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Research Article

Evaluation of Cooking Time and Impact of Retort Processing, Packaging Material, and Calcium Chloride Additive on Pulse (*Phaseolus vulgaris*, *Phaseolus coccineus*, and *Cicer arietinum*) Quality Attributes

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Dry beans (pulses) offer many benefits yet are often undervalued. There are many barriers preventing consumers from selecting pulses, including poor perceptions of ready-to-eat (RTE) options. Retort processing, which produces commercially sterile and shelf-stable food products, has been previously evaluated on bean varieties processed within metal cans and plastic pouches, but not within glass jars. The goal of this research was to understand differences in average cooking time, measured via Mattson cooker, followed by how packaging material, bean variety, and use of calcium chloride ($CaCl_2$) additive impacted various retort processed quality attributes, including hydration coefficient (HC), washed drained coefficient (WDC), texture, color attributes (L^*, chroma, and hue angle), brine viscosity, and brine clarity. Glass jars required the longest retort processing time at 121.1°C (14 min), while metal cans and plastic pouches had shorter processing times (6 min). There were significant ($p < 0.001$) variations in average cooking times across bean variety. All measured quality attributes were significantly impacted ($p < 0.001$) by the interaction between variety and packaging, while $CaCl_2$ independently impacted texture and brine viscosity, resulting in a moderate negative correlation ($r = -0.60$) due to seed coat splitting. Bean texture was negatively correlated ($r = -0.60$) with bean L^*, indicating that darker colored beans generally have firmer textures due to increased content of phenolic compounds, also contributing to more opaque brine clarity ($r = -0.64$). $CaCl_2$ generally resulted in higher quality products due to firmer texture and reduced brine viscosity, and quality attributes were found to be the most variable within samples processed in plastic pouches. Ultimately, this study provides a comparison of standardized retort processing protocols for pulses within metal cans, plastic pouches, and glass jars, and the generated quality attribute data introduces possible product innovation and opportunities to continue to optimize RTE pulses for increased consumer acceptance.

1. Introduction

Pulses are defined as the edible seed of a legume, which include dry beans (*Phaseolus vulgaris*) and chickpeas (*Cicer arietinum* L.), among others [1]. Many different pulse market classes are produced around the world with varying morphological characteristics, including seed color, size, and shape, which appeal to consumers [2]. Pulses are inexpensive [3], nutritious, and have environmental benefits which positively impact the cropping system [4]. However, despite these benefits, pulse consumption is low [3]. There are several barriers preventing consumers from choosing pulses, including associations of having bitter, astringent, or "beany" off-flavors [5]; perceived inconvenience; negative culinary image; and possible intestinal discomfort [6]. Dry beans are cumbersome to prepare at home, and canned bean

options deliver fully cooked, shelf-stable, and ready-to-eat (RTE) bean products to consumers [7]. While canned beans provide a solution to the inconvenience of preparing pulses at home, there are also negative perceptions of canned beans among consumers, including that they are not healthy, do not taste good, and contain preservatives [8]. Furthermore, both consumers and processors will reject a canned bean with poor quality attributes after processing [9].

Canned food products are produced within a high-temperature retort machine, and retort processing is a thermal food sterilization technique which utilizes durations of high temperatures under increased pressure to ensure safe and shelf-stable food products [10]. The terms retort processing time/processing time will be used throughout this paper to define the method used to sterilize and produce canned pulse samples within this study. *Clostridium botulinum* (*C. botulinum*) is an important target microorganism within canned food products due to its ability to produce the neurotoxin responsible for Botulism within anaerobic environments [11]. Pulses are also classified as a low-acid food due to their pH of 5.60–6.50 [12], requiring high-temperature retort processing to ensure commercial safety and sterility of canned bean products. Given this, processing must occur at temperatures above 100°C, as lower temperatures do not properly destroy *C. botulinum* [13]. Sterilization of a food product is obtained with a lethality time (F_0), which represents how thermal processing at 121.1°C affects microorganisms [14], resulting in a 12D log reduction of *C. botulinum* spores at the coldest spot within the processing container [15]. Batch retorts can process a variety of packaging materials, including metal cans, flexible pouches, and glass jars [16]. Heat from the retort is transferred to the food product through a heating medium, which includes steam, water, or a steam/water mixture [13]. Steam-injection heating uses steam and air to rapidly heat products, often resulting in shorter processing times, while water-immersion heating requires partial or full submersion of the container in water within the retort [16]. Metal cans are better suited for steam-injection heating due to their rigidity, while plastic retort pouches and glass jars are more susceptible to damage or pressure changes, requiring the less rapid temperature increasement that water-immersion heating provides. The impacts of retort processing on various quality attributes of pulses processed within metal cans and flexible retort pouches have been previously evaluated by Wang et al. [7, 17], where wide variation in quality attributes across different varieties was observed. Currently, RTE bean products are predominantly available to consumers in metal cans, although retort pouches are gaining commercial acceptance [18]. However, there is a lack of literature to understand the implications of retort processing for pulses within glass jars or comparing the impact of processing within different packaging materials on quality attributes, presenting possible innovation opportunities. Additionally, the use of glass as a food packaging material has positive consumer perceptions, as consumers have shown to favor glass food packaging as high quality, safe, and healthy [19], further emphasizing a purpose in understanding the implications of retort processing of pulses within glass packaging materials.

The use of preservatives within canned food products contributes to overall negative perceptions consumers have about canned bean products [8]. Calcium chloride ($CaCl_2$) is a commonly used food additive within canned food products for its stabilizing, thickening, and texturizing properties [20]. Within plant cell walls, Ca^{2+} ions cross-link with carboxyl groups, improving the texture of vegetable products by increasing the strength and firmness of the cell wall tissue [21]. Within canned pulse products, $CaCl_2$ is typically added within various steps of the preparation processing, including within soaking water, blanching water, and brine to improve product firmness [7]. Due to recent rising consumer interest in food products containing fewer additives and preservatives [22], the effects of retort processing pulse product with and without $CaCl_2$ within the brine will also be evaluated in this study.

The objectives of this study were to (1) establish a standardized and research-scale retort processing protocol for dry beans within glass jars, adapted from previously published protocols for pulses within metal cans and plastic pouches; (2) understand variations in cooking time across bean varieties using a Mattson cooker apparatus; (3) assess the processed quality attributes of both common and less common pulse market classes/varieties; (4) compare the implications on product quality attributes of pulse retort processed within metal cans, glass jars, and plastic pouch packaging materials; and (5) assess the impact of brine with or without added $CaCl_2$ on processed pulse quality attributes.

2. Materials and Methods

The Mattson cooker method, retort processing protocols, and data collection methods and variables were adapted and modified from protocols described by Wang et al. [7, 17], with portions of the methods description closely mirroring their language. Figure 1 provides an overview of the general retort processing procedures and methodologies used for data collection.

2.1. Dry Beans. A total of 10 dry beans of various market classes and one Kabuli chickpea were selected, obtained from both research farms and commercial sources. The known market class, variety, growing area, and harvest date are listed in Table 1. For the less commonly known market classes in the United States used within this study, including cassoulet (Flat White), Flageolet, Red and white mottled ('UC Southwest Red') (SW), scarlet runner bean ('Ayocote Morado') (Morado), Flor de Mayo (Mayo), and Bayo, there is little available literature regarding retort processing protocols. For this reason, the processing protocols were adapted and adjusted from those of common US market classes, described in Table 2, along with general color characteristics. As described by Wang et al. [7], all dry beans were washed within a strainer thoroughly to remove any residual dirt or debris and allowed to air-dry. The washed beans were then manually sorted to remove any split, malformed, or disease-infected seeds to ensure the highest quality seeds were used for analysis. Upon cleaning and sorting, all dry

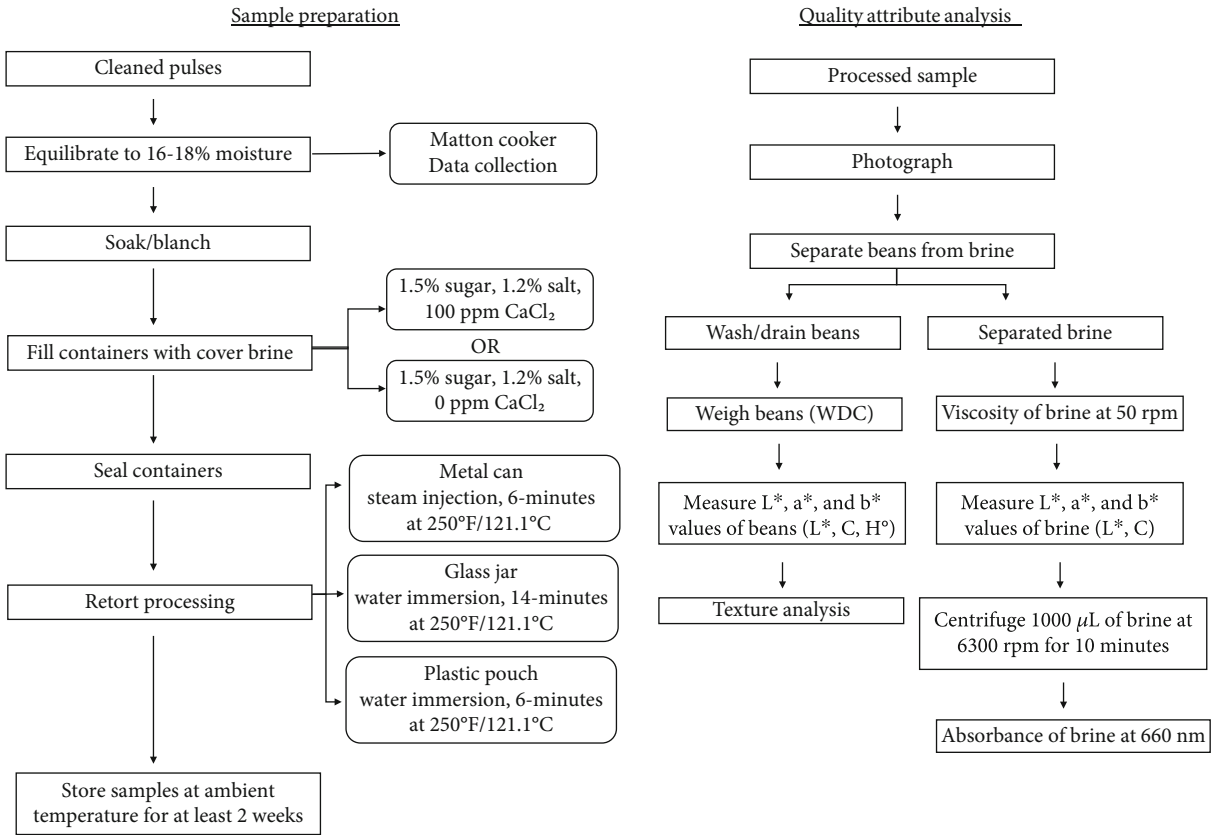


Figure 1: Diagram of major sample preparation, processing, and data collection steps. Sample preparation methods and retort processing occurred in multiple independent batches over the course of the study. Data collection for quality attribute analysis was conducted in triplicate for each bean variety, packaging material, and brine treatment ($n = 198$) upon completion of retort processing.

TABLE 1: Information related to bean market class, variety, growing region, and harvest date of dry beans used for this study. "N/A" denotes information not available (NA) to the authors at the time the study was conducted.

Genus	Market class	Variety/genotype	Harvest time	State/region grown	Provider
Phaseolus vulgaris	Yellow	RRY1803-1-1	September 2023	Idaho, United States	USDA-ARS
Phaseolus vulgaris	Navy	Alpena	September 2023	Michigan, United States	USDA-ARS
Phaseolus vulgaris	Cranberry	RR1910-2-1	September 2023	Michigan, United States	USDA-ARS
Cicer arietinum	Kabuli chickpea	Sierra	September 2022	Washington, United States	Ardent Mills
Phaseolus vulgaris	Pinto	N/A	N/A	United States	Goya
Phaseolus vulgaris	Cassoulet	Flat White	October 2023	Wisconsin, United States	GenTec Seeds
Phaseolus vulgaris	Flageolet	Flageolet	October 2023	Idaho, United States	Primary Beans
Phaseolus vulgaris	Flor de Mayo	Flor de Mayo	November 2023	Morelos, Mexico	Primary Beans
Phaseolus vulgaris	Red and white mottled	Southwest Red	October 2023	Idaho, United States	Primary Beans
Phaseolus coccineus	Scarlet runner bean	Ayocote Morado	November 2023	Puebla, Mexico	Primary Beans
Phaseolus vulgaris	Bayo	Bayo	November 2023	Morelos, Mexico	Primary Beans

beans were stored at room temperature. Photos of dry beans prior to cooking or processing are shown in Figure 2.

2.2. Dry Bean Cooking Time. To better understand possible variations in cooking time across bean varieties within this study, a Mattson cooker apparatus was used to determine average cooking time. Following the procedures of Wang et al. [17] with slight adjustments, two replicates of 30 seeds were equilibrated to 16%–18% moisture content and were soaked for 12 h in deionized (DI) water. Of these seeds, 25 were individually placed into wells within the Mattson cooker, where the ends of the pins were gently placed on the surface of the bean seed coat before the apparatus was placed into continuously boiling (100°C) DI water to cook.

TABLE 2: US common market class associations and seed coat color characteristics for each evaluated market class. "N/A" denotes information not available (NA) to the authors at the time the study was conducted.

Market class	Variety/genotype	Common market class association	Seed coat color characteristics
Yellow	RRY1803-1-1	Yellow	Yellow
Navy	Alpena	Navy	White
Cranberry	RR1910-2-1	Cranberry	Tan with dark brown mottled
Pinto	Pinto	Pinto	Tan with light brown mottled
Kabuli chickpea	Sierra	Pinto	Tan
Cassoulet	Flat White	Great Northern	White
Flageolet	Flageolet	Great Northern	Light green
Flor de Mayo	Flor de Mayo	Pink	Purple/tan with white mottled
Red and white mottled	Southwest Red	Dark red kidney	Dark red with white mottled
Scarlet runner bean	Ayocote Morado	Pinto	Purple
Bayo	N/A	Pinto	Tan



FIGURE 2: Photographs of dry seed of the 11 varieties utilized within this study.

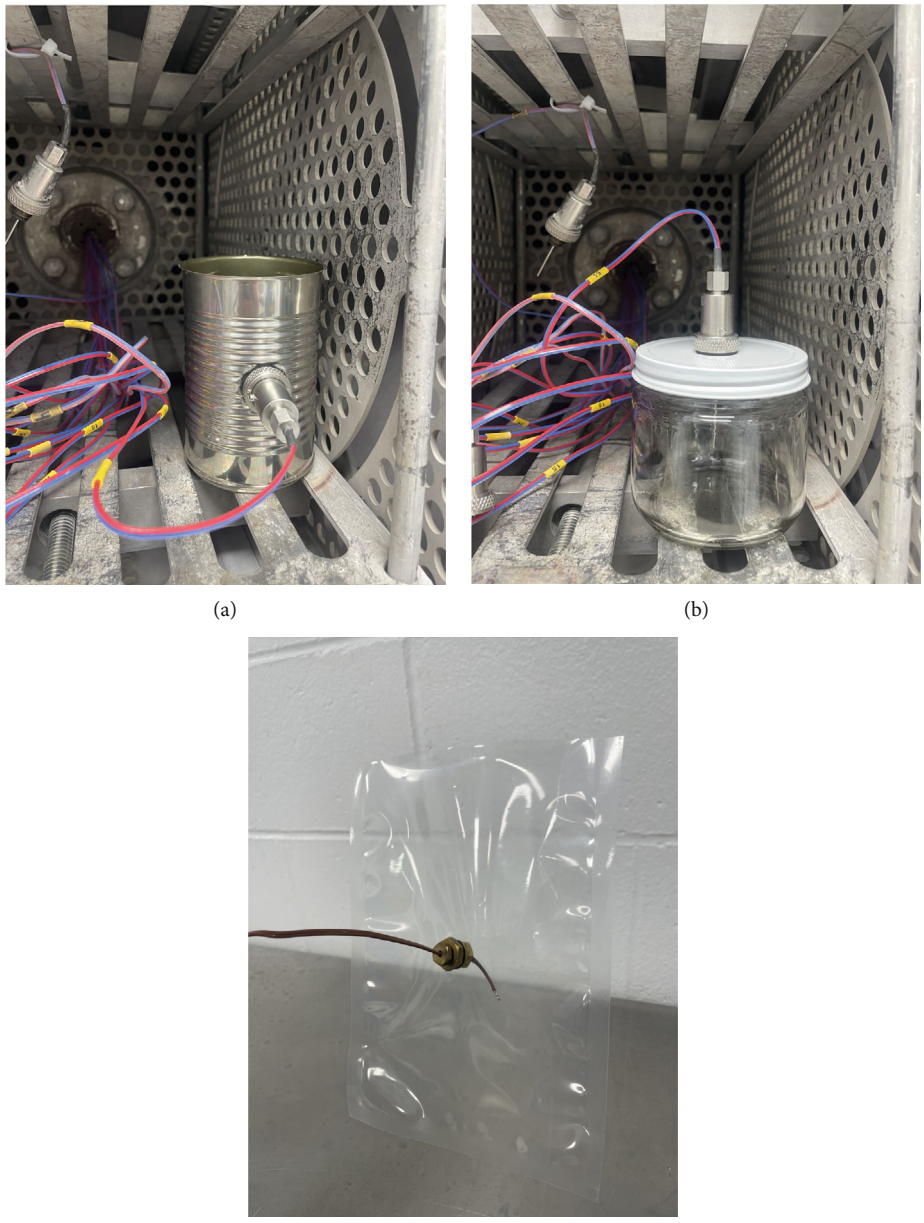
Cooking time is defined as the time required for the seed coat and cotyledon to become soft enough for the apparatus pin to pierce through 80% of the seeds [23]. This procedure was conducted for each bean variety, using two replicates each. The recorded measurement was the average time for 80% of the pins to drop between the two trials.

2.3. Packaging Materials. Three different packaging containers, size 307 × 407 metal cans (Burnette Foods, East Jordan, Michigan, United States), 12-ounce/355-mL glass jars (ULINE, Pleasant Prairie, Wisconsin, United States), and 16 × 22 – cm flexible retort plastic pouches (AliExpress, Hangzhou, China), were used as processing vessels throughout this study. Examples of each packaging material are shown in Figure 3.

2.4. $CaCl_2$. Food-grade $CaCl_2$ (Earthborn Elements, San Diego, California, United States) additive was used within the preprocessing treatment steps and within brine. One hundred parts per million (ppm) of $CaCl_2$ was added to the water used for soaking and blanching, regardless of brine treatment. For containers filled with brine treatment containing $CaCl_2$, 100 ppm was added to the brine and was excluded from the brine treatment not containing $CaCl_2$.

2.5. Sample Preparation. All samples were prepared and analyzed within the Food Processing Complex (FPC) at Michigan State University (MSU) (East Lansing, Michigan, United States), described in the following steps, summarized in Figure 1.

The initial moisture content of dry seeds was measured using a moisture analyzer (AgraTronix MT-16 Moisture



(a) (b)

(c)

Figure 3: (a) Metal can, (b) glass jar, and (c) plastic pouch packaging materials utilized within this study, containing thermocouples at the geometric center.

Tester, AgraTronix, Streetsboro, Ohio, United States). The dry seeds were allowed to equilibrate to 16%–18% moisture content within a moist environment and were measured daily until target moisture content was reached.

Samples were prepared with respective sample weight, dependent on bean market class and packaging material for processing, described in Table 3. Sample weights were adapted from Wang et al. [7, 17] for the metal cans and plastic pouches and based on preliminary findings for the glass jars. The target sample weight (TSW) was calculated using sample weight and measured final moisture content, and TSW was recorded within ±0.5 g of calculated TSW for each sample.

Samples were placed within mesh bags for soaking and blanching within a stainless steel steam kettle (Solaris, Montebello, New York, United States). Soaking within tap water with 100 ppm added $CaCl_2$ occurred either overnight (12 h) at ambient temperature (21.1°C) or for 30 min at 51.6°C, depending on market class (Table 3). Upon the completion of soaking, samples were immediately blanched at 93.3°C for either 5 or 15 min, also depending on market class (Table 3).

Prior to filling packaging containers, brine for each respective brine treatment was prepared within a steam kettle, containing tap water, 1.5% sugar, 1.2% salt, and 100 ppm $CaCl_2$ for $CaCl_2$-containing brine treatment and tap water, 1.5% sugar, and 1.2% only for no $CaCl_2$-containing brine treatment. Regardless of treatment, both brine treatments were heated to 93.3°C and allowed to cool to < 48.8°C prior to filling and sealing containers.

TABLE 3: Summary of target sample weight, soak time/temperature, and blanch time/temperature utilized for each bean variety and packaging container processed.

Bean market class/variety	Sample weight (g) (can)	Sample weight (g) (jar)	Sample weight (g) (pouch)	Soak time/temp (min or h/°C)	Blanch time/temp (min/°C)
Navy	100 g	60 g	90 g	30 min @ 51.6°C	5 min @ 93.3°C
Flor de Mayo	100 g	60 g	90 g	30 min @ 51.6°C	15 min @ 93.3°C
Yellow	85 g	60 g	90 g	30 min @ 51.6°C	15 min @ 93.3°C
Flat White	100 g	60 g	90 g	30 min @ 51.6°C	15 min @ 93.3°C
Flageolet	100 g	60 g	90 g	30 min @ 51.6°C	15 min @ 93.3°C
Pinto	85 g	60 g	90 g	12 h @ 21.1°C	5 min @ 93.3°C
Ayocote Morado	85 g	60 g	90 g	12 h @ 21.1°C	5 min @ 93.3°C
Bayo	85 g	60 g	90 g	12 h @ 21.1°C	5 min @ 93.3°C
Southwest Red	85 g	60 g	90 g	12 h @ 21.1°C	5 min @ 93.3°C
Cranberry	85 g	60 g	90 g	12 h @ 21.1°C	5 min @ 93.3°C
Chickpea	85 g	60 g	90 g	12 h @ 21.1°C	15 min @ 93.3°C

2.6. Sealing Containers and Retort Processing. The soaked and blanched samples were placed into respective containers and filled with respective brine treatments, with each container and brine treatment made in triplicate for each pulse variety. For each bean variety, packaging material, and brine treatment, an additional container was created to act as a thermocouple (TC) holding container for internal temperature data collection and F_0 calculations during retort processing, as TCs are instruments used to track temperature within food containers [16]. TC holding containers were not used for quality attribute data collection purposes.

The method of inserting TCs within each packaging material closely followed the procedures described by Bangar and Whiteside [24]. A hole at the geometric center of the metal can was made using a handheld hole punch (Ecklund-Harrison Technologies, Fort Myers, Florida, United States), where a 3.81-cm wire need TC (Ecklund-Harrison Technologies, Fort Myers, Florida, United States) was inserted into the puncture hole. Metal can containers were filled with enough respective brine treatment to leave 0.63-cm headspace and were hermetically sealed using a double seamer (Dixie, Athens, Georgia, United States). TCs were inserted at the geometric center of the metal glass jar lid, using 5.15-cm wire TCs (TechniCAL, Metairie, Louisiana, United States) at the puncture hole. Glass jars were also filled with brine to leave 0.63-cm headspace and were manually sealed, due to the lack of jar sealing machinery within the MSU FPC. For plastic pouches, a hole was created in the geometric center of the pouch, and a 91.4-cm flexible pouch TC (TechniCAL, Metairie, Louisiana, United States) was inserted. Pouches were filled with 270 mL of brine and vacuum-sealed using a vertical conveyorized system (All Packaging Machinery, Ronkonkoma, New York, United States) at 162.7°C at a speed of 30 feet per minute (fpm).

For retort processing, a batch retort (ALLPAX 2402-R3 Retort, Allpax, Covington, Louisiana, United States) was used for the entire duration of the study along with various processing softwares. "Allpax MONITOR" (Version 6.0.105) was used to program and schedule recipes, allowing for adjustments of processing times and heating mechanisms. "AllLog" (Version 6.0.0254) was used as the retort was running, ensuring each step of the recipe was properly conducted. "Allpax AllView Retort" (Version 6.0.528) was used to operate the retort itself. Each packaging material had a different heating method and retort processing time, as described in Figure 1. A fixed heating method and processing time for each packaging material were applied across all evaluated bean market classes, rather than optimizing processing conditions for each bean variety, to develop a standardized protocol for evaluation of canning quality attributes across bean market classes and packaging material. The effects of processing condition and packaging material are considered confounded, and observed differences may result as a combination of these two factors.

Each container containing a TC was connected to leads within the retort prior to operation. The "TechniCAL CALSoft 6" (Version 6.1.1) software was used for thermal data collection and calculation of F_0 values, recording data every 10 s. Each mentioned software was customized specifically for MSU. For food safety purposes, the retort temperature targeted for all containers to ensure sterility was 121.1°C [14], regardless of packaging material, with a minimum lethality value of $F_0 = 6$ min [17].

2.7. Post-Processing Quality Attribute Evaluation. The methods for quality evaluation and data collection were closely adapted and modified from Wang et al. [7, 17], as summarized in Figure 1.

Upon the completion of the retort processing, unopened samples were allowed to equilibrate for at least 2 weeks at ambient temperature prior to quality analysis. When opened, cooked beans and brine were separated from each other using a mesh strainer and collected separately. The separated beans were rinsed and drained under tap water prior to analysis.

2.7.1. Hydration Coefficient (HC). Upon the completion of soaking and blanching and prior to retort processing, samples were removed from mesh bags, and their weight was recorded to measure HC, an indicator of water uptake

during soaking and blanching compared to dry weight [7], calculated as shown in Table 4.

2.7.2. Washed Drained Coefficient (WDC). WDC was calculated by weighing rinsed and drained processed beans, using processed weight to indicate water uptake during thermal processing [7] (Table 4).

2.7.3. Texture. Instrumental texture analysis of beans was measured using a texture analyzer (TA.XT Plus Connection 100, Texture Technologies, Hamilton, Massachusetts, United States), attached with a cell blade attachment (SMS Kramer Shear Cell 10 blade attachment, Texture Technologies) to simulate a single bite of food. The measurement is an indicator of firmness or softness of the beans, measured by placing 100 g of beans into the cell and recording the maximum kilograms of force (kgf) required to cut through the sample [7]. Uebersax and Hosfield [25] previously determined ideal texture ranges for processed beans by their Kramer shear cell force measurements, with an ideal range being from 40 to 80 kgf. These standards for common US market classes are useful for understanding texture analysis results and creating products which meet consumer standards. Texture is an important sensory characteristic of food products, as Kesiime et al. [26] found that consumers are often more concerned about the texture and overall visual appeal of processed bean products, and Wang et al. [7] found a significant correlation between appearance and texture, as samples with higher appearance ratings were often firmer in texture.

2.7.4. L^*, Chroma (C), Hue Angle (H°). The instrumental color of cooked beans and brine was measured separately using a ColorFlex EZ Spectrophotometer (HunterLab, Reston, Virginia, United States). L^*, a^*, and b^* values were measured and recorded: L^* measuring the lightness or darkness of the sample from 0 (pure black) to 100 (pure white), a^* measuring redness (more negative value) to greenness (more positive value), and b^* measuring yellowness (more negative value) to blueness (more positive value) [7]. From these color values, C (for both beans and brine) and H° (beans only) were calculated, as shown in Table 4, indicating color brightness and human perception of primary colors [7].

2.7.5. Brine Viscosity. Rotational viscometry is used to measure the properties of fluids [27]. The method of soaking beans prior to cooking has been shown to alleviate splitting and breakage of seed coats during cooking [28], as beans are composed of starches [29]. Starch is impacted by the presence of moisture and heat, and as starch granules are heated in water, the reduction of structure and breakdown of granules creates a viscous, thickened liquid during a process known as starch gelatinization [30]. With this, seed coat splitting allows for starches within the bean seed coat to enter the brine, undergoing starch gelatinization during processing and resulting in a thickened brine liquid. To measure viscosity of brine, 50 mL of brine was placed into a beaker. Viscosity was measured using a Brookfield AMETEK DVNext Viscometer (AMETEK Brookfield, Middleborough, Massachusetts, United States) at 50 rotations per minute (rpm), with a size 05 spindle attachment completely submerged within the brine. The measurement was recorded in units of centipoise (cP).

TABLE 4: Equations for calculating TSW, HC, WDC, C, and H°.

Quality attribute	Associated equation/calculation
Target sample weight (TSW)	$Solid\ weight\ (g)/[1 - (moisture\ content/100)]$
Hydration coefficient (HC)	$Blanched\ weight\ (g)/TSW\ (g)$
Washed drained coefficient (WDC)	$Cooked\ weight\ (g)/blanched\ weight\ (g)$
Chroma (C)	$\sqrt{a^2 + b^2}$
Hue angle (H°)	$\tan^{-1}(b/a)$

2.7.6. Brine Clarity. To measure brine clarity, 1000 μL of brine was collected from each sample and pipetted into a 1.5-mL centrifuge tube. The sample tube was spun at 6300 rpm for 10 min within a centrifuge (Thermo Scientific, Waltham, Massachusetts, United States). Upon separation of solid particles, 200 μL of liquid was pipetted into a 96-well cell culture cluster plate (Coming Costar, Corning, New York, United States), in triplicate. The plate was placed into a PerkinElmer EnSpire Multimode Plate Reader (PerkinElmer, Waltham, Massachusetts, United States) and analyzed using EnSpire Manager software (Version 4.10.3005.1440) at 660 nm under an absorbance test. A higher absorbance value indicated a more opaque brine, while a lower value indicated a more transparent brine.

2.8. Statistical Analysis. Statistical analysis was conducted using RStudio (R.4.4.1). For Mattson cooker results and retort processing quality attributes, the average cooking time was analyzed using multiple linear regression and analysis of variance (ANOVA). Post hoc pairwise comparisons were made using estimated marginal means, applying a Bonferroni adjustment. Retort processing quality attribute variables were analyzed individually across all three factors of brine (B), variety (V), and packaging (P), visualized graphically based on significant two-way interaction between V × P or three-way interactions between B × V × P. Pearson's correlation analysis was conducted between all 10 measured quality attributes, excluding Mattson cooker cooking time results. Samples which had missing results ($n = 7$), due to brine that was too viscous to allow for accurate measurements, were excluded from analysis. Statistical significance began at $p < 0.05$ for all statistical analysis. Lastly, TC internal temperature data from retort processing of chickpea samples was visualized using MATLAB (update 24.2.0.2833386) to showcase general trends.

3. Results and Discussion

A total of 10 dry bean samples and Kabuli chickpeas were first cooked using a Mattson cooker apparatus and were then separately retort processed within metal cans, glass jars, and plastic pouches using brine containing or not containing $CaCl_2$. Significant differences in cooking time and measured

TABLE 5: ANOVA results and p values identifying impact of brine (B), packaging (P), and/or variety (V) on Mattson cooker cooking time results and measured quality attributes, with significance beginning at $p < 0.05$.

Source of variation	Cooking time	HC	WDC	Texture	Bean L^*	Bean C	Bean H°	Brine L^*	Brine C	Viscosity	Clarity
Brine (B)	—	—	0.222	$1.516e-05^{***}$	0.519	0.624	0.341	0.200	0.208	$3.57e-06^{***}$	0.698
Bean variety (V)	$1.37e-07^{***}$	$<2.20e-16^{***}$	$<2.20e-16^{***}$	$<2.20e-16^{***}$	$<2.20e-16^{***}$	$<2.20e-16^{***}$	$<2.20e-16^{***}$	$<2.20e-16^{***}$	$2.09e-14^{***}$	$<2.20e-16^{***}$	$<2.20e-16^{***}$
Packaging (P)	—	—	$4.48e-08^{***}$	$2.94e-12^{***}$	$<2.20e-16^{***}$	$5.75e-08^{***}$	$7.17e-05^{***}$	$2.25e-05^{***}$	0.228	$<2.20e-16^{***}$	0.002^{**}
B × V	—	—	0.464	$1.50e-05^{***}$	0.313	0.443	0.859	0.584	0.835	$2.22e-04^{***}$	0.205
B × P	—	—	0.316	0.921	0.177	0.568	0.660	0.125	0.202	0.398	0.352
V × P	—	—	$<2.20e-16^{***}$	$<2.20e-16^{***}$	$3.60e-06^{***}$	$2.38e-05^{***}$	0.009^{**}	$<2.20e-16^{***}$	$9.54e-12^{***}$	$<2.20e-16^{***}$	$6.29e-14^{***}$
B × V × P	—	—	0.0425^{*}	0.146	0.021^{*}	0.084	0.044^{*}	0.871	0.492	0.039^{*}	0.367

Note: Significance levels: $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

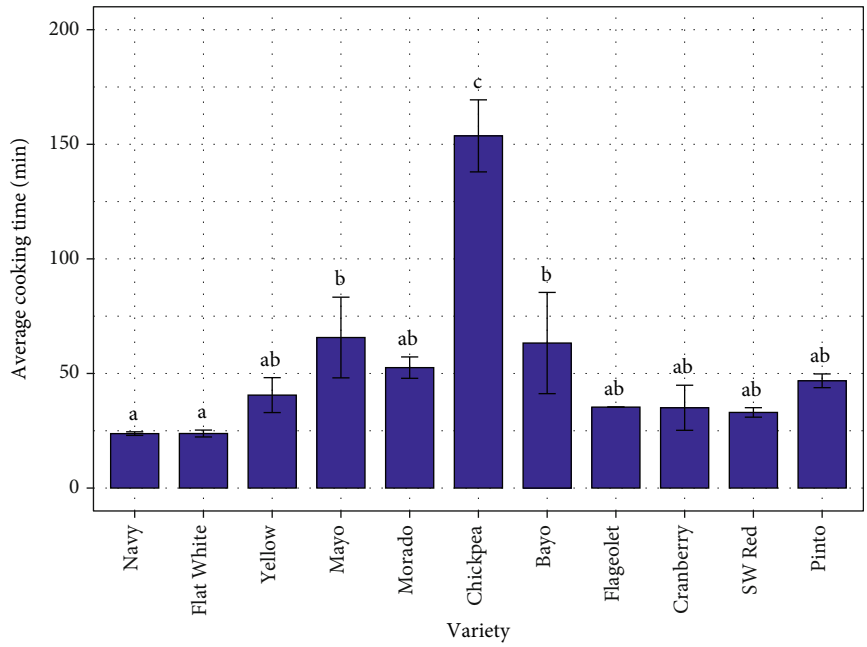


Figure 4: Average cooking time required for pins of Mattson cooker apparatus to pierce through 80% of bean seed coats. Error bars represent the standard error of the mean (±2 SE). Groups not sharing the same letter are significantly different ($p < 0.05$).

quality attributes were identified, with ANOVA results and respective p values shown in Table 5.

3.1. Mattson Cooker. Average cooking times significantly ($p < 0.001$) varied across V, as shown in Figure 4. It is observed that the average cooking time was shortest for the Navy variety (23 min) and longest for Chickpeas (153 min). With this information, it was reasonably expected that there would be significant quality differences between short cooking and long cooking varieties when thermally processed under fixed time and temperature processing conditions, respective to each packaging material utilized. This information will allow for a better understanding of what bean varieties are better suited for retort processing based on quality attribute results within this study, specifically under the standardized retort processing conditions utilized. Cookability is understood as the time required for a bean to reach a desirable cooked texture, and poor cookability can result in loss of nutrients, increased energy input required, and consumer rejection [31]. For this study, ideal texture measurements will be defined as 40–80 kgf [25], and determining the best suited bean varieties under standardized processing conditions is necessary to ensure production efficacy and high-quality product output. While the Mattson cooker provides valuable insight on cooking time for each bean variety assessed in this study, it is important to recognize that only two replicates of Mattson cooker trials were conducted for each bean variety within this study, and future studies should conduct multiple replicates to increase the reliability of Mattson cooker results.

3.2. Time and Temperature of Packaging Materials During Retort Processing. For food safety purposes, the internal temperature of containers for each bean variety, packaging material, and brine treatment was recorded during each retort processing run using TCs. The heating curves and cumulative F_0 values for chickpeas ($CaCl_2$ brine treatment only) across all three packaging types are shown in Figure 5 to illustrate key trends. In general, samples within metal cans reached the minimum $F_0 = 6$ min the most quickly, followed by plastic pouches, while the glass jar required the longest retort processing time. This difference in heating is also indicated in Figure 6, where it is observed that the metal can and plastic pouch reach 121.1°C more quickly than the glass jar. The observed differences in time required to reach 121.1°C and minimum lethality values in this study are likely related to general differences in thermal conductivity and rates of heat transfer across the metal, plastic, and glass packaging materials. Thermal conductivity is the ability for a material to conduct heat [32], and metal has a much higher thermal conductivity than plastic and glass [33], likely allowing for faster heating which resulted in a higher end F_0 value compared to plastic and glass packaging (Figure 5). Sullivan and Spencer [32] also indicated steel's higher thermal conductivity, requiring less energy to increase temperature compared to plastic. However, the comparable processing times of the plastic pouches are likely attributed to the material characteristics of the plastic pouch itself. Bangar and Whiteside [24] noted that high heat transfer rates within plastic pouches can be attributed to their larger surface area, resulting in faster processing times. Along with increased surface area, the thin profiles of plastic pouches also allow for swift heating, faster cooking, and more energy efficiency [34]. While the exact thermal conductivities and heat transfer coefficients for each packaging material used within this study are not known, the observed

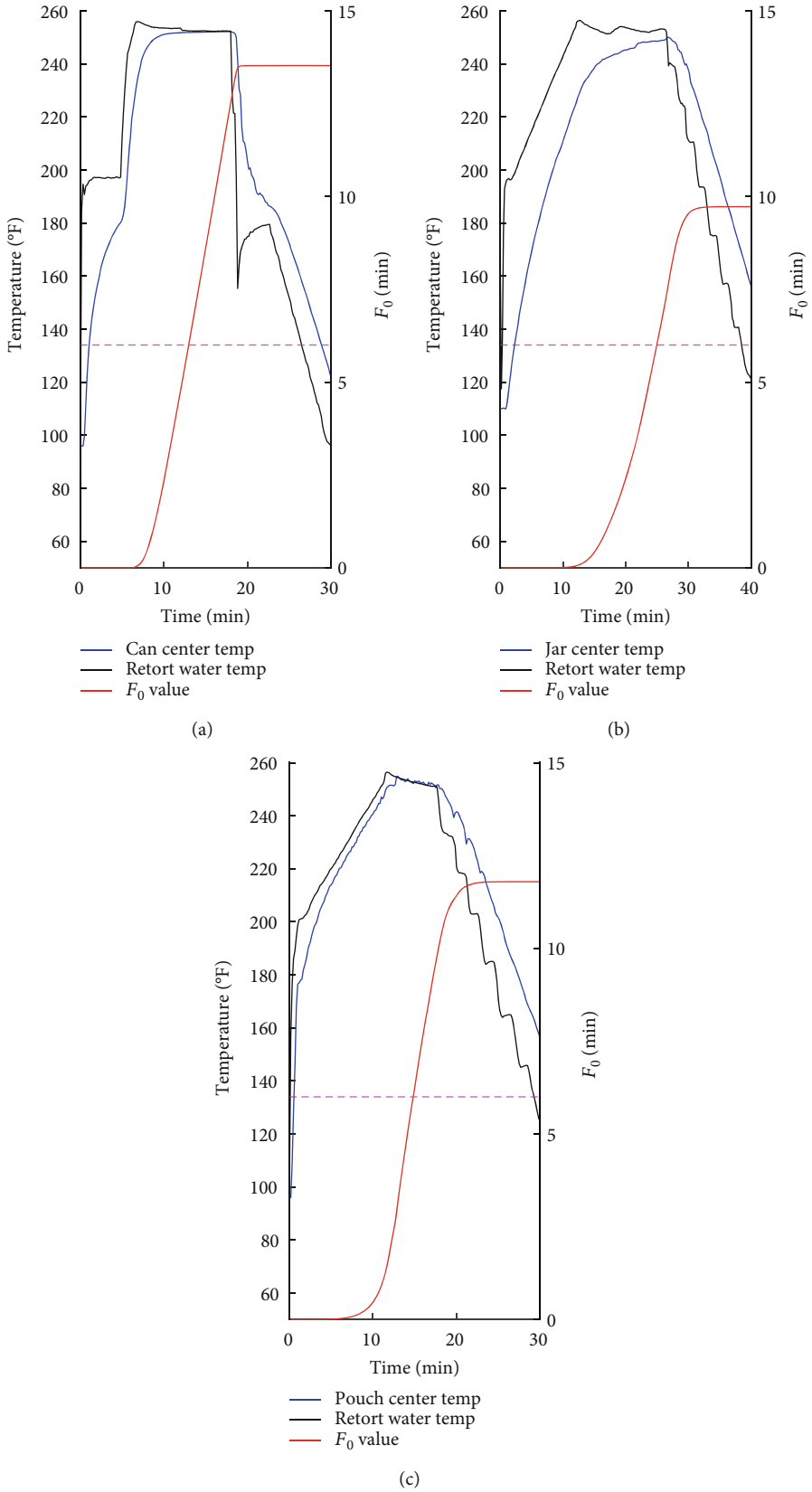


Figure 5: Time temperature and F_0 values during (a) steam-injection heating for metal cans, (b) water-immersion heating for glass jars, and (c) water-immersion heating for plastic pouches. The blue line indicates the internal temperature of the respective container, the black line indicates the temperature within the retort during processing, and the red line indicates the F_0 throughout the retort process. A reference line at $F_0 = 6$ min indicates the minimum required F_0 value at this processing temperature.

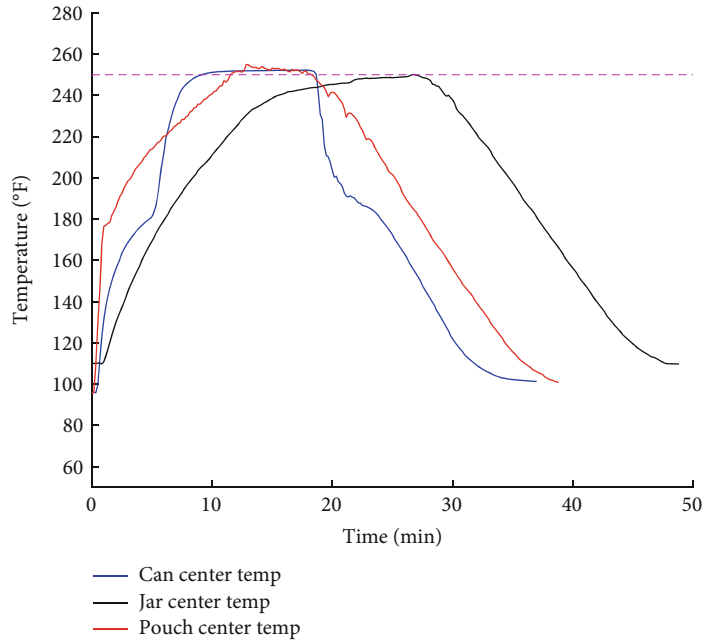


Figure 6: Time required for chickpeas processed within metal cans (blue line), glass jars (black line), and plastic pouches (red line) to reach the target processing temperature of 250°F/121°C.

rapid heating of the metal can, closely followed by the plastic pouch, within this study is likely due to the inherent thermal properties and characteristics of these materials.

As mentioned, the protocols used within this project were adapted from Wang et al. [7, 17], primarily with adjustments to fill weight and retort processing times, which were adjusted from 19 min (metal can) and 7.5 min (nonfoil plastic pouch) at 121°C to 6 min at 121°C for both materials. This reduction in retort processing time, while still ensuring proper commercial sterility, is a significant finding. Due to their utilization of high temperature and pressure, retort machines are very energy intensive [35], and reduction of processing time allows for reduction in overall energy inputs. Wang et al. [17] discussed the shorter processing time of nonfoil pouches to be less energy intensive to be an inherent advantage to the pouches due to their thin nature. However, because the metal can and plastic pouch were able to be processed for the same amount of time in this study, this advantage is weakened when considering an optimal packaging material. While a significant finding, it is important to note the retort within the MSU FPC is small and used for research purposes and larger retorts may require extended processing times to ensure sterility. Ultimately, results of this study found metal cans to be the most energy-efficient packaging material due to their shortest required processing time to meet target temperature and lethality values, while glass jars were the least energy efficient due to their long processing time requirements.

3.3. Quality Attribute Evaluation. ANOVA results (Table 5) indicated that B, V, and P significantly impacted measured quality attributes. It was observed that V × P resulted in a consistent and significant ($p < 0.05$) two-way interaction for all measured quality variables, while B × V × P was only significant for some quality variables—indicating that generally, V × P had a stronger impact on quality attribute variation than B. When considering factors independently, V and P each significantly ($p < 0.05$) impacted all quality attributes, while B was only significantly ($p < 0.05$) impactful to bean texture and brine viscosity, further implying a strong impact V and P had on the observed quality attribute findings. Additionally, the correlation matrix across the measured quality attributes (Figure 7) identified significant correlation trends between each attribute, excluding cooking time.

3.3.1. HC and WDC. Across the different varieties evaluated, HC significantly varied ($p < 0.001$), indicating that water absorption during soaking and blanching significantly varied by V. It is considered optimal for beans to absorb 1.80 times their weight in water during soaking and blanching, indicating a well-hydrated seed prior to thermal processing [25]. Gelete et al. [36] suggested that larger seeds require longer soaking times to meet industry requirements, which can possibly explain the lower HC ratio of some varieties with larger seed size (Flat White) in this study (Figure 8). Additionally, while bean hydration is a complex yet important process during bean processing, Devkota et al. [37] attributed variations in hydration across different bean varieties to morphological, physical, and chemical properties within the seed coat. A strong negative ($r = -0.90$) correlation between HC and WDC indicated that seeds which took up more water during soaking did not absorb as much water during processing, implying an inverse relationship between the two variables. Similar to HC, the optimal ratio for water absorption during thermal processing is a WDC within 1.40 and 1.60 [25]. In this study, a significant ($p < 0.05$) interaction between B × V × P was observed (Figure 8). When

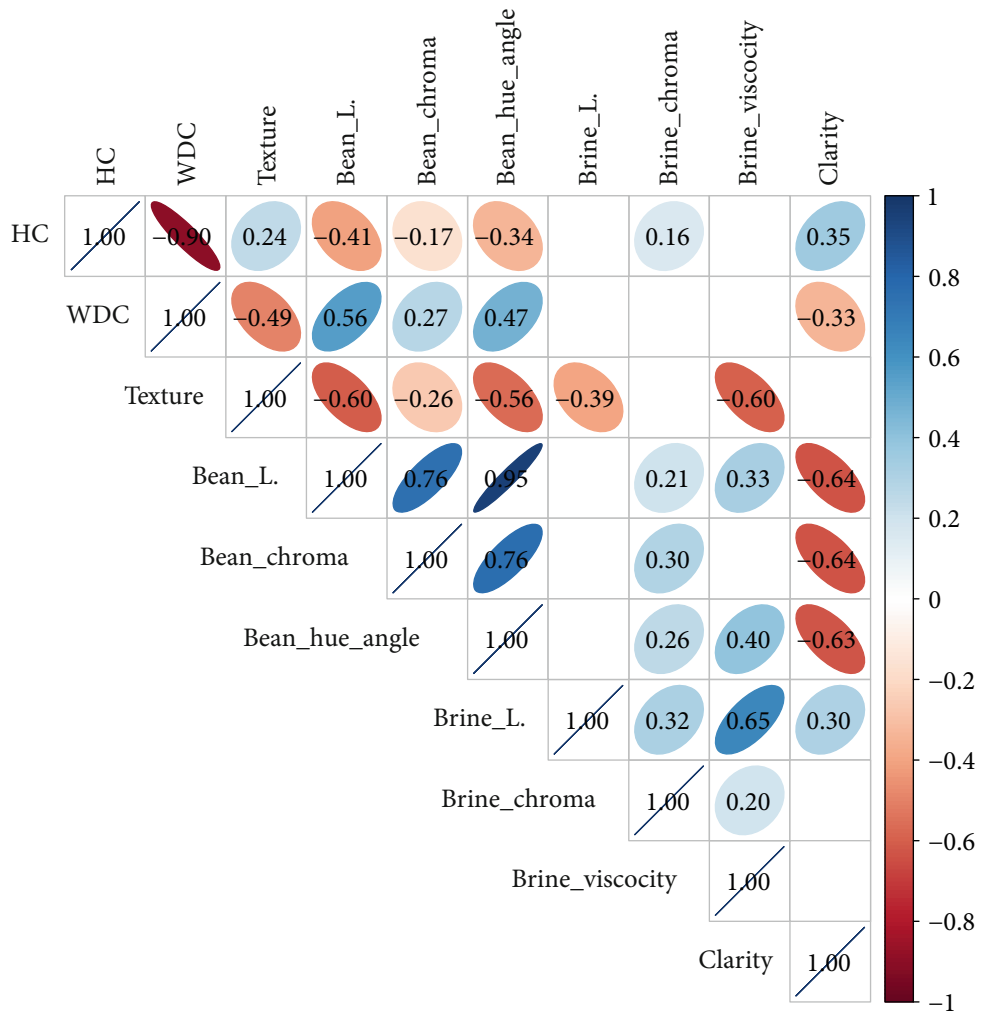


Figure 7: Pearson's correlation matrix of 10 measured quality attributes based on $n = 191$ observations. The plot displays correlation coefficients, ellipses indicating strength and direction of correlation, and color gradient for visual interpretation. Statistically insignificant correlations ($p < 0.05$) are left blank.

comparing the impact of $CaCl_2$ in beans processed within metal cans or plastic pouches, Wang et al. [38] found that although less water was absorbed in samples containing $CaCl_2$ than those which did not, differences in WDC were more attributed to variety differences than packaging differences. In this study, it is likely that differences in retort processing times for different packaging materials to ensure food safety, as discussed, resulted in variations in water uptake. Additionally, there was a moderate negative ($r = -0.49$) correlation between WDC and texture, generally indicating that as more water was absorbed, texture became softer. This correlation was expected, as water absorption results in softened beans [39].

3.3.2. Bean Texture and Brine Viscosity. Independently, B significantly ($p < 0.001$) impacted bean texture measurements, generally resulting in firmer texture measurements (Figure 9), but there was not a significant ($p = 0.146$) three-way interaction including B, only two-way interactions between V × P ($p < 0.001$) and B × V ($p < 0.001$). The firmer texture with the inclusion of $CaCl_2$ in brine matches previous findings, where Alpos et al. [40] found that black beans treated with $CaCl_2$ had significantly less texture degradation than samples without $CaCl_2$, as the heating of processing allowed for the formation of calcium–pectin complexes within the cell walls to maintain firmness, therefore reducing the amount of seed coat splitting by the addition of $CaCl_2$ within brine [41]. In general, the texture of processed vegetables is expected to soften during thermal processing [34], but the cross-linking of Ca^{2+} and pectin from $CaCl_2$ results in improved cell wall strength and tissue firmness [21], allowing for improved texture retention compared to samples with brine not containing $CaCl_2$. Given the significant variation in cooking times across the bean varieties shown in Figure 4, significant variations in texture measurements across bean varieties under standardized retort processing times likely indicate that some varieties are better suited for thermal processing under these conditions than others. Varieties whose processed texture measurements were within the ideal range (40–80 kgf), particularly across various packaging materials within this study, including Flat White, Flor de Mayo, Chickpea, and Bayo beans, should be

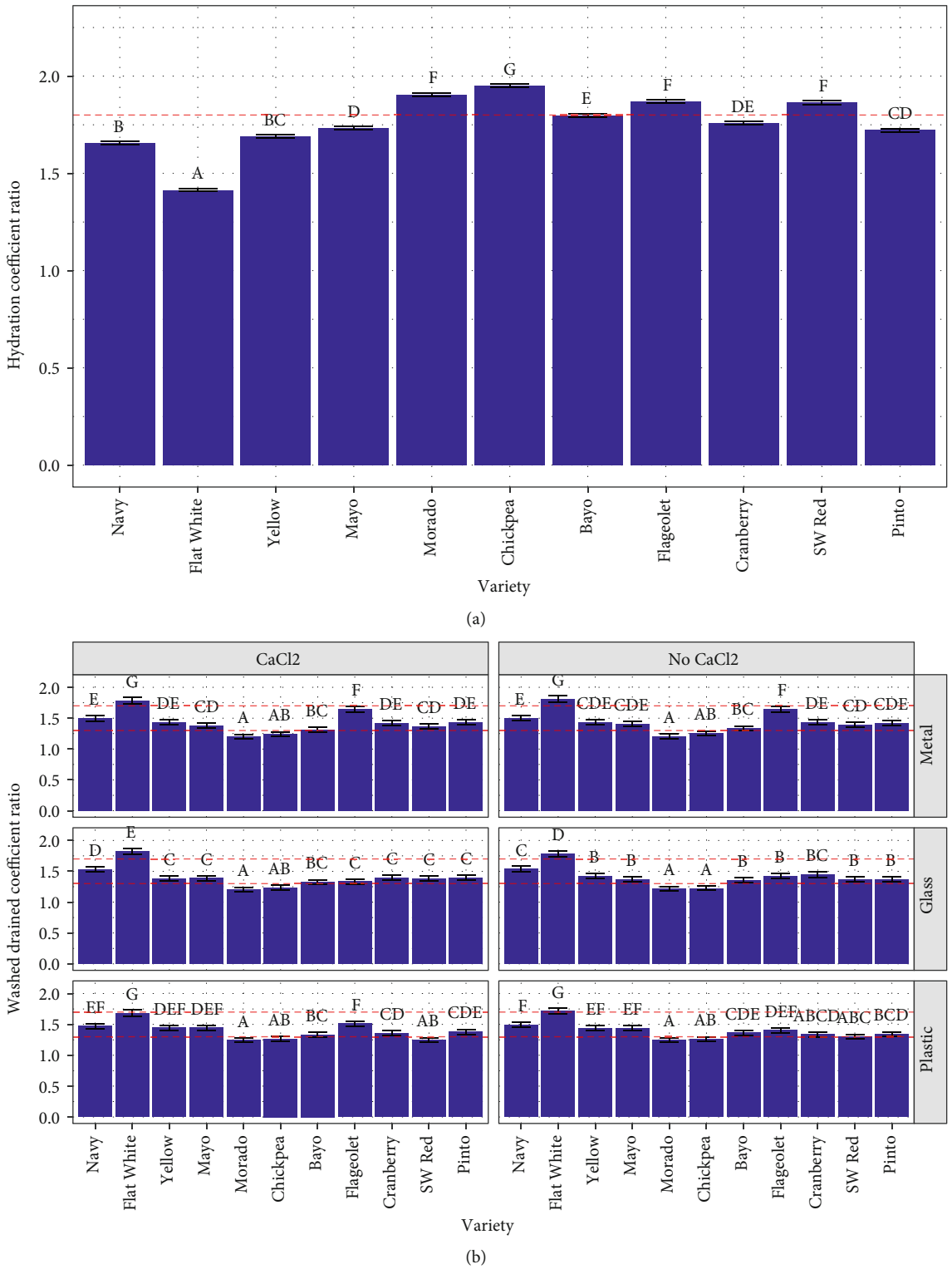


Figure 8: (a) Interaction between V on hydration coefficient (HC) ratio. The ideal industry ratio of HC for pulses is indicated with a red dashed line at $y = 1.80$. (b) Three-way ANOVA interaction between B × V × P on washed drained coefficient (WDC) ratio. The ideal industry range of WDC ratios is indicated at $y = 1.40$ and $y = 1.60$. Post hoc comparison of (b) is limited to within-panel (interaction of V × P within each brine treatment) differences for interpretability. Error bars represent the standard error of the mean (±2 SE). Groups not sharing the same letter are significantly different ($p < 0.05$).

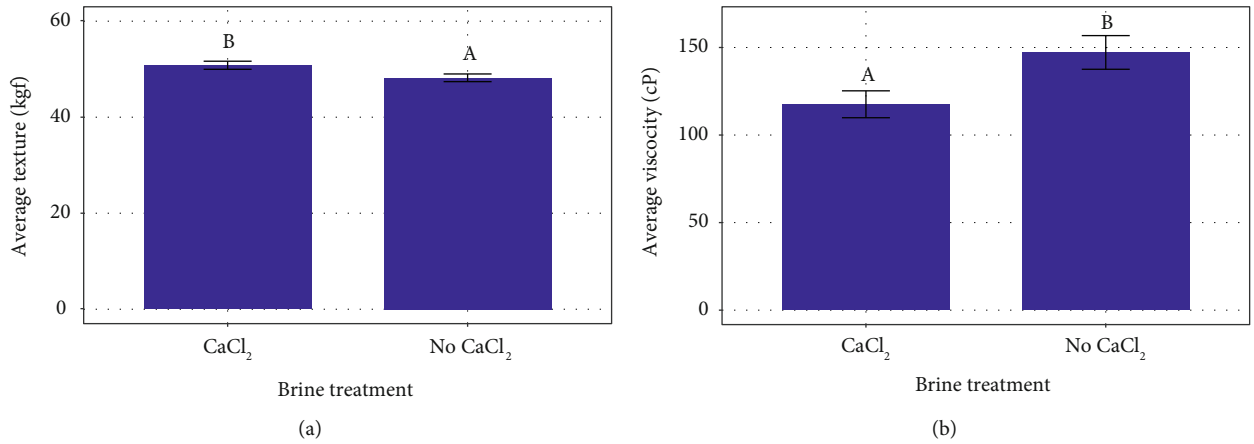


FIGURE 9: (a) Impact of $CaCl_2$ treatment within brine on measured bean texture, measured in kilograms of force (kgf). (b) Impact of $CaCl_2$ treatment within brine on measured brine viscosity, measured in centipoise (cP). Error bars represent the standard error of the mean (±2 SE). Groups not sharing the same letter are significantly different ($p < 0.05$).

considered for future processing of industrially accepted pulse products under standardized conditions (Figure 10). Future research should investigate further optimization of retort processing conditions to improve the texture of varieties that did not meet quality attribute expectations within this study.

When considering texture across different P, large variations in texture measurements were observed in samples processed within plastic pouches compared to metal cans and glass jars (Figure 10), possibly attributed to uneven heating within the retort—as the plastic pouches used in this study did not stack in uniform layers as easily as the metal cans and glass jars. Due to their thin nature and lack of rigidity, product within plastic pouches is more susceptible to damage compared to rigid materials (metal and glass) which provides better protection. Typically, increased processing times result in higher amounts of seed coat splits and decreased firmness [25], which was a consideration given that the glass jars required the longest processing time of the three packaging materials in this study. It is hypothesized that although the glass jars had the longest retort processing time, the observed variability of texture measurements from samples within the plastic pouches was likely due to uneven heating of the plastic pouches and the lack of structure and rigidity of the plastic pouch—ultimately resulting in a reduced ability to protect the product inside from harsh retort processing conditions which lead to excessive seed coat splitting or potential undercooking. Future research should further optimize retort processing of flexible plastic pouches, such as using layered retort trays or improving the rigidity of the pouches themselves, to prevent texture variability and ensure product consistency.

Brine viscosity had a moderate negative ($r = -0.60$) correlation with bean texture, meaning that as texture measurements decreased, brine viscosity tended to increase. Higher amounts of seed coat splitting result in decreased firmness [25], indicating that beans with softer textures may also have increased amounts of seed coat splits, allowing for leaching of cellular contents into the brine medium. Beans are high in amylose starch content [42], and Kesiime et al. [26] found that increased brine viscosity within canned beans is due to splitting that allows for free starch to enter the canning medium. This increase in brine viscosity is likely due to increased free starch content within the brine as a result of seed coat splitting, which undergoes heat-induced starch breakdown and starch gelatinization to create a thickened brine liquid [30]. In this study, high brine viscosity was viewed as a negative quality attribute, since viscous brine decreases the visual appearance of processed beans, particularly when packaged within transparent materials, and makes the beans more difficult to remove from their respective container. When assessing brine viscosity, there was a significant ($p < 0.05$) three-way interaction between B × V × P, as shown in Figure 10**. The addition of $CaCl_2$ within brine generally resulted in less seed coat splits, therefore firmer textures, which consequently resulted in lower brine viscosity, while beans processed without $CaCl_2$ had generally higher brine viscosity (Figure 9). While $CaCl_2$ effectively improved brine viscosity by reducing the amount of seed coat splits, therefore improving texture; it is also important to recognize the varietal differences also attributing to cooking time, therefore resulting in softer or firmer textures under standardized retort processing times, as discussed. Packaging material also significantly ($p < 0.001$) impacted brine viscosity, but varied widely across all three materials for each bean variety. There is limited literature explaining the brine viscosity of retort processed beans, particularly within packaging materials other than metal cans. However, this variation across packaging materials is another important food processing consideration, as consistency in products is essential.

3.3.3. Bean L^*, C, and H°. Bean texture had moderate negative correlations with bean L^* ($r = -0.60$), bean C ($r = -0.26$), and bean H° ($r = -0.56$), indicating that beans with darker color attributes generally had higher (firmer) texture measurements. This can likely be attributed to polyphenols, which are phytochemical compounds which include phenolic acids,

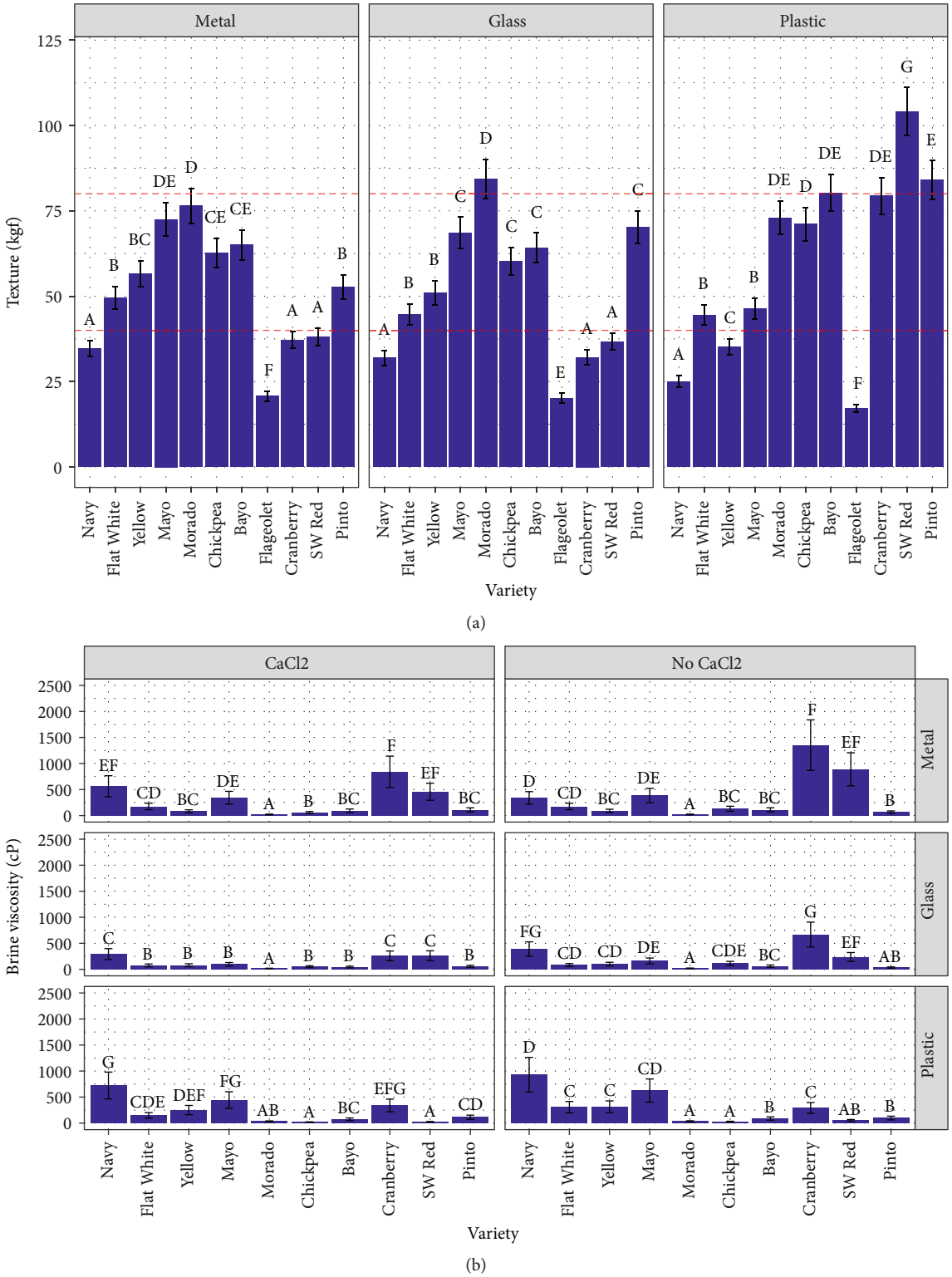
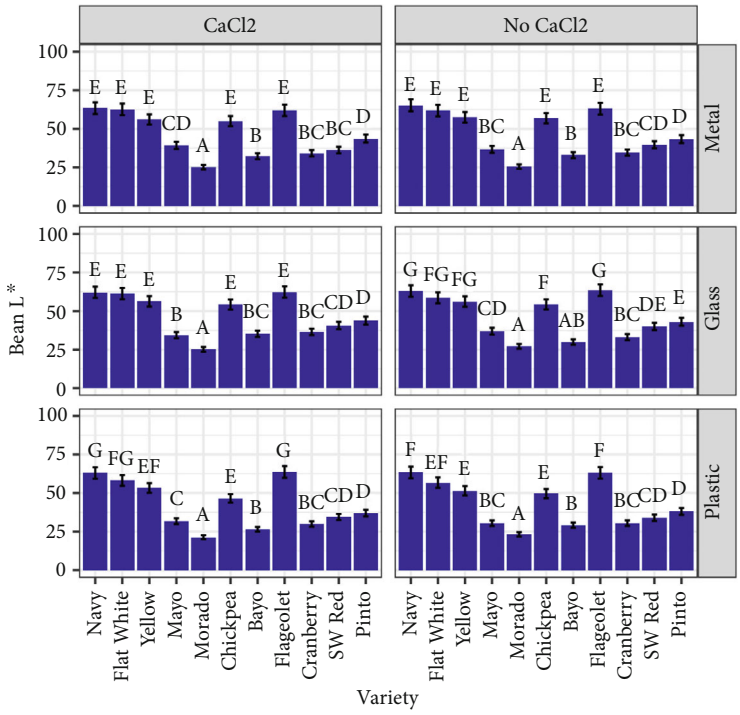
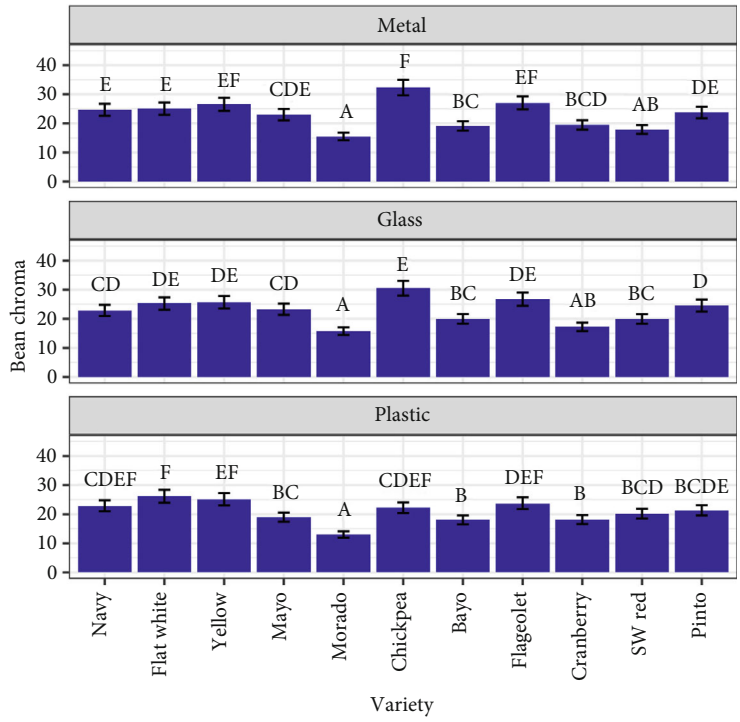


Figure 10: (a) Two-way ANOVA interaction between V × P on measured bean texture, measured in kilograms of force (kgf). The ideal industry range of texture for pulses is indicated at $y = 40$ and $y = 80$. (b) Three-way ANOVA interaction between B × V × P on measured brine viscosity, measured in centipoise (cP). Post hoc comparisons were conducted within each panel (V × P interactions within each brine treatment) for interpretability. Error bars represent the standard error of the mean (±2 SE). Groups not sharing the same letter are significantly different ($p < 0.05$). **No data available for Flageolet variety, as brine was too viscous to record measurements.



(a)



(b)

Figure 11: Continued.

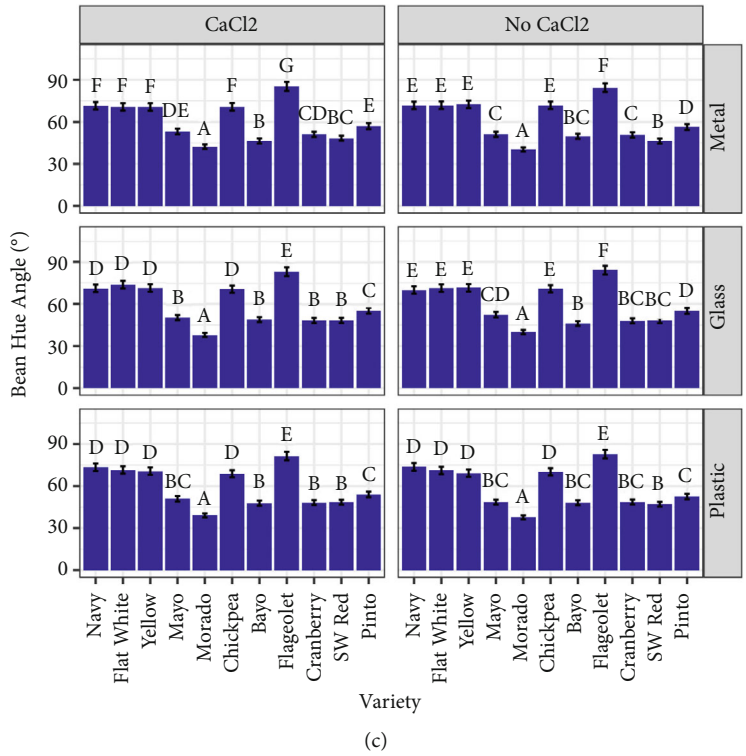
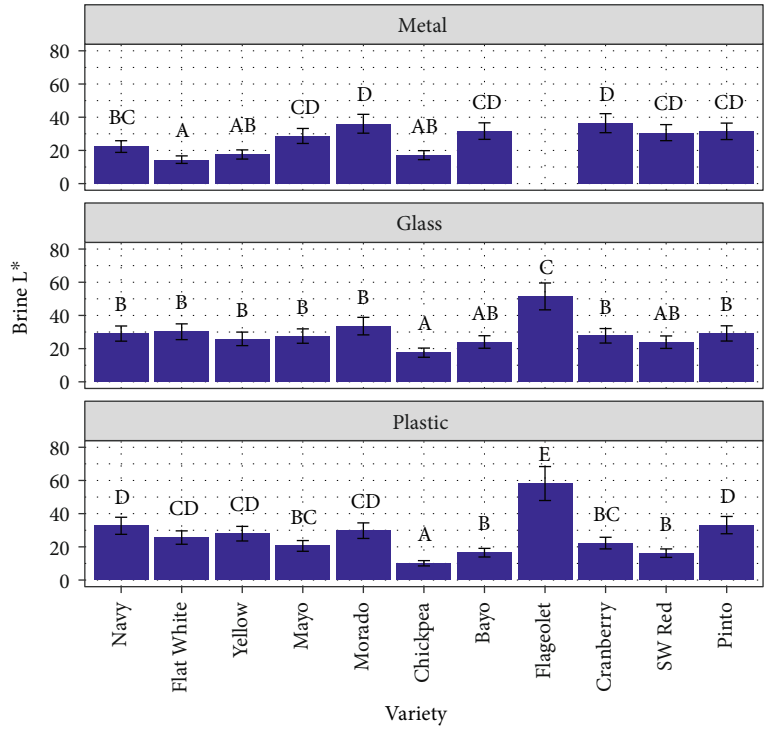
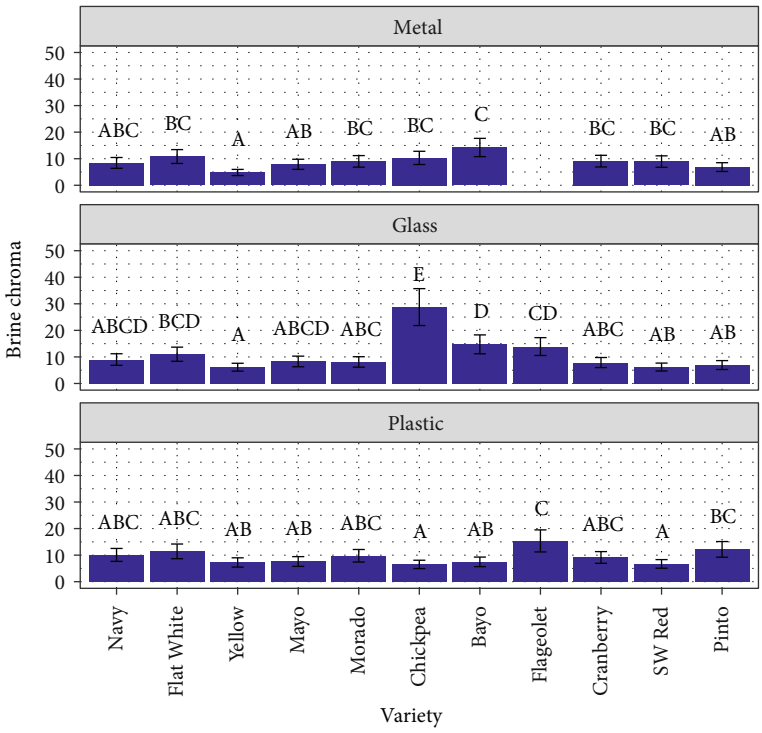


Figure 11: (a) Three-way ANOVA interaction between B × V × P on measured bean L^*. Post hoc comparisons were conducted within each panel (V × P interactions within each brine treatment) for interpretability. (b) Two-way ANOVA interaction between V × P on measured brine chroma (C). (c) Three-way ANOVA interaction between B × V × P on measured bean hue angle (H°). Post hoc comparisons were conducted within each panel (V × P interactions within each brine treatment) for interpretability. Error bars represent the standard error of the mean (±2 SE). Groups not sharing the same letter are significantly different ($p < 0.05$).

flavonoids, stilbenes, lignans, and tannins, with phenolic acids and flavonoids making up 50% of total phenolic components within dry beans [43]. These compounds are primarily located within the seed coat [44], and condensed tannins and anthocyanins are correlated with seed coat color, with their levels impacting the color, tone, and strength of color [45]. When assessing polyphenol content within dry beans, Madrera et al. [46] found that total phenolic content was the lowest in beans with white seed coats and highest in beans with black and red seed coats. Furthermore, seed coat color has been shown to influence water uptake, as darker colored beans absorb water more slowly due to oxidative reactions within the phenolic compounds in the seed coat which result in hydrophobic substances [47]. Hydrophobic compounds within bean seed coats have been attributed to resistance in water absorption, including phenolic compounds within the outer layer of the seed coat [37]. In this study, it was generally observed that some varieties which were lighter in color (Navy, Flat White, and Flageolet) had consistently softer textures across all packaging materials compared to some darker colored (Ayocote Morado, Flor de Mayo, and Bayo) varieties. Like other measured attributes, there was significant ($p < 0.001$) variation in color attributes across V alone. Furthermore, bean L^* had a strong positive correlation with bean C ($r = 0.76$) and bean H° ($r = 0.95$). When assessing color properties of various bean varieties, Herrera-Hernández et al. [48] found that bean varieties with dark colored seed coats had lower L^* and, respectively, lower C values when compared to lighter colored varieties, as also observed in this study. It was anticipated to have wide variation in these color values, as the bean varieties used in this study varied widely in seed coat color characteristics (Table 2, Figure 2). Variations in bean color attributes within this study are shown in Figure 11. In this study, samples processed within plastic pouches had lower L^* and were noticeably darker in color compared to those processed within metal cans or glass jars. Wang et al. [49] previously attributed a lower L^* in canned pinto and Navy beans to the Maillard browning reaction, as high-temperature processing favors the creation of dark pigment colors. Dark color formation due to the Maillard browning reaction is primarily caused by the formation of melanoidins, creating the reaction's distinct brown color [50]. While the Maillard reaction often provides desirable sensory characteristics, for certain food products, the formation of a darkened color can result in negative consumer feedback [51]. Within this study, the thin nature of the plastic pouch likely allowed for more direct heating to the inside product, potentially increasing the rate of the Maillard reaction compared to metal can and glass jar samples. Wang et al. [49] also found the inclusion of $CaCl_2$ significantly increased the L^* of canned beans, which was also observed in our study in samples processed with $CaCl_2$ in brine. The observed variations in

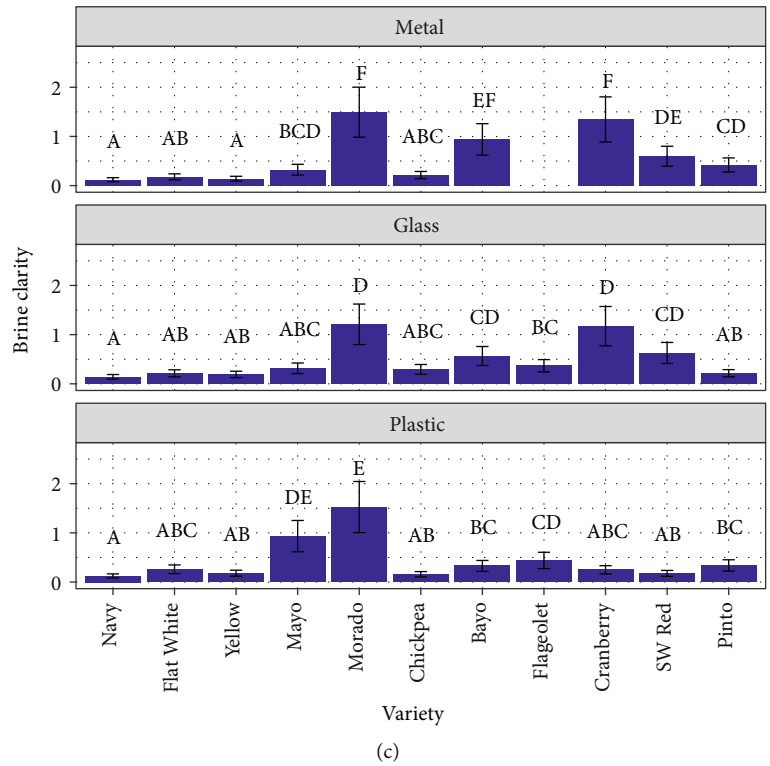


(a)



(b)

Figure 12: Continued.



(c)

Figure 12: (a) Two-way ANOVA interaction between V × P on measured brine L^*. (b) Two-way ANOVA interaction between V × P on measured brine chroma (C). (c) Two-way ANOVA interaction between V × P on measured brine clarity. Error bars represent the standard error of the mean (±2 SE). Groups not sharing the same letter are significantly different ($p < 0.05$). **No data available for Flageolet variety, as brine was too viscous to record measurements.

L^*, a^*, and b^* values across B × V × P provide valuable quality attribute insights, particularly when considering transparent packaging materials, as product developers must consider product appearance to increase consumer acceptance [52].

3.3.4. Brine L^*, C, and Clarity. Brine clarity had moderate negative correlations to bean L^* ($r = -0.64$) and bean C ($r = -0.64$), which indicated that darker colored beans resulted in brine that was lower in clarity; therefore, it was less transparent and more opaque. This result is to be expected, as phenolic compounds are generally water soluble [53] and retort processing reduces the total polyphenol content as phenolic compounds leach into the brine medium with applied heating, disintegrating cells and tissues and allowing polyphenols to migrate to the brine medium [54]. The weak positive correlation ($r = 0.30$) between brine L^* and brine clarity further indicated that lighter colored brines, therefore those with less polyphenol leaching, resulted in generally more transparent brines, but not completely transparent. While there is a high tendency for polyphenol loss during high-temperature processes, the degree of polyphenol loss is dependent on the initial polyphenol content of the dry bean [56]. Because variation in seed coat color properties is attributed to polyphenol content, it is likely that the temperature degradation of these compounds within this study via retort processing impacted the observed brine color and clarity results across each variety. Brine L^*, brine C, and brine clarity were significantly impacted ($p < 0.001$) by V × P (Figure 12**). The variation across packaging material could possibly be explained by the variation in processing times and packaging material properties, resulting in more seed coat splitting and consequent loss of phenolic compounds into the brine medium. The variation in color loss across different packaging materials is another important finding for future food industry recommendations, particularly when considering transparent packaging materials.

4. Conclusions

This study assessed variations in cooking time across bean varieties, followed by evaluating the impact of bean variety, $CaCl_2$ additive, and retort processing within metal, glass, or plastic packaging, where wide variations in quality attributes were observed. As observed by the Mattson cooker trials, variation across the average cooking time of different bean varieties can be expected, resulting in some varieties having better retention of canning qualities than others under the same retort processing conditions. This study also evaluated the retort processed quality of less common market classes within the United States, exploring the opportunity of possible industrialization and expansion of retort processing protocols to lesser known market classes to increase consumer awareness of diverse pulse options. This study also showed the general effectiveness of $CaCl_2$ as a

food additive, and its use within pulse products attributed to relatively higher quality, particularly when considering bean texture and brine viscosity. The addition of $CaCl_2$ generally resulted in processed samples with lighter color, and samples processed within plastic pouch packaging were typically darkest in color. Darker colored beans resulted in more opaque brines, likely due to polyphenol leaching, while lighter colored varieties generally resulted in more transparent brines. Visually noticeable variations in quality attributes are especially important considerations for transparent packaging materials, where they are more easily observed. Glass jars were ultimately an effective packaging material that successfully produced RTE pulse products that could be considered high quality, with quality attributes relatively comparable to those of samples processed within metal cans, while samples processed within plastic pouches had less comparable quality attributes within this study. While retort processing within plastic pouches could further be optimized to prevent quality losses, the glass jars required the longest cooking time to reach the minimum F_0 value, resulting in the highest energy input considerations. Because this study was able to successfully produce retort processed pulses within glass jars, future research should be conducted to evaluate consumer perceptions of pulses packaged within various packaging materials, expanding quality attribute evaluation beyond instrumental analysis. Expansion and further standardization of retort processing protocols for pulses within metal cans, plastic pouches, and glass jars, have the possibility to contribute to future research to further improve the quality of RTE bean products, with the goal of improving consumer perceptions and increasing acceptability of a highly nutritious food.

The authors would like to note study limitations and provide suggestions for future research. While evaluating quality attributes of canning qualities under standardized retort processing conditions for each packaging material allowed for beneficial initial quality attribute evaluation, future research should consider adjusting retort processing conditions for specific bean varieties to allow for maximum evaluation of canning performance and peak quality attributes for product developers. Additional analysis techniques would further strengthen the results of this study, including validation of starch content within brine, how/if nutritional composition varies across different packaging material and cooking times, and sensory evaluation. These suggestions should be considered for future studies of a similar design.

Data Availability Statement

The data that supports the findings of this study are available in the supporting information of this article.

Conflicts of Interest

The authors declare no conflicts of interest.

Author Contributions

Lauren Thomas: conceptualization, formal analysis, investigation, writing – original draft. **Jeffrey Swada:** conceptualization, funding acquisition, supervision, writing – review and editing. **Karen Cichy:** conceptualization, funding acquisition, supervision, writing – review and editing.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section. *(Supporting Information)*

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