Meat and Muscle Biology™

Quality of Plant-Based Ground Beef Alternatives in Comparison with Ground Beef of Various Fat Levels[1,2]

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Abstract: The objective of this study was to compare the quality characteristics of current plant-based protein ground beef alternatives (GBA) to ground beef (GB) patties of varying fat percentages. Fifteen different production lots ($n = 15$/fat level) of 1.36 kg GB chubs of 3 different fat levels (10%, 20%, and 27%) were collected from retail markets in the Manhattan, KS area. Additionally, GBA products including a foodservice GBA (FGBA), a retail GBA (RGBA), and a traditional soy protein–based GBA (TGBA) currently available through commercial channels were collected. Consumers ($n = 120$) evaluated sample appearance, juiciness, tenderness, overall flavor liking, beef flavor liking, texture liking, and overall liking. Additionally, samples were evaluated for color, texture profile, shear force, pressed juiciness percentage (PJP), pH, and fat and moisture percentage. All 3 GB samples rated higher ($P < 0.05$) than the 3 GBA samples for appearance liking, overall flavor liking, beef flavor liking, and overall liking by consumers. Similar results were found with trained sensory panelists, which rated the GBA as less ($P < 0.05$) juicy, softer ($P < 0.05$), and lower ($P < 0.05$) for beef flavor and odor intensity and higher ($P < 0.05$) for off-flavor intensity than the GB. Moreover, the GBA had less ($P < 0.05$) change in shape through cooking and a lower ($P < 0.05$) percentage of cooking loss and cooking time than the GB. Also, the GBA all had lower ($P < 0.05$) shear force and PJP values than the GB. The color of the GBA differed ($P < 0.05$) from the GB, with the GB samples being more ($P < 0.05$) red in the raw state. These results indicate that the GBA provide different eating and quality experiences than GB and should thus be considered as different products by consumers and retailers.

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

Ground beef (GB) is the most highly consumed beef product in the United States. Beef consumption in the United States is estimated at 26.3 kg per capita, with an estimated 45% of the total representing GB (Ishmael, 2020). This means that the average American consumes 11.8 kg of GB each year, with GB included in approximately 60% of all beef dishes prepared in the home (Beef2Live, 2021). Though annual total GB production is difficult to estimate because of variation in production channels, GB sales represent about 63% and 49% of beef sales volume through foodservice and retail, respectively (Speer et al., 2015). This equates to approximately 37% of beef-related revenue for foodservice establishments and 39% for retailers (Speer et al., 2015). Additionally, the retail price of GB has continued

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to climb over the past 20+ y, with the price for 0.45 kg of GB in 2020 142% higher than in 2000 (Statista, 2021). This large market and demand for GB has created an opportunity for the creation of numerous plant-based ground beef alternatives (GBA) in an attempt to capture market share and consumer interest.

Plant-based meat alternatives are not a new concept. There have been several iterations of plant-based "meat" concepts over the past 40+ y. In the 1980s, many plant-based GBA first became available in retail markets. Most of these products attempted to serve as a replacement for traditional beef hamburgers and targeted consumers who were vegetarian and consuming a plant-based diet (Eater, 2019). These patties were typically comprised of a soy-based protein as the primary ingredient (Kraft Foods, 2019). Today, there has been a resurgence of interest in plant-based GBA. Newer technologies have allowed modern GBA to attempt to more closely imitate GB than the previous generations of GBA. Many of today's GBA use protein sources comprised of both pea and various bean proteins to help the products more closely resemble beef (Capritto, 2019). Moreover, these products have also worked to incorporate heme-based proteins that, similar to beef, will appear red in color in a fresh form (Capritto, 2019). Previous works have evaluated the nutrient specifications (Bohrer, 2019), environmental sustainability (van der Weele et al., 2019), and have reviewed the processing technologies (Sha and Xiong, 2020) used with today's GBA. Plant-based meat alternatives have increased in sales at retail by more than 45% over the past year (Garver, 2021) and have increased by 20% of their market share in foodservice (Kansas Beef Council, 2021). These trends show a clear indication that consumers are purchasing these products both at retail and foodservice, with the global market for plant-based meat alternatives expected to grow by 318% from 2019 through 2027 (Grand View Research, 2020).

Unlike previous plant-based burgers, today's products are actively targeting and marketing beef consumers, with 31% of consumers reporting eating meat alternatives at least once a week (Kansas Beef Council, 2021). This reflects a growing number of today's consumers who are participating in a "flexitarian" diet; one in which the diet is primarily plant-based but allows for greater consumption of animal-sourced foods (Marengo, 2020). In this way, these products serve more as a form of variety in many consumers' diets rather than a strict replacement for beef products. Though many of these products position themselves as "substitutes" or "similar" to traditional GB, little to no published literature has evaluated these products in comparison with GB. Therefore, the objective of this study was to evaluate the quality traits of 3 GBA in comparison with GB of 3 fat levels.

Materials and Methods

The Kansas State University (KSU) Institutional Review Board approved the procedures used in this study (IRB #7440.7, 2021).

Treatments and sample preparation

Three GB (IMPS #136) treatments ($n = 15$ 1.36-kg chubs/treatment) were purchased from 4 supermarkets in the Manhattan, KS area over a 3-mo period. The variety of fat levels included (lean/fat percentage): 90/10 GB, 80/20 GB, and 73/27 GB. Each of the 15 replicates were of differing production lot numbers and/or freeze-by dates. Upon purchase, each 1.36-kg chub was assigned an individual identification number, and frozen at 0 to 4°C for no more than 2 mo prior to patty formation. Ground beef was stored frozen (0 to 4°C) at the KSU Meat Laboratory in Manhattan, KS, prior to patty fabrication.

Additionally, 3 commercially available plant-based GBA treatments ($n = 15$ production lots/treatment) were purchased from various suppliers. The first plant-based GBA was selected as a product most representative of a GBA sold at foodservice establishments, and thus was identified as a Foodservice Ground Beef Alternative (FGBA). The raw FGBA was procured from 3 restaurants in the Kansas City, KS, area in 2.27-kg chubs over a 2-mo period. Fifteen 2.27-kg chubs were procured and stored at the KSU Meat Laboratory in the same manner as the GB prior to fabrication. The second GBA was most representative of a GBA commonly available in retail settings and was therefore identified as a Retail Ground Beef Alternative (RGBA). Fifteen production lots (6 227-g packages/lot) of raw RGBA were procured from supermarkets in the Manhattan, KS area over a 3-mo period. The third GBA used in the study was a "traditional" soy-based patty, which was identified as a Traditional Ground Beef Alternative (TGBA). The TGBA was primarily comprised of soy protein and, unlike the FGBA and RGBA, the TGBA was a fully cooked patty at purchase. Fifteen lots (4 256-g packages/lot) of TGBA were procured over a 3-mo period from supermarkets in the Manhattan, KS area. The listed ingredients for each of the GBA are presented in Table 1.

Table 1. Ingredients listed on packaging of the ground beef and ground beef alternatives (GBA) used in the current study

Treatment[1]	Listed Ingredients
90/10	Beef
80/20	Beef
73/27	Beef
Retail GBA[2]	Water, pea protein isolate, expeller-pressed canola oil, refined coconut oil, rice protein, natural flavor, cocoa butter, mung bean protein, methylcellulose, potato starch, apple extract, pomegranate extract, salt, potassium chloride, vinegar, lemon juice concentrate, sunflower lecithin, beet juice extract
Foodservice GBA[3]	Water, soy protein concentrate, coconut oil, sunflower oil, natural flavors, potato protein, methylcellulose, yeast extract, cultured dextrose, food starch modified, soy leghemoglobin, salt, mixed tocopherols, soy protein isolate, vitamins and minerals zinc gluconate, thiamine hydrochloride, niacin, pyridoxine hydrochloride, riboflavin, vitamin B12
Traditional GBA[4]	Water, wheat gluten, vegetable oil (corn, canola, and/or sunflower oil), soy protein isolate, soy flour, egg whites, natural flavor, cornstarch, methylcellulose, cooked onion and carrot juice concentrate, salt, whey, garlic powder, spice, onion powder, tomato paste, xanthan gum

[1]Ground beef treatment lean content presented as percent lean/percent fat.

[2]Retail GBA = plant-based ground beef alternative most notably present in retail markets (grocery stores, supermarkets).

[3]Foodservice GBA = plant-based ground beef alternative most notably present in foodservice establishments (restaurants).

[4]Traditional GBA = plant-based ground beef alternative most indicative of a traditional soy-based frozen patty (pre-formed, fully cooked).

Prior to fabricating GB and GBA treatments into patties, all treatments were thawed for 12 h at 3°C. Upon thawing, each production lot was unpackaged, hand mixed for approximately 10 s, weighed into 114-g balls, and hand-pressed using a table-top 11-cm wide, 1.2-cm thick patty forming dye. After forming, patties were randomly assigned to consumer sensory, trained sensory, shear force, texture profile, or estrogen and toxicology analysis (data not reported), with 2 patties assigned for each of the sensory tests and 1 patty for all other analyses. Patties were placed on trays and crust frozen for approximately 30 min and then individually packaged using a rollstock packaging machine (Model Bulldog 42a 300, Ultrasource, Kansas City, MO) and frozen (−20°C) until analysis. Traditional GBA patties remined in their pre-formed patty but were repackaged with unique identification numbers similar to all other treatments.

Consumer sensory testing

Consumer sensory testing was conducted at KSU. Panelists ($N = 120$) were recruited from the Manhattan, KS area and monetarily paid for their participation. Consumers sampled GB and GBA patties under florescent lighting in a large lecture-style room. Five sessions of panels were conducted with 24 consumers at each panel session. Each panel lasted approximately 1 h.

Patties for each panel were thawed at 4°C for 24 h prior to cooking. Patties were cooked to a peak-endpoint temperature of 71°C on a Cuisinart Griddler Deluxe clam-shell style grill (Stamford, Connecticut, USA) set to a surface temperature of 177°C. Patties were removed from the grill at 67.2°C to allow for the post-cooking temperature rise. Endpoint temperature was verified using a Beckman Industrial Doric 205 thermocouple thermometer (Brea, California, USA). Patties were then cut into 8 equally sized wedges with one wedge being immediately served to each predetermined consumer.

Consumers were asked to complete a demographic questionnaire which included questions related to gender, household size, marital status, age, income level, education level, ethnicity, palatability trait preferences, preferred degrees of doneness, and GB consumption habits. Consumers were given utensils, an expectorant cup, a Lenovo TB-850SF handheld electronic tablet with an electronic ballot, and palate cleansers for use between samples (unsalted crackers and apple juice). Prior to testing, participants were given verbal instructions regarding the tablet and ballot, testing procedures, and the use of palate cleansers.

Ground beef and GBA samples were all served blind, with no information given to consumers prior of evaluation. Consumers evaluated one sample from each of the 6 treatments in a random order. Each sample was evaluated for appearance liking, juiciness, tenderness, overall flavor liking, beef flavor liking, texture liking, and overall liking. Each trait was evaluated on a continuous line scale anchored with descriptive terms at the ends and mid-points: 100 = extremely juicy, tender, and like appearance/overall flavor/beef flavor/texture/overall extremely; 50 = neither juicy nor dry, tough nor tender, or neither like or dislike appearance/overall flavor/beef flavor/texture/overall; 0 = extremely dry, tough, and dislike appearance/

overall flavor/beef flavor/texture/overall extremely. Additionally, consumers rated each trait as either acceptable or unacceptable.

Trained sensory testing

Panelists were trained using the *Research Guidelines for Cookery, Sensory Evaluation, and Instrumental Tenderness Measurements of Meat* (American Meat Science Association [AMSA], 2016). Each panelist was required to attend a minimum of 3 training sessions in the 2 wk prior to the beginning of panels. In each training session, panelists evaluated and were trained for sensory ratings from samples across all experimental treatments. For sample cooked color evaluation, the panelists were trained using the GB patty cooked color guide, as presented by Marksberry et al. (1993). Based on the guide, the numbers 1 through 5 correlated with different degrees of doneness based on the amount of red color remaining in the internal center of the patty; 1 = 65°C, 2 = 68°C, 3 = 71°C, 4 = 74°C, 5 = 77°C. Each sample was evaluated for juiciness, tenderness, beef flavor identity, beef flavor intensity, off-flavor, and texture (Table 2). Each characteristic was evaluated on a continuous line scale. Anchors were set at 0 and 100 with a midpoint of 50. The 0-anchor was labeled as: extremely dry, extremely tough, extremely un-beef-like, extremely bland, extremely soft. The midpoint anchor was labeled as: neither juicy nor dry, neither tough nor tender, neither soft nor hard. The 100-anchor was labeled as: extremely juicy, extremely tender, extremely beef-like, intense flavor, extremely hard. For off-flavor, panelists had a "not applicable" option if none were detected.

Patties were thawed at 2 to 4°C approximately 24 h prior to sensory panel evaluation. Patties were cooked in the same manner as described for consumer sensory panel evaluations. Each trained sensory panel consisted of 8 panelists, with a total of 15 panels conducted. To begin the panel, the white 800 lumen incandescent lights were left on and each panelist evaluated the same single wedge of each treatment, one at a time, in a random order, for cooked internal color. Upon completion of evaluating all 6 treatment samples, panelists were served in individual booths under red, low intensity (<107.64 lumens), incandescent lights. For odor evaluation, the panelists were then given a closed jar with one cut sample from each treatment in separate 4 oz. Quilted Crystal glass jelly jars (Ball, Westminster, CO). The panelists evaluated the beef odor and non-beef odor for each sample. Samples were passed from panelist to panelist with the jar lids closed, with each panelist opening the jar just briefly enough to evaluate the sample for odor characteristics.

Once the odor evaluation was complete, a warmup sample was evaluated to provide panel calibration for the panelists and prevent panel drift. Each panelist was provided deionized water, cut apple slices, and unsalted crackers to cleanse the palate, an expectorant cup, and a napkin. Each panelist evaluated 6 samples (1 from each treatment) in random order. An electronic tablet (Lenovo TB-850SF) was used along with an online digital survey (Qualtrics Software, Provo, UT) for the recording of sensory panel evaluation scores.

Shear force

Patties for shear force analysis were prepared and cooked as previously described for consumer sensory

Table 2. Definitions and selected references for ground beef palatability traits evaluated by trained sensory panelists

Trait	Definition	Reference
Juiciness	Amount of moisture released when chewing the sample	80% lean ground beef = 65
Tenderness	Level of tenderness of the sample throughout the chewing process	80% lean ground beef = 65
Beef flavor identity	How closely the flavor of the samples resembles beef flavor	80% lean ground beef = 90
Beef flavor intensity[1]	Amount of beef flavor identity within the sample	Swanson's beef broth = 3180% lean ground beef = 44
Off-flavor	Amount of flavors not normally associated with ground beef within the sample	Plant-based ground beef alternative patty = 70
Texture	How soft or firm the sample is when chewing	80% lean ground beef = 70
Color[2]	The degree of doneness internally to which the sample appears to be cooked	1 = 65°C, 2 = 68°C, 3 = 71°C, 4 = 74°C, 5 = 77°C
Beef odor	How closely do the odors of the sample resemble beef odor	80% lean ground beef = 65
Non-beef odor	Amount of odors not normally associated with ground beef within the sample	Plant-based ground beef alternative patty = 70

[1]Adapted from beef identity described by Adhikari et al. (2011).

[2]Internal cooked color ratings scale adapted from Marksberry et al. (1993).

evaluation. Methods from the *Research Guidelines for Cookery, Sensory Evaluation, and Instrumental Tenderness Measurements of Meat* (AMSA, 2016) were used for shear force testing of GB and GBA patties. Following cooking, samples were allowed to cool to room temperature (21 to 23°C) prior to testing. Shear force was measured on 2 strips (2.5-cm wide × patty thickness) removed from the center across the width of the patty. Each strip was sheared straight through the perpendicular cooked patty surface with the patty laying horizontally, 3 times using a straight edge slice-shear force blade attached to an INSTRON Model 5569 testing machine (Instron, Canton, MA). Shear force values were recorded in kilograms and 6 readings were averaged for each patty.

Pressed juice percentage

Ground beef and GBA patties designated for instrumental juiciness were evaluated using a pressed juice percentage (PJP) method modified from Lucherk et al. (2017). Patties were thawed at 2 to 4°C for 12 h prior to evaluation. Preparation and cooking methods were the same as consumer evaluation. Immediately following cooking, one 1-cm patty-width slice was cut across the diameter of the patty. From each patty-width slice, samples were removed perpendicular to the outer cooked surface to create three 1 cm^3 samples. Each sample was placed on 2 sheets of filter paper (VWR Filter Paper 415, 12.5 cm, VWR International, Radnor, PA) and was compressed for 30 s at 8-kg of force using an INSTRON Model 5569 testing machine. The percentage of weight lost through compression for each sample was calculated as PJP. The 3 measurements for each patty were averaged.

Texture profile analysis

Texture profiling of GB and GBA patties was conducted using methods described by the AMSA (2016). Following cooking, patties were allowed to cool to room temperature (21 to 23°C). Three 2.54-cm cores were removed, perpendicular to the cooked surface, in the center of each patty. Each core was compressed to 70% of its original height in 2 cycles using an INSTRON Model 5569 testing machine. Chewiness, springiness, gumminess, hardness, and cohesiveness were calculated using the methods of Bourne (1978).

Instrumental color analysis

Raw instrumental color (L^*, a^*, b^*) was obtained during sample preparation and patty formation of the GB and GBA lots. Once lots were formed into patties, patties were allowed to bloom for 30 min. Next, 6 scans were taken from the center of the horizontal surface exposed to air of 6 different patties from each GB and GBA lot using a Hunter Lab Miniscan spectrophotometer (Illuminant A, 2.54-cm aperture, 10° observer; Hunter Associates Laboratory, Reston, VA) using the methods outlined by the AMSA Color Guidelines (AMSA, 2012). The 6 scan readings were averaged for L^*, a^*, and b^* values. Cooked surface color was obtained on patties utilized for texture profile analysis and shear force. Approximately 10 min after cooking, surface color was measured by scanning 3 areas on the surface of each patty of GB and GBA using the same method and equipment as was used for the raw color measurements. The 3 scan readings were averaged for L^*, a^*, and b^* values. Next, a 3-cm^2 portion of each GB and GBA patty was center-sliced parallel to the cooked surface, exposing a 3 × 3 cm square of the cooked interior of the patty. Using the same method and equipment as was used for the cooked surface color, cooked internal color was measured by scanning 3 areas on the exposed internal patty surface. The 3 scan readings were averaged for L^*, a^*, and b^* values.

Fat and moisture percentage

Patties designated for fat and moisture analysis were thawed at 2 to 4°C for approximately 24 h. Patties were then cut into 1-cm^3 cubes, submerged in liquid nitrogen and homogenized using a commercial 4 blade blender (Model 33BL 79, Waring Products, New Hartford, CT). Powdered samples were then placed in Whirl-Pac (Nasco, Ft. Atkinson, WI) bags and stored (−80°C) until further analysis. The procedures followed for lipid extraction are described by Martin et al. (2013). Moisture content was determined using the AOAC approved oven drying method (AOAC, 2005).

Statistical analysis

Statistical analysis was completed using SAS (Version 9.4 SAS Inst., Inc., Cary, NC) PROC GLIMMIX. Treatment comparisons were considered significant with an α of 0.05. Statistical analyses were performed using GB and GBA production lot as the experimental unit. All data were analyzed as a completely randomized design with the fixed effect of treatment. The model for all sensory data included the random effect of panel session. A model that included a binomial error distribution was used for consumer acceptability data. For all analyses, the Kenward-Roger adjustment was used.

Results and Discussion

Consumer demographics

Consumer demographic information from panelists who sampled GB and GBA samples are presented in Table 3. Panelists' genders were almost evenly spilt, with 50.8% of panelists being male and 49.2% female. The majority of panelists were Caucasian/White (84%), married (66.4%), and had a household size of between 2 and 4 people (78.4%). Furthermore, over half of panelists (59.7%) had an annual household income greater than $75,000, and 89.9% of panelists had accomplished at minimum some college/technical school. The most important palatability trait when consuming GB was identified as flavor (71.4%), followed by juiciness (23.5%). The majority of panelists (84.2%) consumed GB 1 to 3 times per week. This demographic profile is similar to previous consumer studies conducted at KSU (Drey et al., 2019; Olson et al., 2019; Prill et al., 2019a).

Table 3. Demographic characteristics of consumers (n = 120) who participated in sensory panels

Characteristic	Response	Percentage of Consumers
Gender	Male	50.8
	Female	49.2
Household size	1 people	15.0
	2 people	41.7
	3 people	17.5
	4 people	19.2
	5 people	3.3
	6 people	2.5
	>6 people	0.8
Marital status	Married	66.4
	Single	33.6
Age, y	Under 20	6.7
	20 to 29	20.0
	30 to 39	21.7
	40 to 49	17.5
	50 to 59	23.3
	Over 60	10.8
Ethnicity	African-American	4.2
	Asian	8.4
	Caucasian/White	84.0
	Hispanic	0.8
	Native American	0.8
	Mixed Race	1.7
Annual household income, $	<25,000	10.9
	25,000-34,999	4.2
	35,000-49,999	5.9
	50,000-74,999	19.3
	75,000-99,000	17.7
	100,000-149,999	26.9
	150,000-199,999	10.1
	>199,999	5.0
Highest level of education completed	Non–high school graduate	3.4
	High school graduate	6.7
	Some college/ technical school	20.2
	College graduate	31.9
	Post-college graduate	37.8
Most important palatability trait when consuming ground beef	Flavor	71.4
	Juiciness	23.5
	Tenderness	5.0
Preferred degree of doneness for ground beef	Medium-rare	24.4
	Medium	26.7
	Medium-well	29.4
	Well-done	17.7
	Very well-done	1.7
Ground beef consumption, times per week	1 to 3	84.2
	4 to 6	12.3
	7 to 9	1.8
	>9	1.8

Panelists were split on preferred degree of doneness for GB, with 24.4% preferring medium-rare, 26.7% preferring medium, 29.4% preferring medium-well, and 17.7% preferring well-done (Table 3). Previous works have identified consumers relate 63° C to a medium-rare degree of doneness when visually assessing cooked beef (Prill et al., 2019b). The USDA recommends cooking GB products to an endpoint of 71°C or greater in order to reduce the risk of illness associated with multiple food-borne pathogens including shiga-toxin producing *E. coli* species (Food Safety Inspection Service, 2013). Thus, close to a quarter of the consumers in the current study preferred GB cooked to levels that would not guarantee food safety.

Consumer palatability evaluation

Consumer palatability ratings are presented in Table 4. Few differences existed among the 3 GB

Table 4. Least squares means for consumer (n = 120) ratings[1] of the palatability traits of ground beef and plant-based ground beef alternatives

Treatment[2]	Appearance Liking	Juiciness	Tenderness	Overall Flavor Liking	Beef Flavor Liking	Texture Liking	Overall Liking	Purchase Intent[3]
90/10	56.9[a]	65.8[a]	64.5[a]	57.2[a]	65.9[a]	62.5[a]	58.5[a]	51.7[a]
80/20	59.4[a]	63.8[a]	57.3[bc]	58.6[a]	64.3[a]	59.8[b]	56.5[a]	50.6[a]
73/27	63.2[a]	68.3[a]	63.5[ab]	59.0[a]	67.5[a]	64.3[a]	59.6[a]	56.2[a]
Retail GBA[4]	26.7[c]	47.0[b]	56.4[c]	27.5[c]	28.7[c]	28.0[d]	23.8[c]	17.9[c]
Foodservice GBA[5]	46.9[b]	68.0[a]	64.9[a]	44.6[b]	37.0[b]	46.6[b]	41.2[b]	34.1[b]
Traditional GBA[6]	41.0[b]	32.7[c]	62.3[abc]	40.0[b]	27.2[c]	37.7[c]	34.7[b]	26.2[bc]
SEM[7]	2.93	3.01	2.52	2.87	2.59	2.57	2.95	3.03
P value	<0.01	<0.01	0.04	<0.01	<0.01	<0.01	<0.01	<0.01

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

[1]Sensory scores: 0 = dislike appearance/overall flavor/texture/beef flavor/overall extremely, not juicy/tender; 50 = neither tough nor tender, dry nor juicy, or neither like nor dislike appearance/overall flavor/texture/beef flavor/overall; 100 = extremely juicy/tender, like appearance/overall flavor/texture/beef flavor/overall extremely.

[2]Ground beef treatment lean content presented as: percent lean/percent fat.

[3]If price were not a factor, how likely would you be to purchase the sample; 1 = not likely, 100 = extremely likely.

[4]Retail GBA = plant-based ground beef alternative most notably present in retail markets (grocery stores, supermarkets).

[5]Foodservice GBA = plant-based ground beef alternative most notably present in foodservice establishments (restaurants).

[6]Traditional GBA = plant-based ground beef alternative most indicative of a traditional soy-based frozen patty (pre-formed, fully cooked).

[7]SE (largest) of the least squares means.

treatments for the palatability traits evaluated. There were no differences ($P > 0.05$) among GB treatments for appearance liking, juiciness, overall flavor liking, beef flavor liking, and overall liking. These results are similar to previous reports that have shown little to no variation in consumer palatability ratings for GB of various fat levels (Wilfong et al., 2016; Beavers, 2017; Pohlman, 2017); however, in the Wilfong et al. (2016) study, the authors showed an increase in juiciness with increased fat percentage, which was not observed in the current work.

Furthermore, all 3 GB treatments were rated higher ($P < 0.05$) than all 3 GBA for appearance liking, overall flavor liking, beef flavor liking, and overall liking. Most notably, all 3 GB treatments rated at least 37% higher for overall liking and 28% higher for flavor liking scores than all 3 GBA treatments. Retail GBA rated lowest ($P < 0.05$) for appearance liking, overall flavor liking, texture liking, and overall liking among all treatments. Among the GBA samples, FGBA rated highest ($P < 0.05$) for juiciness, beef flavor liking, and texture liking; and TGBA rated lowest ($P < 0.05$) for juiciness. However, FGBA rated higher ($P < 0.05$) for tenderness than the 20% fat GB samples. Moreover, among the GBA samples, FGBA and TGBA were similar ($P > 0.05$) for appearance liking, tenderness, overall flavor liking, and overall liking.

The lower appearance, juiciness, flavor liking, and overall liking scores for the 3 GBA were likely the reason for the much lower ($P < 0.05$) purchase intent ratings for the 3 products. Consumers rated their likelihood to purchase the 3 GB treatments 1.5 to 3.1 times higher than each of the GBA. To date, no published literature has evaluated the eating quality of contemporary GBA in comparison with GB. However, numerous popular press articles have reported informal, non-scientific taste test results. Many of these have claimed the GBA evaluated were similar to GB in taste and appearance (Hallinan, 2019; Moskin, 2019; Nyerges, 2020; Wade, 2021; Williams et al., 2021). Our results clearly show a difference in eating quality between the GB and the GBA evaluated. With few exceptions, none of the GBA evaluated were similar to any of the 3 GB treatments for any of the traits evaluated, providing clear evidence that the GBA provided a very different eating experience than GB.

The percentage of samples rated acceptable by consumers provide similar results to the consumer palatability ratings (Table 5). All 3 GB treatments had a similar ($P > 0.05$) percentage of samples rated acceptable for appearance, juiciness, overall flavor, beef flavor, texture, and overall, with consumers rating more the 70% of GB samples acceptable for each trait. All 3 GB treatments had a higher ($P < 0.05$) percentage of samples rated acceptable for appearance, overall flavor, beef flavor, texture, and overall than the 3 GBA. Each GB treatment had greater than

Table 5. Least squares means for the percentage of ground beef and plant-based ground beef alternative samples rated acceptable for each palatability trait by consumers ($n = 120$)

Treatment[1]	Appearance Liking	Juiciness	Tenderness	Overall Flavor Liking	Beef Flavor Liking	Texture Liking	Overall Liking
90/10	83.9[a]	88.2[a]	92.8[a]	77.5[a]	83.6[a]	89.0[a]	77.5[a]
80/20	83.9[a]	84.9[a]	82.1[bc]	70.8[a]	77.0[a]	81.7[a]	73.3[a]
73/27	90.4[a]	84.1[a]	84.6[ab]	78.3[a]	84.5[a]	86.6[a]	79.2[a]
Retail GBA[2]	28.7[c]	61.3[b]	71.3[c]	30.8[c]	28.9[c]	34.4[c]	22.5[c]
Foodservice GBA[3]	67.9[b]	88.2[a]	84.6[ab]	51.7[b]	41.5[b]	63.1[b]	51.7[b]
Traditional GBA[4]	59.4[b]	38.8[c]	81.3[bc]	50.8[c]	28.9[c]	50.9[b]	45.8[b]
SEM[5]	5.01	5.18	4.49	4.56	4.38	5.42	4.56
P value	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

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

[1]Ground beef treatment lean content presented as: percent lean/percent fat.

[2]Retail GBA = plant-based ground beef alternative most notably present in retail markets (grocery stores, supermarkets).

[3]Foodservice GBA = plant-based ground beef alternative most notably present in foodservice establishments (restaurants).

[4]Traditional GBA = plant-based ground beef alternative most indicative of a common soy-based frozen patty (pre-formed, fully cooked).

[5]SE (largest) of the least squares means.

21.5% more samples rated acceptable overall than each GBA.

Retail GBA had the lowest ($P < 0.05$) percentage of samples rated acceptable for appearance, overall flavor, texture, and overall. Traditional GBA had the lowest ($P < 0.05$) percentage of samples rated acceptable for juiciness. Among the GBA samples, FGBA had the highest ($P < 0.05$) percentage of samples rated acceptable for juiciness and beef flavor. Furthermore, among the GBA treatments, FGBA and TGBA had a similar ($P > 0.05$) percentage of samples rated acceptable for appearance, overall flavor, texture, and overall. Similar to the consumer palatability ratings, these results indicate that GBA provide a different eating experience to consumers compared with GB. It is noteworthy that 48.3 to 77.5% of the 3 GBA treatments were rated unacceptable overall.

Additionally, our results indicate that the 3 GBA evaluated each provided a different eating experience to consumers. Comparing the 2 "modern" GBA, the FGBA was preferred by consumers for nearly every trait evaluated, with consumers almost 2 times as likely to purchase the FGBA product than the RGBA. The TGBA was most similar in eating quality to the FGBA, with the exception of being unquestionably the driest sample among all products evaluated as well as having one of the lowest scores for both overall and beef flavor liking.

Trained sensory panel evaluation

The results for trained sensory panel analysis of GB and GBA samples are presented in Table 6. Among the GB samples, 90/10 GB was rated as less juicy ($P < 0.05$), and lower ($P < 0.05$) for both beef flavor identity and beef flavor intensity than either 80/20 or 73/27 samples. Additionally, 73/27 was rated as more tender ($P < 0.05$) than 90/10 samples and with a stronger ($P < 0.05$) beef odor than either 80/20 or 90/10 samples. There were no differences ($P > 0.05$) among the 3 GB treatments for off-flavor intensity, texture, or non-characteristic beef odors.

Our results are similar to previous studies that have reported improved palatability traits with increased fat percentages for trained sensory panelists (Cross et al., 1980; Huffman and Egbert, 1990; Miller et al., 1993; Blackmon et al., 2015). These results differ from those previously discussed regarding consumer sensory analysis in which consumer sensory panelists failed to detect many differences among the GB samples, indicating that the differences present and identifiable by the trained sensory panelists were not large enough for the consumer panelists to discern.

When comparing the GB to the GBA, the 3 GB treatments were all rated as juicier ($P < 0.05$), less tender ($P < 0.05$), and firmer ($P < 0.05$) than the GBA. The GB was much juicier than the GBA, with GB treatments 2.5 to 12.8 times as juicy as the GBA. Similar to the consumer panel results, some of the most distinctive differences between the GB and GBA occurred within the flavor traits evaluated. Panelists gave higher ($P < 0.05$) ratings to the GB samples for beef flavor identity, beef flavor intensity, beef odor intensity, and much lower ($P < 0.05$) ratings to off-flavor intensity and non-characteristic beef odor than the GBA.

Table 6. Least squares means for the palatability characteristics[1] rated by trained sensory panelists for ground beef and plant-based ground beef alternatives

Treatment[2]	Juiciness	Tenderness	Beef Flavor Identity	Beef Flavor Intensity	Off-Flavor	Texture	Color[3]	Beef Odor	Non-Beef Odor
90/10	52.8^{b}	62.5^{c}	85.2^{b}	60.3^{b}	2.5^{c}	71.6^{a}	2.5^{c}	60.9^{b}	7.8^{b}
80/20	65.1^{a}	66.0^{bc}	87.7^{a}	67.3^{a}	6.4^{c}	68.3^{a}	3.0^{b}	62.1^{b}	3.5^{b}
73/27	69.0^{a}	67.6^{b}	89.0^{a}	68.6^{a}	1.6^{c}	68.2^{a}	3.2^{b}	66.7^{a}	2.1^{b}
Retail GBA[4]	21.1^{c}	83.0^{a}	2.9^{c}	2.1^{c}	69.1^{b}	18.8^{c}	4.2^{a}	3.4^{c}	72.3^{a}
Foodservice GBA[5]	17.1^{c}	79.8^{a}	2.6^{c}	2.1^{c}	75.0^{a}	23.1^{b}	4.2^{a}	3.1^{c}	67.7^{a}
Traditional GBA[6]	5.4^{d}	81.2^{a}	1.6^{c}	2.2^{c}	71.1^{ab}	16.9^{c}	4.5^{a}	2.2^{c}	73.0^{a}
SEM[7]	2.01	1.36	1.16	1.24	2.55	2.04	0.18	1.77	4.51
P value	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

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

[1]Sensory scores: 0 = extremely dry/tough/soft/unbeef-like, bland; 50 = neither dry nor juicy, tough nor tender, soft nor firm, beef-like or unbeef-like; 100 = extremely juicy/tender/firm/beef-like/intense

[2]Ground beef treatment lean content presented as: percent lean/percent fat

[3]Internal cooked color rating scale adapted from Marksberry et al (1993); 1 = 65°C, 2 = 68°C, 3 = 71°C, 4 = 74°C, 5 = 77°C

[4]Retail GBA = plant-based ground beef alternative most notably present in retail markets (grocery stores, supermarkets)

[5]Foodservice GBA = plant-based ground beef alternative most notably present in foodservice establishments (restaurants)

[6]Traditional GBA = plant-based ground beef alternative most indicative of a common soy-based frozen patty (pre-formed, fully cooked)

[7]SE (largest) of the least squares means.

The 3 GBA all had means of less than 2.5 on the 100-point scale for beef flavor intensity and more than 69 for off-flavor intensity, providing clear evidence that the flavor profile of the 3 GBA differed greatly from that of the GB. Some of the most common descriptors used by the panelists to describe the flavors of the GBA were: "fermented bean," "musty bean," "sour," and "sour bean" for the RGBA and FGBA, and "starchy" and "fried-food" for the TGBA. These differences in flavor between the GBA and GB likely help to explain the observed differences in flavor liking and flavor acceptability reported by the consumers. Lastly, the cooked color of the 3 GB treatments appeared more rare ($P < 0.05$) than the 3 GBA indicating that though all of the samples were cooked to the same final end-point temperatures, the change in state of myoglobin resulting in the cooked color of the GB differed from the substrates responsible for cooked color within the GBA.

Fewer differences were found by trained sensory panelists among the GBA than consumer panelists. No difference ($P > 0.05$) was found among GBA for tenderness, beef flavor identity, beef flavor intensity, cooked color, beef-like odor, or non-beef-like odor. Traditional GBA was rated much lower ($P < 0.05$) for juiciness than either the FGBA or RGBA. This is similar to the results of the consumer panels in which TGBA was rated lower for juiciness than all other treatments. Additionally, trained panelists found FGBA as firmer ($P < 0.05$) than both the RGBA and the TGBA, but still much softer than any of the GB treatments. It is noteworthy that the consumers in the current work found differences for many of the palatability traits between the RGBA and the FGBA including tenderness, but the same differences were not observed by the trained sensory panelists. This may be due in part to the differences in the scales utilized (liking vs intensity) and the specific traits evaluated by the 2 panel groups.

Cooking characteristics

Table 7 presents the cooking characteristics of the GB and GBA treatments. Among the GB, 90/10 shrank less ($P < 0.05$) in diameter through cooking and had a lower ($P < 0.05$) percentage of cooking loss than either of the other 2 GB treatments. However, no difference ($P > 0.05$) was found between the 2 higher fat GB treatments for the change in shape (thickness and diameter) of patties as a result of cooking nor in the percentage of weight lost through cooking, with both the 80/20 and 73/27 treatments losing more than 25% of their raw weight during cooking. Additionally, as the fat percentage in the GB treatments increased, the amount of cooking time also increased, with 90/10 samples taking less ($P < 0.05$) time to reach the same endpoint temperature than 73/27 patties. Despite these differences in cooking time on the grill, there were no differences ($P > 0.05$) among the 3 GB treatments for the time it took to complete the post-cooking temperature rise, with all 3 treatments rising in temperature for more than 43 s post-cooking prior to reaching their final

Table 7. Physical changes in shape of ground beef and ground beef alternative patties (n = 90) as a result of cooking, and fat and moisture percentages

Treatment[1]	Diameter[2]	Thickness[2]	Cook Loss[3]	Cook Time[4] (s)	Total Time to Peak Temp (s)	Post-Cook Temp Rise Time (s)	Fat[5] %	Moisture[5] %	pH[5]
90/10	11.2[b]	12.2[a]	17.6[b]	125.9[cd]	169.3[bc]	43.4[ab]	8.5[d]	70.9[a]	6.2[c]
80/20	16.2[a]	5.8[ab]	25.9[a]	134.8[bc]	178.9[ab]	44.1[ab]	21.2[b]	60.9[b]	6.1[c]
73/27	15.5[a]	3.2[b]	27.5[a]	142.7[b]	188.5[a]	45.7[a]	25.7[a]	56.8[d]	6.1[c]
Retail GBA[6]	1.0[c]	-10.3[c]	12.9[c]	119.3[de]	156.2[cd]	36.9[c]	16.6[c]	59.0[c]	6.9[a]
Foodservice GBA[7]	-1.5[d]	-15.3[c]	8.5[d]	107.9[e]	148.0[d]	40.1[bc]	15.5[c]	59.5[c]	6.1[c]
Traditional GBA[8]	0.4[c]	3.1[b]	1.3[e]	171.1[a]	190.9[a]	19.8[d]	9.7[d]	52.5[e]	6.5[b]
SEM[9]	0.64	2.55	0.65	5.00	5.44	1.89	0.90	0.64	0.08
P value	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

[abcde]Least squares means without a common superscript differ ($P < 0.05$).

[1]Ground beef treatment lean content presented as: percent lean/percent fat

[2]Values expressed as % shrink [(Raw Patty Measurement – Cooked Patty Measurement)/Raw Patty Measurement] * 100; Negative values indicate patty expansion for both diameter and/or thickness

[3]Cook loss = [(raw mass – cooked mass)/raw mass] * 100

[4]Cook time = total seconds patty spent on griddle; patties were removed at 67.2°C to account for post-cooking temperature rise

[5]Measured on raw samples

[6]Retail GBA = plant-based ground beef alternative most notably present in retail markets (grocery stores, supermarkets)

[7]Foodservice GBA = plant-based ground beef alternative most notably present in foodservice establishments (restaurants)

[8]Traditional GBA = plant-based ground beef alternative most indicative of a common soy-based frozen patty (pre-formed, fully cooked)

[9]SE (largest) of the least squares means.

peak-endpoint temperature. Troutt et al. (1992) demonstrated a decreased cooking time with increased fat percentages in GB patties. This differs from the current work, though in that study the authors cooked using a single-sided electric skillet set at a lower temperature with patties flipped during cooking compared with the clam-shell grill used in the current study and, as a result, cooking times were 2 to 3 times greater within their work (Troutt et al., 1992). Additionally, in the study by Troutt et al. (1992), the authors reported patties of the same fat percentage as in the current work only shrinking by 5 to 6% in diameter through cooking as opposed to the 11 to 16% found in our study, but the thickness of their patties decreased by over 25% in comparison with the less than 12.5% we observed. Moreover, their patties resulted in 5 to 7% greater cooking loss than that observed in the current study, likely due in part to the lower pH values of their samples compared with those in the current work (Troutt et al., 1992).

When comparing the GBA to the GB for cooking traits, several differences were observed. Most notably, the GBA all had less ($P < 0.05$) change in both their diameter and thickness during cooking than the 3 GB treatments. Although the GB treatments all shrank and decreased in thickness and diameter while cooked, the GBA had only minimal changes in size, with the FGBA actually getting wider and both the FGBA and RGBA both increasing in thickness while cooked. Furthermore, the GBA had a much lower ($P < 0.05$) cooking loss percentage than the GB, with all 3 GB treatments losing 5 to 26 % more weight through cooking than the GBA. Both the RGBA and the FGBA cooked faster ($P < 0.05$) than the GB and had a shorter ($P < 0.05$) post-cooking temperature rise period than the GB. However, these trends differed for the TGBA. Traditional GBA had a greater ($P < 0.05$) amount of shrink in patty thickness through cooking than either of the other 2 GBA. Additionally, TGBA had much less ($P < 0.05$) cooking loss than any of the GB or GBA treatments (1.3% vs. > 8.5%) and took the longest ($P < 0.05$) time to cook, which was 28 s longer than the next closest treatment. But, the TGBA was the fastest ($P < 0.05$) treatment to reach peak temperature post-cooking, being more than 46% shorter in time than the next closest treatment. These unique characteristics that distinguished the TGBA from the 2 contemporary GBA are likely the result of not only the plant-based protein used and differences in composition, but also the fact that TGBA was a pre-cooked patty. Unlike the other 2 GBA, the TGBA had previously been cooked and therefore the previous physiochemical changes from cooking likely contributed to the differences in cooking characteristics observed in the current study.

Fat, moisture, and pH

The percentage of fat and moisture and pH of the treatments are presented in Table 7. To no surprise, fat percentage increased ($P < 0.05$) and moisture percentage decreased ($P < 0.05$) as the GB treatment fat percentage increased from 10% to 27%. The reported fat percentages are lower than the labeled fat percentages at retail. But this is similar to previous works that have reported the fat percentage of various retail GB (Wilfong et al., 2016; Najar-Villarreal et al., 2019). This could also be the result of differences in measurement techniques. The fats in the current study were measured using a chloroform:methanol extraction method as opposed to the near infrared spectroscopy technique that is most commonly used in the beef industry for fat determination of grinds (Tøgersen et al., 2003). This difference may explain the observed discrepancies between the reported and labeled fat percentages. There were no differences ($P > 0.05$) among the GB treatments for pH, with the means differing by less than 0.1 units. However, the reported means are higher than is traditionally found in fresh beef (Page et al., 2001). The observed increased pH could be due to the inclusion of Lean Finely Textured Beef (LFTB) in the formulation of the products for retail sale. Through processing, the pH of LFTB is often increased above that of normal fresh beef and at inclusion, has been previously shown to increase the pH of the final blended GB (Van Laack et al., 1997; Moon et al., 2016).

The GBA all had less ($P < 0.05$) fat than the 80/20 and 73/27 GB treatments and less ($P < 0.05$) moisture than all 3 GB treatments. Despite having a higher fat percentage than the 90/10 GB, both the RGBA and the FGBA were rated lower for juiciness traits for the trained sensory panel and the RGBA lower for juiciness in the consumer panels. Previous work has demonstrated that a combined measure of both fat and moisture is a better predictor of beef juiciness than either trait alone (Drey et al., 2019). In the current study, the 3 GB treatments had a combined moisture and fat percentage ranging from 79.4 to 82.5%. Whereas the 3 GBA had a range of 62.2 to 75.6% for the same trait. This difference in combined moisture and fat likely is responsible for the lower juiciness ratings reported by sensory panelists. Lastly, the pH of the RGBA and TGBA was higher ($P < 0.05$) than the GB treatments, with only FGBA having a similar ($P > 0.05$) pH to the GB.

Color characteristics

Only minimal differences in raw, cooked surface, and cooked internal color was found among the GB treatments (Table 8). Within the raw measures of color, fat percentage only had a large impact on b^* values, with the 80/20 treatment having a greater ($P < 0.05$)

Table 8. Raw, cooked surface, and cooked (71°C) internal color values for ground beef and plant-based ground beef alternatives ($n = 90$)

Treatment[1]	Raw Color			Cooked Surface Color			Cooked Internal Color		
	L^{*2}	a^{*3}	b^{*4}	L^*	a^*	b^*	L^*	a^*	b^*
90/10	53.6^{ab}	22.4^{bc}	22.6^{c}	37.3^{bc}	8.4^{c}	17.1^{e}	51.7^{b}	11.3^{ab}	19.3^{bc}
80/20	53.4^{ab}	24.0^{b}	25.5^{b}	38.9^{ab}	9.1^{b}	19.7^{bc}	56.1^{a}	9.2^{c}	18.7^{c}
73/27	54.3^{a}	21.3^{c}	19.1^{e}	40.4^{a}	8.2^{c}	18.0^{de}	57.2^{a}	7.6^{d}	17.5^{d}
Retail GBA[5]	52.4^{b}	11.6^{e}	14.0^{f}	36.0^{c}	12.7^{a}	18.7^{cd}	42.3^{c}	11.6^{a}	16.6^{e}
Foodservice GBA[6]	49.4^{c}	17.8^{d}	20.6^{d}	37.3^{bc}	8.1^{c}	20.8^{b}	41.5^{c}	12.7^{a}	19.9^{b}
Traditional GBA[7]	42.7^{d}	31.4^{a}	29.7^{a}	34.0^{d}	12.6^{a}	24.4^{a}	42.7^{c}	10.0^{bc}	28.0^{a}
SEM[8]	0.66	0.60	0.45	0.66	0.24	0.47	0.54	0.53	0.25
P value	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

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

[1]Ground beef treatment lean content presented as: percent lean/percent fat.

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

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

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

[5]Retail GBA = plant-based ground beef alternative most notably present in retail markets (grocery stores, supermarkets).

[6]Foodservice GBA = plant-based ground beef alternative most notably present in foodservice establishments (restaurants).

[7]Traditional GBA = plant-based ground beef alternative most indicative of a common soy-based frozen patty (pre-formed, fully cooked).

[8]SE (largest) of the least squares means.

b^* value than either of the other 2 GB treatments. Within the cooked surface color, patties got lighter in color as fat percentage increased, with the 90/10 treatment having a lower ($P < 0.05$) L^* value than the 73/27 treatment. The same was observed on the cooked internal surface, with the 90/10 treatment being the darkest ($P < 0.05$) of the 3 GB. However, a^* value decreased ($P < 0.05$) with increased fat percentage (90/10 > 80/20 > 73/27). Other authors have previously reported increased L^* values with no change in a^* within raw samples as fat percentage increased from 5 to 30% (Troutt et al., 1992), though the reported L^* values within that study were much lower than those found within the current work. Moreover, the same authors reported no variation in internal cooked color a^* values as well as in cooked surface color and internal color sensory scores (Troutt et al., 1992). This differs some from our work, which found trained sensory panelists rated the internal cooked color of the lower fat GB as more red, which also corresponded to the higher a^* values for the lower fat GB treatment.

The 3 GBA differed ($P < 0.05$) in the raw state for each of the color measures (L^*, a^*, and b^*) evaluated. Retail GBA was lighter (L^*; $P < 0.05$), less red (a^*; $P < 0.05$), and less yellow (b^*; $P < 0.05$) than the other 2 GBA. Conversely, the TGBA was the darkest ($P < 0.05$), most ($P < 0.05$) red, and most ($P < 0.05$) yellow color of the 3, with the FGBA being intermediate of the 2 for all traits. These same trends did not hold true in the cooked form, with the color of both the cooked outer and internal surface being more similar among the 3 GBA. For the cooked surface, the TGBA remained darker ($P < 0.05$) than the other 2 GBA, which were similar ($P > 0.05$) for L^* value. Additionally, the FGBA was less red ($P < 0.05$) on the cooked surface than either the RGBA or TGBA. On the internal cooked surface, no differences ($P > 0.05$) in L^* was found among the GBA nor between the RGBA and FGBA for a^*. The same trend in b^* value was observed internally as was found in the raw and cooked surface, with all 3 treatments differing ($P < 0.05$; TGBA > FGBA > RGBA).

When comparing the GB to the GBA for the color traits evaluated, the largest differences observed were in the a^* values (redness) of the raw product and the L^* values (lightness) in the cooked internal surface. All 3 of the GB treatments were redder ($P < 0.05$) than the RGBA and FGBA in the raw state. The FGBA contained soy leghemoglobin, a pigment that has been approved by the Food and Drug Administration for use in GB analog products as a color additive (Food and Drug Administration, 2019) to allow for greater red pigmentation. Despite the soy leghemoglobin, the FGBA was not as red as any of the GB evaluated. But this ingredient was likely responsible for the greater redness (a^*) within the FGBA compared with the RGBA, though this initial redness advantage was not observed with the FGBA over the RGBA in either the cooked surface or cooked internal color. This provides evidence that the increased redness provided by the soy leghemoglobin is eliminated through protein denaturation associated with cooking and provides a similar cooked color to the RGBA that did not include this ingredient. Within the cooked internal surface, the 3 GBA were all darker ($P < 0.05$) than the 3 GB treatments.

Texture characteristics

The texture profiles of the 3 GB treatments differed ($P < 0.05$) for most of the traits evaluated (Table 9). The 80/20 GB was harder ($P < 0.05$), more cohesive ($P < 0.05$), gummier ($P < 0.05$), and had a higher chewiness value than both the 90/10 and 73/27 treatments. The 90/10 and 73/27 treatments were similar ($P > 0.05$) for cohesiveness and gumminess, but the 90/10 treatment had a higher ($P < 0.05$) value for both hardness and chewiness. When comparing the GB to the GBA, the RGBA and FGBA differed ($P < 0.05$) from the 3 GB treatments for all traits. The RGBA and FGBA were much softer ($P < 0.05$), less ($P < 0.05$) cohesive, springy, gummy, and chewy than all 3 GB treatments, but were similar ($P > 0.05$) to each other for all traits other than hardness. The TGBA was the GBA that had a texture profile most similar to the GB, with the TGBA having similar ($P > 0.05$) values as 90/10 GB for each of the texture traits evaluated. Previous authors have shown increased fat percentages are associated with lower hardness, cohesiveness, gumminess, and chewiness values (Berry, 1994; Wilfong et al., 2016), though in the current study no distinct trends associated with fat level were observed.

The shear force value did not differ ($P > 0.05$) among the 3 GB treatments but were all tougher ($P < 0.05$) than the 3 GBA. The RGBA and FGBA had similar ($P > 0.05$) shear force values and were more tender ($P < 0.05$) than the rest of the treatments evaluated. The lower shear force and hardness values for the 3 GBA is in alignment with the lower tenderness values reported by sensory panelists, providing additional evidence of the softer texture of the GBA in comparison with the GB samples. Pressed Juice Percentage is an objective measure of juiciness that has previously

Table 9. Texture profile analysis[1], shear force, and percent juice press results for ground beef and plant-based ground beef alternatives (n = 90)

Treatment[2]	Hardness	Cohesiveness	Springiness	Gumminess	Chewiness	Shear force (kg)	Pressed Juice Percentage[3]
90/10	17.2[b]	31.4[b]	65.6[a]	5.4[b]	3.5[b]	3.4[a]	17.5[b]
80/20	21.9[a]	34.5[a]	68.6[a]	7.7[a]	5.2[a]	3.5[a]	20.6[a]
73/27	14.5[c]	31.4[b]	55.3[b]	4.6[b]	2.6[c]	3.1[a]	22.0[a]
Retail GBA[4]	3.6[e]	21.5[c]	39.8[c]	0.8[c]	0.3[d]	1.8[c]	12.6[c]
Foodservice GBA[5]	8.0[d]	19.8[c]	42.8[c]	1.6[c]	0.7[d]	2.0[c]	16.5[b]
Traditional GBA[6]	17.1[b]	31.5[b]	65.3[a]	5.4[b]	3.6[b]	2.5[b]	4.7[d]
SEM[7]	0.8	0.7	1.2	0.4	0.2	0.2	0.6
P value	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

[abcd]Least squares means in the same column lacking a common superscript differ ($P < 0.05$).

[1]Texture profile methods as described by Bourne (1978).

[2]Ground beef treatment lean content presented as: percent lean/percent fat.

[3]Pressed juice percentage = percentage of sample weight lost as fluid during compression of sample between filter paper at 8 kg for 30 s.

[4]Retail GBA = plant-based ground beef alternative most notably present in retail markets (grocery stores, supermarkets).

[5]Foodservice GBA = plant-based ground beef alternative most notably present in foodservice establishments (restaurants).

[6]Traditional GBA = plant-based ground beef alternative most indicative of a common soy-based frozen patty (pre-formed, fully cooked).

[7]SE (largest) of the least square means.

been shown to be closely related to consumer juiciness scores (Lucherk et al., 2017; McKillip et al., 2017). In the current study, both the RGBA and TGBA had PJP values that were lower ($P < 0.05$) than all 3 GB treatments. Moreover, the mean PJP value for the TGBA was only 4.7%. In beef steaks, a PJP value of 14.6% is required for a 50% likelihood of a consumer to rate the steak as acceptable for juiciness and a PJP value of 18.9% is required for a 75% likelihood for an acceptable juiciness rating (Lucherk et al., 2017). The 3 GBA in the current study all had PJP values lower than this 75% threshold and both the RGBA and TGBA were below the 50% threshold. This provides additional evidence supporting the low juiciness ratings observed in the consumer and trained sensory panels and providing additional evidence of the GBA being drier and less juicy than GB.

Conclusions

The results of the current study provide clear evidence of the differences in many quality characteristics between GB and plant-based GBA. Overall, the GBA evaluated had few similarities with GB. The GBA were softer, less juicy, and had a different flavor than the GB. Additional differences in color, cooking characteristics, and texture were also observed. Many of these GBA products are often marketed as being similar to or as substitutes for traditional GB. Our results would indicate that consumers who purchase these products should not expect the same eating experience or quality characteristics as they would receive with GB. These GBA are very different products from GB and should be considered as such by consumers, retailers, and marketers of these products.

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