were harvested fresh at a marketable size, kept on ice, and frozen within a day of harvest. The perch were then kept frozen at -16°C until testing. Following measurement of weight and length, the fish samples were filleted in half so that small flesh samples could easily be removed. All procedures were approved by the university’s Institutional Animal Care and Use Committee.

2.2. Quality parameters and total fat and protein

To quantify potential differences in quality parameters, we assessed fish texture, color, and moisture. Sample sizes represent the number of biological replicates (fish) included per group. Texture analysis ($n = 14$) was performed using a texture analyzer (TMS-Pro, Food Technology Corporation) equipped with a 6 mm probe after baking skin-on samples at 190°C for 12 minutes. Firmness ($n = 14$) of the sample was analyzed as the distance (mm) the probe traveled before the sample skin broke. Skin strength ($n = 14$) was measured as the force (Newtons) required to break the skin of the sample. Raw flesh samples were measured for color (L*, a*, b*) using a colorimeter ($n = 20$) (ColorFlex EZ, Hunter Labs). Moisture content of raw samples was determined as the weight lost following freeze-drying as a percentage of initial wet weight ($n =$ 12-14). We also focused on nutritional attributes of greatest interest to consumers – fat and protein are among the most influential nutrition claims for seafood consumers (FMI, 2021). Hence, total lipids and protein content were measured to assess whether the production method altered fish macronutrient profile. To increase the number of fish represented from each method, the fleshes from three fish were combined to create a single analytical sample for both lipid and protein analysis. A sample size of five (three fish per sample, 15 fish total) per group was chosen based on the approach of Mæhre et al. (2018) for protein determination in fish. Lipid analysis ($n = 5$) was performed using a single solvent extraction method described by Lee et al. (1996).

Briefly, samples from three fish were pooled and combined with a 2:1 chloroform-methanol solvent and blended together. The homogenate was then filtered and evaporated to calculate total lipid content. Protein analysis ($n = 5$) was determined using the combustion method (Padmore, 1990) following freeze-drying and grinding. Findings were reported on a wet weight basis.

Normality and homogeneity of variances of data were determined using Shapiro-Wilk's and Levene's tests, respectively. For normally distributed data, potential differences between quality parameters and total fat and protein of yellow perch samples were determined using one-way ANOVA followed by a Tukey's post-hoc test for pair-wise comparisons. When assumptions of normality or homogeneity of variances were not met, Kruskal-Wallis non-parametric test was used to compare distributions.

2.3. Sensory evaluation for consumer acceptance

We compared sensory acceptance of aquaponic fish with wild-caught fish in a blind sensory evaluation. Because wild-caught fish are considered the taste standard consumers desire, as discussed above, farm-raised fish were not included in the sensory test. Fish from the previously described aquaponics system were harvested, descaled, filleted, cut into bite-size squares (approximately 2cm x 2cm; the entire fillet was used), and frozen for a maximum of 3 days. Wild-caught yellow-perch fillets were purchased fresh from a local grocery store, cut into bite-size samples, and frozen. Prior to serving, frozen perch samples were placed skin-side up on a lightly greased baking sheet and cooked in a pre-heated oven at 177 ºC for 10 minutes. Samples were either served immediately or covered with aluminum foil and placed in an oven set at approximately 80 ºC to keep warm for a maximum of 20 minutes before being served or discarded. Samples (one aquaponic sample and one wild-caught sample) were served side-by-side to participants in 2 oz. disposable plastic cups labeled with a 3-digit blinding code in a counter-balanced order. Participants were recruited from the university campus and local community (inclusion criteria: consume fish within the last three months, no issues with taste or smell, no food allergies; $n = 63$, 70% female, $M_{\text{Age}} = 22.8$). A sample size of 63 was chosen to achieve 80% power to detect an effect size of 0.5 at $\alpha = 0.05$. Participants provided informed consent before beginning study procedures. Participants evaluated samples in individual tasting booths using an iPad equipped with RedJade software (RedJade Sensory Solutions, LLC).

Overall liking, taste liking, texture liking, and appearance liking were assessed using the 9-point hedonic scale (Lawless & Heymann, 2010). The texture was also evaluated using a 7-point Just-About-Right scale anchored by “very much too firm” and “very much not firm enough” (Lawless & Heymann, 2010). Participants were instructed to take a bite of the sample and wait for a minimum of 10-seconds (enforced by an on-screen timer) before answering questions. A 30-second wait time was enforced between each sample, during which participants were instructed to rinse their mouth with water. Participants were compensated with a gift card for their time.

Differences in liking between wild-caught and aquaponic yellow perch were analyzed using a paired samples *t*-test. To determine potential differences in Just-About-Right texture ratings, we condensed responses into three categories: not firm enough, just-about-right, and too firm. Differences between samples were then assessed using a marginal homogeneity (Stuart-Maxwell) test (Lawless & Heymann, 2010).

2.4. Consumer perception survey

In Study 3, we examined the effect of information availability of the fish harvesting method on consumer perceived tastiness, healthiness, and purchase intention. A 3 (fish production method: aquaponics vs. farm-raised vs. wild-caught) × 2 (information availability: presence vs. absence) between-subjects factorial experiment was conducted. Participants were recruited from Amazon Mechanical Turk and provided informed consent before beginning the survey. The experiment was set up to automatically terminate the study when participants incorrectly answered an attention check question, which was included among the dependent measure questions. We received data of 344 subjects who passed the attention check (n = 344, 52% female). Of these, 37% were 18-34 years old, 38% were 35-49 years old, and 25% were aged 50 or older. Participants received a $0.70 incentive for completing the experiment.

Participants were shown a scenario wherein they considered purchasing some fish for dinner at a grocery store and wanted to see what types of fish the store had. To manipulate information availability of fish production method, we created a product page with the image of a yellow perch fillet and the production method information. All participants were randomly assigned to one of the six experimental conditions: (a) aquaponic production method information presence (n

= 55); (b) aquaponic production method information absence (*n* = 57); (c) farmed-raised production method information presence (*n* = 51); (d) farmed-raised production method information absence (*n* = 61); (e) wild-caught production method information presence (*n* = 59); and (f) wild-caught production method information absence (*n* = 61). The production method information was manipulated by presenting (vs. not presenting) the details of the harvesting method, nutritional diet, and the impacts of the respective production method on the environment, as shown in Figure 2. For information absence, only the first sentence was presented to participants, whereas participants in the information presence condition were presented with the entire paragraph.

After reading the information for the randomly assigned condition, participants responded to seven-point scales measuring their perceived tastiness and perceived healthiness of the fish (Schuldt & Hannahan, 2013): how tasty do you think these fish would be (1 = not at all tasty; 7 = very tasty) and how healthy do you think these fish would be (1 = not at all healthy; 7 = very healthy), and their purchase intention ($\alpha = .95$; Grewal et al., 1998): the likelihood of purchasing these fish would be (1 = very low; 7 = very high); if I were going to buy fish, I would consider buying these fish (1 = strongly disagree; 7 = strongly agree); and the probability that I would consider buying these fish is (1 = very low; 7 = very high). Participants also answered one question measuring their perceived information concreteness (Yang et al., 2015): to what extent do you feel the information is an abstract form (i.e., provides information in a general and vague way) or in a concrete form (i.e., provides information in a specific and detailed way) (1 = very abstract; 7 = very concrete), three questions measuring their subjective perceived knowledge ($\alpha = .82$; Li et al., 2002): I feel very knowledgeable about these fish; if I have to purchase these fish today, I would need to gather very little information in order to make a wise decision; and if a friend asks me about these fish, I can give my friend advice about it (1 = strongly disagree; 7 = strongly agree), and provided basic demographic information.

3. Results

3.1. Quality parameters and total fat and protein analysis

Assumptions of normality and homogeneity of variances were met for weight, moisture, skin strength, and L*, but not for length, firmness, percent fat, and percent protein (normality), and a* and b* (homogeneity of variances). All data are presented as mean ± standard deviation in Table 1. Differences in both weight and length were found between the samples ($H(2) = 15.368$, $p < .001$; $F(2,57) = 10.011$, $p < .001$, respectively). The aquaponic perch varied significantly in weight (gm) compared with both the farm-raised perch ($p < .001$) and the wild-caught perch ($p = .006$). Length (mm) varied only between the farm-raised perch and the wild-caught perch ($p = <.001$). Percent moisture content did not vary significantly between groups ($F(2,35) = 1.085$, $p = .349$). No overall differences in skin strength (Newtons) and firmness (mm) were detected between samples (respectively, $F(2,39) = 1.176$, $p = .319$; $H(2) = 2.027$, $p = .363$). Color of raw flesh samples varied slightly between products for both lightness (L* value, $F(2,57) = 4.609$, $p = .014$) and redness (a* value, $H(2) = 21.144$, $p < .001$). The raw aquaponic filets were lighter than the raw farm-raised filets ($p = .014$) and less red than the wild-caught raw filets ($p < .001$). No differences were detected in b* color values ($H(2) = .903$, $p = .637$). No significant differences were found in percent total fat ($H(2) = .815$, $p = .665$) or protein ($H(2) = 1.860$, $p = .395$) between samples (Table 1).

3.2. Sensory acceptance analysis

In a blind taste test, we found no significant differences in overall liking ($t(124) = 1.513$, $p = .133$), taste liking ($t(124) = 1.407$, $p = .162$), texture liking ($t(124) = .539$, $p = .591$), or appearance liking ($t(124) = .519$, $p = .605$) between fish from the aquaponic system and wild-caught fish (Table 2). Furthermore, a similar percentage of participants rated sample firmness just-about-right (62% for aquaponic perch; 63% for wild-caught perch; data not shown), and no overall differences were detected in firmness just-about-right ratings between the two samples ($p = .056$).

3.3. Consumer perception and purchase intention analysis

The information manipulation was effective, such that participants in the information-presence groups perceived the fish information they received as more concrete ($M_{\text{Presence}} = 5.26$, $M_{\text{Absence}} = 4.08$; $F(1, 342) = 44.203$, $p < .001$) and perceived higher product knowledge ($M_{\text{Presence}} = 4.78$, $M_{\text{Absence}} = 4.07$; $F(1, 342) = 24.778$, $p < .001$) than the information-absence groups. A series of multivariate analyses of covariance (MANCOVA) were conducted with gender and age as covariates. No significant differences were found for the covariates on perceived tastiness, perceived healthiness, and purchase intention ($ps > .10$) and thus were removed from further analysis. The MANOVA results revealed significant main effects of fish production method ($\lambda = .92$; $F(6, 670) = 5.051$, $p < .001$) and information availability ($\lambda = .96$; $F(3, 335) = 4.631$, $p = .003$). Subsequent ANOVA analysis indicated a significant effect of fish production method on perceived tastiness ($M_{\text{Aquaponic}} = 5.39$, $M_{\text{Farm-raised}} = 5.08$, $M_{\text{Wild-caught}} = 5.81$; $F(2, 337) = 9.255$, $p < .001$) and perceived healthiness ($M_{\text{Aquaponic}} = 5.53$, $M_{\text{Farm-raised}} = 5.13$, $M_{\text{Wild-caught}} = 5.54$; $F(2, 337) = 3.667$, $p = .027$) and a significant effect of information availability on tastiness ($M_{\text{Presence}} = 5.69$, $M_{\text{Absence}} = 5.20$; $F(1, 337) = 12.744$, $p < .001$), healthiness ($M_{\text{Presence}} = 5.63$, $M_{\text{Absence}} = 5.20$; $F(1, 337) = 10.242$, $p = .002$), and purchase intention ($M_{\text{Presence}} = 5.20$, $M_{\text{Absence}} = 4.89$; $F(1, 337) = 4.131$, $p = .043$).

A 3 (fish production method: aquaponic vs. farm-raised vs. wild-caught) × 2 (information availability: presence vs. absence) MANOVA showed a significant interaction effect ($\lambda = .94$; $F(6, 670) = 3.703$, $p = .001$). Subsequent ANOVAs further indicated an interaction on perceived tastiness ($F(2, 337) = 6.564$, $p = .002$, perceived healthiness ($F(2, 337) = 8.191$, $p < .001$, and purchase intention ($F(2, 337) = 9.899$, $p < .001$, Table 3). In the absence of production method information, participants in the aquaponic fish group reported significantly lower perceptions than wild-caught fish group in tastiness ($t(115) = -4.133$, $p < .001$), healthiness ($t(116) = -3.165$, $p = .002$), and purchase intention ($t(116) = -2.879$, $p = .005$). There was no significant differences between aquaponic and farm-raised fish groups in tastiness ($t(115) = -.568$, $p = .571$), healthiness ($t(116) = -.349$, $p = .728$), and purchase intention ($t(116) = -.920$, $p = .359$). On the other hand, in the presence of production method information, participants in the aquaponic fish group reported significantly higher perceptions than wild-caught fish group in healthiness ($t(112) = 3.273$, $p = .001$) and purchase intention ($t(112) = 3.884$, $p < .001$), but no difference in tastiness ($t(112) = .821$, $p = .413$). There was also a significant difference between aquaponic and farm-raised fish groups in tastiness ($t(104) = 3.095$, $p = .003$), healthiness ($t(104) = 3.314$, $p = .001$), and purchase intention ($t(104) = 2.722$, $p = .008$).

To examine whether perceived tastiness and perceived healthiness mediate the interaction effect of fish production method and information availability on purchase intention, we conducted a moderated mediation analysis using the PROCESS macro (Model 8, 5,000 bootstrapped samples; Hayes, 2017) to construct 95% confidence intervals (CIs). Because the fish production method has three categories, we used indicator coding with aquaponics set as the base level. For information availability, we coded information presence as 1 and information absence as 0.

The indirect effect of the production method × information availability interaction on purchase intention through perceived tastiness was significant for both aquaponics vs. farm-raised (indirect effect = -.336, SE = .160, CI = -.683, -.066) and for aquaponics vs. wild-caught (indirect effect = -.439, SE = .155, CI = -.773, -.174). Conditional indirect effects reveal that when information is not provided, the indirect effect of production method on purchase intention through perceived tastiness is not significant for farm-raised vs. aquaponics (indirect effect = .055, SE = .100, CI = -.131, .263), but is significant for wild-caught vs. aquaponics (indirect effect = .375, SE = .123, CI = .160, .637). Conditional indirect effects also reveal that when information is provided, the indirect effect through perceived tastiness is significant for farm-raised vs. aquaponics (indirect effect = -.281, SE = .118, CI = -.541, -.080), but not for wild-caught vs. aquaponics (indirect effect = -.063, SE = .079, CI = -.234, .084).

The indirect effect of the production method × information availability interaction on purchase intention through perceived healthiness is significant for both farm-raised vs. aquaponics (indirect effect = -.460, SE = .195, CI = -.878, -.105) and for wild-caught vs. aquaponics (indirect effect = -.654, SE = .181, CI = -1.047, -.337). Conditional indirect effects reveal that when information is not provided, the indirect effect through perceived healthiness is not significant for farm-raised vs. aquaponics (indirect effect = .035, SE = .125, CI = -.221, .281), but is significant for wild-caught vs. aquaponics (indirect effect = .329, SE = .123, CI = .110, .595). Conditional indirect effects also reveal that when information is provided, the indirect effect through perceived healthiness is significant for both farm-raised vs. aquaponics (indirect effect = -.425, SE = .149, CI = -.760, -.167) and for wild-caught vs. aquaponics (indirect effect = -.325, SE = .110, CI = -.560, -.130).

4. Discussion

This research compared the physical properties, sensory acceptance, and consumer perception of yellow perch raised in an aquaponic system with yellow perch using other production methods. We found that aquaponic yellow perch were comparable in texture, moisture content, total fat, and total protein with only minor color differences to wild-caught and farm-raised yellow perch. Importantly, aquaponic fish were liked as much as wild-caught fish. Through an online consumer survey, we revealed that the presence of environmental benefits of aquaponic fish enhanced perceived tastiness and healthiness that subsequently increased consumer purchase intention beyond that of wild-caught and farm-raised counterparts.

4.1. Quality parameters and total fat and protein of aquaponic fish

In Study 1, we compared the size, texture, appearance, fat, and protein of aquaponic fish with traditionally farmed-raised and wild-caught fish. Although we did detect size differences, these were likely due to differences in age rather than the production method alone. In a commercial aquaponic system, producers can partially control fish size by accounting for age. Together with others that have also found a minimal impact of production method on fish moisture (González et al., 2006; Manthey-Karl et al., 2016; Parma et al., 2019), our finding that moisture content between samples was comparable suggests that aquaponic production has a minimal effect on moisture-related quality outcomes. Because muscle tissue structure, age, and size can all affect moisture content (Silva et al., 2008), ensuring maturation prior to consumption could help aquaponic fish maintain moisture levels that optimize quality. Our finding that aquaponic perch were less red than wild-caught perch is consistent with others' observations in farmed fish (González et al., 2006). The results may be explained by the similarity in diet between farmed and aquaponic fish, considering the impact of diet on fish color (Maiti et al., 2017; Wallat et al., 2005). Furthermore, we found that aquaponic yellow perch were comparable in texture, fat content, and protein content to other production methods. These results are consistent with the conclusion from the 2015 Dietary Guidelines for Americans Advisory Committee that the production method does not affect the fat content of fish (Dietary Guidelines Advisory Committee, 2015). Texture, appearance, and nutrient content can also be influenced by factors under the producer's control, such as diet (Maiti et al., 2017; Wallat et al., 2005), rather than differences due to the production method alone. Ensuring that aquaponic perch are of comparable quality and nutrition as wild-caught perch should help promote consumer acceptance of the aquaponic products.

Overall, we observed few significant differences in the objective quality parameters and total fat and protein that could be directly ascribed to the production method alone. While attempting to control for factors such as diet and age in this study would have provided a more precise assessment of the impact of aquaponics on fish properties, our goal was to compare aquaponic fish with fish currently available to consumers. Both diet and age are controllable factors in aquaponic fish production, and producers could use various techniques to manage quality parameters and nutritional characteristics. In addition to diet, producers may use other practices that influence the fish composition. For example, fish stocking densities and the use of biofloc technology can affect growth rate and stress response, which in turn influence fish quality (Saseendran et al., 2021). While these data suggest that the impact of aquaponic production on fish composition is likely minimal, further studies are needed to confirm whether other outcomes (i.e., micronutrients, specific fatty acids, etc.) are affected. Investigating potential differences between aquaponic fish and wild-caught fish is vital from a consumer acceptance perspective, especially since wild-caught fish are generally considered the quality gold standard by consumers. from a consumer acceptance perspective, especially since wild-caught fish are generally considered the quality gold standard by consumers.

4.2. Consumer sensory acceptance of aquaponic fish

From a sensory perspective, our finding that aquaponic fish were as accepted as wild-caught fish suggests that aquaponic fish could compete with wild-caught fish on the indispensable quality of taste. Although we detected objective redness differences between aquaponic and wild-caught yellow perch in Study 1, the comparable appearance liking ratings in Study 2 suggest that these color differences do not change consumer acceptance. Furthermore, comparable texture liking and firmness just-about-right ratings align with our findings from Study 1 of no difference in objective flesh firmness. The results from Study 1 and Study 2 suggest that aquaponic fish are equally as accepted as wild-caught fish on a number of important quality indicators. Considering that many consumers are often unaware of how their fish are produced (Bronnmann &

Hoffmann, 2018; Claret et al., 2014), a transition to sourcing fish from aquaponic systems in place of wild-caught sources could likely be implemented with minimal sensory impact.

4.3. Consumer perception and purchase intention of aquaponic fish

Results of Study 3 show that providing information of fish production method significantly increases taste and health perceptions and subsequently enhances purchase intention for aquaponic fish, but has mostly no effect on farm-raised and wild-caught fish. The full moderated mediation model further shows that when information is present, the indirect effect of traditional production methods vs. aquaponics on purchase intention through tastiness decreases (i.e., aquaponics perceived tastiness increases relative to traditional production methods, which further increases purchase intentions). Digging deeper, without information, the conditional indirect effect through tastiness reveals that consumers expect wild-caught to be tastier than aquaponics, which increases purchase intention for wild-caught vs. aquaponics. However, when information is provided, this effect goes away. When comparing aquaponics with farm-raised, the conditional indirect effect through tastiness shows that consumers expect aquaponics to be tastier when information is provided, which increases purchase intention for aquaponics vs. farm-raised, but this effect is not present when information is not provided. These findings align with others that have found detailed information, not just labels, are needed to garner a price premium for eco-labeled fish (Uchida, Roheim, et al., 2014).

Similarly, the indirect effect of traditional production methods vs. aquaponics on purchase intention through healthiness decreases (i.e., aquaponics perceived healthiness increases relative to traditional production methods, which further increases purchase intention). Examining the effects closer, without information, the conditional indirect effect through healthiness reveals that consumers expect wild-caught to be healthier than aquaponics, which increases purchase intentions for wild-caught vs. aquaponics. However, when information is provided, this effect completely reverses, and consumers expect aquaponics to be healthier than wild-caught, increasing purchase intention for aquaponics vs. wild-caught. When comparing aquaponics with farm-raised, the conditional indirect effect through healthiness shows that consumers expect aquaponics to be healthier than farm-raised with information provided, which increases purchase intention for aquaponics vs. farm-raised, but this effect is not present when information is not provided.

In summary, our findings suggest that even though consumers generally hold taste and quality biases favoring wild-caught over farm-raised fish (Claret et al., 2016; Kole et al., 2009; Rickertsen et al., 2017; Verbeke et al., 2007), these negative biases do not hold for aquaponic fish if the aquaponic production method is presented with a focus on its positive environmental impact. On the other hand, if aquaponic information is not provided, consumers perceive strong negative taste and health biases toward aquaponics vs. wild-caught, mainly due to the lack of knowledge regarding this innovative production method and its benefits. In addition to the effect of information availability, our results show that consumer purchase intention of fish is mediated by their perceived tastiness and healthiness. Once consumers learn more about aquaponics, they prefer aquaponic fish more than its wild-caught and farm-raised counterparts because they perceive aquaponic fish tastier and healthier. Taken together, our results support the presence of a general "green halo" (a positive effect of environmentally friendly information on unrelated attributes), in line with others that have found an effect of eco-labeling on outcomes such as actual taste, perceived health, and willingness-to-pay (Sorqvist et al., 2013; 2015).

5. Conclusions

In a series of studies spanning multiple disciplines, we found that aquaponic production methods minimally impact quality parameters, total fat and protein, and sensory characteristics of yellow perch, compared with perch from farm-raised and wild-caught sources. Furthermore, we found that providing an explanation of aquaponics' benefits improved the perceived tastiness, perceived healthiness, and purchase intention to a level at least as high (tastiness) or higher (healthiness and purchase intention) than that of wild-caught fish, the gold quality standard to consumers. Our work extends previous research – while others previously identified the potential of eco-labeling to overcome a quality bias against farm-raised fish (Bronnmann & Asche, 2017), we demonstrate that environmentally-oriented information may actually *alter* quality perception, which in turn improves purchase intention. Considering both the salience of information for new product introduction and the perpetual importance of taste in acceptance of habitually consumed products (Tijssen et al., 2019), our findings highlight the potential of aquaponic fish to succeed from the water to the table. Specifically, we uncover both the first “moment of truth” when consumers are first exposed to products from aquaponics, a novel production system, and the second “moment of truth” when consumers eat the fish. This research helps to establish RIMTAS aquaponics as an environmentally and economically sustainable seafood production source. Our findings can also be used by future producers to help educate them on aquaponics, promote the implementation of aquaponic systems, and improve marketing of aquaponic products.

This research has several limitations that present opportunities for future research. First, we only measured total protein and total fat, thus additional studies are encouraged to examine the impact of aquaponics on specific nutrients, such as Omega-3 fatty acids. Furthermore, investigating the impact of aquaponics on properties of other fish species would improve the generalizability of our findings. Second, while we provided evidence of likely consumer acceptance of fish from an aquaponic system, further research is needed to understand the profitability of the system. We also acknowledge methodological limitations of our study, such as small fish composition sample sizes and the relatively homogenous population of sensory participants. Therefore, expanding the sample size in future compositional studies and targeting a representative sample of seafood consumers would improve the validity of our findings.

Funding

This research was supported by funding from the National Oceanic and Atmospheric Administration (award number NA19OAR4170342), a branch of the United States Department of Commerce.

Declarations of interest

None to declare.

Table 1: Physiochemical and Total Fat and Protein Comparison of Various Yellow Perch (*Perca flavescens*).

Test	Sample size	Aquaponics	Farm-raised	Wild-caught
Weight (grams)	16	151.81 ± 28.85^{a}	219.18 ± 42.82^{b}	111.59 ± 32.12^{c}
Length (millimeters)**	20	222.85 ± 24.50^{ab}	241.05 ± 22.17^{b}	209.30 ± 20.71^{a}
Moisture (percent)	12-14	76.89 ± 1.19^{a}	76.91 ± 0.57^{a}	76.45 ± 0.82^{a}
Force (Newtons)	14	3.64 ± 1.89^{a}	3.17 ± 2.02^{a}	4.36 ± 2.24^{a}
Distance (millimeters)**	14	8.37 ± 1.99^{a}	7.71 ± 1.84^{a}	8.41 ± 1.53^{a}
Color				
L*	20	33.82 ± 2.94^{a}	31.08 ± 3.46^{b}	31.72 ± 2.46^{ab}
a* #	20	-2.86 ± 0.41^{a}	-2.68 ± 0.48^{a}	-2.25 ± 0.25^{b}
b* #	20	1.00 ± 1.42^{a}	0.73 ± 0.90^{a}	0.58 ± 0.65^{a}
Fat (percent)**	5	6.82 ± 0.64^{a}	6.35 ± 0.76^{a}	7.50 ± 0.47^{a}
Protein (percent)**	5	24.11 ± 5.00^{a}	20.32 ± 0.75^{a}	19.51 ± 2.47^{a}

Means ± standard deviations are displayed.

Force: N needed to break the skin

Distance: mm the probe traveled in order to break the skin

L*: lightness, value close to zero being darker

a*: redness/greenness, + redder, - greener

b*: yellowness/blueness, +yellower, -bluer

Fat: percent per 3-gram wet sample

Protein: percent per gram protein per gram wet weight sample

*Values that share the same letter are not significantly different within a test ($p > .05$).

Table 2: Liking of Aquaponic vs. Wild-caught Yellow Perch (*Perca flavescens*)

Test	Sample size	Aquaponics	Wild-caught	*p* value
Overall liking	63	6.75 ± 1.65	6.30 ± 1.65	.133
Taste liking	63	6.57 ± 1.60	6.17 ± 1.56	.162
Texture liking	63	6.19 ± 2.09	6.00 ± 1.88	.591
Appearance liking	63	5.76 ± 1.97	5.59 ± 1.80	.605

All outcomes were rated on a 9-point hedonic scale from 1 (dislike extremely) to 9 (like extremely). Means ± standard deviations are displayed.

Table 3: Perceived Tastiness, Perceived Healthiness, and Purchase Intent by Information Availability and Production Method

	Aquaponics		Farm-Raised		Wild-Caught		*p* values		
	Info. Absent	Info. Present	Info. Absent	Info. Present	Info. Absent	Info. Present	Prod.	Info.	Prod. × Info.
Perceived Tastiness	4.80 ± .17^{a}	5.98 ± .17^{b}	4.95 ± .16^{ad}	5.24 ± .18^{cd}	5.80 ± .16^{e}	5.81 ± .17^{bce}	<.001	<.001	.002
Perceived Healthiness	4.93 ± .17^{a}	6.13 ± .17^{b}	5.02 ± .16^{ad}	5.28 ± .18^{cd}	5.61 ± .16^{e}	5.48 ± .17^{cde}	.028	.001	<.001
Purchase Intent	4.93 ± .17^{a}	6.13 ± .17^{b}	5.02 ± .16^{ace}	5.28 ± .18de	5.61 ± .16^{cf}	5.48 ± .17^{cdf}	.441	.044	<.001

Means ± standard errors are displayed

* Values that share the same letter are not significantly different within a test ($p > .05$).

Appendix A: Figure captions

Figure 1: Recirculating Integrated Multitrophic Aquaculture System (RIMTAS) Aquaponic System Diagram. Containing yellow perch (*Perca flavascens*) and calico crayfish (*Orconectes immunis*) connected to a raceway containing tomatoes (*Solanum lycopersicum*) suspended on Styrofoam disks.

Figure 2: Production Method and Information Availability Conditions. For information absence, only the first sentence was shown to study participants. For information presence, the rest of the information was also shown.

Acknowledgements

We gratefully acknowledge and thank Ms. Natalie Nieschwitz for her assistance in analyzing the fish samples, Mr. Frank Schemenauer for his adept assistance in managing the greenhouse, and Mr. Bill Lynch for donating the farm-raised perch samples.

References

Alam, S., Khan, N., Nasir, M., Javid, A., Khan, T. A., Tayyab, R., & Zikria, N. (2012). Chemical and sensory quality changes in wild and farmed fish flesh (*Labeo rohita*) at frozen storage (-18°C). *Journal of Animal and Plant Sciences*, *22*(3), 614–618.

APHA. (1998). *Standard methods for the examination of water and wastewater* (20th ed.). American Public Health Association, American Water Works Association, and Water Environment Federation. Washington, DC, USA.

Banovic, M., Aschemann-Witzel, J., & Deliza, R. (2021). Taste perceptions mediate the effect of a health goal on food choice. *Food Quality and Preference 94*:104305. https://doi-org.ezproxy.bgsu.edu/10.1016/j.foodqual.2021.104305

Barrington, K., Ridler, N., Chopin, T., Robinson, S., & Robinson, B. (2010). Social aspects of the sustainability of integrated multi-trophic aquaculture. *Aquaculture International*, *18*(2), 201–211. https://doi.org/10.1007/s10499-008-9236-0

Bronnmann, J., & Asche, F. (2017). Sustainable seafood from aquaculture and wild fisheries: Insights from a discrete choice experiment in Germany. *Ecological Economics*, *142*, 113–119. https://doi.org/10.1016/j.ecolecon.2017.06.005

Bronnmann, J., & Hoffmann, J. (2018). Consumer preferences for farmed and ecolabeled turbot: A North German perspective. *Aquaculture Economics & Management*, *22*(3), 342–361. https://doi.org/10.1080/13657305.2018.1398788

Claret, A., Guerrero, L., Gartzia, I., Garcia-Quiroga, M., & Ginés, R. (2016). Does information affect consumer liking of farmed and wild fish? *Aquaculture*, *454*, 157–162. https://doi.org/10.1016/j.aquaculture.2015.12.024

Claret, A., Guerrero, L., Ginés, R., Grau, A., Hernández, M. D., Aguirre, E., Peleteiro, J. B., Fernández-Pato, C., & Rodríguez-Rodríguez, C. (2014). Consumer beliefs regarding farmed versus wild fish. *Appetite*, *79*, 25–31. https://doi.org/10.1016/j.appet.2014.03.031

Conte, F., Passantino, A., Longo, S., & Voslářová, E. (2014). Consumers' attitude towards fish meat. *Italian Journal of Food Safety*, *3*(3), 1983. https://doi.org/10.4081/ijfs.2014.1983

Davidson, K., Pan, M., Hu, W., & Poerwanto, D. (2012). Consumers' willingness to pay for aquaculture fish products vs. wild-caught seafood—A case study in Hawaii. *Aquaculture Economics & Management*, *16*(2), 136–154. https://doi.org/10.1080/13657305.2012.678554

Dietary Guidelines Advisory Committee. (2015). *Seafood and Sustainability Evidence Portfolio (Appendix E-2.38)*. U.S. Department of Health and Human Services. https://health.gov/our-work/food-nutrition/2015-2020-dietary-guidelines/advisory-report/appendix-e-2/appendix-e-238

dos Santos, M. J. P. L. (2016). Smart cities and urban areas—Aquaponics as innovative urban agriculture. *Urban Forestry & Urban Greening*, *20*, 402–406. https://doi.org/10.1016/j.ufug.2016.10.004

FAO. (2020). *The State of the World Fisheries and Aquaculture 2020. Sustainability in action.*

FMI. (2021). *The power of seafood 2021: An in-depth look at seafood through the shopper's eyes.*

Forchino, A. A., Lourguioui, H., Brigolin, D., & Pastres, R. (2017). Aquaponics and sustainability: The comparison of two different aquaponic techniques using the life cycle assessment (LCA). *Aquacultural Engineering*, *77*, 80–88. https://doi.org/10.1016/j.aquaeng.2017.03.002

Fuentes, A., Fernández-Segovia, I., Serra, J. A., & Barat, J. M. (2010). Comparison of wild and cultured sea bass (*Dicentrarchus labrax*) quality. *Food Chemistry*, *119*(4), 1514–1518. https://doi.org/10.1016/j.foodchem.2009.09.036

Gaviglio, A., & Demartini, E. (2009). Consumer attitudes towards farm-raised and wild-caught fish: variables of product perception. *New Medit, VIII*(3, Supp.), 34-40.

Godfray, H. C. J., Aveyard, P., Garnett, T., Hall, J. W., Key, T. J., Lorimer, J., Pierrehumbert, R. T., Scarborough, P., Springmann, M., & Jebb, S. A. (2018). Meat consumption, health, and the environment. *Science*, *361*(6399), eaam5324. https://doi.org/10.1126/science.aam5324

González, S., Flick, G. J., O'Keefe, S. F., Duncan, S. E., McLean, E., & Craig, S. R. (2006). Composition of farmed and wild yellow perch (*Perca flavescens*). *Journal of Food Composition and Analysis*, *19*(6–7), 720–726. https://doi.org/10.1016/j.jfca.2006.01.007

Graziano da Silva, J. (n.d.). *Feeding the World Sustainably | United Nations*. Retrieved March 10, 2021, from https://www.un.org/en/chronicle/article/feeding-world-sustainably

Greenfeld, A., Becker, N., McIlwain, J., Fotedar, R., & Bornman, J. F. (2019). Economically viable aquaponics? Identifying the gap between potential and current uncertainties. *Reviews in Aquaculture*, *11*(3), 848–862. https://doi.org/10.1111/raq.12269

Grewal, D., Monroe, K. B., & Krishnan, R. (1998). The effects of price-comparison advertising on buyers' perceptions of acquisition value, transaction value, and behavioral intentions. *Journal of Marketing*, *62*(2), 46–59. https://doi.org/10.2307/1252160

Huss, H. H. (1995). *Quality and quality changes in fresh fish. FAO fisheries technical paper.* (No. 348). Food and Agriculture Organization of the United Nations. http://www.fao.org/3/v7180e/V7180E00.HTM#Contents

Kaya, Y., & Erdem, M. E. (2009). Seasonal comparison of wild and farmed brown trout (*Salmo trutta forma fario* L., 1758): Crude lipid, gonadosomatic index and fatty acids. *International Journal of Food Sciences and Nutrition*, *60*(5), 413–423. https://doi.org/10.1080/09637480701777886

Klinger, D., & Naylor, R. (2012). Searching for solutions in aquaculture: Charting a sustainable course. *Annual Review of Environment and Resources*, *37*(1), 247–276. https://doi.org/10.1146/annurev-environ-021111-161531

Knowler, D., Chopin, T., Martínez-Espiñeira, R., Neori, A., Nobre, A., Noce, A., & Reid, G. (2020). The economics of Integrated Multi-Trophic Aquaculture: Where are we now and where do we need to go? *Reviews in Aquaculture*, *12*(3), 1579–1594. https://doi.org/10.1111/raq.12399

Kole, A. P. W., Altintzoglou, T., Schelvis-Smit, R. A. A. M., & Luten, J. B. (2009). The effects of different types of product information on the consumer product evaluation for fresh cod in real life settings. *Food Quality and Preference*, *20*(3), 187–194. https://doi.org/10.1016/j.foodqual.2008.09.003

Lawless, H. T., & Heymann, H. (2010). *Sensory evaluation of food: Principles and practices*. Springer Science & Business Media.

Lee, C. M., Trevino, B., & Chaiyawat, M. (1996). A simple and rapid solvent extraction method for determining total lipids in fish tissue. *Journal of AOAC International*, *79*(2), 487–492.

Lefevre, F., & Bugeon, J. (2008). Biological basis of fish quality. *Sciences des aliments*, *28:*365-377.

Li, H., Daugherty, T., & Biocca, F. (2002). Impact of 3-D advertising on product knowledge, brand attitude, and purchase intention: The mediating role of presence. *Journal of Advertising*, *31*(3), 43–57.

Love, D. C., Fry, J. P., Genello, L., Hill, E. S., Frederick, J. A., Li, X., & Semmens, K. (2014). An International Survey of Aquaponics Practitioners. *PLOS ONE*, *9*(7), e102662. https://doi.org/10.1371/journal.pone.0102662

Luten, J., Kole, A., Schelvis, R., Veldman, M., Heide, M., Carlehög, M., & Akse, L. (2002). Evaluation of wild cod versus wild caught, farmed raised cod from Norway by Dutch consumers. *Nofima*, *2002*(12), 44–60.

Mæhre, H. K., Dalheim, L., Edvinsen, G. K., Elvevoll, E. O., & Jensen, I.-J. (2018). Protein Determination—Method Matters. *Foods, 7*(1), 5. https://doi.org/10.3390/foods7010005

Maiti, M. K., Bora, D., Tl, N., Sahoo, S., Bk, A., & Kumar, S. (2017). Effect of dietary natural carotenoid sources on colour enhancement of Koi carp, *Cyprinus carpio* L. *International Journal of Fish and Aquatic Studies*, *5*(4), 340–345.

Manthey-Karl, M., Lehmann, I., Ostermeyer, U., & Schröder, U. (2016). Natural chemical composition of commercial fish species: Characterisation of pangasius, wild and farmed turbot and barramundi. *Foods*, *5*(3). https://doi.org/10.3390/foods5030058

Moustafa, K., Cross, J., & Gasim, S. (2018). Food and starvation: Is Earth able to feed its growing population? *International Journal of Food Sciences & Nutrition*, *69*(4), 385–388.

O'Neill, B., Le Roux, A., & Hoffman, L. C. (2015). Comparative study of the nutritional composition of wild versus farmed yellowtail (*Seriola lalandi*). *Aquaculture*, *448*, 169–175. https://doi.org/10.1016/j.aquaculture.2015.05.034

Padmore, J. M. (1990). *Protein (Crude) in Animal Feed—Combustion Method, Method No. 990.03. Official Methods of Analysis of the Association of Official Analytical Chemists* (Kenneth Helrich 15th). AOAC Inc.

Parma, L., Badiani, A., Bonaldo, A., Viroli, C., Farabegoli, F., Silvi, M., Bonvini, E., Pirini, M., & Gatta, P. P. (2019). Farmed and wild common sole (*Solea solea* L.): Comparative assessment of morphometric parameters, processing yields, selected nutritional traits and sensory profile. *Aquaculture*, *502*, 63–71. https://doi.org/10.1016/j.aquaculture.2018.12.029

Rickertsen, K., Alfnes, F., Combris, P., Enderli, G., Issanchou, S., & Shogren, J. F. (2017). French consumers' attitudes and preferences toward wild and farmed fish. *Marine Resource Economics*, *32*(1), 59–81. https://doi.org/10.1086/689202

Roheim, C. A., Asche, F., & Santos, J. I. (2011). The Elusive Price Premium for Ecolabelled Products: Evidence from Seafood in the UK Market. *Journal of Agricultural Economics*, *62*(3), 655–668. https://doi.org/10.1111/j.1477-9552.2011.00299.x

Saseendran, S., Dube, K., Chandrakant, M. H., & Babitha Rani, A. M. (2021). Enhanced growth response and stress mitigation of genetically improved farmed Tilapia in a biofloc integrated aquaponic system with bell pepper. *Aquaculture*, *533*, 736200. https://doi.org/10.1016/j.aquaculture.2020.736200

Schuldt, J. P., & Hannahan, M. (2013). When good deeds leave a bad taste. Negative inferences from ethical food claims. *Appetite*, *62*, 76–83. https://doi.org/10.1016/j.appet.2012.11.004

Shuve, H., Caines, E., Ridler, N., Chopin, T., Reid, G. K., Sawhney, M., Lamontagne, J., Szemerda, M., Marvin, R., Powell, F., Robinson, S., & Boyne-Travis, S. (2009). Survey finds consumers support Integrated Multi-Trophic Aquaculture. Effective marketing concept key. *Global Aquaculture Advocate*, *12*, 22–23.

Silva, V. M. da, Silva, L. A., Andrade, J. B. de, Veloso, M. C. da C., & Santos, G. V. (2008). Determination of moisture content and water activity in algae and fish by thermoanalytical techniques. *Química Nova*, *31*(4), 901–905. https://doi.org/10.1590/S0100-40422008000400030

Sorqvist, P., Haga, A., Langeborg, L., Holmgren, M., Wallinder, M., Nöstl, A., Seager, P. B., & Marsh, J. E. (2015). The green halo: Mechanisms and limits of the eco-label effect. *Food Quality and Preference*, *43*, 1–9. https://doi.org/10.1016/j.foodqual.2015.02.001

Sorqvist, P., Hedblom, D., Holmgren, M., Haga, A., Langeborg, L., Nöstl, A., & Kågström, J. (2013). Who needs cream and sugar when there is eco-labeling? Taste and willingness to pay for “eco-friendly” coffee. *PLOS ONE*, *8*(12), e80719. https://doi.org/10.1371/journal.pone.0080719

Sveinsdóttir, K., Martinsdóttir, E., Thórsdóttir, F., Schelvis, R., Kole, A., & Thórsdóttir, I. (2010). Evaluation of Farmed Cod Products by a Trained Sensory Panel and Consumers in Different Test Settings. *Journal of Sensory Studies*, *25*(2), 280–293. https://doi.org/10.1111/j.1745-459X.2009.00257.x

Tijssen, I. O. J. M., Zandstra, E. H., den Boer, A., & Jager, G. (2019). Taste matters most: Effects of package design on the dynamics of implicit and explicit product evaluations over repeated in-home consumption. *Food Quality and Preference*, *72*, 126–135. https://doi.org/10.1016/j.foodqual.2018.09.009

Tilman, D., & Clark, M. (2014). Global diets link environmental sustainability and human health. *Nature*, *515*(7528), 518–518. https://doi.org/10.1038/nature13959

Uchida, H., Onozaka, Y., Morita, T., & Managi, S. (2014). Demand for ecolabeled seafood in the Japanese market: A conjoint analysis of the impact of information and interaction with other labels. *Food Policy*, *44*, 68–76. https://doi.org/10.1016/j.foodpol.2013.10.002

Uchida, H., Roheim, C. A., Wakamatsu, H., & Anderson, C. M. (2014). Do Japanese consumers care about sustainable fisheries? Evidence from an auction of ecolabelled seafood. *Australian Journal of Agricultural and Resource Economics*, *58*(2), 263–280. https://doi.org/10.1111/1467-8489.12036

Verbeke, W., Sioen, I., Brunsø, K., De Henauw, S., & Van Camp, J. (2007). Consumer perception versus scientific evidence of farmed and wild fish: Exploratory insights from belgium. *Aquaculture International*, *15*(2), 121–136. https://doi.org/10.1007/s10499-007-9072-7

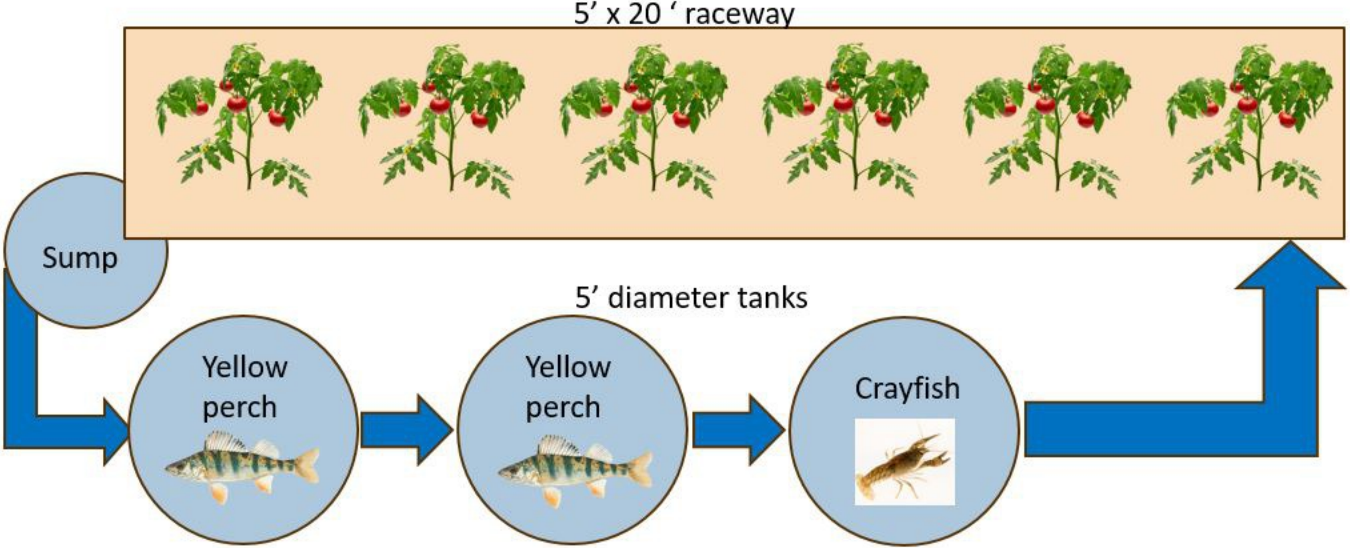
Wallat, G. K., Lazur, A. M., & Chapman, F. A. (2005). Carotenoids of different types and concentrations in commercial formulated fish diets affect color and its development in the skin of the Red Oranda variety of goldfish. *North American Journal of Aquaculture*, *67*(1), 42–51. https://doi.org/10.1577/FA03-062.1

Weir, M. J., Uchida, H., & Vadiveloo, M. (2021). Quantifying the effect of market information on demand for genetically modified salmon. *Aquaculture Economics & Management*, *25*(1), 1–26. https://doi.org/10.1080/13657305.2020.1803447

Yang, D., Lu, Y., Zhu, W., & Su, C. (2015). Going green: How different advertising appeals impact green consumption behavior. *Journal of Business Research*, *68*(12), 2663–2675. https://doi.org/10.1016/j.jbusres.2015.04.004

Yip, W., Knowler, D., Haider, W., & Trenholm, R. (2016). Valuing the willingness-to-pay for sustainable seafood: Integrated multitrophic versus closed containment aquaculture.

Canadian Journal of Agricultural Economics, *65*(1), 93–117. https://doi.org/10.1111/cjag.12102



5’ x 20 ‘ raceway

Sump

5’ diameter tanks

Yellow perch

Yellow perch

Crayfish

Aquaponic Condition

These fish were harvested using aquaponic methods.

In an aquaponic system, fish are raised alongside plants and other species in a water recirculating system that resembles a natural ecosystem; fish naturally fertilize the plants, and the plants filter the water for the fish. Aquaponic fish are fed a nutritionally complete diet and swim in water sourced from municipal sources free from significant chemical contaminants. Aquaponics minimizes overfishing (the depletion of natural fish populations below sustainable levels) and prevents damage to underwater habitats caused by some fishing methods. Aquaponics generates almost no waste products, which lowers the impact of fish production on water pollution and potential negative effects on the surrounding ecosystem.

Farm-raised Condition

These fish were harvested using traditional fish farming methods, such as ponds or indoor systems.

In these systems, fish are stocked into either man-made ponds or artificial recirculating systems with filtration systems to ensure water quality is adequate. Farm-raised fish are fed a nutritionally complete diet and swim in water sourced from municipal sources free from significant chemical contaminants. Fish farming minimizes overfishing (the depletion of natural fish populations below sustainable levels) and prevents damage to underwater habitats caused by some fishing methods. Fish farming generates concentrated waste products, which contribute to water pollution when unintentionally released into the environment, resulting in negative effects on the surrounding ecosystem.

Wild-caught Condition

These fish were harvested using traditional wild-caught methods, such as trawl nets or rod and reel.

In wild-caught harvest methods, fish are raised in their natural ecosystem with no man-made involvement. Wild-caught fish feed on a natural diet in their native habitat and swim in lake and ocean waters, some of which contain chemical contaminants. Wild-caught fishing methods may result in overfishing (the depletion of natural fish populations below sustainable levels) and damage underwater habitats. The methods generate air pollution due to fishing boat diesel fuel consumption. Wild-caught fishing methods avoid the generation of concentrated fish waste products, which lowers the impact of fish production on water pollution and potential negative effects on the surrounding ecosystem.