Can Domestic Aquaculture Compete? Consumer Willingness to Pay and Cost Benchmarks in the Arabian Peninsula

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Abstract

In countries with limited water resources that increasingly rely on imported food, sustainable fish farming offers a promising pathway to improve food security. This study focuses on Saudi Arabia, an arid country prioritizing domestic aquaculture expansion under its Vision 2030 initiative, and investigates consumer preferences for domestically farmed rainbow trout (*Oncorhynchus mykiss*) as a viable substitute for imported salmon. Using a discrete choice field experiment at point-of-sale with 333 consumers in Riyadh and Jeddah, we estimate willingness-to-pay (WTP) for key rainbow trout attributes, including origin, certification, product form, processing method, and color. Results show strong preferences for domestically produced, SAMAQ-certified (a national aquaculture quality label), fresh fillets with orange color, and significant WTP premiums for these traits. We also compare these WTP estimates with production cost scenarios to assess the economic feasibility of substituting imported salmon with domestically farmed rainbow trout. Findings suggest that, under efficient production scales, domestically produced trout can be cost-competitive with imports when aligned with consumer preferences. This study contributes new evidence from an arid, import-dependent country and highlights how aligning supply with consumer demand can support aquaculture expansion. The results offer practical guidance for food system transformation in similar contexts globally.

Keywords

Sustainable aquaculture, Rainbow trout, Arabian Peninsula, Import Substitution, Willingness-to-Pay

1. Introduction

Ensuring sustainable and resilient food systems remains a pressing challenge for many developing and resource-scarce economies. As global fish consumption continues to rise, driven by growing populations, shifting dietary preferences, and increased awareness of the health benefits of aquatic foods, countries with limited natural water resources face challenges to meet domestic demand through imports (Food and Agriculture Organization [FAO], 2022a; Sabine et al., 2019; Claret et al., 2014, Ankamah-Yeboah et al., 2019). These challenges are more pressing in arid and semi-arid regions, where freshwater aquaculture remains underdeveloped despite its potential to reduce reliance on protein imports and improve nutritional security. Sustainable aquaculture is therefore recognized as a critical pathway for advancing both national food strategies and broader development goals (UN, 2015; Béné et al., 2016; FAO, 2020).

As an arid country, the Kingdom of Saudi Arabia (KSA) exemplifies these challenges and opportunities. Between 1997 and 2017, per capita meat consumption, primarily beef, veal, and poultry (as pork is not consumed for religious reasons) increased steadily, rising from approximately 45 kg to over 55 kg per person per year, with an annual growth rate of about 1% (Our World in Data n.d.). On the other hand, although fish consumption remains much smaller than meat consumption, it has been expanding at a more rapid pace. During the same period, total consumption of all the fish and fish products (both capture and aquaculture products, including shellfish and crustaceans) increased nearly 300%, rising from approximately 125 thousand tons to 375 thousand tons. Per capita consumption grew from 6.4 kg to 11.3 kg, with an average annual growth rate of 2.9%, which notably exceeds the global per capita consumption average annual growth rate of 1.4% from 15.5 kg to 20.3 kg (FAO, 2022b), highlighting rising consumer interest in seafood and the country's shifting protein demand structure.

Looking ahead, by 2030, Saudi Arabia's population is projected to reach 39.3 million, with per capita fish consumption expected to rise to 16.4 kg. To meet this demand, aquaculture would need to grow by 14.4% annually, adding roughly 256,000 tons per year to current production levels (FAO, 2022b). Despite production increasing from 6,004 tons in 2000 to 75,400 tons in 2019, domestic supply remains far below demand. Imports rose from 71,318 tons in 2000 to 252,251 tons in 2019; an average annual increase of 10.4%, underscoring the country's heavy reliance on imported seafood and the importance of developing domestic aquaculture to enhance food security (FAO, 2022b; Alkuraieef et al., 2021).

Recognizing the vulnerability of its food supply, KSA's Vision 2030 outlines ambitious targets for economic diversification, environmental sustainability, and food security (Burger et al., 2014; Khan et al., 2016; ElShehawy et al., 2016; Alnasser & Musallat 2022; Government of Saudi Arabia, 2016). A key goal of the Saudi Vision 2030 is to reduce reliance on protein imports while promoting sustainable economic growth. To this end, the Ministry of Environment, Water, and Agriculture (MEWA) has committed investments of $347 million in the aquaculture sector from 2019 to 2030. This investment aims to boost fish production from 75,400 tons to 600,000 tons by 2030, with 88% of the increase coming from aquaculture (Government of Saudi Arabia, 2016; MEWA, 2019).

Saudi Arabia relies heavily on imported seafood, which account for about 65% of domestic consumption (U.S. Department of Agriculture, Foreign Agricultural Service 2025). Because species-level consumption data are not published, import composition serves as the best proxy for consumer preferences. In 2023, salmon, mackerel, and cod accounted for nearly 90% of seafood import value, with salmon alone rising from 11% of import value in 2019 to 21% in 2023. Domestic aquaculture is dominated by Nile tilapia, sea bass, sea bream, and shrimp (Al-Kinani, 2024).

Salmon[1], primarily imported from Norway and Chile, is offered fresh, frozen, and smoked and occupies a clear premium tier. Fresh fillets typically retail for 100–130 SAR/kg, and whole salmon for 65–90 SAR/kg, compared with 23–30 SAR/kg for local tilapia and 14–20 SAR/kg for small pelagic species. Field observations show that country-of-origin labels are often absent in physical retail outlets but more consistently displayed online. Domestic production of salmon is not economically viable, and trout imports remain minimal, leaving Saudi markets highly dependent on foreign salmonid supply. Given this dependence and the government's interest in expanding domestic aquaculture, efforts have focused on identifying locally adaptable, high-value species (Broom et al., 2023). Rainbow trout (Oncorhynchus mykiss) has emerged as a promising candidate: it closely resembles salmon in appearance and flavor, is widely accepted in global markets, and is viewed as a potential substitute for imported salmon in meeting Saudi Arabia's rising demand (FAO, 2020; Landazuri-Tveteraas et al., 2021).

A critical, yet underexamined, factor in the success of such initiatives is consumer demand: whether consumers are willing to accept and pay for domestically produced alternatives to high-status imports like salmon. To fill this gap in the literature, this study investigates the role of consumer preferences in shaping the feasibility of an aquaculture-driven import substitution in KSA, using rainbow trout production as a test case. While traditionally not produced in KSA, rainbow trout can be farmed in recirculating systems[2] under controlled conditions. We implement a discrete choice (DC) field experiment at point-of-sale (e.g., supermarkets, malls) with 333 consumers in two major KSA cities, Riyadh and Jeddah, to estimate willingness-to-pay (WTP) for key product attributes, such as price, origin, quality certification, color, processing, and product

[1] We use salmon to refer to all imported salmonids, with Atlantic salmon (Salmo salar) constituting the dominant share of imports.

[2] Recirculating Aquaculture Systems (RAS) are land-based farms that minimize water usage by filtering, adjusting, and reusing water and allow year-round production with controlled conditions. A reference text is provided by Timmons and Vinci (2022).

form. We also compare WTP estimates with production cost scenarios and the freight on board (FOB) price of imported salmon. These analyses allow us to assess the economic feasibility of substituting imported salmon and assess whether domestic trout can realistically compete with imported salmon in the retail marketplace.

The DC field experiment indicates high consumer preferences for rainbow trout that is domestically produced, SAMAQ-certified, fresh fillets with orange coloration, and significant WTP premiums for these traits. The analysis combining production costs and WTP estimates suggests that domestically produced rainbow trout can be cost-competitive with imported salmon, especially when aligned with consumer preferences. Our findings offer broader insights into the intersection of consumer behavior, sustainability certification, and aquaculture policy in developing economies. By comparing WTP estimates with modeled production costs at various scales, we evaluate the economic viability of domestic rainbow trout aquaculture as a substitute for fish imports. If aligned with product development and public policy, consumer demand can play a catalytic role in shifting food systems toward greater self-sufficiency and resilience. The results have implications for other water-scarce countries and net food-importing nations seeking to build more self-reliant food systems through sustainable aquaculture.

2. Literature Review

Understanding consumer preferences is critical to the success of aquaculture development. Numerous studies have shown that consumers evaluate fish products based on intrinsic (e.g., taste, texture, color) and extrinsic attributes (e.g., country of origin, price, certification, and processing method). Intrinsic attributes are often tied to perceived freshness and quality, with color—especially rich orange to deep reddish-orange salmon—consistently associated with higher consumer preference (Steine et al., 2005; Rosenau et al., 2023). Rainbow trout, a salmonid species with similar sensory characteristics, offers a promising substitute if it aligns with consumer expectations (Teimouri et al., 2013).

Extrinsic cues such as origin, certification, and product form significantly influence consumers' WTP for seafood. Studies have shown that consumers in developed countries prefer domestically produced fish and are willing to pay a premium for products with credible certifications such as Marine Stewardship Council (MSC) or Aquaculture Stewardship Council (ASC) labels (Claret et al., 2012; Davidson et al., 2012; Chen et al., 2015). Similar dynamics appear in developing markets: Hossain, Nielsen, and Islam (2024) find that in Bangladesh, affordability, availability, and perceptions of safety are equally important determinants of WTP. Across contexts, consumers also show strong preferences for fish that is fresh, filleted, and easy to prepare, reflecting broader trends toward convenience and perceived cleanliness in food preparation (Birch et al., 2012; Ankamah-Yeboah et al., 2019; Thong et al., 2015).

In emerging aquaculture markets like Saudi Arabia, similar dynamics apply, but with added emphasis on government involvement. Certification systems, particularly those administered or endorsed by the state, can play a key role in building consumer trust and fostering acceptance of domestic products. Studies in other contexts have shown that government-backed certifications can improve consumer confidence and encourage acceptance of local products, especially in markets historically dependent on imports (Hinkes & Schulze-Ehlers, 2018; Risius et al., 2019). In KSA, the SAMAQ certification functions not only as a quality assurance label but also as an extension of state-led efforts to promote domestic food production.

Despite this growing body of work, research gaps remain. Most research on consumer preferences for aquaculture products is concentrated in North America, Europe, or East Asia, with relatively little empirical evidence from Gulf countries. Moreover, few studies integrate consumer preference data with production cost analysis, limiting the ability to evaluate the economic viability of scaling aquaculture initiatives in developing import-dependent economies. This study addresses these gaps by combining a Discrete Choice Experiment (DCE) at point-of-sale with production cost modeling to assess the feasibility of domestic rainbow trout production in the KSA. In doing so, it offers a novel approach for aligning consumer demand with aquaculture development strategies in dry, food-importing regions.

3. Experimental Design

The study was carried out in two major cities in the KSA: Riyadh (the capital city) and Jeddah (a coastal city). In each location, two study stations were set up, one in a shopping mall and the other in a supermarket, with a display table showcasing both salmon and rainbow trout. The booth also included a display board and a screen monitor presenting the study's objectives and purpose (See section A in the Supplementary material). The cities and the study stations were selected to represent a diverse range of the KSA population in the sample. The experimental procedures were designed in collaboration with the KSA research team and key stakeholders from the local government and the aquaculture industry. The study received approval from the University Institutional Review Board and the relevant KSA authorities.

We developed and administered the survey through Qualtrics™, creating both Arabic and English versions. Data was stored in an Excel workbook from Qualtrics and analyzed using STATA software. The final sample consisted of 333 participants who completed the experiment in full. The participants were at least 18 years old, regular fish consumers, and were responsible or shared responsibility for purchasing food and preparing family meals. As a token of appreciation, we offered a souvenir gift to participants upon completing the experiment. To ensure accurate data collection, survey enumerators underwent a training program before initiating the data-gathering phase.[3] Participants were recruited and provided informed consent via an electronic tablet before proceeding to the DCE and completing a questionnaire on consumption habits and sociodemographic characteristics.

Discrete Choice Experiments are widely used in consumer behavior research for their ability to simulate real purchasing scenarios, requiring consumers to make trade-offs between products with varying attributes (Lusk & Schroeder, 2004). Given the hypothetical context of the CE tasks, a cheap talk script was shown to all respondents right before starting the experiment to mitigate hypothetical bias (Cummings & Taylor, 1999; Menozzi et al., 2020). Following established methodology (Cummings & Taylor, 1999; Lusk, 2003), our script informed participants about the common tendency to overstate their willingness to choose or pay in hypothetical scenarios and encouraged them to approach their selections as if making actual financial decisions. Participants were instructed to assume the role of a fish shopper, evaluating each alternative with the same level of scrutiny they would apply in a supermarket setting. This approach reinforced the realism of the task and helped align stated preferences more closely with actual purchasing behavior.

The attributes for the DCE were informed by a literature review and market research on the limited availability of imported rainbow trout in local retail outlets. To ensure that rainbow trout is a suitable substitute for salmon from a sensory perspective, we conducted a blind taste evaluation among participants prior to the DCE. Participants were given two coded samples (one

[3] Before data collection, we conducted two separate full-day training sessions, one in each city, to were equally well-prepared to administer the survey effectively and consistently. The training covered study objectives, participant recruitment, and screening criteria, followed by a hands-on session where enumerators completed the DCE experiment to familiarize themselves with the survey flow. We emphasized standardized phrasing, neutrality, and the importance of cheap talk to reduce hypothetical bias. Enumerators, fluent in both English and Arabic, practiced survey administration through mock interviews and role-playing exercises to ensure clarity and consistency. Additionally, we discussed logistics and ethical considerations, including how to obtain informed consent, protect participant confidentiality, and report any challenges encountered in the field. Each training concluded with a Q&A session and a post-training evaluation, ensuring that all enumerators were fully prepared.

of each species) and asked to evaluate their taste, texture, appearance, and odor one at a time. The tasting order was randomized to prevent order bias, and participants were instructed to cleanse their palates with water and crackers between samples. The fish were prepared using identical cooking methods under controlled conditions by the same chef (see section B for the detailed analysis of the sensory evaluation in the Supplementary material). Consistent with prior studies, sensory tasting results showed no significant differences in taste or texture between the two species, but consumers preferred the color of rainbow trout, supporting its inclusion as a key DCE attribute. **Table 1** summarizes the six DCE attributes and levels. Based on market data, a 0.35 kg portion size was selected.

Price – 19.99 SAR ($5.33), 27.99 SAR ($7.46), 35.99 SAR ($9.60), and 43.99 SAR ($11.73), reflecting retail prices.

Color – Orange and white, the two natural variations in rainbow trout meat depending on diet. Color is a critical attribute since rainbow trout competes directly with salmon in the local market.

Product form – Whole fish; fillet with skin, no bone; and fillet without skin or bone. These levels reflect both prior literature (Birch et al., 2012; Davidson et al., 2012; Ankamah-Yeboah et al., 2019) and cultural preferences for plate-sized fish.

Processing form – Fresh, frozen, and smoked, consistent with consumer-relevant categories identified in earlier studies (Ankamah-Yeboah et al., 2019). Although whole smoked trout is not currently available in Saudi retail markets, consultations with industry stakeholders and government partners identified plate-size trout as a potential product for future development. Its inclusion in the DCE therefore serves as a forward-looking product form intended to gauge consumer preference of value-added salmonid products.

Origin and quality certification – Imported; KSA-produced; and KSA-produced with SAMAQ certification. This attribute reflects both stakeholder interest and its prominence in the literature as a determinant of consumer choice (Ankamah-Yeboah et al., 2019). The SAMAQ program (Saudi Aquaculture Product Quality Program, سماك) is a government initiative under the Ministry of Environment, Water, and Agriculture (MEWA). It certifies compliance with responsible aquaculture practices via external audits conducted by trained Aquaculture Society staff. SAMAQ reassures consumers that domestic fish are fresh, safe, and high quality (SAMAQ, n.d.). Certification is free for producers.

Based on these attributes and their levels, we employed a D-optimal design using the JMP software to construct the choice sets. The unlabeled DCE contained 24 choice sets and was divided into three blocks. Each participant was assigned a randomized block of eight choice sets. In each choice set, participants were asked to evaluate two rainbow trout options (Trout A and Trout B), or not to buy any available options (Not buy). The opt-out option was included as the status quo to avoid imposing unwanted products on respondents (Koemle & Yu, 2020; Menozzi et al., 2020). The choice sets achieved a D-efficiency of 99.32. We randomized the order in which choice sets and alternatives were presented to remove order effects. A representative example of the choice set presentation is depicted in **Figure 1**.

After completing the DCE, participants filled out a short questionnaire in three parts. The first part collected demographic information (e.g., age, gender, nationality, education, household size, and monthly income). The second part focused on fish purchasing and consumption habits, including shopping frequency, whether the respondent was the primary household shopper, preferred retail outlet (e.g., open market, supermarket) and reasons for that choice, preferred size when purchasing whole fish, and frequency of consuming different fish types. The final part asked participants to rate the importance of factors such as price, origin, color, product form, processing form, and quality certification on a Likert scale from 1 (“Not important at all”) to 5 (“Very important”).

4. Empirical Methods

Following previous studies, we employed a Random Utility Model to analyze the choice experiment data (Claret et al., 2012; Stefani et al., 2012; Carlucci et al., 2015; Alfnes et al., 2018; Ankamah-Yeboah et al., 2019; Cantillo et al., 2020), and the DCE methodology is consistent with Lancaster's consumer theory and McFadden’s (1974) random utility theory. The Lancaster consumer theory of utility maximization states that given a budget constraint, the consumer's optimal choice is the bundle of goods that gives the combination of attributes providing the highest utility. Specifically, we estimated a random parameters multinomial logit model (mixed logit model) to explore consumers’ WTP for domestically produced rainbow trout in the KSA. To analyze the DCE data, the random utility theory was applied with the assumption that consumers choose the alternative that provides them with the maximum utility (Lancaster, 1966; Train, 2009). The decision maker *n* chooses the alternative *j* from the choice set *t* based on the utility function (U_{njt}), which contains two parts: the observed utility, V_{njt}, which is a function of observable attributes X_{njt} of the alternatives; and the unobserved part. ε_{njt} in Eq. 1 is the random component of the utility (Train, 2009).

The utility function is given as follows:

(1) $$U_{njt} = V_{njt} + \varepsilon_{njt} = \beta_n X_{njt} + \varepsilon_{njt}$$

Where β_n is a vector of parameters to be estimated representing the impact of the product attributes on utility. The probability that decision maker *n* chooses alternative *j* is

(2) $$P_{njt} = Prob\left(U_{njt} > U_{nit}\right)$$

$$= Prob\left(V_{njt} + \varepsilon_{njt} > V_{nit} + \varepsilon_{nit}\right) \;\; \forall\, i \neq j$$

Consumers choose alternative *j* which has higher utility than alternative *i*. In other words, if the consumer chooses *Fish A* after evaluating the attributes of the two fish alternatives, this indicates that the consumer obtains the highest utility from *Fish A* compared with the other two alternatives (i.e., *Fish B* or the *Not buy* alternative).

The probability for respondent *n* choosing alternative *j* is given by

$$P_{njt} = \frac{e^{V_{njt}}}{\sum_i e^{V_{nit}}} \tag{3}$$

In the original discrete choice random utility model (McFadden, 1974), consumers' preferences are assumed to be homogenous (the empirical specification is the conditional logit model). However, in this study, we relax this assumption and test for heterogeneity of preferences among consumers. Thus, we use a Random Parameters Logit (RPL) model, also known as a mixed logit (MXL) model, to estimate consumers' preferences and the associated WTP for the different attributes. The MXL accounts for preference heterogeneity among respondents by allowing one or more parameters in the model to be randomly distributed (Train, 2009).

In this study, the explanatory variables included the attributes of all alternatives: price, origin and certification, color, product shape, and processing form. The model considers the price to be non-random. The variables *KSA produced and KSA produced with SAMAQ* were included in the analysis where the *Imported* served as the omitted variable. *Orange* was included in the analysis, where *White* served as the reference variable; *Fillet with skin and no bone* and *Fillet without skin and no bone* were included in the analysis where the *Whole* served as the reference variable; and *Fresh* and *Frozen* were included in the analysis where the *Smoked* served as a reference variable. The utility derived by respondent *n* from choosing alternative *j* at choice occasion *t* is:

(4) $$U_{njt} = \beta_{n0}Not\_buy_{njt} + \beta_{n1}Orange_{njt} + \beta_{n2}KSA_{njt} + \beta_{n3}KSA\_SAMAQ_{njt} + \beta_{n4}FilletSkin\_NoBone_{njt} + \beta_{n5}FilletNoSkin\_NoBone_{njt} + \beta_{n6}Fresh_{njt} + \beta_{n7}Frozen_{njt} + \beta_{n8}Price_{njt} + \varepsilon_{njt}$$

The ***Not_buy*** variable enters the utility model as a dummy, equal to 1 if the "Not buy" option is chosen and 0 otherwise. ***Price*** captures the price attribute and is expected to negatively affect utility. ***Orange*** equals 1 for orange-colored fish and 0 for white. ***KSA*** equals 1 for domestically produced fish, while ***KSA_SAMAQ*** equals 1 for fish produced in KSA with SAMAQ certification. ***FilletSkin_Nobone*** and ***FilletNoSkin_Nobone*** equal 1 for fillets with skin/no bone or without skin/no bone, respectively. ***Fresh*** and ***Frozen*** equal 1 for those processing forms. White, whole, imported, and smoked fish serve as the base category, and all utilities are interpreted relative to this baseline.

The probability that respondent n chooses alternative *j* at scenario *t* evaluated at β_n is

(5) $$P_{njt} = \int \left(\frac{e^{\beta' x_{njt}}}{\sum_j e^{\beta' x_{nit}}}\right) f(\beta) d\beta$$

And the logit probability depending on parameter β_n is

(6) $$L_{njt}(\beta_j) = \left(\frac{e^{\beta_i x_{njt}}}{\sum_j e^{\beta_i{}^{x_{nit}}}}\right) f(\beta) d\beta$$

In order to compare Saudi consumers' WTP to the production cost of rainbow trout to assess the economic viability of the domestic rainbow trout sector relative to imported salmon, we have calculated consumers' WTP, that is

(7) $$WTP_j = -\frac{\bar{\beta}_j}{\bar{\beta}_{price}}$$

where $\bar{\beta}_j$ and $\bar{\beta}_{price}$ are the mean values of the estimated random coefficients.

5. Data Description and Results

This section discusses the descriptive statistics of the sample collected and the results of the statistical models employed in the analysis.

5.1 Sample Description

The sample comprised 333 consumers, 175 from Riyadh and 158 from Jeddah, over 18, who regularly consumed fish and had no dietary restrictions (**Table 2**). Among the respondents, 50% were women, 49% were men, and 1% preferred not to state their gender. The average age of the respondents was 38 years old. Regarding age ranges, the largest groups were from 25 to 34 (32%) and from 35 to 44 years (29%). About 24% of the households had a monthly income ranging from 5,000 to 10,000 SAR, about 23% had a monthly income of less than 5,000 SAR, and 25% of participants preferred to keep their monthly household income private. More than half of the participants were non-Saudi (55%), while 45% were Saudi citizens. This composition reflects the demographic reality of Saudi Arabia, where non-Saudis make up approximately 44% of the total population and contribute substantially to national seafood consumption (Global Media Insight, 2025). Including both Saudi and non-Saudi consumers therefore provides a more accurate representation of the country's overall fish demand.

Regarding family size, 68% of the participants stated that they were in households composed of 4 to 7 members. About 59% of respondents had completed their higher education degrees, 13% had a postgraduate degree, and 21% had a high school diploma. This information should be considered when tailoring marketing strategies and defining consumer segments.

5.2 Fish Purchase and Consumption Habits

Regarding consumption frequency and the type of fish consumed in KSA households, most respondents consumed fish at least twice a month. Salmon is the most common type of fish consumed twice a month (40%), followed by grouper (34%), other types of fish (31%), and rainbow trout (28%), suggesting that fish is a regular part of the diet for many households in KSA.

This indicates a steady demand for fish products in the market. We also find most fish were purchased from hypermarkets (29%), open markets (29%), and specialty gourmet stores (22%). Few consumers stated they purchased their fish directly from the producer, the neighborhood mini market, or farmed it themselves. The most important reasons for purchasing fish in these establishments are good product quality (51%), a wider variety of product selection (23%), and reasonable prices (15%).

The mean comparison scores for the essential characteristics that consumers consider when purchasing fish in the market are presented in **Table 3**. The three most important characteristics that affect the purchase of fish are fish type (4.5), SAMAQ quality certification (4.4), and processing form (4.3). Price ranked fourth. Consumers were less concerned with the harvesting method and the country of origin for the fish[4]. Regarding the most preferred product form, mean scores show that most consumers prefer whole fish (4.2), followed by fillets (3.9) and steak (3.4) over other product forms. This implies that KSA consumers prioritize the freshness and quality of fish over cost, suggesting a willingness to pay for premium products. Concerning the processing form, the majority of the participants have a strong desire for fresh fish (4.5), followed by tinned (2.9) and smoked (2.8), and value less frozen (2.3) or salt-dried fish (2.2). This reinforces the importance of freshness in consumer decision-making.

We conducted pairwise Wilcoxon signed-rank tests to assess whether differences in mean attribute scores were statistically significant. The results confirm that type of fish was rated significantly higher than most other attributes, emphasizing its dominant role in consumer choice. Quality certification was also rated significantly above most attributes, highlighting the importance of product quality assurance and trust. Among the mid-ranking attributes (processing form, price, color, size, and product form), several pairwise differences were statistically significant, though

[4] In the USA, seafood is required to have COOL (country of origin labelling) labelling.

not all. For instance, processing form was rated significantly higher than most attributes except price and color, while price and color did not differ significantly from each other. This suggests moderate differences across these attributes, and their perceived importance in consumer choice is quite similar.

5.4 Choice Experiment: Results of the Mixed Logit Model

The estimated coefficients measuring the impact of product attributes on consumer preferences from the MXL model (equation 4) are given in **Table 4**. This model has 7,992 observations with a log-likelihood ratio test statistic of -1,959. Variables considered in the model include price levels, color (orange, while white serves as the reference variable), product form (fillet with skin, no bone, and fillet without skin, no bone, while whole fish serves as the reference variable), processing form (fresh, frozen, and smoked serves as the reference variable), and origin and certification (KSA produced, KSA produced with SAMAQ certification and imported serves as the reference variable).

The results show that all coefficients, except those for frozen and KSA-produced fish, are statistically significant at the 1% level. The parameter estimates measure preferences for attributes compared to a fish with white color, smoked, whole, and imported (the benchmark fish). A positive (negative) sign on a given coefficient means that consumers prefer (dislike) the attribute level associated with it in comparison to the attribute level of the benchmark fish. For added rigor, we have also conducted a robustness check for the MXL model, specifically, we ran the model using alternative estimation techniques, including the conditional logit model, the multinomial logit model, and a mixed logit model allowing for correlation across the coefficients (see section C in the Supplementary material). Our results are robust to alternative specifications, but the mixed logit model has the lowest AIC, BIC, and largest Log likelihood. Therefore, we will report only the MXL results in **Table 4**.

The price coefficient is negative and significant at the 1% level, indicating that consumers prefer lower-priced fish. This is consistent with the demand theory stating that the higher the price, the lower the demand and the propensity to purchase. The coefficient for *Orange* is positive and significant at the 1% level, indicating that consumers prefer an orange over a white rainbow trout. The *Fresh* fish form coefficient is positive and statistically significant at the 1% level, indicating that consumers prefer fresh fish over smoked fish. However, the *Frozen* fish coefficient is statistically insignificant, suggesting consumers are indifferent between frozen and smoked fish. The coefficients for *Fillet with skin, no bone* and *Fillet without skin, no bone* are positive and statistically significant, indicating that consumers prefer fillet (skinless or with skin) to whole fish for its easiness of preparation. Moreover, the results suggest that consumers slightly prefer skinless fillets over fillets with skin. The positive and statistically significant coefficient of *KSA produced and SAMAQ certified* attributes suggest that consumers prefer domestically produced rainbow trout with the SAMAQ certification over imported rainbow trout without a quality certification. The coefficient for *KSA-produced* rainbow trout without SAMAQ certification is not statistically significant, suggesting that consumers do not show a preference between KSA-produced and imported rainbow trout.

Although the coefficient on the Frozen coefficient is not significant, the coefficient and standard error on the standard deviation are significant at the 1% alpha level. This can be interpreted as a substantial variation in how individual consumers feel about frozen fish. Traditionally, it is almost a universal response from consumers that fresh is always preferred over frozen, probably originating from when aged fresh fish were frozen and then sold to preserve some market value. However, today's freezing technologies have advanced to the point that in blind testing of fresh vs. frozen products, the consumer will prefer frozen over fresh (Iwata et al., 2015). This presents an opportunity for creative market strategies. With the proper pricing and marketing strategies, consumers could be encouraged to try frozen products, potentially dispelling the myth that fresh is always superior to frozen.

Similarly, the strong preference for KSA SAMAQ certification reflects consumers' WTP for high quality. Although KSA products alone do not show as strong a preference, the significant standard deviation suggests there is potential for higher price acceptance, especially if the product quality and attributes are properly communicated to consumers.

We present the estimated WTP in **Table 5** for each rainbow trout attribute using the estimated parameters from Table 4 to provide more meaningful results.

The results indicate that, in terms of color, consumers are willing to pay a price premium of 39.27 SAR ($10.47) for an orange rainbow trout of 0.35 kg compared to a white one of similar size. For processing form, results suggest that consumers are willing to pay 29.79 SAR ($7.95) for a fresh rainbow trout relative to frozen or smoked alternatives. The most valued product form is a fillet without skin and bones: Saudi consumers are willing to pay an additional 26.70 SAR ($7.12) for such fillets and 17.78 SAR ($4.74) for fillets with skin but no bones, relative to a whole fish of equivalent size. Regarding origin, consumers are willing to pay an additional 24.31 SAR ($6.48) for domestically produced rainbow trout with the SAMAQ quality certification logo compared with imported trout.

These values represent marginal price premiums, not total prices, and are consistent with actual market conditions in Saudi Arabia. During the fieldwork period (October 2022), the average retail price of fresh salmon fillets in Riyadh and Jeddah was approximately 110 SAR/kg (≈ $30/kg), suggesting that the estimated WTP values, although on the higher end, fall within realistic price ranges for premium imported fish. The magnitude of these premiums also aligns with prior studies. For example, Ankamah-Yeboah et al. (2019) reported that German consumers were willing to pay a price premium of about €18/kg (≈ $19/kg) for domestically produced trout and €10/kg (≈

$12.5/kg) for sustainably produced fish. Yin et al. (2020), for their part, found that Chinese consumers were willing to pay a 84–120% price premiums for organic and traceable shrimp. Together, these findings indicate that Saudi consumers exhibit similar strong preferences for freshness, color, and certified quality attributes—consistent with global evidence from high-value seafood markets.

5.5 Comparative analysis of WTP estimates and product costs

We use the consumer WTP estimates in combination with production cost estimates of domestically produced rainbow trout, to assess the economic viability of the domestic rainbow trout sector relative to imported salmon (**Table 6**). To do this, we employed a basic principles mass balance model[5] to predict the production costs of rainbow trout in the KSA (Broom, 2023). The model inputs included: target annual production, stocking and harvest densities, outside air and dry and wet bulb temperatures, building thermal characteristics, water chiller characteristics, and all key financial cost parameters, e.g., feed prices, electric prices, labor and management costs. The study determined that the minimum production cost for a rainbow trout (with the preferred attributes of color, product form, and processing form) is $8.62 per kg for a fully utilized production facility with an annual capacity of 1,000 tons at modest stocking densities (**Table 6**). We compared production costs at various levels of facility utilization for rainbow trout with the import prices of salmon. To estimate retail prices for both species, we added a typical markup observed along the supply chain— from production facility to retail for rainbow trout, and from import seaport to retail for salmon. Additionally, we used the WTP estimates for domestically-produced, SAMAQ-certified rainbow trout to assess how its retail prices compare to those of imported salmon. This comparison offers valuable insights into the economic viability of rainbow trout aquaculture in the KSA.

[5] This Excel workbook is available upon request from the authors.

We conducted a sensitivity analysis of production costs at various production capacity levels: 190, 280, 550, 640, 730, 820, 910, and 1000 tons per year. We compared the costs of domestically produced rainbow trout with imported salmon at various levels of production facility utilization in Table 6. For instance, at 1,000 tons per year, the production cost is estimated at $8.62 per kg, and per unit production costs increase as facility utilization levels decrease. We note that the FOB import price for salmon is lower ($7.5 per kg.) at all levels of production facility utilization. MEWA governs the SAMAQ certification to ensure that producers comply with responsible aquaculture practices. To encourage producers to adopt the SAMAQ certification and promote sustainability in the aquaculture sector, MEWA offers the certification at no cost to producers.

Assuming an average supply chain markup of 300% between the production facility (or FOB price) and retail store[6], the retail price of domestically produced rainbow trout with SAMAQ certification is $25.86 per kilogram ($8.62 * 3). In comparison, the import FOB price for fresh salmon is $7.50 per kilogram (FAOSTATA, various years), leading to an estimated retail price of $22.50 per kilogram ($7.50 * 3). Thus, the estimated retail price difference between KSA-produced rainbow trout with SAMAQ certification and imported salmon is $3.36 per kilogram. It should be noted that our mixed logit model results estimate that consumers are willing to pay a price premium of $17.76 per kg for domestically produced trout with SAMAQ certification, converted from 24.31 SAR/0.35 kg (Row 8 in Table 6), rather than a total price value. The willingness to pay (WTP) price premium estimate of $17.76 per kg, although on the higher side, aligns with findings from previous research on consumer preferences for fish products. Studies

[6] The 300% markup from the production facility (or FOB price) to the retail price for salmon is supported by both the author's calculations and expert opinions. According to FAO data (FAOSTAT, various years), the imported price for fresh/chilled salmon fillets in 2019 was approximately 33 SAR/kg, while the retail price for similar products was around 90 SAR/kg. This significant difference in pricing suggests a retail markup of about 300%, which reflects standard industry practices for covering costs such as transportation, handling, and profit margins. The markup is consistent with expert opinions on pricing structures within the seafood supply chain.

have consistently shown that country of origin and quality attributes are critical factors in purchasing decisions (Jaffry et al., 2004; Birch et al., 2012), with domestic products often perceived as superior in terms of freshness, safety, and reduced carbon footprints (Onozaka and McFadden, 2011). For example, Ankamah-Yeboah et al. (2019) found that German consumers were willing to pay €18 price premium per kg (approximately $19.18) for domestically produced trout, a value comparable to the WTP estimate in this study. Additionally, the premium for sustainable production methods (€10.03 per kg or $12.52) supports the high WTP for SAMAQ certification, reflecting strong consumer preferences for both local production and certified quality attributes.

These WTP estimates far exceed the $3.36 retail price gap between KSA-produced trout and imported salmon, making domestic trout production competitive with imported salmon. Our analysis in Table 6 further reveals that as production levels rise, the production costs for domestically produced rainbow trout in KSA decrease, narrowing the retail price gap between domestic trout and imported salmon, thereby enhancing KSA rainbow trout producers' ability to compete with imported salmon.[7] In sum, given consumer WTP a price premium for domestic SAMAQ-certified rainbow trout, the domestic aquaculture sector for this fish species could compete successfully for market share with imported salmon.

6. Discussion

The rapid growth in fish demand in the KSA, coupled with limited domestic production, raises questions about the country's ability to expand the country's aquaculture sector. In response to this growing demand, the KSA government has made significant investments in developing its

[7] Please note this analysis assumes static market conditions and consumer preferences, and doesn't account for potential fluctuations in production inputs, consumer behavior, or international trade. Therefore, it should be used cautiously, as real-world market dynamics could affect profitability differently than this controlled analysis suggests. This point has been highlighted in the Conclusion section as a limitation.

domestic aquaculture sector. Specifically, research has identified rainbow trout as a promising species for domestic production due to its similarities to salmon, a popular imported fish. To explore this potential, we conducted a DC field experiment at point-of-sale with 333 consumers in two major cities, Riyadh and Jeddah, to examine their preferences and WTP for rainbow trout attributes. The DCE assesses consumer preferences consisted of five key attributes: price, color, origin and certification, product form, and processing form. A comparative analysis of the WTP estimates and production costs was conducted to evaluate the feasibility of establishing a domestic rainbow trout production system in KSA using imported salmon as a benchmark.

The DCE revealed strong consumer preferences for orange-colored, fresh, filleted, skinless, SAMAQ-certified, and domestically produced rainbow trout compared with white, whole, smoked, and imported trout. Consumers reported WTP premiums of 39.27 SAR/0.35kg for orange color, 29.79 SAR for fresh, 26.70 SAR for a skinless/boneless fillet, 17.78 SAR for a skin-on fillet, and 23.31 SAR for local SAMAQ certification relative to non-certified imports. These results highlight the importance of visual appeal and convenience, consistent with Teimouri et al. (2013) and Rosenau et al. (2023).

While prior studies in Germany, the United States, and Spain show preferences for domestically produced finfish (Claret et al., 2012; Stefani et al., 2012; Mauracher et al., 2013; Ankamah-Yeboah et al., 2019), our findings indicate that KSA consumers value domestic fish only when coupled with credible certification. SAMAQ thus plays a critical role in establishing trust and signaling quality. The survey results also suggest that, although quality is essential, many consumers in KSA lack confidence in assessing it directly. They favor familiar species that are easy to prepare and nutritionally valuable. Enhancing packaging and labeling—especially emphasizing domestic origin and certification—can build trust and promote local aquaculture. As

Tran et al. (2013) noted, government-backed certification schemes such as SAMAQ strengthen consumer confidence and reshape value chain governance.

The high ranking of fish type also reflects strong species attachment among Saudi consumers. Salmon, as a well-established imported species with high presence in Saudi Market, represents this attachment, which may initially make it challenging to shift preferences toward rainbow trout. However, results from the sensory evaluation and field interviews suggest that trout's more intense orange color, richer and fatty flavor, attributes highly appreciated in Saudi food culture (Alqarni, 2016), can help overcome this attachment when paired with strategic marketing that positions trout as a domestic "salmon-like" product. As production and availability increase, familiarity and trust are likely to strengthen consumer acceptance.

The study evaluated the potential for domestically farmed rainbow trout to compete with imported salmon by integrating consumer WTP analysis with production cost modeling. As domestic production scales up, production costs decrease, narrowing the price gap and boosting the competitiveness of local producers. This alignment between consumer demand and production feasibility supports KSA's broader goals of strengthening food security and reducing reliance on imports. Like findings from Myanmar showing that aquaculture can stimulate rural employment and local economies (Filipski & Belton, 2018), expanding inland aquaculture in KSA offers opportunities for rural employment generation, private sector development, and broader economic diversification.

Policymakers in KSA could continue supporting free access to SAMAQ certification for producers while investing in cold chain infrastructure to ensure product freshness and quality. The results suggest that consumers place greater value on species type, quality certifications (e.g., SAMAQ, Halal) than on price. This indicates that purchasing decisions are driven more by product attributes and trust than by price differences. Therefore, enhancing product quality, certification credibility in domestic aquaculture may be more effective for strengthening food security than focusing solely on lowering prices. Additionally, efforts should focus on promoting consumer education campaigns to build familiarity and trust in domestically farmed fish species. Strengthening post-harvest handling, marketing, and branding strategies around certified products will further enhance the competitiveness of KSA's aquaculture and maximize its contribution to national food security and rural development.

This study provides insights with direct implications for both policy and industry in Saudi Arabia, where aquaculture is central to reducing reliance on imports and strengthening domestic food supply under Vision 2030. By demonstrating consumer preferences for certified, ready-to-cook domestic fish, the findings highlight opportunities for targeted investment and regulatory support that can enhance market development in arid, import-dependent regions. Beyond national relevance, the results also contribute to the broader literature on sustainable aquaculture by showing how certification and product attributes shape demand in emerging economies. As global wild stocks decline and seafood demand continues to rise, aligning aquaculture production with consumer preferences will be essential for achieving resilient and competitive food systems.

While Saudi Arabia's experience shows that strong government financial investment can help build a domestic aquaculture industry, we must note that this approach may not be realistic for many developing economies. Countries with fewer financial resources could start with smaller or more focused programs, such as improving production standards, certification systems, and supply-chain facilities. The level and design of investment should match each country's economic capacity and institutional strength. In the long run, success depends not only on financial support but also on building trust in local products, improving distribution systems, and developing stable markets for domestic fish.

Although this study provides valuable insights for the KSA government and contributes to the consumer preference literature, it has several limitations. The absence of domestically produced rainbow trout confined this research to hypothetical choice tests, limiting the observation of actual customer behavior. Future studies should consider real-market experiments or observational data once domestically produced rainbow trout becomes available. Additional research could explore other influencing attributes, such as eco-labels, nutrition information, and branding, to capture evolving consumer behavior. Moreover, while this study provides a comparative analysis of the production cost and WTP estimates between domestically produced rainbow trout and imported salmon, it assumes static market conditions and consumer preferences. In practice, fluctuations in production input costs, international fish markets, and consumer preferences could affect profitability and should be examined in future research. Another limitation is that imported salmon was treated as a single benchmark category without distinguishing between salmon with a quality assurance label and without this label. Based on our fieldwork, most salmon available in Saudi supermarkets have no quality assurance labels. Because systematic data by label status were unavailable, we could not estimate separate willingness-to-pay for labeled versus unlabeled imported fish. Future research could incorporate these distinctions where reliable data exist.

7. Conclusion

This study provides important empirical evidence on KSA consumer preferences for rainbow trout and the potential for domestic aquaculture to substitute for imported seafood. By combining a DC field experiment with production cost analysis, we demonstrate that strong consumer demand exists for domestically produced, certified, fresh trout fillets and that scaling up production could significantly improve cost competitiveness. These findings directly affect policymakers and aquaculture stakeholders seeking to strengthen local food production systems, reduce reliance on imports, and enhance food security. Future research should investigate real-market behavior as domestic rainbow trout becomes available and explore the role of additional attributes, such as eco-labeling and branding, in shaping consumer acceptance.

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Table 1: Attributes and attribute levels used in the choice experiment

Attributes	Levels
Color	Orange
	White
Origin & Certification	Imported
	KSA Produced
	KSA Produced and SAMAQ-certified
Product form	Whole (gutted)
	Fillet with skin, no bone
	Fillet without skin, no bone
Processing form	Fresh
	Frozen
	Smoked
Price	19.99 SAR ($5.33)
	27.99 SAR ($7.46)
	35.99 SAR ($9.60)
	43.99 SAR ($11.73)

Table 2: Social demographics of the survey sample

Demographic characteristics		Sample (n=333)
Gender	Male	164 (49.3%)
	Female	166 (49.9%)
	Prefer not to say	3 (0.9%)
Age	18-24	49 (14.7%)
	25-34	107 (32.1%)
	35-44	97 (29.1%)
	45-54	40 (12.0%)
	55-64	28 (8.4%)
	65+	12 (3.6%)
Income (Household Monthly, SAR)	Less than 5,000 SAR	78 (23.4%)
	5,001-10,000 SAR	81 (24.3%)
	10,001-30,000 SAR	61 (18.3%)
	30,001-50,000 SAR	17 (5.1%)
	50,001-70,000 SAR	2 (0.6%)
	More than 70,001	12 (3.6 %)
	Prefer not to say	82 (24.6%)
Nationality	Saudi Arabia	149 (44.7%)
	Other Country	184 (55.3%)
Household size	1-3	83 (24.9%)
	4-7	225 (67.6%)
	8+	25 (7.5%)
Education	Illiterate	4 (1.2%)
	Elementary	5 (1.5%)
	Secondary	16 (4.8%)
	High School	70 (21.0%)
	University	195 (58.6%)
	Postgraduate	43 (12.9%)

Table 3: Consumer preferences for different fish characteristics (Using a 5-point Likert scale 1 = 'Not important at all', 5 = 'Very important' or (1 = 'I dislike it very much', 5 = 'I like it very much')

	Mean Importance	Significantly Different From[1]
Consumers' evaluation of the importance of different characteristics		
Type of fish	4.5	All except Quality certification
Quality certification (SAMAQ, Halal)	4.4	All except type of fish
Processing form (fresh, frozen, smoked)	4.3	All except Price and Color
Price	4.2	All except color, Size, Processing form
Color	4.2	All except price, processing form
Size	4.1	All except product form
Product form	4.05	All except Size
Country of origin	3.8	All
Consumers' preference for processing form		
Fresh	4.5	
Tinned	2.9	
Smoked	2.8	
Frozen	2.3	
Salted/Dried	2.2	
Consumers' preference for product form		
Whole	4.2	
Fillet	3.9	
Steak	3.4	
Other (e.g. fish sticks)	2.2	

Note: [1] Based on Wilcoxon signed-rank pairwise tests among 333 respondents. Bolded *p* values < 0.05 are considered significant; Bonferroni-adjusted $\alpha = 0.0018$.

Table 4: Estimation results of mixed logit model

	Mean		Standard Deviation	
Variables	**Coefficient**	**Standard Error**	**Coefficient**	**Standard Error**
Not_buy	-2.404***	(0.188)		
Price	-0.013***	(0.004)		
Orange	0.681***	(0.093)	1.262***	(0.112)
Fresh	0.404***	(0.098)	0.814***	(0.151)
Frozen	-0.152	(0.096)	1.006***	(0.117)
Fillet with skin, no bone	0.285***	(0.095)	0.573***	(0.155)
Fillet without skin, no bone	0.430***	(0.100)	1.007***	(0.119)
KSA Produced	0.044	(0.101)	0.788***	(0.142)
KSA Produced & SAMAQ	0.312***	(0.086)	0.503***	(0.156)
Log Likelihood	-1959.601			
AIC	3951.203			
BIC	4062.982			
No. of observations	7,992			
No. of participants	333			

*Note: *** denotes significance at the α =0.01 levels.*

Table 5: Willingness-to-Pay for rainbow trout from the mixed logit model

Attributes	Mean (SAR/0.35 Kg)	Mean (USD/0.35kg)	95 Percent Confidence Interval
Orange	39.27***	10.47	(26.86, 51.68)
Fresh	29.79***	7.94	(18.05, 41.53)
Frozen	5.08	1.35	(-2.70, 12.85)
Fillet with skin, no bone	17.78***	4.74	(7.66, 27.90)
Fillet without skin, no bone	26.70***	7.12	(15.31, 38.08)
KSA Produced	14.34	3.82	(4.25, 24.43)
KSA Produced & SAMAQ	23.31***	6.22	(13.14, 33.48)

*Note: *** denotes significance at the* α *=0.01 levels*

Table 6: Competitiveness of KSA-produced rainbow trout relative to imported salmon

Production level (Tons/year)	**Production cost - KSA trout** ($/kg)	**Retail price - KSA trout + SAMAQ** ($/kg)	**FOB price - imported salmon** ($/kg)	**Retail price - imported salmon** ($/kg)	**Retail price difference** ($/kg)	**Consumer WTP - KSA trout + SAMAQ (premium)** ($/kg)	**Competitive with imported salmon?**
1000	8.62	25.86	7.50	22.5	3.36	17.76	Yes
910	9.08	27.24	7.50	22.5	4.74	17.76	Yes
820	9.78	29.34	7.50	22.5	6.84	17.76	Yes
730	10.57	31.71	7.50	22.5	9.21	17.76	Yes
640	11.59	34.77	7.50	22.5	12.27	17.76	Yes
550	12.94	38.82	7.50	22.5	16.32	17.76	Yes
280	22.2	66.6	7.50	22.5	44.10	17.76	No
190	56.15	168.45	7.50	22.5	145.95	17.76	No

Figure 1: Example of a choice alternative in the choice experiment

Source: This figure is from the survey questionnaire administered in this study