Meat and Muscle Biology™

Consumer Evaluation of Plant-Based Ground Beef Alternatives in Real-World Eating Scenarios[1]

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Abstract: The objective of this study was to evaluate the palatability of 3 plant-based ground beef alternatives (GBA) in comparison to ground beef under real-world hamburger and taco scenarios. The 3 plant-based GBA alternatives used represented a modern GBA sold at retail (RGBA), a modern GBA sold in foodservice (FGBA), and a traditional soy-based GBA (TGBA). Additionally, 80% lean ground beef was evaluated. Consumers ($N = 240$; $n = 120$ per panel type) evaluated samples for juiciness, tenderness, texture, beef flavor, overall flavor, overall liking, purchase intent, and purchase price and rated traits as either acceptable or unacceptable. For hamburger panels, consumers were served samples on buns and were given the option to add cheese, lettuce, pickles, ketchup, and/or mustard. For taco panels, samples were seasoned with a taco seasoning blend and served on flour tortillas, with consumers given the option to add cheese, lettuce, and/or tomatoes. In both scenarios, ground beef was rated higher ($P < 0.05$) by consumers for juiciness, texture liking, overall flavor liking, beef flavor liking, overall liking, purchase intent, and price willing to be paid than all 3 GBA but was rated similar ($P > 0.05$) for tenderness to FGBA and RGBA. Additionally, a higher ($P < 0.05$) percentage of ground beef samples were rated acceptable overall and for flavor characteristics than all 3 GBA. Few differences were found between FGBA and RGBA for any palatability characteristics evaluated. TGBA was rated lower ($P < 0.05$) than all other treatments for all palatability traits for taco panels and was similar ($P > 0.05$) to only RGBA for beef flavor and overall flavor liking within hamburger panels. These results indicate that GBA currently available to consumers do not have improved palatability characteristics when used as an ingredient in a taco or hamburger scenario.

Key words: beef, ground beef, consumer, plant-based, ground beef alternative, palatability
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Introduction

Plant-based ground beef alternatives (GBA) have been in the retail market for several decades and have evolved through time from initial products comprised of soy-based proteins to recent GBA that are commonly comprised of bean, mushroom, pea, or other plant-sourced proteins (Wild et al., 2014). These products have served as both a direct competitor and attempted replacement for traditional beef products, as well as complementary protein product for consumers wanting to vary their diets (Carlsson et al., 2022; Neuhofer and Lusk, 2022; White et al., 2022). As the popularity and demand for these products have grown in recent years, so has research been evaluating them. Recent published studies have evaluated the overall eating quality (Davis et al., 2021; Caputo et al., 2023), flavor characteristics (Godschalk-Broers et al., 2022; Hernandez et al., 2023), color (Sakai et al., 2022; Ryu et al., 2023), economic and willingness-to-pay characteristics (Caputo et al., 2023; Tonsor et al., 2023), environmental impacts (van der Weele et al., 2019; Lusk et al., 2022), nutrient content

(Bohrer, 2019; Alessandrini et al., 2021), and the impact of informing consumers of the product type prior to consumption on consumer perceptions (Grasso et al., 2022) of many of these plant-based meat alternatives.

In one such study, Davis et al. (2021) thoroughly evaluated the quality attributes of ground beef of 3 fat levels (10%, 20%, and 27%) in comparison to 3 different GBA: a modern GBA commonly sold at retail (RGBA), a modern GBA commonly sold within foodservice (FGBA), and a traditional soy-based GBA (TGBA) (Davis et al., 2021). In all sensory and product quality aspects measured, the 3 GBA were found to be different than the 3 ground beefs. The GBA were much softer and drier and had different raw and cooked colors, as well as had less change in shape or "shrink" when cooked compared to the ground beef (Davis et al., 2021). From an eating quality standpoint, blinded consumer panelists rated the 3 GBA as less juicy and much lower for appearance, flavor, and overall liking than the ground beef samples (Davis et al., 2021). Additionally, less than half of consumers rated each of the 3 GBA as acceptable overall compared to greater than 73% for all 3 ground beef treatments. Only 17% to 34% of the consumer panelists indicated they would likely purchase the GBA after tasting them (Davis et al., 2021).

However, real-world purchasing and demand data for GBA differ greatly from what would be expected based on the results of the Davis et al. (2021) study. From 2020 to 2021, sales of plant-based meat alternatives increased by over 40% at retail as well as grew in market share at both retail and foodservice (Garver, 2021; Kansas Beef Council, 2021). Despite recent trends in which demand for these products has dropped (Dean, 2023), consumers continue to purchase these plant-based products at both retail and foodservice. One possible explanation for this discrepancy is that in the Davis et al. (2021) study the samples were served, as is traditionally done in meat science research, unseasoned as only a patty. But, in real-world eating scenarios consumers most commonly consume these products as a single ingredient within a larger meal (i.e., patty on a complete hamburger, protein within a burrito, etc.). It is plausible that these added flavors from other food ingredients impact the consumer's overall impression of the eating quality of the GBA and would produce different consumer impressions than those reported by Davis et al. (2021). Therefore, it is the objective of the current study to build off the knowledge gained in the Davis et al. (2021) study and evaluate the eating quality of GBA in comparison to ground beef under real-world eating scenarios as both a patty (hamburger) and ground/crumbled (taco) product.

Materials and Methods

All procedures for the use of human subjects in the current study were reviewed and approved by the Kansas State University (KSU) Institutional Review Board (IRB #7440.7, February 2, 2021).

Treatment and sample preparation

All ground beef and GBA samples used for the current study were purchased from retail markets throughout northeastern Kansas over a 5-mo period leading up to sensory evaluation to allow for differing production lots for each GBA used. Ground beef (IMPS #136) ($N = 40$; 0.45 kg-chubs; 20/panel type) used in the current study consisted of 80% lean and 20% fat, with each chub representing a different production lot and day. Moreover, 3 plant-based GBA treatments ($N = 40$ production lots/treatment; 20/panel type) of varying types were selected for the study. The differing GBA treatments were identified through popularity of industry usage. The 3 plant-based GBA were categorized as FGBA, RGBA, and TGBA. Though all treatments were purchased at retail, the FGBA was the most popular GBA used in foodservice throughout the region. These treatments were also the same as the products used and described by Davis et al. (2021), with only the TGBA differing in this study than the previous work. The primary protein sources of FGBA were a combination of pea and potato protein. The primary protein source of RGBA was pea protein, and soy protein was the primary protein in the TGBA. The FGBA was purchased in 0.34 kg-chubs requiring the purchase of 2 packages per production lot. Differing from the other GBA, TGBA was sold in a case of 4 preformed, 71-g patties as is common and representative of "traditional" soy-based products. Following purchase, all ground beef and GBA lots were frozen at −20°C and stored frozen prior to fabrication.

Prior to patty formation, lots were thawed for 24 h at 4°C. Differing ground beef and GBA production lots selected for hamburger consumer analysis were assigned an individual identification number and assigned to individual consumer panels immediately prior to patty fabrication. Following the thawing period, individual lots were unpackaged, weighed into 75-g samples, and hand-pressed using a table-top 8-cm wide, 1.0-cm thick patty forming die. Six patties per

identification number were crust frozen at −20°C for approximately 30 min to allow for packaging without deforming the patties. Assignment of consumer panel sessions for taco panels followed similar procedures as for hamburger panels. All products used for taco consumer panels were thawed for 24 h at 4°C prior to individual sample identification and sorting. Individual lots were unpackaged, hand mixed for 15 s, and weighed into 0.45-kg samples. For FGBA, this included the mixing of the 2 packages from the same production lot. For both panel types, samples were packaged using a commercial rollstock packing machine (Model Bulldog 42a 300, Ultrasource, Kansas City, MO) and frozen (−20°C) until consumer panel analysis.

pH and color measurement

pH data were collected during patty fabrication. Immediately following the formation of patties, 3 patties from each sample lot were centrally probed parallel to the horizontal surface using a Model HI 99163 pH probe (Hanna Instruments, Smithfield, RI). The three measurements were averaged for the individual lot pH value. Following pH measurement, the same 3 patties were measured for instrumental color (L^*, a^*, b^*) using a Hunter Lab Miniscan spectrophotometer (Illuminant A, 2.54-cm aperture, 10° observer; Hunter Associates Laboratory, Reston, VA) following the AMSA Color Guidelines (King et al., 2023). The designated patties were allowed a 30-min bloom period prior to color data collection. Following the bloom period, 3 scans were taken from the center of the horizontal surface exposed to the air on the samples and were averaged to produce a single L^*, a^*, and b^* value per sample lot.

Consumer sensory testing

Consumer sensory panelists ($N = 240$; 120/panel type) were recruited from Manhattan, KS and the surrounding area and compensated monetarily for their participation in the study. Panelists sampled treatments in a large-lecture style classroom under fluorescent lighting at KSU. For each panel type, a total of 7 sessions were conducted, with 6 consisting of 18 consumers and 1 consisting of 12 consumers. For panels that included 18 consumers, sessions lasted approximately 1 h, and sessions with 12 consumers lasted approximately 45 min.

Consumers were requested to complete a demographic survey regarding gender, age, ethnicity, marital status, household size, annual income, education, and beef consumption habits. Following the demographic survey, consumers were asked to indicate the importance of multiple factors considered when purchasing ground beef on a 100-point continuous line scale anchored with descriptive terms at endpoints: 0 = extremely unimportant and 100 = extremely important.

For hamburger panels, patties were thawed at 4°C approximately 24 h prior to consumer sensory analysis. Patties were cooked on Cuisinart Griddler Deluxe clam-shell style grill (Stamford, CT) set to a surface temperature of 177°C. Patties were cooked to an internal temperature of 67.2°C, removed from the grill, and allowed to rise to the peak-endpoint temperature of 71°C. Cooking and endpoint temperature was monitored using a Beckman Industrial Doric 205 thermocouple thermometer (Brea, CA). For taco panels, samples were thawed following the same procedure as the hamburger patties. Samples were crumbled into an Oster 12" electric skillet (FL, USA) set to a surface temperature of 177°C. Crumbles were cooked to an endpoint surface temperature of 71°C and monitored using an infrared gun-style thermometer (Model 422 Cooper Atkins, FL). Once samples were thoroughly cooked, a generic taco seasoning (Kroger, OH) was added and allowed approximately 3 min to simmer following the manufacturer's instructions.

Consumers were served all 4 treatment samples simultaneously in a 4-compartment tray. Samples were served blind to consumers with each sample identified with a unique 4-digit number. For the hamburger panels, patties were served on a white bread bun and plated on a 33.0 × 25.4 × 7.6 cm, 4-compartment compostable sugarcane half pan takeout container (Eco Products, CO, USA). For the taco panels, approximately 75 g of each sample was plated onto flour tortillas (Mission Foods, TX) in a 17.8 × 12.7 × 7.6 cm, 2-compartment taco fiber clamshell container (Eco Products, CO). The clamshell container was served open allowing for the usage of 4 compartments.

Prior to sample evaluation, consumers were given the opportunity to add toppings to their samples. Consumers were instructed to apply equivalent amounts of each topping to each sample. Consumers were provided and applied toppings in a self-serve, cafeteria-like scenario. For the hamburger panels, consumers were allowed to apply cheese, ketchup, mustard, lettuce, and pickle. For taco panels, consumers were given the opportunity to apply cheese, lettuce, and tomatoes. The white hamburger buns, sliced American cheese, 1-oz. ketchup packets, and 1-oz. mustard packets used in the hamburger panels were purchased from a foodservice supplier (Sysco, TX).

All shredded iceberg lettuce for both panel types, sliced pickles for hamburger panels, and canned diced tomatoes and shredded Mexican-style cheese used for taco panels were purchased from local supermarkets in the Manhattan, KS area (Kroger, OH; Great Value, AR). Prior to sample evaluation, consumers recorded the toppings they had used as well as the approximate amount of each applied.

Consumers evaluated the samples for juiciness, tenderness, overall flavor liking, beef flavor liking, texture liking, overall liking, and willingness to purchase. Panelists rated each palatability trait on a 100-point continuous line scale verbally anchored at end and mid-points: 0 = extremely dry, tough, extremely dislike overall flavor/beef flavor/texture/overall, and extremely unlikely to purchase; 50 = neither juicy nor dry, tough nor tender, neither like nor dislike overall flavor/beef flavor/texture/overall, or neither likely nor unlikely to purchase; 100 = extremely juicy, tender, extremely like overall flavor/beef flavor/texture/overall, and extremely likely to purchase. Furthermore, panelists rated each of the samples as acceptable or unacceptable for the sensory traits evaluated. In addition, consumers designated a purchase price they would be willing to pay if purchasing a similar product at foodservice. Lastly, consumers designated each sample as either premium, better than every day, every day, or unsatisfactory quality.

Consumers were provided with a fork, napkin, expectorant cup, and palate cleansers (water, apple juice, and unsalted crackers) for use between each sample. Consumer responses were recorded on a Lenovo TB-850SF handheld electronic tablet using an electronic ballot. Panelists were given verbal instructions for sample preparation, tablet and ballot usage, testing procedures, and routine usage of palate cleansers before the start of the panel sessions.

Statistical analysis

Statistical analysis was performed using SAS (Version 9.4, SAS Inst., Inc., Cary, NC) PROC GLIMMIX. Individual production lot was designated as the experimental unit for all analyses. Data were analyzed as a completely randomized design with treatment as a fixed effect and panel session as a random effect. A model with a binomial error distribution was used for all acceptability data. For treatment comparisons, an α of 0.05 was considered significant, and for all models, the Kenward-Roger adjustment was used for the denominator degrees of freedom.

Results and Discussion

Consumer panel demographics and purchasing motivators

Table 1 contains the demographic characteristics of the 240 consumers who participated in the consumer panels in this study. For taco panels, there were slightly more males (55%) than females (45%). Most (46.7%) of the panelists were from 2-person households, and the majority (65.8%) were married. The majority (72.5%)

Table 1. Demographic characteristics of consumers ($N = 240$; 120 consumers/product type) who participated in the hamburger and taco consumer sensory panels

		Percentage of consumers	
Characteristic	Response	Taco panels	Hamburger panels
Gender	Male	55.0	50.0
	Female	45.0	50.0
Household size	1 person	16.7	20.8
	2 people	46.7	38.3
	3 people	8.3	15.8
	4 people	12.5	15.8
	5 people	8.3	6.7
	6 people	5.8	0.0
	Greater than 6 people	1.7	2.5
Marital status	Married	65.8	57.5
	Single	34.2	42.5
Age	Under 20	8.3	5.8
	20–29	19.2	31.7
	30–39	6.7	6.7
	40–49	12.5	16.7
	50–59	28.3	19.2
	Over 60	25.0	20.0
Ethnic origin	African American	1.7	0.8
	Asian	0.0	1.7
	Caucasian/White	90.0	90.8
	Latino	4.2	2.5
	Mixed Race	1.7	1.7
	Native American	1.7	0.8
	Other	0.8	1.7
Income	Under $25,000	15.8	20.0
	$25,000–$34,999	5.0	8.3
	$35,000–$49,999	12.5	11.7
	$50,000–$74,999	12.5	15.0
	$75,000–$99,999	15.0	17.5
	$100,000–$149,999	15.0	11.7
	$150,000–$199,999	12.5	9.2
	Greater than $199,999	11.7	6.7

Table 1. (*Continued*)

Characteristic	Response	Percentage of consumers	
		Taco panels	Hamburger panels
Education level	Non-high school graduate	1.7	0.8
	High school graduate	12.5	11.7
	Some college/technical school	30.8	30.8
	College graduate	34.2	40.0
	Post-college graduate	20.8	16.7
Most important palatability trait when consuming ground beef	Tenderness	14.2	6.7
	Juiciness	8.3	28.3
	Flavor	77.5	65.0
Preferred degree of doneness when consuming ground beef	Very rare	0.0	0.0
	Rare	3.3	1.7
	Medium rare	18.3	30.8
	Medium	25.8	29.2
	Medium well	33.3	26.7
	Well done	16.7	10.8
	Very well done	2.5	0.8
Weekly ground beef consumption	1 to 3 times	42.6	62.5
	4 to 6 times	39.3	29.2
	7 to 9 times	13.8	5.0
	10 or more times	4.3	3.3

were at least 30 y of age and Caucasian (90%). Most (54.2%) were from households that made at least $75,000 annually and had completed at least a college degree (55%). Most (57.4%) of the consumers consumed ground beef 4 or more times a week. Flavor (77.5%) was considered the most important trait when eating ground beef, followed by tenderness (14.2%) and juiciness (8.3%). Of consumers, 52.5% preferred ground beef cooked to at least medium-well.

Demographics for the hamburger panels are also presented in Table 1 and are similar to the panelists who participated in the taco panels. For hamburger panels, males and females were evenly split (50%), with the majority (79.2%) from a multimember household. Fewer (57.5%) were married than in the taco panels, with the vast majority (90.8%) being Caucasian. The majority (62.6%) were greater than 30 y of age and had a household income of greater than $50,000 annually (60.1%). College graduates and post-college graduates again represented the majority (56.7%) of panelists, and flavor was again the most preferred palatability trait (65.0%). Consumers for hamburger panels preferred their ground beef cooked to lower degrees of doneness, with 61.7% preferring a medium degree of doneness or less, and they consumed ground beef less, with 62.5% consuming ground beef only 1 to 3 times a week. These reported preferred degrees of doneness for ground beef are similar to recent studies that have shown that 10% to 35% of consumers report cooking ground beef to a medium-rare or lower degree of doneness (Davis et al., 2021; Harr et al., 2022a, 2022b) and are somewhat concerning. Most published resources cite a temperature of less than 63°C to correspond with medium-rare, with consumers reporting temperatures of less than 68°C and chefs reporting 57°C or lower for this same degree of doneness in beef steaks (Prill et al., 2019b). The USDA suggests cooking ground beef products to an internal temperature of at least 71.1°C to ensure food safety (USDA-FSIS, 2020), corresponding to a medium or higher degree of doneness. However, less than 5% of consumers report using a food thermometer when preparing beef (Prill et al., 2019b). Beef is one of the leading commodities associated with foodborne illness in the US (Painter et al., 2013), with ground beef linked to 73% of all such beef-related illnesses (Canning et al., 2023). Taken together, this highlights the need for additional consumer education related to the proper preparation of ground beef products. Overall, the demographics in the current study are similar to previous beef consumer sensory studies conducted in Manhattan, KS (McKillip et al., 2017; Drey et al., 2019; Olson et al., 2019; Prill et al., 2019a; Rice et al., 2019; Beyer et al., 2021).

The importance of various purchasing motivators considered by consumers when purchasing ground beef are presented in Table 2. For taco panels, no difference ($P > 0.05$) was found among the product-related traits including "lean to fat ratio," "fat content," "price," and "color," which were all among the most important traits and more important than several animal production related claims. "Preformed patty," "brand of the product," "natural/organic claims," and "packaging type" were of lower ($P < 0.05$) importance than all traits other than "environmental impact." Similar results were found for consumers who participated in the hamburger panels. However, for these consumers, "color" was more important ($P < 0.05$) than all other traits. "Lean to fat ratio," "fat content," and "price" were all more important ($P < 0.05$) than all traits other than "color." Additionally, and similar to the taco panelists, "preformed patty," "brand of the product," "natural/organic claims," and "packaging type" were among the lowest in importance and had a lower ($P < 0.05$) rating than all traits other than "environmental impact." In a pair of similar studies evaluating consumer purchasing motivators of ground beef, Harr et al. (2022a, 2022b) reported "fat content," "color," and "lean to fat ratio" to be among the most important traits

Table 2. Ground beef purchasing motivators of consumers ($N = 240$; 120 consumers/product type) who participated in the taco and hamburger consumer sensory panels

	Importance[1]	
Trait	Taco panels	Hamburger panels
Lean to fat ratio	75.1[a]	74.6[b]
Fat content	73.7[a]	69.8[b]
Price	72.6[ab]	72.6[b]
Color	69.4[abc]	81.2[a]
Healthfulness	66.8[bc]	60.7[c]
Protein source	66.2[c]	62.1[c]
Environmental impact	42.1[d]	39.5[d]
Packaging type	36.1[de]	32.1[e]
Natural/organic claims	36.0[de]	35.6[de]
Brand of product	35.4[e]	29.2[e]
Preformed patty	33.1[e]	32.2[e]
SEM[2]	2.3	2.3
P value	<0.01	<0.01

[a–e]Least-squares means in the same column without a common superscript differ ($P < 0.05$).

[1]Purchasing motivators: 0 = extremely unimportant, 100 = extremely important.

[2]SEM (largest) of the least-squares means.

considered, with "price" rated lower by some of their consumers than in the current study. Other studies that have evaluated a similar list of traits for steak cuts have identified "price," "size, weight, and thickness," "steak color," and "marbling level" among the most important traits considered (Olson et al., 2019; Farmer et al., 2022), again highlighting the importance consumers place on the product-related characteristics over many marketing and animal production traits.

Consumer sensory evaluation

The number of consumers who chose to include selected toppings in the current study are presented in Table 3. For taco panels, over 67% of consumers chose to include all 3 toppings (lettuce, tomato, and cheese) on their samples. Moreover, 20% chose to include both cheese and lettuce, without tomato. Only 6% of consumers included a single topping, with none choosing to exclude toppings. The most popular topping was cheese, included by more than 96% of consumers, followed by lettuce at more than 90% of consumers, and tomato at 74% of consumers. Similar preferences were observed in the hamburger panels, though a greater number of preferred topping combinations were used. Only 18% of consumers used all 5 toppings (cheese, lettuce, ketchup, pickle, and mustard) available. Five percent of consumers elected to include no toppings, and an additional 6% chose to include only a single ingredient. Again, cheese was the most popular topping, included by more than 78% of consumers. Consumers also included ketchup (73%), pickles (63%), lettuce (56%), and mustard (53%). An informal consumer survey of more than 9,000 US adults reported similar hamburger topping preferences as in the current work, with cheese rated as the most preferred topping, followed by lettuce, and ketchup (YouGov, 2021), though no such data could be found for tacos.

Originally it was intended to analyze data by topping to evaluate the impact of the inclusion or exclusion of single ingredients or ingredient combinations on consumer palatability perceptions. However, the high percentage of consumers who elected to include all available ingredients within the taco panels as well as the high amount of diversity of ingredient combinations within the hamburger panels made such an analysis impractical and non-meaningful. Thus, this analysis was not included in this paper. Moreover, differences in topping amount that was reported by consumers was considered, but was found to be non-meaningful, again related to the high percentage of consumers who reported including a similar amount of each.

The inclusion of ingredients with the products in the current work is unique, as most previous meat-focused studies often exclude the use of additional ingredients in order to present sensory panelists with as similar of product as possible across all treatments. In fact, such is advised by the current AMSA Sensory Guidelines (American Meat Science Association, 2016). However, the specific objectives of the current work related to how the products would be evaluated when used as a single ingredient in a larger food product requiring the use of these toppings as well as the ability of consumers to match the toppings used to their preferences, limiting the ability to standardize ingredient inclusion. Previous research has utilized Home-Use-Test consumer testing methods in which consumers were able to control all aspects of their eating experience, including how the product was prepared, degree of doneness used, and seasonings and ingredients utilized, among other factors, to best mimic how the product would be used under "normal" conditions (Lorenzen et al., 1999; Neely et al., 1999; Savell et al., 1999). Though such methods were considered for the current study, in many of these studies the high amount of variability in consumer preparation and use limits the ability to draw robust conclusions. Thus, a

Table 3. Number of consumers ($N = 240$; 120 consumers/product type) who selected each topping to add to ground beef and plant-based ground beef alternatives (GBA)[1] in taco and hamburger panels

Toppings used	Taco panels[1]	Hamburger panels[2]
No toppings	0	6
Cheese	6	4
Lettuce	1	0
Ketchup	-	3
Cheese and ketchup	-	4
Cheese and lettuce	24	2
Cheese and mustard	-	2
Cheese and pickle	-	1
Cheese and tomato	5	-
Ketchup and lettuce	-	3
Ketchup and mustard	-	2
Ketchup and pickle	-	2
Lettuce and pickle	-	1
Lettuce and tomato	3	-
Cheese, ketchup, and lettuce	-	11
Cheese, ketchup, and mustard	-	4
Cheese, ketchup, and pickle	-	5
Cheese, lettuce, and mustard	-	2
Cheese, lettuce, and pickle	-	2
Cheese, lettuce, and tomato	81	-
Cheese, mustard, and pickle	-	5
Ketchup, lettuce, and pickle	-	1
Ketchup, mustard, and pickle	-	3
Cheese, ketchup, lettuce, and mustard	-	1
Cheese, ketchup, lettuce, and pickle	-	11
Cheese, ketchup, mustard, and pickle	-	11
Cheese, lettuce, mustard, and pickle	-	7
Ketchup, lettuce, mustard, and pickle	-	5
Cheese, ketchup, lettuce, mustard, and pickle	-	22

[1]Consumers were served samples seasoned with a taco seasoning blend on a flour tortilla with an option to add cheese, lettuce, and tomato to their taco samples.

[2]Consumers were served a hamburger patty on a white bun with an option to add cheese, ketchup, lettuce, mustard, and pickle to their hamburger samples.

Central Location Test method was used in which the research team could standardize the exact ingredients, portions, and preparation methods used while still allowing the consumers to personalize the products to their liking. This method allowed for a somewhat hybrid approach to Home-Use and Centralized Location Testing, allowing for the strengths of both methods.

Table 4 presents the mean consumer sensory ratings for both taco and hamburger panels. Within the taco panels, ground beef was rated higher ($P < 0.05$) than all 3 GBA for all traits evaluated, other than tenderness, in which the ground beef sample was similar ($P > 0.05$) to both FGBA and RGBA. Moreover, ground beef had the highest ($P < 0.05$) purchase intent rating and purchase price willing to be paid by panelists. For all traits, no difference ($P > 0.05$) was found between FGBA and RGBA, but TGBA was rated lower ($P < 0.05$) than both for all palatability traits. TGBA was similar ($P > 0.05$) only to RGBA for purchase price willing to be paid. It is noteworthy that the TGBA comprised different, primarily soy-based proteins and represented a product that had been on the market for much longer than both the FGBA and RGBA. It is possible that the different protein sources coupled with the newer technology in the manufacturing of the RGBA and FGBA could help explain these observed differences.

Similar results were found for hamburger panels (Table 4). Again, ground beef was rated higher ($P < 0.05$) than the 3 GBA for juiciness, texture liking, overall flavor liking, beef flavor liking, overall liking, purchase intent, and the price willing to be paid at foodservice. Similar to the taco panels, there was no difference ($P > 0.05$) between ground beef and either FGBA or RGBA for tenderness. Once more, RGBA and FGA did not differ ($P > 0.05$) for juiciness, tenderness, texture, overall flavor liking, or overall liking. However, FGBA was rated higher ($P < 0.05$) for beef flavor liking and purchase intent than RGBA. Overall, TGBA was still rated the lowest for most traits, though within the hamburger panels, TGBA had a similar ($P > 0.05$) rating as RGBA for overall flavor liking, beef flavor liking, purchase intent, and the price willing to be paid.

Recently, the amount of research focusing on GBA has increased as an increased number of these products have been introduced. Similar to the current work, other authors have reported differences in eating quality between ground beef and GBA. Hernandez et al. (2023) found GBA to be more similar in juiciness to ground beef than was found in the current work, but identified large differences in flavor traits, especially beef flavor identity. These authors also characterized the volatile flavor compound differences of their treatments and again reported large differences in chemical compounds which explained some of the observed differences in flavor (Hernandez et al., 2023). Similar flavor-related differences were also observed by Godschalk-Broers et al. (2022) between ground beef and GBA. In an attempt to determine whether product awareness had an impact on eating quality of GBA,

Table 4. Least-squares means for consumer ($N = 240$; 120 consumers/product type) panel ratings for tacos and hamburgers with ground beef and plant-based ground beef alternatives (GBA)[1]

Trait[2]	Ground beef	Foodservice GBA	Retail GBA	Traditional GBA	SEM[3]	*P* value
Taco panels[4]						
Juiciness	74.3[a]	60.8[b]	66.6[b]	45.4[c]	2.4	<0.01
Tenderness	68.6[a]	67.1[a]	65.4[a]	58.8[b]	2.2	<0.01
Texture	70.9[a]	55.1[b]	53.7[b]	43.1[c]	2.9	<0.01
Overall flavor	68.7[a]	51.3[b]	49.0[b]	36.0[c]	3.2	<0.01
Beef flavor	68.3[a]	50.4[b]	46.4[b]	35.0[c]	3.1	<0.01
Overall liking	69.7[a]	51.7[b]	47.4[b]	34.5[c]	3.3	<0.01
Purchase intent[5]	63.7[a]	42.6[b]	39.6[b]	27.3[c]	3.4	<0.01
Purchase price[6]	2.8[a]	1.9[b]	1.6[bc]	1.3[c]	0.2	<0.01
Hamburger panels[7]						
Juiciness	66.4[a]	55.3[b]	53.5[b]	39.1[c]	2.2	<0.01
Tenderness	64.7[a]	61.4[a]	62.6[a]	48.8[b]	2.1	<0.01
Texture	64.6[a]	55.0[b]	50.0[b]	40.5[c]	2.3	<0.01
Overall flavor	67.7[a]	48.6[b]	43.4[bc]	37.4[c]	2.5	<0.01
Beef flavor	66.1[a]	47.2[b]	41.0[c]	36.8[c]	2.7	<0.01
Overall liking	67.5[a]	49.6[b]	42.3[b]	34.1[c]	2.6	<0.01
Purchase intent[5]	63.3[a]	42.2[b]	34.5[c]	28.3[c]	2.7	<0.01
Purchase price[6]	4.8[a]	3.2[b]	2.7[bc]	2.1[c]	0.2	<0.01

[a–c]Least-squares means in the same row without a common superscript differ ($P < 0.05$).

[1]Foodservice GBA = plant-based ground beef alternative most commonly sold in foodservice establishments (restaurants).

Retail GBA = plant-based ground beef alternative most commonly sold in retail markets (grocery stores, supermarkets).

Traditional GBA = plant-based ground beef alternative most indicative of a traditional soy-based product.

[2]Sensory scores: 0 = extremely dry/tough, dislike texture/overall flavor/beef flavor/overall; 50 neither dry nor juicy/neither tough nor tender, neither like nor dislike texture/overall flavor/beef flavor/overall; 100 = extremely juicy/tender, like texture/overall flavor/beef flavor/overall.

[3]SEM (largest) of the least-squares means.

[4]Consumers were served samples seasoned with a taco seasoning blend on a flour tortilla with an option to add cheese, lettuce, and tomato to their taco samples.

[5]If price were not a factor, likelihood of purchase; 1 = not likely, 100 = extremely likely.

[6]Price, in US dollars, willing to be paid at foodservice for comparable product.

[7]Consumers were served a hamburger patty on a white bun with an option to add cheese, ketchup, lettuce, mustard, and pickle to their hamburger samples.

Grasso et al. (2022) fed consumers in both a blinded and an informed sensory scenario. When fed without additional information, consumers reported ground beef to have a higher overall acceptability than GBA, but when informed of the product they were evaluating, the plant-based GBA was found to be similar to the ground beef (Grasso et al., 2022). This was due to the more than 25% increase in taste ratings of the GBA when panelists were informed of the product type (Grasso et al., 2022). In a study to evaluate the economics of GBA and evaluate consumers' willingness-to-pay for a pea-protein–based GBA and mushroom GBA/ground beef blended product, Caputo et al. (2023) reported that consumers had a higher overall preference for ground beef than both products and reported a willingness-to-pay a premium of $4.26 for ground beef over the pea-based GBA, with the blended product preferred, with a premium of $3.91 compared to the pea-protein GBA.

However, the Davis et al. (2021) study remains the best comparison for the current work due to the similarities in methodology, study design, and treatments used. Though results in the current work show similar results to Davis et al. (2021) in relation to ground beef performance in comparison with GBA, the two studies together provide greater insight related to the impact of the "real world" eating scenario's impact on palatability perception of these products. Collectively, the majority of ratings increased in the current work compared to those in the blinded, unseasoned ground beef patty scenario used by Davis et al. (2021) and other similar ground beef studies (Wilfong et al., 2016; Najar-Villarreal et al., 2019; Harr et al., 2022a, 2022b). Compared to Davis et al. (2021), sensory

ratings for ground beef increased by 19% and 13% for overall liking, 3% and 6% for beef flavor liking, 16% and 17% for overall flavor liking, and 25% and 26% for purchase intent for hamburger and taco panels, respectively. This increase was even greater for FGBA and RGBA. FGBA was 20% and 69% higher for overall liking, 28% and 36% higher for beef flavor liking, 52% and 54% higher for overall flavor liking, and 24% and 25% higher for purchase intent for hamburger and taco panels, respectively. RGBA showed an even greater impact related to the "real world" scenario, rating 78% and 99% higher for overall liking, 43% and 62% higher for beef flavor liking, 58% and 78% higher for overall flavor liking, and 93% and 121% higher for purchase intent for the hamburger and taco panels. This large discrepancy on the impact of the "real world" eating scenario across treatments shows how the added ingredients have a disproportional impact on the various treatments, with ground beef being the least impacted and RGBA being the most impacted when the treatment product was included as an ingredient as opposed to standing alone as was the case in the Davis et al. (2021) study. Moreover, this shows that the impact of the taco panels was greater than the hamburger panels for all GBA treatments. This could be due to the taco seasoning blend added to the taco panels compared to the lack of added seasoning included with the hamburgers, cooking methods used, or even a difference in the ingredients offered to consumers for each panel type.

It is also informative to evaluate the difference between ground beef ratings and the GBA sensory ratings within both studies. In both cases the ground beef was rated higher by consumers, but this difference differed greatly between the Davis et al. (2021) study and the current work. Within the Davis et al. (2021) study, ground beef was rated 37%, 74%, 31%, and 48% higher than the FGBA for overall liking, beef flavor liking, overall flavor liking, and purchase intent, respectively. In the current study this difference ranged between 34% and 40% for all traits and was 50% higher for purchase intent in both hamburger and taco panels. Conversely, the difference between the ground beef and RGBA treatment was much smaller in magnitude in the current work. Davis et al. (2021) reported over a 113% difference in sensory rating between 80% lean ground beef and RGBA for overall liking, beef flavor liking, and overall flavor liking and a 183% higher purchase intent rating. In the current study, these same traits were only 40% to 61% higher for both hamburger and taco panels and only 84% higher purchase intent ratings for hamburger panels. It is noteworthy that the TGBA differed from the other GBA. In the current study, ground beef was rated 80% to 102% higher for these same traits, including more than 123% higher for purchase intent than the TGBA. In the Davis et al. (2021) study, ground beef had only a 46% to 63% advantage over TGBA, with the exception of beef flavor liking, which was rated 136% higher. This difference between the two studies is likely the result of the different TGBA used between the two studies. Due to retail availability and market share, the TGBA was changed for the current work. In the Davis et al. (2021) study, consumers rated the TGBA more similar to the two "modern" GBA than the consumers in the current study, which consistently rated the TGBA as the lowest for close to all traits evaluated.

Table 5 presents the results for the percentage of samples rated acceptable for all sensory traits. For taco panels, ground beef had the highest ($P < 0.05$) percentage of samples rated acceptable for overall liking, texture liking, beef flavor liking, and overall flavor liking. A similar ($P > 0.05$) percentage of ground beef samples were rated acceptable for juiciness and tenderness as FGBA. For all traits, no difference ($P > 0.05$) was found between FGBA and RGBA for the percentage of samples rated acceptable, with the exception of beef flavor, in which a greater ($P < 0.05$) percentage of FGBA were rated acceptable than RGBA. Similar to the palatability rating data, for taco panels, TGBA had a lower ($P < 0.05$) percentage of samples rated acceptable than all other treatments, other than for texture, in which a similar ($P > 0.05$) percentage were rated acceptable as RGBA.

Similar results were found for hamburger panels (Table 5). Similar to tacos, a higher ($P < 0.05$) percentage of ground beef samples were rated acceptable for overall flavor liking, beef flavor liking, and overall than all other treatments. A similar ($P > 0.05$) percentage of ground beef samples were rated acceptable for both juiciness and texture liking as FGBA and both FGBA and RGBA for tenderness acceptability. Similar to taco panels, FGBA and RGBA did not differ ($P > 0.05$) in the percentage of samples rated acceptable for juiciness, tenderness, texture, and beef flavor liking. However, a greater ($P < 0.05$) percentage of FGBA were rated acceptable for overall flavor and overall than RGBA. Fewer ($P < 0.05$) TGBA samples were rated acceptable for juiciness, tenderness, and texture liking than all other treatments. However, a similar ($P > 0.05$) percentage were rated acceptable for overall flavor liking, beef flavor liking, and overall as RGBA.

Table 5. Least-squares means for the percentage of ground beef and plant-based ground beef alternative (GBA)[1] taco and hamburger samples rated acceptable for each palatability trait by consumers ($N = 240$; 120 consumers/product type)

Trait	Ground beef	Foodservice GBA	Retail GBA	Traditional GBA	SEM[2]	*P* value
Taco panels[3]						
Juiciness	94.1[a]	91.8[a]	90.3[a]	63.4[b]	5.4	<0.01
Tenderness	98.0[a]	96.7[a]	96.7[a]	84.7[b]	4.2	<0.01
Texture	94.6[a]	83.2[b]	76.5[bc]	67.7[c]	5.8	<0.01
Overall flavor	94.2[a]	73.1[b]	62.6[b]	39.2[c]	5.6	<0.01
Beef flavor	93.4[a]	71.2[b]	58.0[c]	41.9[d]	5.7	<0.01
Overall liking	93.5[a]	71.5[b]	61.7[b]	46.4[c]	5.9	<0.01
Hamburger panels[4]						
Juiciness	89.7[a]	81.5[ab]	79.0[b]	50.0[c]	5.1	<0.01
Tenderness	93.4[a]	92.5[a]	86.7[a]	70.1[b]	4.3	<0.01
Texture	86.7[a]	82.5[ab]	72.5[b]	55.0[c]	4.5	<0.01
Overall flavor	90.9[a]	67.6[b]	50.8[c]	45.0[c]	4.6	<0.01
Beef flavor	89.4[a]	61.8[b]	52.5[bc]	39.9[c]	4.8	<0.01
Overall liking	90.2[a]	69.4[b]	49.2[c]	49.9[c]	4.8	<0.01

[a–d]Least-squares means in the same row without a common superscript differ ($P < 0.05$).

[1]Foodservice GBA = plant-based ground beef alternative most commonly sold in foodservice establishments (restaurants).

Retail GBA = plant-based ground beef alternative most commonly sold in retail markets (grocery stores, supermarkets).

Traditional GBA = plant-based ground beef alternative most indicative of a traditional soy-based product.

[2]SEM (largest) of the least-squares means.

[3]Consumers were served samples seasoned with a taco seasoning blend on a flour tortilla with an option to add cheese, lettuce, and tomato to their taco samples.

[4]Consumers were served a hamburger patty on a white bun with an option to add cheese, ketchup, lettuce, mustard, and pickle to their hamburger samples.

To no surprise, the results for the percentage of samples rated acceptable for each trait followed similar trends as observed within the palatability rating data. Overall, samples in the taco panels tended to have a higher percentage of samples rated acceptable than in the hamburger panels, again potentially due to the added seasoning. When compared to previous work that has assessed the acceptability of 80% lean ground beef, the results from the hamburger portion of the current study indicate that our samples had close to 10% to 20% more samples rated acceptable for each palatability trait (Wilfong et al., 2016; Najar-Villarreal et al., 2019; Davis et al., 2021; Harr et al., 2022a, 2022b). Ground beef samples in the current work had more than 86% of samples rated acceptable for each trait for hamburgers and more than 93% of samples acceptable for taco panels, indicating the high level of acceptability found within this product by consumers. Similar increases in the percentage of samples rated as acceptable by consumers were found for the GBA as with the ground beef. Close to 20% more FGBA and RGBA were rated acceptable overall in hamburger and taco panels than in previous work with unseasoned patties (Davis et al., 2021). However, it is noteworthy that the mean percentage of both RGBA and TGBA samples rated acceptable overall in the current work fell below 50% for hamburger samples, indicating these samples were still viewed as "unacceptable" overall by many consumers.

The percentage of samples categorized into various quality categories by consumers is presented in Table 6. For taco panels, there was no difference ($P > 0.05$) between the percentage of samples rated as "premium" quality among the treatments, with fewer than 5% of any treatment classified in this category. A greater ($P < 0.05$) percentage of ground beef samples were classified as "better than everyday" quality than FGBA and TGBA. A similar ($P > 0.05$) percentage of ground beef and FGBA were classified as "everyday" quality, both of which were higher ($P < 0.05$) than the percentage rated as "everyday" quality for RGBA and TGBA. Fewer than 7% of ground beef samples were classified as "unacceptable," which was lower ($P < 0.05$) than all GBA. Moreover, more than half (57.9%) of TGBA were classified as "unacceptable," which was more ($P < 0.05$) than all other treatments.

For hamburger panels, more ($P < 0.05$) ground beef samples were classified as "premium" quality than

Table 6. Least-squares means for the percentage of ground beef and plant-based ground beef alternative (GBA)[1] taco and hamburger samples categorized into different quality levels by consumers ($N = 240$; 120 consumers/product type)

Trait	Ground beef	Foodservice GBA	Retail GBA	Traditional GBA	SEM[2]	*P* value
Taco panels[3]						
Premium	4.2	1.1	1.1	1.1	2.3	0.16
Better than everyday	26.7[a]	10.8[b]	17.5[ab]	2.5[c]	4.0	<0.01
Everyday	60.1[a]	60.1[a]	39.1[b]	38.2[b]	4.6	<0.01
Unsatisfactory	6.8[d]	26.5[c]	41.2[b]	57.9[a]	5.4	<0.01
Hamburger panels[4]						
Premium	9.8[a]	1.6[b]	5.7[ab]	1.6[b]	3.0	0.02
Better than everyday	28.9[a]	17.2[b]	10.6[b]	9.8[b]	4.4	<0.01
Everyday	51.7[a]	47.5[a]	33.2[b]	23.1[b]	5.8	<0.01
Unsatisfactory	8.7[d]	32.8[c]	50.0[b]	65.5[a]	5.6	<0.01

[a–d]Least-squares means in the same row without a common superscript differ ($P < 0.05$).

[1]Foodservice GBA = plant-based ground beef alternative most commonly sold in foodservice establishments (restaurants).

Retail GBA = plant-based ground beef alternative most commonly sold in retail markets (grocery stores, supermarkets).

Traditional GBA = plant-based ground beef alternative most indicative of a traditional soy-based product.

[2]SEM (largest) of the least-squares means.

[3]Consumers were served samples seasoned with a taco seasoning blend on a flour tortilla with an option to add cheese, lettuce, and tomato to their taco samples.

[4]Consumers were served a hamburger patty on a white bun with an option to add cheese, ketchup, lettuce, mustard, and pickle to their hamburger sample.

any treatment other than RGBA. Likewise, a higher ($P < 0.05$) percentage of ground beef samples were classified as "better than everyday" quality than all other treatments, with no difference ($P > 0.05$) found among the GBA. Similar to taco panels, a similar ($P > 0.05$) percentage of ground beef and FGBA samples were classified as "everyday" quality, both of which were higher ($P < 0.05$) than either RGBA or TGBA. Each treatment differed ($P < 0.05$) in the percentage of samples classified as "unsatisfactory" (TGBA > RGBA > FGBA > ground beef), with both RGBA and TGBA having at least half of samples classified into this category. These data show an overall shift downward in the quality perception of the GBA products in comparison to the ground beef samples, with a greater proportion of GBA classified into the bottom two categories of "everyday" and "unsatisfactory" quality compared to ground beef.

Color and pH measurements

Table 7 presents the instrumental color measurements and pH values for the treatments. For pH, all 4 treatments differed ($P < 0.05$; RGBA > TGBA > FGBA > ground beef). Ground beef had the lowest ($P < 0.05$) pH but was in-line with the pH commonly associated with fresh beef (Page et al., 2001). The GBA all had a higher pH than the ground beef but were similar to the values reported by Davis et al. (2021) for the same treatments. For instrumental color, a^* value (a measure of redness) differed ($P < 0.05$) among all treatments (ground beef > FGBA > RGBA > TGBA), indicating ground beef was the reddest in color. The FGBA used in the current work contained beet extract as an

Table 7. Least-squares means for ground beef and plant-based ground beef alternatives (GBA)[1] external instrumental color[2] and pH values

Trait	Ground beef	Foodservice GBA	Retail GBA	Traditional GBA	SEM[3]	*P* value
L^*[4]	57.2[a]	50.5[b]	57.2[a]	43.4[c]	0.5	<0.01
a^*[5]	27.7[a]	19.7[b]	14.9[c]	10.9[d]	0.3	<0.01
b^*[6]	21.1[a]	19.5[b]	19.7[b]	13.5[c]	0.3	<0.01
pH	5.7[d]	6.2[c]	7.0[a]	6.4[b]	0.04	<0.01

[a–c]Least-squares means in the same row without a common superscript differ ($P < 0.05$).

[1]Foodservice GBA = plant-based ground beef alternative most commonly sold in foodservice establishments (restaurants).

Retail GBA = plant-based ground beef alternative most commonly sold in retail markets (grocery stores, supermarkets).

Traditional GBA = plant-based ground beef alternative most indicative of a traditional soy-based product.

[2]Samples were allowed a 30-min bloom time prior to L^*, a^*, b^* data collection.

[3]SEM (largest) of the least-squares means.

[4]L^* = lightness (0 = black and 100 = white).

[5]a^* = redness (−60 = green and 60 = red).

[6]b^* = blueness (−60 = blue and 60 = yellow).

ingredient, providing a more perceived red color in comparison to other GBA. In the current study, this resulted in a redder (higher a^* value) color than the other 2 GBA. These a^* values for the 3 GBA indicate a less than 50% chance a consumer would purchase the products at full-price in a retail case based on redness, and for RGBA and TGBA, even if the product was discounted (Lybarger, 2022). Thus, the redness of these products is not enough to satisfy consumers based on appearance as would be expected with ground beef. L^* values were higher ($P < 0.05$) for ground beef and RGBA than either FGBA or TGBA, indicating these products were lighter in color. Moreover, ground beef samples had a higher ($P < 0.05$) b^* value than all GBA. No difference ($P > 0.05$) in b^* was found between RGBA and FGBA, but both were higher ($P < 0.05$) than TGBA. The instrumental color readings in the current study are similar to those reported by Davis et al. (2021) for FGBA, but Davis et al. (2021) reported RGBA to have lower L^*, a^*, and b^* values. Additionally, the TGBA in the Davis et al. (2021) study had similar L^* values, but much higher a^* and b^* values, though these were different TGBA products.

Conclusions

Plant-based beef alternatives are a current and ever evolving segment of the protein sector, with the number of product offerings changing how consumers view protein foods. Unlike in the past, these products are not solely being marketed to vegetarian consumers, but instead are being offered as a direct substitute for beef products. Results from the current study provide evidence of the consumer preferred eating quality offered by beef products in comparison to these plant-based alternatives, even if other commonly used taco and hamburger ingredients are included. As the growing body of work highlights how these products differ from beef, the current study underscores that the use of these products as an ingredient does not compensate for their overall reduced palatability characteristics. Thus, additional industry efforts are needed related to plant protein structures and functionalities in order to improve palatability, as our work would indicate the use of seasonings and ingredients alone does not reduce the palatability gap with beef. Current work combined with previous studies provide clear evidence that these plant-based GBA are different products from ground beef and should be marketed as such by purveyors and considered as such by consumers. Ultimately, the level of eating satisfaction offered by beef products is unique and has not been matched with GBA currently available on the market, even when these GBA have included ingredients commonly found in hamburgers and tacos.

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