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RESEARCH ARTICLE

Cattle Are What They Eat: A Consumer Analysis of Beef Produced from Barley Fodder-Fed Cattle Compared with a Conventional Mixed Ration

Ryan Feuz[1], Dillon Feuz[1], Audrey Lidgard[2], Zachary Crump[3], Kara Thornton[3], Silvana Martini[2], Haotian Cheng[4], Chandler Stafford[2] and Sulaiman Matarneh[2]

[1]Department of Applied Economics, Utah State University, Logan, UT, USA, [2]Nutrition, Dietetics and Food Sciences Department, Utah State University, Logan, UT, USA, [3]Animal, Dairy, and Veterinary Sciences Department, Utah State University, Logan, UT, USA and [4]School of Natural Resources and the Environment, University of Arizona, Tucson, AZ, USA
Corresponding author: Ryan Feuz; Email: ryan.feuz@usu.edu

Abstract
We conduct sensory analysis and assess consumer preferences and willingness to pay (WTP) for beef steaks from cattle fed hydroponically produced barley fodder (B-F) relative to those fed conventional mixed rations (CON). Results suggest consumers do not differentiate between B-F and CON when evaluating sensory attributes and possess similar WTP for both treatments. Preference toward the B-F treatment is demonstrated for sustainability-conscientious consumers informed about the potential sustainability benefits of the B-F treatment. Producers feeding hydroponically produced barley fodder should not expect premiums above beef-fed conventional feedstuff, yet establishing credence value around the sustainability of the B-F treatment may increase marketability.

Keywords: Consumer preferences; sensory analysis; willingness-to-pay

JEL classifications: D10; D12; Q13

1. Introduction

Global beef production is projected to increase to 75 million tons by 2030 (OECD/FAO, 2021). As production increases, the beef industry is experiencing heightened pressure to increase the sustainability of production systems. One method to increase sustainability within beef production is to increase the sustainability of feedstuff.

Hydroponically produced fodder is one innovative feedstuff explored, with research indicating that it could contribute to climate mitigation objectives when paired with complementary energy and land use policies (Bekuma, 2019; Newell et al., 2021). Green fodder can be produced from a variety of forages, including barley. Barley fodder produced hydroponically has been shown to have increased water usage efficiency over conventional field cultivation (Elmulthum et al., 2023) as well as compared to fodders produced from other crops, including alfalfa, sorghum, wheat, and cowpea (Al-Karaki and Al-Hashimi, 2012). In addition to increased water efficiency, hydroponically produced fodders may reduce land and labor requirements and can provide quality greenfeed produced throughout the year in a controlled environment breaking traditional seasonality constraints (Ahamed et al., 2023; Girma and Gebremariam, 2018; Shit, 2019). However, much of the research cited exploring hydroponic fodder production originates from areas around the world that have large land and climate constraints when producing conventional feeds for livestock. Thus, some of the notable advantages of feeding hydroponically produced fodders may not hold in regions not facing similar land and climate constraints. Additionally, economic metrics such as cost-benefit ratios, returns over investment, and break-even prices and yield suggest that growing barley fodder under the hydroponic technique may not be an economically sustainable alternative over conventionally grown fodder and other conventional feedstuffs (Elmulthum et al., 2023; Fazaeli et al., 2011; Sneath and McIntosh, 2003). This suggests that if producers are profit-driven, then hydroponically produced fodder may not be ready for adoption by the US beef industry despite possible environmental benefits. It is possible, however, that beef produced from cattle fed hydroponically produced barley fodder may have economic advantages to the beef production system when considering consumer preferences and willingness to pay (WTP).

Research comparing beef from cattle fed various feedstuffs has demonstrated effects on consumer acceptance, preferences, and WTP. Several studies investigated grass-fed beef relative to grain-fed beef (Evans et al., 2011; Feuz et al., 2004; Umberger et al., 2002; Umberger, Boxall, and Lacy, 2009; Van Elswyk and McNeill, 2014; Xue et al., 2010). Other research compared legume-finished beef (Chail et al., 2016), fodder beet-finished (Garmyn et al., 2019), or corn/sorghum distillery grain-finished beef (Gill et al., 2008) with traditional grain or grass-finished beef. The methods and objectives of these studies differed significantly, yet the results collectively demonstrated how consumer preferences, WTP, and ratings of sensory attributes could be impacted by the cattle finishing diet. This suggests that consumer preferences and WTP may be similarly affected for beef produced from cattle fed hydroponically produced barley fodder as the primary feedstuff.

Within the literature, we find no research that has evaluated consumer preferences and the WTP associated with beef produced from cattle fed hydroponically produced barley fodder. Filling this gap in the literature could potentially motivate the adoption of such feedstuffs if consumers demonstrate preference and increased WTP premiums for beef produced from these cattle. Alternatively, if no significant effects are found, then the results would provide caution for profit-maximizing producers considering adoption of hydroponically produced fodder. The objective of this study is to evaluate consumer preferences and WTP for beef produced from cattle fed hydroponically produced barely fodder as compared to cattle fed a conventional mixed ration. We also conduct sensory analysis to evaluate potential differences in meat sensory attributes.

2. Materials and methods

2.1. Data collection

For the sensory analysis and preference elicitation, we relied on a sampling of participants recruited from the Utah State university sensory lab during the summer of 2023. Participants included faculty and staff, undergraduate and graduate students, and members of the general public who responded to our open call for participation (emails were sent and flyers were posted around the campus). The study received ethical approval from the university's Institutional Review Board (IRB number: 13656). Participants in the sensory tasting session provided their written informed consent prior to the study and were assured of the confidentiality and anonymity of their responses. The original collected sample size was 200. However, two participants were excluded from analyses due to response and recording errors, resulting in a usable sample size of 198. Summary statistics for the sample are included in Table 1. The sample was nearly equally represented by men and women and had good variability within education, income, and steak consumption frequency. Sample limitations included limited variability within ethnicity and low sampling of middle-aged individuals (45–64 years). The sample size and variability within the other demographics are similar to other beef consumer preference research (O'Sullivan et al., 2021; Sitz et al., 2006; Umberger et al., 2002; Umberger, Boxall, and Lacy, 2009). Despite the noted limitations in the sample, this analysis provides a strong starting point for future research with

Table 1. Sample demographics ($n = 198$)

Variable	Count	Percentage (%)
Frequency of steak consumption		
More than once a day	0	0.0
Once a day	3	1.5
More than once a week	6	3.0
Once a week	31	15.7
Twice a week	11	5.6
Every two weeks	44	22.2
Once a month	57	28.8
Less than once a month	45	22.7
Never	1	0.5
Consider sustainability[a]		
Very unlikely	16	8.1
Unlikely	29	14.6
Neither unlikely or likely	49	24.7
Likely	77	38.9
Very Likely	27	13.6
Age		
18–24 years	49	24.7
25–34 years	34	17.2
35–44 years	22	11.1
45–54 years	11	5.6
55–64 years	11	5.6
65–74 years	33	16.7
75 years or older	37	18.7
Prefer not to answer	1	0.5
Education		
Less than high school	0	0.0
High school/GED	9	4.5
Some college	34	17.2
2-year college degree	22	11.1
4-year college degree	67	33.8
Graduate degree	64	32.3
Prefer not to answer	2	1.0
Gender[b]		
Gender queer	1	0.5
Gender questioning	1	0.5

(*Continued*)

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Table 1. (*Continued*)

Variable	Count	Percentage (%)
Man	98	49.5
Non-binary	1	0.5
Woman	95	48.0
Prefer not to answer	2	1.0
Ethnicity		
American Indian/Alaska Native	2	1.0
Asian	11	5.6
Black or African American	1	0.5
Hispanic/Latino	13	6.6
Native Hawaiian/Pacific Islander	1	0.5
White	166	83.8
Prefer not to answer	4	2.0
Income		
Less than $30,000	57	28.8
$30,000 to $59,999	32	16.2
$60,000 to $89,999	39	19.7
$90,000 to $119,999	22	11.1
$120,000 to $149,999	15	7.6
$150,000 to $250,000	15	7.6
$250,000 or more	4	2.0
Prefer not to answer	14	7.1
Information groups[c]		
Informed	105	53.0
Uninformed	93	47.0

[a]How likely to consider the sustainability of production when making food purchasing decisions.
[b]Other genders were available for participant selection but only those with responses have been included in this table.
[c]Indicates the number of participants who were either informed or uninformed within the questionnaire about the feed/production practices of the samples.

similar objectives to build upon and can give producers empirical evidence to consider when evaluating the adoption decision surrounding hydroponically produced barley fodder as a feedstuff.

2.2. Sample collection and preparation

Two types of beef samples were prepared: a control sample (CON) sourced from cattle fed a conventional mixed ration and a barley-fed (B-F) sample sourced from cattle fed hydroponically produced barley fodder as part of a total mixed ration. All beef used in this study was produced from cattle raised in the same herd at the Utah State University Agricultural Experiment Station. The cattle are typical of a commercial Angus-influenced herd in the region. The rations fed the B-F cattle were altered to include hydroponically produced barley fodder while still being nutritionally balanced similar to the conventional mixed ration. A summary of the rations fed to

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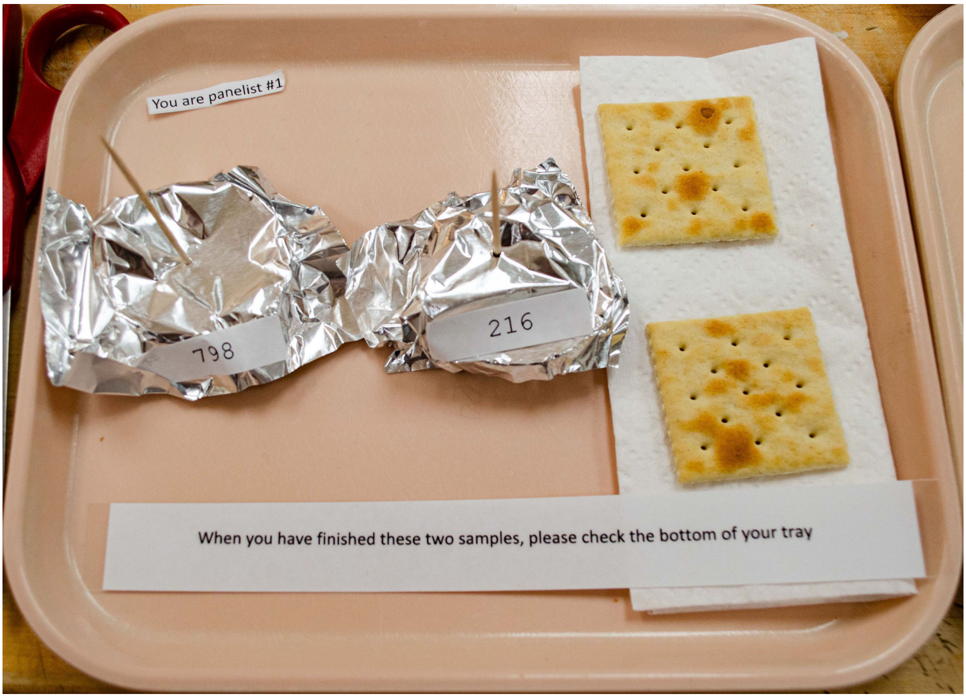

Figure 1. Tray with samples prepared for sensory analysis and subsequent questionnaire provided to participants.

the CON and B-F cattle is contained in Appendix A (Table A1). All animals were fed to an industry standard average of 10 mm of backfat as measured by ultrasound (ExaGo[1]) and harvested at a commercial processing facility. Boneless strip loins were collected from one side of each carcass 48 hours post-harvest and aged for 12 days at 39.2°F. Each loin was subsequently fabricated into 1-in. thick steaks and two were randomly selected for sensory analysis. These steaks were vacuum packaged and stored in a refrigerator for four additional days before the sensory panel took place. Steaks from each treatment were cooked on separate electric clamshell-type grills (Blue Diamond Electric Sizzle Griddle, Model # CC002899-002, Hong Kong, China) to a consistent 159.8°F internal temperature measured by digital thermocouple thermometers (AMSA, 1995). Ten samples, approximately 1 inch square in size, were cut from each cooked steak and served to the participants. Separate individuals were randomly assigned to each treatment to cook and cut the steaks from within their assigned treatment to ensure no cross-contamination between treatments. The steaks were cooked directly prior to serving to participants and kept warm when fluctuations in the participant queue necessitated lag times between cooking and serving via heat lamps and heated bricks. No sample was under heat lamps for more than 10 minutes.

All participants received a tray containing both CON and B-F samples placed in small aluminum cups, covered with aluminum foil, in a randomized and balanced order identified only by three-digit random numbers as in Figure 1. Both tenderness and marbling levels were controlled for within the experimental design. This was accomplished by creating pairings ($n = 11$) of CON and B-F animals that were known to have marbling and tenderness levels within a similar range. The marbling score, provided by the harvest facility, was used in conjunction with Warner–Bratzler shear force (WBSF) measurements[2] taken three days prior to the sensory analysis to create pairings wherein marbling scores varied within a range of less than 24 units,

[1]Portable ultrasound machine is used as a noninvasive procedure to assess the cattle body composition.
[2]A description of how the Warner–Bratzler shear force measurements were taken is contained within Appendix A.

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Table 2. Sample parings tenderness and marbling scores

	Tenderness (kg)[b]		Marbling[c]	
Pairing[a]	B-F	CON	B-F	CON
1	1.98	1.74	333	361
2	2.02	2.13	488	460
3	2.09	2.22	529	572
4	2.28	2.28	380	376
5	2.43	2.53	389	363
6	2.54	2.52	470	448
7	2.58	2.59	406	383
8	2.67	2.59	497	527
9	2.77	2.67	373	371
10	2.83	2.87	372	378
11	3.23	3.26	500	543

[a]Pairings are such that the average difference in Tenderness between CON and B-F treatments is 0.078 with a standard deviation of 0.070 and the average difference in marbling is 23.18 with a standard deviation of 14.14.
[b]Tenderness as measured using the Warner–Bratzler shear force method (kg).
[c]Marbling score as reported by the commercial harvest facility providing an objective measure of the marbling for each animal.

while WBSF varied less than 0.08 kg. Table 2 contains a summary of the steak pairings and describes each pair according to WBSF and marbling score. Controlling for tenderness and marbling variability helped ensure participant ratings of sensory attributes were independent of the tenderness and marbling variability across samples. Within the study, 11 B-F animals were used and paired with 11 CON animals with similar tenderness and marbling levels. The target sample size for participants was $n = 200$. The experimental design called for 10 usable samples to be cut from two steaks from each treatment within a pairing. This resulted in 20 steak samples from each treatment within a pair. Thus, the 11th pairing was only prepared as a backup measure to be used if needed.

2.3. Sensory analysis and questionnaire

After receiving the prepared tray (Figure 1), participants were instructed to remove the foil from the first sample and rate it according to "appearance" and "aroma" using a 7-point hedonic scale ranging from "1-dislike very much" to "7-like very much". The participants were then instructed to eat the sample and continue rating it according to "overall acceptance," "flavor," "tenderness," and "juiciness." After completing the ratings for the first sample, the participants were asked to cleanse their palettes using the provided unsalted crackers and water. The rating exercise was then repeated for the remaining sample.

Following the sensory rating exercise, participants were randomly assigned[3] to one of two treatment groups – "informed" ($n = 105$) and "uninformed" ($n = 93$) before proceeding to complete the questionnaire. The "uninformed" group remained completely "blind" throughout the experiment as to sample characteristics and experimental design. The "informed" group,

[3]Green ("informed") or red ("uninformed") labels were placed on the bottom of participant trays prior to distribution to the participant following a preconstructed randomized design. After the sensory analysis attribute rating portion of the questionnaire, participants were instructed to look under their tray and input the color into the software system which then directed them to either the educational script (if green) or directly onto the additional questions without receiving the educational script (red).

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Sample #_____________ was from beef fed sprouted barely as a major component of the feed ration while sample #____________ was produced using a conventional feed ration not including sprouted barely. Other than the cattle feed, each sample was produced using the same production practices and is of a similar quality. Sprouted barley can be produced using less water and land than conventional production using a new innovative technology. Using a single unit of this technology can produce enough fodder to be equivalent to 15 acres of alfalfa hay a year while consuming approximately 93% less water. Both land and water availability are major threats to the sustainability of beef production.

Figure 2. Educational script provided to "Informed" participant group.

however, was informed directly after the sensory rating exercise about the different characteristics of the feed used to produce the steak samples. The educational script/nudge provided to the participants within the "informed" group not only revealed the difference in feeds used to produce the beef but also educated participants on some of the potential sustainability characteristics of the hydroponically produced barley fodder. The educational script seen by the "informed" group is contained in Figure 2.[4]

All participants were then asked to select which sample they would be most likely to purchase in a retail environment based on their sensory experience (and knowledge of the production system used to produce the samples if in the "informed" group).

To assess WTP for this study, we relied upon an open-ended contingent valuation question. Open-ended contingent valuation (CV) is a survey-based method used to estimate the economic value of goods and services. It involves asking respondents an open-ended question about the maximum amount they are willing to pay (WTP) for a particular good or service. Single-bounded and double-bounded contingent valuation are variations of this method that impose certain constraints (values) for the good and ask for a dichotomous response of WTP (Johnson, Bregenzer, and Shelby, 2019). Each approach has comparative advantages and disadvantages, suggesting that the choice between them ultimately depends on the objectives of the research and context of use.

Noted advantages of open-ended CV include simplicity, ease of administration, and potential reduced anchoring bias compared to bounded CV (Green et al., 1998). Open-ended CV surveys are often simpler and quicker to administer compared to their bounded counterparts. Respondents are asked a single, open-ended question, making the survey less complex. Open-ended CV may have reduced anchoring bias compared to bounded CV (Green et al., 1998). Anchoring bias occurs when respondent answers are influenced by the initial values presented to them. In bounded CV, researchers provide starting points, which can anchor respondent valuations. Open-ended CV avoids this issue by not providing such starting points. However, some argue that the double-bounded format is more familiar for respondents since typically consumers are faced with a given price in a retail setting and not afforded the opportunity to state their maximum WTP as in the open-ended format (Loomis, 1990). Additionally, open-ended questions may encourage free-riding and hence strategic overstatement (Arrow et al., 1993). In the context of contingent valuation, free-riding refers to a situation where respondents in a survey or study deliberately misstate their preferences or WTP for a particular environmental or public

[4]After completion of the study and submission of their questionnaires, participants in the uninformed group were also shown the educational script for transparency.

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good. This typically occurs when individuals underestimate their true WTP for a good or service, often in an attempt to avoid financial responsibility or to reduce the perceived cost of the good or service being evaluated. This may in part explain why several studies have shown that the open-ended format yields lower estimates of WTP on average than double-bounded CV (Brown et al., 1996). However, steak is a market good for which consumers are relatively familiar. Within our sample, responses indicate (Table 1) that 76.8% of participants consume steak at least once a month. This suggests that they should be generally familiar with the price of steak. Kealy and Turner (1993) find no differences in WTP between open-ended and double-bounded methods in a familiar private market good (candy bar) suggesting the free-riding problem is mitigated when evaluating familiar market goods. Thus, as we are evaluating a good for which consumers are relatively familiar and seek to reduce anchoring bias, we chose to rely on an open-ended contingent valuation question within this study.

After selecting their preferred steak, participants were asked, "Assuming the average price of ribeye steak of this quality is $9.65 per pound[5], how much MORE would you be willing to pay for your preferred steak relative to your least preferred steak?" The question relied upon a sliding scale response format that allowed participants to indicate any amount from $0.00/lb up to $3.50/lb in $0.10 increments.

Following the WTP question, we asked participants "how likely are you to consider the sustainability of production when you are making food purchasing decisions?" Participant responses were recorded using a 5-point hedonic scale ranging from "very likely" to "very unlikely." This question was then followed up with standard demographic questions collecting information about participants' age, gender, ethnicity, income, and education levels (demographics summary in Table 1).

2.4. Methodology

Attribute rating differences across treatments were evaluated using fixed effect ordinary least squares (OLS) regression models[6] for each attribute as in:

$$\text{Rate}_{a,i,t} = \theta_{0,a} + \beta_{1,a}\text{BF}_{a,i,t} + \beta_{2,a}\text{Tenderness}_{i,t} + \beta_{3,a}\text{Marbling}_{i,t} + e_{a,i,t} \tag{1}$$

where $\text{Rate}_{a,i,t}$ is the 7-point hedonic rating for attribute a (overall acceptance, appearance, aroma, flavor, tenderness, and juiciness), individual i, and treatment t, BF is a fixed treatment dummy variable equal to 1 if the sample was a B-F treatment and equal to 0 otherwise, Tenderness is the WBSF value (kg), Marbling is the marbling score as provided by the harvest facility, and e_{ait} is a random error term $e_{a,i,t} \sim N(0, \sigma_e^2)$. The primary focus for the sensory analysis rests on the evaluation of the sign and significance of the β_1 coefficients for each attribute. Though marbling and tenderness have been controlled for within the experimental design, we still include them within the equation to account for small variability remaining within sample pairings.

To model WTP premiums, we rely on a linear regression model as in:

$$\begin{aligned}\text{WTP}_i = \theta_0 &+ \beta_1\text{BF}_i + \beta_2 \textit{tend\_diff}_i + \beta_3 \textit{marb\_diff}_i + \beta_4 \textit{highsus}_i + \beta_5 \textit{informed}_i \\ &+ \beta_6 \textit{highsus}\text{\_x\_informed}_i + \beta_7 \textit{highsus}\text{\_x\_BF}_i + \beta_8 \text{informed\_x\_BF}_i \\ &+ \beta_9 \textit{highsus}\text{\_x\_informed\_x\_BF}_i + e_i \end{aligned} \tag{2}$$

[5]Average price (2020-June 2023) as taken from the USDA National Weekly Boxed Beef Cutout and Boxed Beef Cuts-Negotiated Sales reports- ribeye boneless light.

[6]We also estimated the same equation using an ordered logistic regression model (assuming ordered categorical dependent variable). We found the practical implications of the results did not differ between the two model specifications and thus chose to retain only the OLS model results within the paper for simplicity.

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where WTP_i is the willingness-to-pay premium ($/lb) for ith participant's preferred steak, BF is a dummy variable equal to 1 if the participant's preferred steak is the B-F sample and equal to 0 otherwise, $\text{tend}_\text{d}\text{iff}$ is the difference between the WBSF values (kg.) of the two samples (B-F tenderness relative to CON), $lt; gt;$ marb_ difflt; /gt; is the difference between the marbling score values of the two samples (B-F marbling relative to CON), highsus_i is a dummy variable equal to 1 if the participant self-identified as either "likely" or "very likely" to consider the sustainability of production when making food purchasing decisions and equal to 0 otherwise, informed is a dummy variable equal to 1 if the respondent was part of the "informed" group and equal to 0 otherwise and $e_{i,c}$ is a random error term $e_{i,c} \sim N(0, \sigma_e^2)$.

2.5. Evaluating preferences

We also analyzed the participant's preferred steak choice selection to determine what attributes have the most impact on their selection. By combining participant sensory ratings with their choice selection, we can evaluate which attributes have the strongest impact on consumer intent to purchase. We model participant selections using a logistic regression model. An indicator variable 'I' is created to represent the participant's preferred steak selection and is set equal to 1 when the participant selects the B-F sample as their preferred steak and set equal to 0 otherwise. A logistic regression model is then estimated as

$$I_i = \theta_0 + \sum_{a=1}^{6} \beta_a \boldsymbol{X}_\mathbf{i} + \beta_7 highsus_i + \beta_8 educated_i + \beta_7 highsus\_x\_educated_i + e_i \tag{3}$$

where $\boldsymbol{X_i}$ is a matrix of sensory attribute ratings differences between samples (e.g., flavor rating B-F less flavor rating CON) for the ith participant, $e_{i,c}$ is a random error term, and all other variables are as previously defined in equation (2). Within the $\boldsymbol{X_i}$ matrix we exclude rating differences for the "overall acceptance" attribute. It is assumed that when participants consider their overall acceptance of a sample, they would jointly consider the other attributes of appearance, aroma, flavor, tenderness, and juiciness when making their ratings. The overall acceptance attribute would thus be correlated with the other attributes and is excluded from the preference model (equation 3) to avoid multicollinearity.

3. Results

3.1. Sensory analysis

The sensory analysis attribute ratings were analyzed using equation (1) estimated via OLS. The results are summarized in Table 3.

In evaluating these results, of most importance is the sign and significance of the coefficient for the B-F treatment fixed effect. The results demonstrate that for all sensory attributes other than "juiciness," the estimated coefficient for the B-F treatment is negative. This suggests that, on average, participants rated the B-F treatment lower than the CON treatment across all remaining sensory attributes. However, none of the estimated coefficients for the B-F treatment fixed effect are significant at the 5% level. Within the "appearance" attribute model, the B-F treatment fixed effect coefficient is negative (−0.223) and significant at the 10% level. This suggests that ceteris paribus, participants tended to rate the B-F treatment on average 0.223 points lower on the Hedonic scale for this attribute. Overall, the main finding in the sensory attribute analysis is that participants did not find any significant differences (p-value < 0.05) within sensory attributes across the CON and B-F treatments. This would imply that producers may freely switch between rations with and without hydroponically produced barley fodder without fear of negative effects on the sensory experience of consumers.

Table 3. Summary results of the effects of treatment, tenderness, and marbling score values on sensory attribute ratings

	Appearance		Aroma		Overall acceptance	
Variable	Coeff.	Std. err.	Coeff.	Std. err.	Coeff.	Std. err.
B-F	−0.223*	0.130	−0.092	0.106	−0.103	0.124
Tenderness	0.140	0.169	−0.171	0.138	−0.192	0.160
Marbling	−0.001	0.001	0.000	0.001	−0.001	0.001
Constant	4.272***	0.548	4.784***	0.448	5.253***	0.520
	Flavor		Tenderness		Juiciness	
B-F	−0.147	0.131	−0.129	0.139	0.051	0.141
Tenderness	−0.090	0.170	−0.173	0.180	−0.142	0.183
Marbling	0.000	0.001	0.002*	0.001	0.001	0.001
Constant	4.858***	0.551	4.231***	0.585	4.190***	0.594

Notes: *, **, and ***indicate statistical significance at the 10%, 5%, and 1% levels.

3.2. Willingness to pay for preferred steak

The WTP premiums for the participants' preferred steaks were modeled as in equation (2) with the results summarized in Table 4.

The results of the estimated coefficient for the B-F dummy variable suggest that on average, participants indicated they would be willing to pay an additional $0.02/lb for the B-F treatment when selected as their preferred steak. However, this small positive premium was not found to be statistically significant. The only variable that was significant (p-value < 0.05) was the self-identified level of importance of sustainability of production when making purchasing decisions (highsus). On average, we find that participants who identified as likely to value sustainability of production would be expected to pay $0.46/lb more for their preferred steak regardless of selection (B-F or CON). Interestingly, we find no evidence that these same participants who were among the informed group and also selected B-F as their preferred steak would be willing to pay more for their preference. Overall, the results of the WTP model suggest that, while consumers who value sustainability of production have increased levels of average WTP, there is not enough evidence to suggest that being informed of the level of sustainability of production changes average WTP for the presumably more sustainably produced (B-F) option.

3.3. Selection of preferred steak

We model the factors affecting the participant selection of their preferred steak using equation (3) with the results summarized in Table 5.

The results as contained in Table 5 provide insight into the factors that affect consumer intent to purchase their preferred steak. We see that participants are highly sensitive to perceived changes in flavor, tenderness, and juiciness. Each has a positive significant marginal effect on the odds ratios of selecting B-F as compared to CON. Thus, we would expect that on average consumers value positive perceived changes in these attributes more highly as compared to the other sensory attributes when making their purchasing decisions. This is consistent with the literature as many studies demonstrate the importance of flavor, tenderness, and juiciness toward consumer preferences for beef (Liu et al., 2020; O'Quinn et al., 2018; Savell et al., 1987, 1989)

Evaluating the results individually, for each 1-unit positive increase in the ratings of flavor, tenderness, and juiciness on the hedonic rating scale for the B-F sample as compared to the CON sample, we would expect the odds of selecting the B-F sample as the preferred purchase selection

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Table 4. Summary of willingness-to-pay model results

Variable	Coefficient	Std. err.
B-F[a]	0.021	0.198
high sustainability[b]	0.455***	0.175
informed[c]	−0.120	0.186
informed × sustainability	0.180	0.198
B-F × high sustainability	0.290	0.229
B-F × informed	−0.180	0.210
B-F × informed × high sustainability	0.061	0.188
Tend_diff[d]	0.079	0.472
Marb_diff[e]	0.001	0.002
Constant	0.798***	0.120

Notes: *, **, *** indicate statistical significance at the 10%, 5%, and 1% levels.
[a]Dummy variable equal to "1" if the participant selected the B-F treatment as their preferred purchase selection and equal to "0" otherwise.
[b]Dummy variable equal to 1 if the participant self-identified as either "likely" or "very likely" to consider the sustainability of production when making food purchasing decisions and equal to 0 otherwise.
[c]Dummy variable equal to 1 if the respondent was part of the "informed" group and equal to 0 otherwise.
[d]Variable equal to the change in WBSF values between the B-F and CON treatment for each participant.
[e]Variable equal to the change marbling score values between the B-F and CON treatment for each participant.

Table 5. Effects of perceived differences in sensory attributes, education to experimental design, and importance of sustainability on participant selection of preferred steak

Variable	Odds ratio	Std. err.
Appearance difference[a]	1.33*	0.21
Aroma difference[a]	1.22	0.21
Flavor difference[a]	2.12***	0.38
Tender difference[a]	1.36***	0.20
Juicy difference[a]	1.35***	0.19
Informed[b]	2.40*	1.23
High sustainability[c]	1.00	0.54
Informed × high sustainability	11.49***	6.28
Constant	0.50**	0.18

Notes: *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels.
[a]Attribute difference variables are equal to the difference in the individual hedonic ratings of each attribute for the B-F relative to Con treatment.
[b]Dummy variable equal to 1 if the respondent was part of the "informed" group and equal to 0 otherwise.
[c]Dummy variable equal to 1 if the participant self-identified as either "likely" or "very likely" to consider the sustainability of production when making food purchasing decisions and equal to 0 otherwise.

to increase 2.12, 1.36, and 1.35 times respectively while holding all else constant. A similar positive marginal effect is estimated for the appearance attribute yet is only significant at the 10% level. Additionally, we find evidence that the selections of consumers are influenced by the individual's level of care for sustainability of production, and educational nudge towards that level of sustainability. With an estimated odds ratio for the "informed" dummy variable of 2.4, we can interpret this to mean that the "informed" group would be 2.4 times more likely (p-value < 0.10) to select the B-F treatment as their preferred steak as compared to CON. Stronger still is the

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evidence to suggest that the joint set of consumers who are both "informed" and identify as being likely to care about the sustainability of production are much more likely (11.49 times more likely) to select the B-F treatment (p-value < 0.01). This large magnitude of odds ratio aligns well with expectations from previous literature. Vandenbroele et al. (2020) provided a review of nudging to encourage sustainable food choices among consumers and found that predispositions towards sustainable behavior are complementary to educational interventions.

Conclusions and implications

The primary aim of this study was to assess consumer preferences and WTP for beef originating from cattle fed hydroponically grown barley fodder, in comparison to those fed a conventional mixed ration. We also conducted a sensory analysis to investigate potential disparities in meat sensory characteristics. From the results of the sensory analysis, we conclude that consumers are not expected to perceive differences between B-F and CON beef when evaluating sensory attributes including "overall acceptance," "appearance," "aroma," "flavor," "tenderness," and "juiciness." This suggests that producers may freely switch between these feedstuffs without fear of negative effects on the consumer sensory experience. Of course, switching feedstuffs is a production decision that would ultimately depend greatly on the cost of inputs. While this study suggests no negative effects on the consumer's sensory experience as a result of feeding cattle hydroponically produced barley fodder, it still may not be economical to make the switch despite possible sustainability benefits.

We also evaluated consumer WTP for their preferred steak both with and without providing educational nudges informing them of the experimental design surrounding the sustainable nature of the B-F treatment. We find that on average, consumers indicated they would pay \$0.80/lb more for their preferred steak indicating they at least individually *perceived* differences in the samples that warranted a premium to ensure they could purchase their preference. Additionally, we find that those participants who self-identify as likely to care about the sustainability of production would be expected to pay \$0.46/lb more for their selection. However, we do not find enough evidence to suggest that those who were provided the educational nudge and who selected the B-F treatment would pay any additional premium for their selection. This suggests that while consumers who care about the sustainability of production may be willing to pay additional premiums in general for their preference, there is not enough evidence to suggest that their premiums would be any higher than the average when selecting the B-F treatment presumed to be more sustainably produced.

Lastly, we investigated what factors are expected to influence consumer selection of preferred steak. Perceived increases in attributes such as flavor, tenderness, and juiciness are expected to increase the odds of selecting the B-F treatment on average across all consumers. Most importantly, we find that consumers who are informed about the sustainability benefits of the feedstuff and self-identify as likely to care about the sustainability of production are much more likely (11.49 times) to select the B-F treatment.

Taken together with the sensory analysis and WTP results, we conclude that (1) consumers, in general, are not expected to discriminate between B-F and CON treatments when rating common sensory attributes, (2) consumers do not demonstrate an increased WTP for the B-F treatment even when nudged with an educational script touting the treatment's potential sustainability benefits, and (3) consumers are much more likely to select the B-F treatment as their preferred steak to purchase in a retail setting if they are provided an educational nudge towards the potential sustainability benefits of the B-F treatment and self-identify as likely to care about the sustainability of production. These conclusions jointly imply that while producers need not fear negative consequences to consumer sensory attributes when feeding hydroponically produced barley fodder, they should also not reasonably expect to receive any premium for their product among average consumers. Previous research has suggested hydroponically produced fodders may be at an economic disadvantage as compared to conventional feedstuffs (Elmulthum et al., 2023; Fazaeli et al., 2011; Sneath and McIntosh, 2003). The results of our current study demonstrate no increased preference towards or increased WTP for beef-fed hydroponically produced barley fodder within our sample of consumers. This implies that producers must carefully consider their unique production system when considering adoption of hydroponically produced barely fodder from a profit maximization perspective. Yet, our results do indicate that through educational efforts to inform consumers about the potential sustainability benefits of feeding hydroponically produced barley fodder, a preference to purchase B-F beef as compared to CON may be established among producers who value sustainability of food production. This suggests increased marketing potential for producers if credence value around the B-F treatment could be established among sustainability-consciousness consumers.

Data availability statement. The data that support the findings of this study are available from the corresponding author, [RF], upon reasonable request.

Author contribution. Conceptualization, R.F, D.F., Z.C., and K.J.T.; data curation, R.F., D.F., A.L., Z.C., K.J.T., C.S, and S.M.; formal analysis, R.F., D.F., C.H., and C.S.; investigation, R.F., D.F., Z.C., H.C., and C.S.; methodology, R.F., D.F., H.C., S.C., and S.M.; project administration, R.F., D.F., A.L., K.J.T., and S.M.; software, R.F., A.L., and S.M.; writing – original draft, R.F., and D.F.; writing – review and editing, R.F., D.F., A.L., Z.C., K.J.T., S.M., H.C., C.S., and S.M.

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Appendix A: Feed Rations Table

Table A1. Feeding rations for controls and barely-fed cattle used in sensory analysis

		Control		Barely fodder	
Step	Component	%DM[a]	%AF[b]	%DM[a]	%AF[b]
Step 1	Fodder			20.80	64.64
	Alfalfa	24.80	17.27	33.00	14.77
	Corn silage	30.70	51.80		
	Barley	43.40	30.22	45.10	20.13
	Mineral	1.10	0.72	1.10	0.46
Step 2	Fodder			20.90	64.87
	Alfalfa	18.80	13.74	25.40	11.31
	Corn silage	25.80	45.80		0.00
	Barley	54.30	39.69	52.50	23.35
	Mineral	1.10	0.76	1.10	0.46
Step 3	Fodder			20.90	64.87
	Alfalfa	12.40	9.84	14.50	6.49
	Corn silage	18.80	36.07		0.00
	Barley	66.50	52.46	62.30	27.80
	Mineral	2.30	1.64	2.30	0.93
Step 4	Fodder	0.00		21.30	65.42
	Alfalfa	8.50	7.55	8.50	3.74
	Corn silage	8.70	18.87	0.00	0.00
	Barley	80.50	71.70	67.90	29.91
	Mineral	2.30	1.89	2.30	0.93

Steps 1–3 were fed for 7 days each while step 4 was fed for the remaining 106 days of the feeding trial until the animals were ready for harvest on day 127.
[a]%DM is the percentage of each feed component in the ration on a dry matter basis.
[b]%AF is the percentage of each feed component in the ration on an as fed basis.

Appendix B: Warner–Bratzler Shear Force Measurement

Tenderness was evaluated using a V-notch attachment connected to a TMS-Pro Texture Analyzer (Food Technology Co., Sterling, VA, USA) following the procedures described by Belk et al. (2015). In brief, steaks were cooked on an electric clamshell grill (Blue Diamond Electric Sizzle Griddle, Model # CC002899-002, Hong Kong, China) to an internal temperature of 159.8 °F. The steaks were then blotted dry and allowed to equilibrate to room temperature before being stored overnight at 39.2 °C. On the following day, six 0.5-in. diameter core samples were removed from each steak parallel to the muscle fiber orientation using a handheld coring device. These cores were sheared perpendicular to the longitudinal axis of the muscle fibers, and the maximal force (*N*) for each core was recorded. The average shear force for each steak was calculated as the average maximum force of the six cores.

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